Università degli Studi del Piemonte Orientale "Amedeo Avogadro"

Department of Translational Medicine
PhD Program in Food, Health, and Longevity
XXXVI cycle

A serious game for surgical endoscopy: an innovative virtual reality simulator to democratize endoscopic training.

SSD MED/18

Candidate	**Dr. Elisa Reitano**
Ph.D. coordinator.	**Prof. Antonia Follenzi**
Tutor	**Dr. Elisa Francone**
Co-tutor	**Prof. Silvana Perretta**

Contents

Introduction

Rescue in the deep: an innovative simulator

UNIVERSITÀ DEL PIEMONTE ORIENTALE
DOTTORATO DI RICERCA
FOOD, HEALTH and LONGEVITY STUDIES

DECLARATION AND AUTHORISATION TO ANTIPLAGIARISM DETECTION

The undersigned Elisa Reitano student of the *Food, Health and Longevity Studies* Ph.D course (**XXXVI** Cycle)

declares:

- to be aware that the University has adopted a web-based service to detect plagiarism through a software system called “Turnit.in”,
- his/her Ph.D. thesis was submitted to Turnit.in scan and reasonably it resulted an original document, which correctly cites the literature;

acknowledges:

- his/her Ph.D. thesis can be verified by his/her Ph.D. tutor and/or Ph.D Coordinator in order to confirm its originality.

Date: 22/01/2024

Signature:

Introduction

1. The importance of surgical training

Minimally invasive surgery represented a significant milestone in modern surgery (1). Continuous innovation and the introduction of new technologies pose new challenges in terms of surgical learning curves (2). The introduction of new surgical procedures and tools is associated with an increased surgical complexity and with a higher risk of complications (3,4). For this reason, surgeons are aware of the beneficial effects of "learning before doing" and the importance of safely implementing new surgical procedures to obtain better patient outcomes (3).

Technical skills are only one component of surgical practice, which also requires theoretical knowledge, risk assessment, decision-making processes, communication, teamwork, cost analysis, and management (3,5). This set of knowledge and its application within an ethical context define the skills necessary for the training of doctors graduating from medical school, as well as for the training of experts.

Technologies advancement allowed a in surgical field allowed a major advance in the 20th century, making possible the minimally invasive access to the intrabdominal cavity (6).

The first laparoscopy was performed on a dog by the German surgeon Georg Kelling in 1901. The Doctor Hans Christian Jacobaeus performed the first laparoscopic surgery in 1911 in humans. The first laparoscopic cholecystectomy was performed in 1989 by Dr.

Philippe Mouret, in Lyon, France, definitively opening the era of minimally invasive surgery (6). However, the emergence of minimally invasive surgery has led to an increase in the number of iatrogenic bile duct injuries, as many surgeons around the world have changed from the open surgery paradigm to these procedures without any prior training (7,8).

The value of minimally invasive access and the consequent reduction of surgical trauma has become increasingly important in surgery, allowing the technological development and use of lenses and cameras (7).

Advances in surgery included endoscopic procedures through natural orifices or artificial openings combined or not with a robotic platform that offers the same surgery in a minimally invasive manner (9,10). In the mid-1990s, advances in the field of optics fibers and image transmission enabled the development of gastrointestinal endoscopy (11).

This technological evolution led to the development of devices that expanded the possibilities of the technique, which changed from a diagnostic to a therapeutic procedure.

The first tool used by surgeons for training and skill acquisition in laparoscopic surgery was an inanimate model in the form of a black box. After intensive training, surgeons were able to improve the skills needed for video-assisted laparoscopic procedures (12,13). However, the main shortcoming of this simple simulator was the limited space to objectively assess student performance. In the last two decades, surgical education has undergone profound transformations due to the revolution caused by minimally invasive surgery and endoscopy (14,15).

In the era of minimally invasive procedures, psychomotor skills must not and cannot be trained directly on the patient but must rather be acquired by surgical simulation using organic, inorganic or virtual models, which precede the phase of surgical field training in humans (8,16).

Anatomical knowledge, sensory perception and manual skills of the surgeon are factors frequently associated with conventional surgery. Thus, advancement of the classical approach is surgeon dependent. On the other hand, minimal invasive surgery is technology dependent. Adequate theoretical-practical training is essential to perform the procedure safely, and training surgeons before treating patients is important to improve outcomes(13,17). For the development of psychomotor skills, one of the most appropriate training techniques is based on the theory of Fitts and Posner, which proposes three learning stages: cognition (when the skill is learned), integration (when performance approaches the skill), and automation (when the skill has become fully automatic and can be performed without thinking too much about the task) (17).

In this contest, training centers and virtual reality simulation are considered of paramount importance to train surgeons before operations in humans.

The following study was performed in two training and research centers of paramount importance in surgery: IRCAD (Institute of Research Against Digestive Cancer) and IHU (Institute of Image-Guided Surgery), both located in Strasbourg, France.

2 IRCAD – Institute of Research Against Digestive Cancer

2.1 *The history*

The Institute of Research Against Digestive Cancer (IRCAD) was funded in 1994 by Prof. Jascques Marescaux. In 1992, surgery was faced with inevitable changes, moving from the industrial era to the computer era.

This private, non-profit research institute was imagined and developed by practitioners who saw that the future of surgery lay in the combination of their techniques and the growing prowess of medical imaging, computer science and digital technologies. Over the years, IRCAD has become part of the history of surgery. Notably thanks to several innovative operations, such as Operation Lindbergh, the first robot-assisted operation between New York and Strasbourg in 2001, or Anubis, the first scarless transvaginal operation in 2007.

IRCAD's concept acquired an international reputation as a research and teaching institute in the field of surgery and innovation. Today, no other French institute is as present as IRCAD throughout the world: Taiwan, Brazil, Lebanon, Rwanda, China and the United States. Its success has led to the creation of mirror centers all over the world, with the same structure as the original institute located in Strasbourg, France. The objective is to allow surgeons from all over the world to benefit from the best training in minimally invasive surgery, under the guidance of an international Faculty of experts supervised by IRCAD France. These international training centers are the result of a close collaboration with hospitals, universities, and governments.

Figure 1: IRCAD in the world.

2.2 Surgical courses

Every year, for the benefit of patients, IRCAD trains thousands of surgeons from all over the world with the best experts in the most advanced techniques in minimally invasive surgery,

In addition to laparoscopic training, IRCAD is also a training center for robotic surgery.

In parallel to its training activity, the impressive number of scientific publications, which is close to 5000 since the creation of the Institute, testifies to a cutting-edge research activity in the surgical field.

Figure 2: IRCAD Course

The strength of the teams lies in their diversity and cooperation: engineers, researchers and fellows work hand in hand in the service of the patient.

By combining expertise in minimally invasive surgery, robotics and medical imaging, IRCAD has become an important center in these specialties in less than thirty years.

IRCAD training courses are conducted under the supervision of the world's leading experts with a network of nearly 800 international experts.

Figure 3: IRCAD da Vinci robotics platforms

Three auditoriums, equipped with the latest image definition technologies (full HD, 4K and 3D), allow participants to watch surgical procedures, broadcasted in real time from the operating rooms of IRCAD's partner hospitals around the world. Everything is done to promote learning and interactivity with the experts present on site. From theory to practice, the surgeons then move on to the experimental operating room equipped with the latest technology and set up to accommodate up to 40 participants. They then practice on live tissue or anatomical specimens, always under the watchful eye of experts. No other center allows such immersion, since participants operate under the conditions of a real operating room.

2.3 IRCAD for research

IRCAD is a research center mostly dedicated to innovation in the field of artificial intelligence, imaging analysis and to the development of new technologies in the field of minimally invasive surgery.

A dedicate "Surgical data science" team, born from the collaboration between engineers and surgeons allow the research in this emerging branch of medicine to improve the current knowledge in surgery.

Artificial intelligence could help surgeons to increase their surgical better understand the location of the target structures to be treated, to improve the decision making and the therapeutic choices and to enhance the guidance of the tools provided by robotics allowing for an improvement of the procedure.

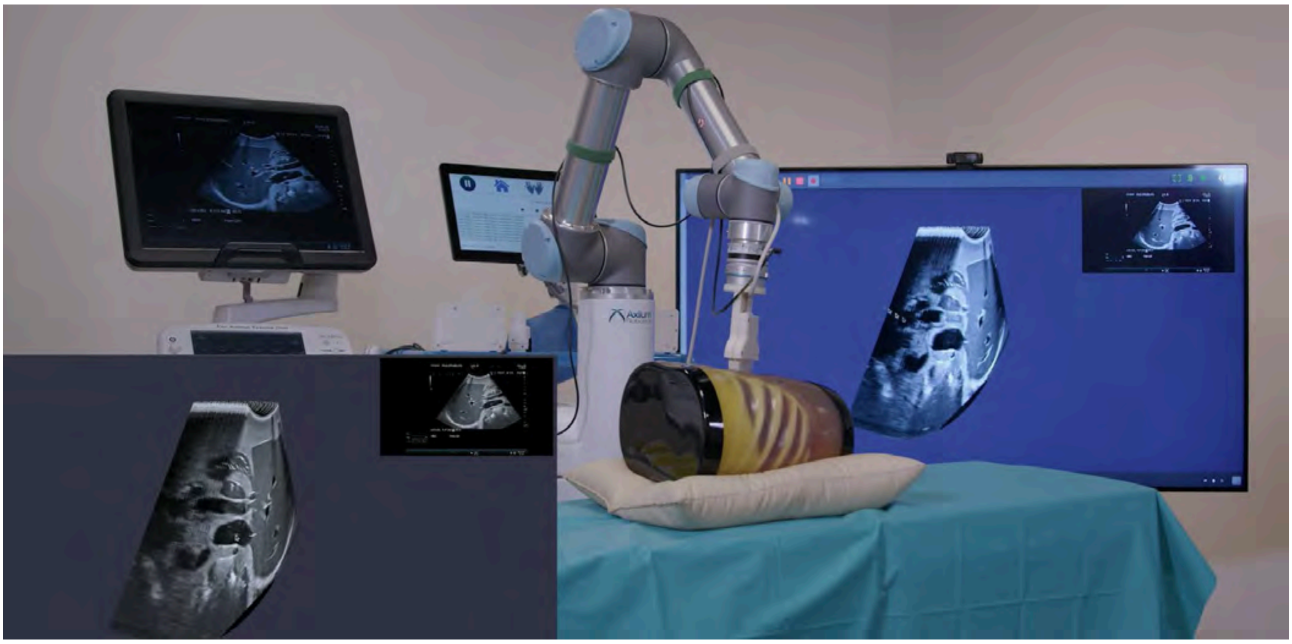

Figure 4: Artificial intelligence station for automated ultrasound diagnosis

3 IHU - Institute of Image-Guided Surgery

The IHU of Strasbourg (Institut Hospitalo-Universitaire de Strasbourg) is entirely dedicated to the development of a new type of surgery, known as hybrid surgery, which combines the most advanced minimally invasive technologies - laparoscopic surgery, flexible endoscopy and interventional radiology - with the latest advances in medical imaging and robotics.

This center is one of six French IHUs created under the “Programme d'Investissements d'Avenir “(PIA) whit the ambition is to lead the new surgical revolution, offering to the patients the most effective therapeutic innovations.

It represents an innovative center focused on training and research in new medical technologies.

The IHU Strasbourg has a unique preclinical experimentation platform, entirely dedicated to research, innovation, and teaching of minimally invasive image-guided surgery.

This experimental platform aims at providing a unique facility for research, training and innovation in the development and evaluation of medical devices and new image-guided procedures within healthcare settings like those found in clinics and hospitals.

The platform is therefore equipped with state-of-the-art imaging equipment on a par with those found in human clinics for diagnosis and research, which allows experiments to be carried out as close as possible to real-life conditions.

The IHU is built on the know-how and expertise of a multidisciplinary expert team made up of surgeons, radiologists, endoscopists, radiology technicians and animal care technicians.

The Institute for Image-Guided Surgery invests in translational research to identify new therapeutic approaches using image-guided minimally invasive surgery tools.

The research strategy is based on the integration of multidisciplinary medical, scientific and industrial skills with the aim to promote innovations and startup creations.

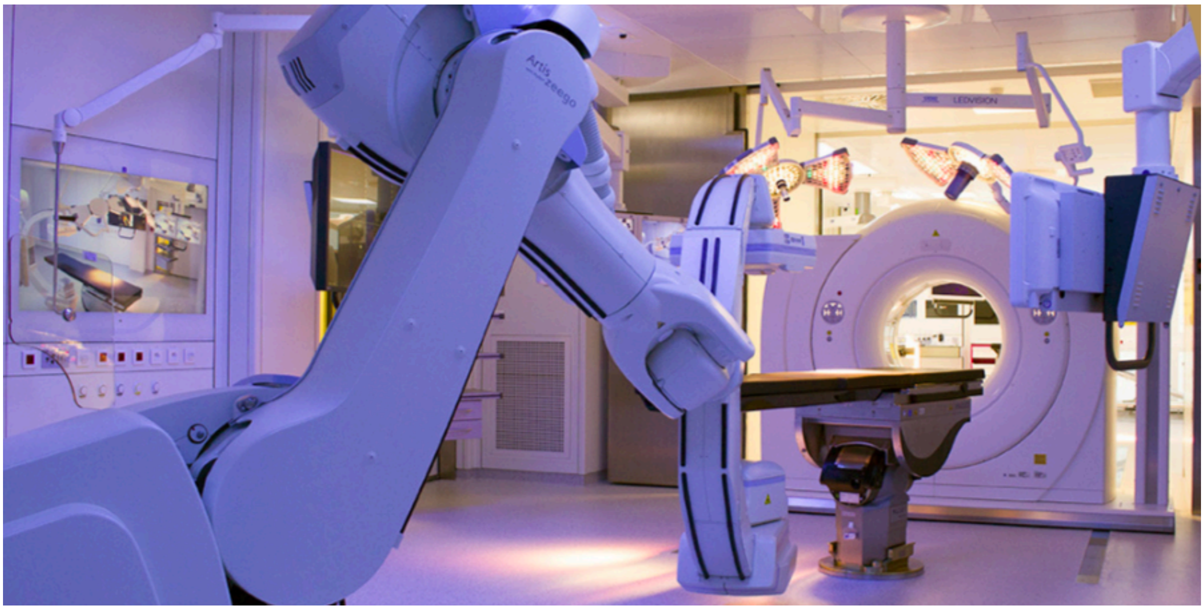

Figure 5: IHU experimental platform.

4. The role of virtual reality simulators in surgery and endoscopy

Training on virtual reality simulators (VRS) is proven beneficial, shortening the learning curve to competency (18). Current simulators are expensive and difficult to access (19). Low-cost portable VRSs could help democratize and standardize endoscopic training.

The learning of surgical techniques necessarily includes the acquisition of several psychomotor skills, which are defined as mental and motor activities that are necessary to perform a given manual task. Despite variations in assessment methods, skills, and surgical parameters, studies have reported the effectiveness of simulation training in clinical practice (17,20).

Simulator-trained surgeons performed surgical procedures faster and more accurately and with a lower percentage of intraoperative errors or postoperative complications than the conventionally trained group, thus minimizing the risks of iatrogenic events and offering surgeons a safe and comfortable environment without the pressure of the operating room (21).

According Vajsbaher et al. (22), it has been well documented that spatial cognition is an important factor for skill acquisition and for the performance of surgeons in minimally invasive surgery. One of these spatial cognitive skills is visuospatial ability.

This skill enables the individual development of internal mental representations of visual patterns and to use these representations to solve complex spatial problems, allowing to retain, retrieve and transform visual and spatial information according to its spatial locus (22).

Simulation using virtual reality at the start of endoscopic training has emerged as a necessary addition to conventional learning. It also provides several benefits, including a low-risk environment, valuable improvement in patient safety, and optimization of endoscopy time(12,23).

Virtual endoscopy simulators are integrated systems that consist of mechanical parts and software. They run a computer program that simulates the procedure of endoscopy using endoscopic images of the gastrointestinal tract while the trainee handles an endoscope attached to a processor that gives a signal to a monitor (24). The moves of the endoscope interact with the monitor image, offering the user a virtual environment for practicing. There are currently two virtual simulators in the market: GI Mentor (Simbionix, Cleveland, United States) and Accutouch Simulator, recently renamed as CAE EndoVR Simulator (CAE Healthcare, Montreal, Quebec, Canada) (24,25).

GI Mentor is an advanced endoscopic simulator for upper and lower endoscopy training. It provides a large library of modules from basic endoscopic skills and simple clinical procedures to complicated situations such as emergency gastric bleeding (19). It also provides modules for endoscopic ultrasound (EUS) and endoscopic retrograde cholangiopancreatography (ERCP) training. The simulation program includes features like a pain indicator and scope locator and trainees can also practice on virtual patient cases based on actual medical data (25).

Figure 6: GI Mentor (Simbionix, Cleveland, United States).

CAE Healthcare (Canada) provides modules of esophagogastroduodenoscopy (EGD), colonoscopy and endoscopic retrograde cholangiopancreatography (ERCP) (26). The trainee can also acquire skills in polypectomy, biopsy and hemostasis (26). CAE offers a realistic endoscopic experience also providing the background of the virtual patients and modifying different paients'parameter during the endoscopy, such as vital signs and patient response to pain and discomfort (27).

Figure 7: CAE EndoVR Simulator (CAE Healthcare, Montreal, Quebec, Canada).

Although these simulators are realistic, they are usually very expensive and not portable. Moreover, the user experience is often repetitive and unfun.

5. Rescue in the deep

Rescue in the Deep consists of an interaction peripheral and a software part that combines digital computation and real-time visualization. The endoscopic “joystick” serves as the main user interface and was designed to retain the essential features of a real flexible endoscope. The movement of the endoscope in the virtual environment corresponds to the motion of a submarine into the sea, which must overcome obstacles and achieve specific goals to successfully complete the training level. The joystick houses sensors to analyze hand movements and controls various functions of the simulator. A real-time physics simulation engine translates the information received from the sensors in the joystick to real movements of an actual endoscope. From the sensor values, a real-time configuration of the digital model of the endoscope is calculated, taking into account interactions with the virtual universe. This universe is created to reflect the constraints of real anatomy, but with a level of abstraction that translates into game levels using the principle of "gamification". Rescue in the Deep is also 3-D printed, allowing scalability and a lower cost for production. The system is lightweight, portable, and convenient to use anywhere the trainee desires with the appropriate software.

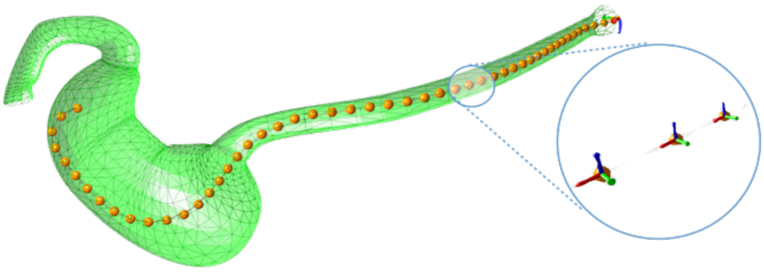

Figure 8: Reproduction of the endoscopic movement.

This universe is created to reflect the constraints of a real anatomy, but with a level of abstraction that allows it to be transformed into a game level (according to the principle of "gamification") (Figure 9).

It is possible to connect dedicated tools to the endoscope in order to simulate the use of endoscopic instruments such as biopsy or snare forceps.

The levels currently available allow the trainee to practice in basic endoscopic movements and skills:

-Level 1: the submarine must be directed through rings placed in the water universe (basic scope manipulation)

-Level 2: the submarine must pass through rings after aspirating its contents (navigation)

-Level 3: 5 oxygen bottles placed in the water universe must be recovered (targeting)

-Level 4: Identification and scanning of specific types of polyps (basic mucosal evaluation)

-Level 5: Identification and remotion of specific types of polyps also using retroflexion (retroflexion)

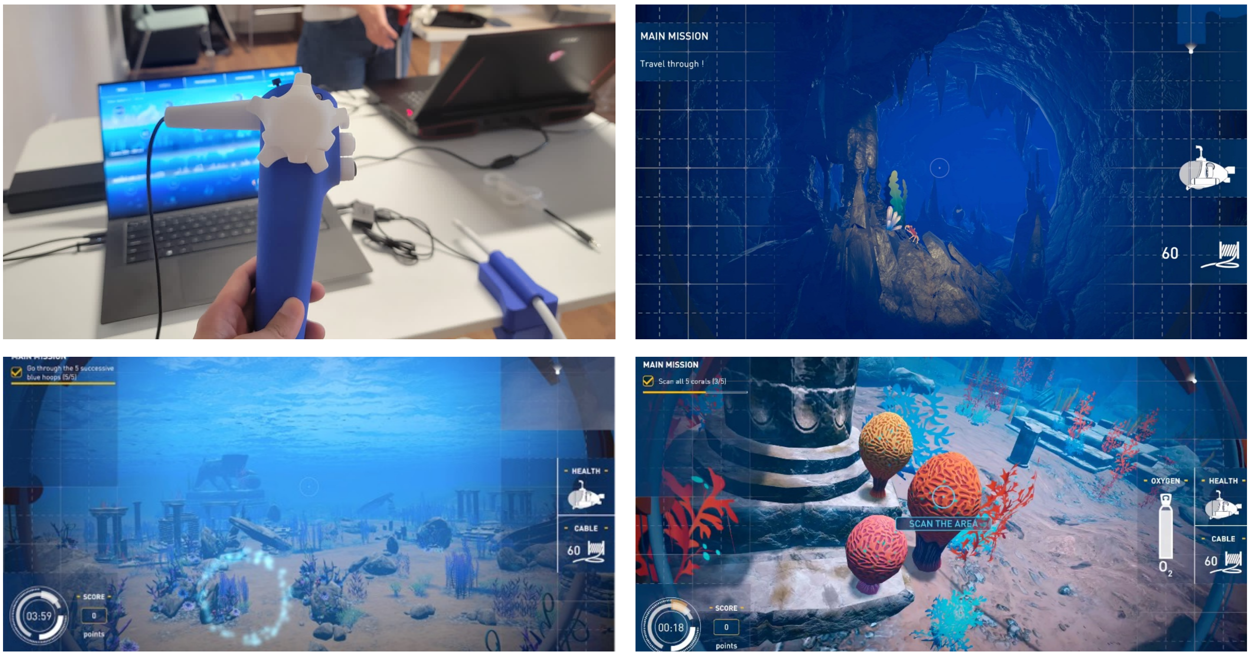

Figure 9: Rescue in the deep device and graphical interface.

RID can trainer novices to the basic principles of the endoscopic movements, navigation and the use of tools (snare forceps, biopsy forceps). It could be useful to medical students, residents and surgeons who have not a major experience in endoscopy to understand the basic principles of the techniques and prepare their self to perform endoscopic procedures on the real patients. In the future, the introductions of more advanced levels will make RID useful also for experts endoscopist to improve their skills.

Unlike other platforms currently on the market, this portable simulator allows the trainee to use it when and where he wants it. This represents an innovation in the field of the endoscopic simulators, that are currently not portables and often available only in few universities and research centers. This could be fundamental especially in critical situations when on-site training is not possible (as the COVID-19 pandemic limitations or geographical distance).

Although RID is not already available on the market, its market cost is expected to be much lower than that of currently available simulators, usually between 35.000 $ and 134.000 $. Therefore, RID promise to democratize the endoscopic training, being a portable and cost-accessible simulator.

6. Scientific articles or patents related to the PhD project

-"Educational Scoring System in Laparoscopic Cholecystectomy: Is It the Right Time to Standardize?" **Reitano E,** Famularo S, Dallemagne B, …Mutter D.

-"Deep sedation versus orotracheal intubation for endoscopic sleeve gastroplasty (ESG):preliminary experience" **Reitano E,** Riva P, Keller D,…Perretta S.

-" A prospective observational study on minimally invasive surgery skill acquisition across novice levels" **Reitano E,** Riva P, Keller D, Badessi G..Perretta S.

Rescue in the deep: an innovative simulator

7. Introduction

Achieving mastery in surgical endoscopy requires a high level of manual skills, knowledge, and experience (11). As the patient population and indication for endoscopic procedures expands, the complexity of endoscopic procedures is increasing accordingly (28,29). There is a need to properly train surgical endoscopists with the full range of technical and non-technical skills to meet these challenges and provide the best patient outcomes (11,16). Conflicting with this need for enhanced training are the current duty hour restrictions in surgical education. Sweeping reforms have mandated that trainees have less time in the hospital, resulting in less time performing procedures and receiving mentorship to improve their skills (30,31). Specific concerns have been raised on the ability to gain competency in surgical endoscopy (32). In order to gain the experience necessary to safely perform endoscopy, alternative learning strategies are needed (3, 33).

Surgical simulation is a validated alternative learning platform for skills acquisition and reaching surgical competency (33). Simulation allows repetitive practice in a controlled, safe, and cost-effective environment without any real-world risks or consequences (34). With simulation, trainees have a platform to acquire and improve technical skills, decision-making capabilities, and situational awareness critical for mastery before actually entering the operating room (20,35). Virtual reality has been incorporated into surgical simulation, and virtual reality simulators (VRS) have demonstrated value in addition to conventional training for surgical endoscopists to improve their skills in multiple controlled clinical scenarios (36,37). Current VRS for endoscopic training provide an extensive library of modules across skill level, procedures, case urgency, and complexity (37). Guidelines support VRS as the best tools to prepare and successfully pass the Fundamentals of Endoscopic Surgery (FES) exam, administered by the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) (38,39). While effective, current VRS have inherent limitations, including that they are expensive, not portable or convenient, and, while the interfaces are realistic, they fail to engage users (19). Given the increasing reliance on alternative learning platforms and value of VRS in surgical education, a convenient, low-cost, endoscopy trainer that uses VRS technology and the principles of gamification is needed. To meet this need, Rescue in the Deep (EVE, Strasbourg, FR), a novel, portable VRS that provides 5 levels of training using a gamified underwater graphic interface was created. To date, beta testing of the Rescue in the Deep platform has been performed, but study on the effectiveness in endoscopic training is necessary.

The goal of this work is to assess the efficacy of the novel, portable gamified Rescue in the Deep VRS for endoscopic skills training. Our hypothesis was that the novel, portable, gamified VRS would be as effective as the standard VRS for task performance, while providing a more enjoyable user experience.

8 Methods:

8.1 Design

A prospective single-center, non-blinded randomized study design was used to test the hypothesis of non-inferiority from July 1, 2022 through September 30, 2022. The study was conducted in our training center (Image-guided Hybrid Surgery Institute - IHU).

8.2 Study population

The study population was recruited from participants at the 2022 Strasbourg B.E.S.T. Course. Participants voluntary applied to trial VRS systems. Volunteers were included if they were over 18 years of age, able to speak and read both English and French in order to understand the study protocol, willing to attend the predetermined training sessions, and signed informed consent to participate. Volunteers were excluded if they had previously received any training or performed any portion of an endoscopic procedure, including bronchoscopy, upper endoscopy, colonoscopy, and endoscopic retrograde cholepancreatography). A total of 20 novices were recruited.

8.3 Randomization and Study Arms

The 20 participants were randomized in a 1:1 fashion into either the control or experimental arms using a sealed envelope randomization method. The control arm used the standard GI Mentor™ Express (3D Systems, Littleton, CO, United States) simulation system, while the Experimental Arm used Rescue in the Deep (EVE, Strasbourg, FR). With the non-inferiority goal, no power analysis was performed.

8.4 Data Source

The data evaluated was derived from the simulator performance. Novice performance metrics were evaluated before and after completion of the training period using the standardized FES examination. Each novice had 45 minutes to run each training session; it was considered completed after that time.

The experimental arm training consisted of 5 different levels of training of increasing difficulty, ranging from learning basic endoscopic movements to reaching targets using specific and appropriate tools.

The control arm GI Mentor™ Express is a not portable VRS. It includes several scenarios that can mimic realistic procedures. The endoscope has an operative channel for the introduction of a tool to simulate the use of endoscopic instruments. There is no unique variable to summarize the progress made for each session, so different variables were considered to assess the advances in this group:

- endo-basket time, i.e., the time taken to complete the “endo-basket” exercise;
- efficiency, i.e., screening efficiency of the colonic mucosa during the dedicated exercise;
- endo-bubble time, i.e., the time taken to complete the “endo-bubble” exercise;

- scope manipulation, i.e., handling skills during the dedicated exercise;
- mucosal time, i.e., the time taken to complete the mucosal screening during the dedicated exercise;
- scope attempt, i.e., attempts to scope targets during the dedicated exercise;
- targeting attempt, i.e., attempts to biopsy virtual targets during the dedicated exercise;
- target time, i.e., the time to complete the target recognition exercise.

As RID currently provides only 5 levels for basic endoscopic learning, similar exercises, not based on realistic scenarios, were chosen on the control arm to express to decrease the differences observed in novices' experiences.

8.5 Main outcome measures

The FES scores were evaluated before the training activity to assess to compare scores across groups and between participants. The individual scores available for each simulator and the final and initial scores FES exam scores, as well as the differences between them were analyzed. Then, the scores difference between initials and finals scores were analyzed to assess the progress in the two groups. Novice feedback on the experience with the corresponding type of simulator was evaluated on a 5-point Likert scale (40).

8.6 Statistical analysis

Data on demographics and years of medical training for all participants were collected.

Available metrics for each VRS were analyzed to assess the training progress between sessions. The overall score achieved at the end of each session was chosen to summarize the progress with RID among sessions, Descriptive statistics were reported for the tests, with frequencies for categorical variables (percentiles) and means (standard deviation) or median (interquartile range) as appropriate for normalized and non-normalized continuous variables. A detailed focus on each simulator was done and scores were separately compared among missions. Graphical representations of individual trajectories were created, considering the total mission score for the Experimental Group and the defined targets assessed for the control arm (endo-basket time, efficiency, endo-bubble time, scope manipulation, mucosal time, scope attempt, targeting attempt, target time). Then, a repeated measures model was constructed considering as outcome the different scores, while the number of missions and the progress over time for each participant were controlled as covariates. Statistical significance was determined using 95% confidence intervals and a threshold set to 0.05 in the two-tailed comparisons. All the analyses were conducted using SAS 9.4 (SAS Institute Inc., Cary, NC, US).

9. Results:

Twenty novices participated in the study, 10 in the experimental and 10 in the control arms. Overall, the participants represented 6 different countries: France n= 13, 65%, Italy and Spain each n=2, 10%, and Brazil, Venezuela, and Taiwan each n=1, 5%.

The median age of the participant pool was 22 years (IQR:20-31.7). The makeup of the participant pool was 70% medical students (n=14) and 15% each general surgery residents and practicing surgeons (n=3 each).

Since the two VRSs have different levels and scores, the goodness of randomization between groups was based on the results of the FES exam before training. At baseline, subjects were similar (p=0.9112) in terms of FES-score: 38.07±8.24 and 38.56±10.88 for simulator one and two, respectively. Generally, subjects had an increase of 26.02±10.20 score, without statistical difference among groups (25.32 ±11.26 and 26.72±9.58, p=0.7685). Finally, when model was performed, subjects trained with the experimental arm had an higher follow-up score [beta 1.74, 95% CI -5.98; 9.46] without statistical significant (p= 0.6404). Figure 10 showed the progress made in achieved final scores of the experimental arm novices in sessions.

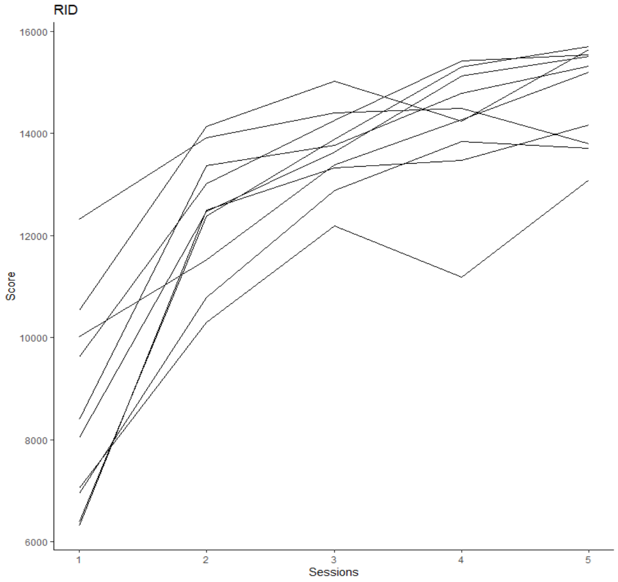

Figure 10: Skills progressions in the RID-trained group

The median achieved score on experimental arm was 8562 points (SD±: 2006.29) at the first training session and increased over time until almost doubling at the last training session [14764 points (SD±: 972.41)]. Table 1 (repeated-measures ANOVA test) showed an increase in the score achieved between the RID sessions, considering each session as a categorical variable, while the increase was 1.417.90 points [95% CI: 1133- 1701] between one session and the following if it was considered a continuous variable.

Table 1: Average increase in scores per sessions as compared to the first training session

RID sessions	**Beta [95% CI]**
2 vs. 1	3.876 [2.939 – 4.812]
3 vs. 1	5.110 [4.167 – 6.052]
4 vs. 1	5.651 [4.455 – 6.846]
5 vs. 1	6.202 [4.970 – 7.433]

Table 1: RID: Rescue int the Deep; CI: Confidence interval

Table 2 showed the repeated-measures ANOVA test calculated for each selected variable of the control arm. An increased score in "efficiency" and a gradual decrease in the time required to complete levels (endo-bubble time, endo-basket time, mucosa time, target time) and in the number of attempts or movements made to reach targets (manipulation, scope attempt, and target attempt) could be observed.

Table 2: Results of repeated measures model considering as outcome the score and as covariate the training session in categorical and continuous way.

Sessions	**2 vs. 1**	**3 vs. 1**	**4 vs. 1**	**5 vs. 1**	**As a continuous variable**
Endo-basket time [sec (95% CI)]	-88.8 [-199.462 ; 21.8624]	-90.7 [-175.656 ; -5.7437]	-114.7 [-220.692 ; -8.7081]	-111.6 [-208.882 ; -14.3178]	-24.91 [-44.1022 ; -5.7178]
Efficacy (score)	10.2 [2.666 ; 17.734]	3 [-13.2121 ; 19.2121]	12.3 [1.9472 ; 22.6528]	12.7 [4.0715 ; 21.3285]	2.75 [0.7341 ; 4.7659]
Endo-bubble time [sec (95% CI)]	-46.6 [-93.7405 ; 0.5405]	-90.6 [-123.584 ; -57.6164]	-105.3 [-146.616 ; -63.9842]	-110.8 [-144.681 ; -76.9195]	-28.03 [-36.1687 ; -19.8913]
Scope	-46.5 [-	-98.9 [-	-105.7 [-	-113.1 [-	-28.54 [-

manipulation time [sec (95% CI)]	88.4462 ; -4.5538]	175.413 ; -22.3873]	179.23 ; -32.1702]	177.227 ; -48.9727]	46.4942 ; -10.5858]
Mucosal time [sec (95% CI)]	-85.8 [-142.22 ; -29.3797]	-115.7 [-212.311 ; -19.0887]	-144.1 [-244.076 ; -44.124]	-171.2 [-239.845 ; -102.555]	-40.07 [-58.0055 ; -22.1345]
Scope attempt (nb of attempts)	-46.5 [-88.4462 ; -4.5538]	-98.9 [-175.413 ; -22.3873]	-105.7 [-179.23 ; -32.1702]	-28.54 [-46.4942 ; -10.5858]	-28.54 [-46.4942 ; -10.5858]
Target attempt (nb of attempts)	-1.9 [-4.8393 ; 1.0393]	-1.8 [-3.9435 ; 0.3435]	-0.9 [-4.2314 ; 2.4314]	-2.9 [-4.6187 ; -1.1813]	-0.48 [-1.0342 ; 0.0742]
Target time [sec (95% CI)]	-19.1 [-122.926 ; 84.7257]	-70.2 [-133.213 ; -7.1874]	-162.1 [-216.743 ; -107.457]	-148.9 [-203.573 ; -94.2269]	-44.08 [-61.9644; -26.1956]

Table 2: CI: confidence interval

Figure 11 showed the graphical representation of the different exercises during sessions.

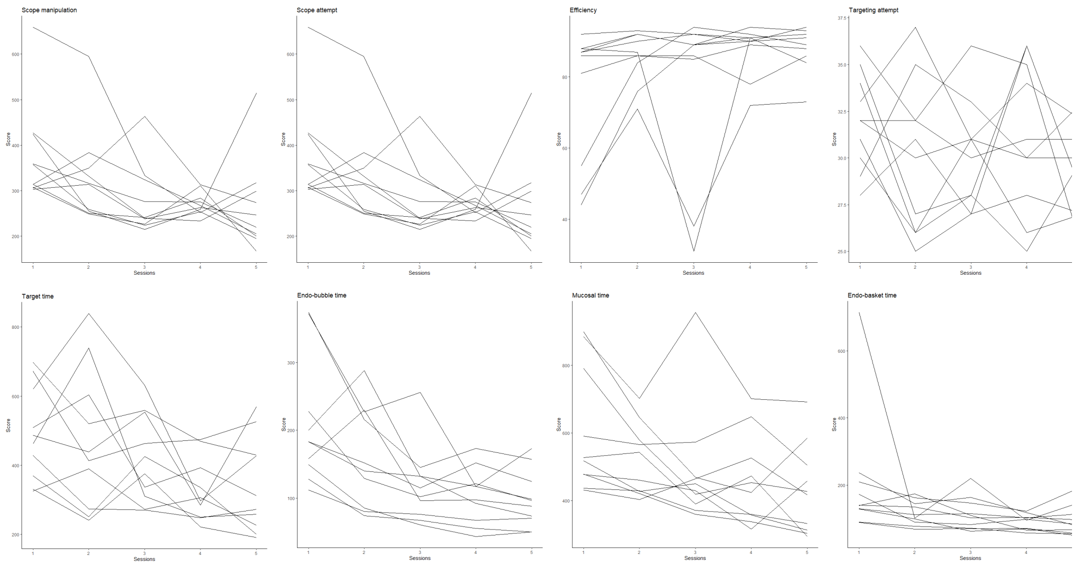

Figure 11: Skills progressions in the VRS-trained group

Eighty percent of trainees in the experimental arm found the training entertaining and felt that this serious game helped them to increase their ability to handle an endoscope and their endoscopic navigation skills. In the control arm, 70% of the trainees found the trainers entertaining, and the percentage of trainers who felt an improvement in their endoscopic skills was reduced to 60%. Only 20% of the control arm and 10% of trainees in the Experimental Arm had previous video games experience, both in low volume (less than 3 hours per week). Finally, all experimental arm trainers felt more like playing a game than performing a training. This feeling was stated by only one trainee in the control arm, whereas 50% of trainees felt more like they were undergoing traditional training.

10. Discussion

This study introduces a novel, portable, gamified VRS- Rescue in the Deep- and demonstrated the non-inferiority of Rescue in the Deep to standard VRS for developing basic endoscopic skills and preparing novices for the FES examination. Novices had similar performance across the experimental and control groups in all metrics and tasks, though more participants in the experimental arm reported their VRS entertaining and subjectively helpful for skills development.

The experimental and control arms showed a similar rate in passing the FES examination after the training, supporting the non-inferiority of the novel Rescue in the Deep VRS. Findings suggest that VRS, regardless of their specific features or technological differences, are equally effective in providing a platform for endoscopic training (19). Despite the growing popularity of VRSs, most simulators are expensive and not portable, hence limiting the training access and opportunity with these tools (18). There are no data that we are aware of in the current literature presents a cost-effective solutions analysis for a VRS tool (41), RID represents an innovative VRS, potentially making the training more cost-effective and affordable for everyone.

RID represents a new generation of VRS that use the concept of gamification in endoscopy. The ability for immersive VRS to stimulate physiological arousal and addiction has been previously shown (42). Here, the application was a proof of concept for gamification in endoscopic training, with the engaging interface and inherent desire to score and advance levels. In the current study, most of the experimental arm reported training felt more like playing a game instead of being trainers. Furthermore, the graphical interface designed to entertain and amuse did so without sacrificing technical proficiency and knowledge. With these features, trainees may be more compliant with deliberate practice and the time needed to ascend to skills mastery (43).

Specific advantages of the experimental Rescue in the Deep platform were found in the study. The experimental arm has the additional advantage of being portable, plug and play, easy to install and use, with a very intuitive interface, therefore being potentially able to democratize endoscopic training. Because of such qualities, it could be used both within university and training institutions and by the individual trainer at home. The experimental arm planform could be helpful in describing the progress made among different training sessions and in offering more intuitive feedback on skills improvements by providing a unique total score for each training session. This can be useful for getting a more precise and intuitive overview of the trainee's learning curve during the different learning sessions. Moreover, the experimental arm showed a more linear increase in learning compared to the control arm. As a result, it could also be helpful to provide more direct feedback on the trainers' improvements during dedicated educational courses and endoscopic training programs (44). As the trainer received direct feedback from the system on skills improvement over time, the concept of "self-training" could be relevant for trainees who would like to improve their endoscopic skills, but who have no frequent access to endoscopic procedures. It could be the case for trainees in universities where there is no endoscopic simulator or dedicated educational program, or in particular circumstances when there is no access to such tools (as recently observed during the COVID-19 pandemic) (42).

We recognize the limitations of this work. The results are based on a small sample size from a single center, which could introduce bias into the interpretation of results and limit the generalizability of these findings. Larger, powered studies across multiple centers are planned from these favorable findings to further support the hypothesis. Additionally, the training was limited to the development of basic endoscopic skills in accordance with the current available levels of difficulty related to the Experimental Arm device. As this VRS is still in its early development stage, only 5 levels are presently available to learn endoscopic basic skills. Regardless of any limitations, the novel portable VRS shows the potential for continuous skills improvement of novices toward competency, while the learners enjoy the task. There are important implications for implementing such training models into routine practice for patient safety, learner convenience, and expanding training outside of the hospital.

In conclusion, this study demonstrates the potential of a novel, portable, gamified VRS- Rescue in the Deep for basic endoscopic skills development. The evidence for its effectiveness in developing the technical and manual skills necessary to promote success in endoscopic procedures was seen, with similar performance across the experimental and control groups. In addition, there was greater subjective engagement and interest from users. Future studies will determine if this translates to sustained use and more efficient skills acquisition. The Rescue in the Deep represents an exciting innovation in the field of endoscopic training compared to the others VRS currently on the market. Further studies with larger sample sizes will corroborate these results as we work to develop more advanced endoscopic skills.

References

1. Siddaiah-Subramanya M, Tiang KW, Nyandowe M. A New Era of Minimally Invasive Surgery: Progress and Development of Major Technical Innovations in General Surgery Over the Last Decade. Surg J [Internet]. 2017 [cited 2023 Dec 5];3:163–6. Available from: https://doi.org/
2. Reitano E, de'Angelis N, Schembari E, Carrà MC, Francone E, Gentilli S, et al. Learning curve for laparoscopic cholecystectomy has not been defined: A systematic review. ANZ J Surg. 2021;91(9):E554–60.
3. Reitano E, Riva P, Keller DS, Badessi G, Vannucci M, Rodríguez-Luna MR, et al. A prospective observational study on minimally invasive surgery skill acquisition across novice levels. Glob Surg Educ - J Assoc Surg Educ [Internet]. 2023;2(1):1–8. Available from: https://doi.org/10.1007/s44186-023-00159-9
4. Ballantyne GH. The pitfalls of laparoscopic surgery: Challenges for robotics and telerobotic surgery. Surgical Laparoscopy, Endoscopy and Percutaneous Techniques. 2002.
5. John AS, Caturegli I, Kubicki NS, Kavic SM. The Rise of Minimally Invasive Surgery: 16 Year Analysis of the Progressive Replacement of Open Surgery with Laparoscopy. 2020 [cited 2023 Dec 5]; Available from: www.SLS.org
6. Wolfe BM, Gardiner B, Frey CF. Laparoscopic Cholecystectomy: A Remarkable

Development. JAMA [Internet]. 1991 Mar 27 [cited 2023 Dec 5];265(12):1573–4. Available from: https://jamanetwork.com/journals/jama/fullarticle/385445

7. Beyer-Berjot L, Palter V, Grantcharov T, Aggarwal R. Advanced Training in Laparoscopic Abdominal Surgery (Atlas): A Systematic Review. Surgery [Internet]. 2014 [cited 2023 Dec 5];156(3):676. Available from: /pmc/articles/PMC4150855/

8. Guilbaud T, Birnbaum DJ, Berdah S, Farges O, Beyer Berjot L. Learning Curve in Laparoscopic Liver Resection, Educational Value of Simulation and Training Programmes: A Systematic Review. World J Surg [Internet]. 2019 Nov 1 [cited 2023 Dec 5];43(11):2710–9. Available from: https://link.springer.com/article/10.1007/s00268-019-05111-x

9. Leroy J, Diana M, Perretta S, Wall J, De Ruijter V, Marescaux J. Original technique to close the transrectal viscerotomy access in a NOTES transrectal and transgastric segmental colectomy. Surg Innov [Internet]. 2011 Sep [cited 2023 Feb 21];18(3):193–200. Available from: https://pubmed.ncbi.nlm.nih.gov/21727099/

10. Chow A, Purkayastha S, Paraskeva P. Appendicectomy and cholecystectomy using single-incision laparoscopic surgery (SILS): The first UK experience. Surg Innov. 2009;16(3):211–7.

11. Rudiman R. Advances in gastrointestinal surgical endoscopy. Ann Med Surg. 2021 Dec 1;72.

12. Sadideen H, Alvand A, Saadeddin M, Kneebone R. Surgical experts: Born or made? 2013 [cited 2023 Dec 6]; Available from: http://dx.doi.org/10.1016/j.ijsu.2013.07.001

13. Kanitra JJ, Khogali-Jakary N, Gambhir SB, Davis AT, Hollis M, Moon C, et al. Transference of skills in robotic vs. laparoscopic simulation: a randomized controlled trial. BMC Surg [Internet]. 2021 Dec 1 [cited 2022 Jun 7];21(1):1–8. Available from: https://bmcsurg.biomedcentral.com/articles/10.1186/s12893-021-01385-y

14. Abaza R. The robotic surgery era and the role of laparoscopy training. [cited 2023 Apr 5]; Available from: http://www.sagepub.co.uk/

15. Vergis A, Hardy K. Cognitive and Technical Skill Assessment in Surgical Education: a Changing Horizon.

16. Reitano E, Famularo S, Dallemagne B, Mishima K, Perretta S, Riva P, et al. Educational Scoring System in Laparoscopic Cholecystectomy : Is It the Right Time to Standardize ? 2023;1–12.

17. Sadideen H, Kneebone R. Practical skills teaching in contemporary surgical education: how can educational theory be applied to promote effective learning? Am J Surg. 2012 Sep 1;204(3):396–401.

18. Khan R, Plahouras J, Johnston BC, Scaffidi MA, Grover SC, Walsh CM. Virtual reality simulation training in endoscopy: A Cochrane review and meta-analysis. Endoscopy [Internet]. 2019 [cited 2023 Feb 14];51(7):653–64. Available from:

http://www.thieme-connect.com/products/ejournals/html/10.1055/a-0894-4400

19. Triantafyllou K, Dimitrios Lazaridis L, Dimitriadis Konstantinos Triantafyllou GD, Dimitriadis GD. Virtual reality simulators for gastrointestinal endoscopy training. 2014 [cited 2023 Oct 26]; Available from: www.wjgnet.com/1948-5190/full/v6/i1/6.htm

20. Grover SC, Scaffidi MA, Khan R, Garg A, Al-Mazroui A, Alomani T, et al. Progressive learning in endoscopy simulation training improves clinical performance: a blinded randomized trial. Gastrointest Endosc [Internet]. 2017 Nov 1 [cited 2023 May 10];86(5):881–9. Available from: http://www.giejournal.org/article/S0016510717317182/fulltext

21. Patil NG, Cheng SWK, Wong J. Surgical competence. World J Surg. 2003;27(8):943–7.

22. Vajsbaher T, Schultheis H, Janssen S, Weyhe D, Bektas H, Uslar V, et al. The development of visuospatial abilities and their impact on laparoscopic skill acquisition: a clinical longitudinal study. Surg Endosc [Internet]. 2022 Dec 1 [cited 2023 Dec 6];36(12):8908–17. Available from: https://pubmed.ncbi.nlm.nih.gov/35641701/

23. McDougall EM. Validation of surgical simulators. Journal of Endourology. 2007.

24. Goodman AJ, Melson J, Aslanian HR, Bhutani MS, Krishnan K, Lichtenstein DR, et al. Endoscopic simulators. Gastrointest Endosc [Internet]. 2019 Jul 1 [cited 2023 May 10];90(1):1–12. Available from:

http://www.giejournal.org/article/S0016510718332504/fulltext

25. Koch AD, Buzink SN, Heemskerk J, Botden SMBI, Veenendaal R, Jakimowicz JJ, et al. Expert and construct validity of the Simbionix GI Mentor II endoscopy simulator for colonoscopy.

26. Eppich W, Reedy G. Advancing healthcare simulation research: innovations in theory, methodology, and method. 2022 [cited 2023 Dec 6];7:23. Available from: https://doi.org/10.1186/s41077-022-00219-y

27. Garstka ME, Slakey DP, Martin CA, Simms ER, Korndorffer JR. Effectiveness of systems changes suggested by simulation of adverse surgical outcomes. BMJ Simul Technol Enhanc Learn [Internet]. 2015 Dec 1 [cited 2023 Dec 6];1(3):83. Available from: /pmc/articles/PMC8990181/

28. Fukami N. Surgery Versus Endoscopic Mucosal Resection Versus Endoscopic Submucosal Dissection for Large Polyps: Making Sense of When to Use Which Approach. Gastrointest Endosc Clin N Am. 2019 Oct 1;29(4):675–85.

29. Valdastri P, Simi M, Iii RJW. Advanced Technologies for Gastrointestinal Endoscopy. 2012 [cited 2023 Feb 14]; Available from: http://www.cervicalcancer.org

30. Tomlinson C, LaBossière J, Rommens K, Birch DW. The Canadian general surgery resident: Defining current challenges for surgical leadership. Can J Surg. 2012;55(4 SUPPL. 2):184–90.

31. Feyissa GT, Balabanova D, Woldie M. How Effective are Mentoring Programs

for Improving Health Worker Competence and Institutional Performance in Africa? A Systematic Review of Quantitative Evidence. 2019 [cited 2023 Oct 26]; Available from: http://doi.org/10.2147/JMDH.S228951

32. Jones RP, Stylianides NA, Robertson AG, Yip VSK, Chadwick G. National survey on endoscopy training in the UK. Ann R Coll Surg Engl. 2015;97(5):386–9.

33. Maulahela H, Gianty Annisa N, Konstantin T, Fahrial Syam A, Soetikno R, Professor A. World Journal of Gastrointestinal Endoscopy Simulation-based mastery learning in gastrointestinal endoscopy training Provenance and peer review: Peer-review model: Single blind Peer-review report's scientific quality classification Grade A (Excellent): 0 Grade B P-Reviewer: Al-Ani RM, Iraq. [cited 2023 Oct 26]; Available from: https://dx.doi.org/10.4253/wjge.v14.i9.512

34. Ziv A, Ben-David S, Ziv M. Medical Teacher Simulation Based Medical Education: an opportunity to learn from errors Simulation Based Medical Education: an opportunity to learn from errors. [cited 2023 May 10]; Available from: https://doi.org/10.1080/01421590500126718

35. Khan R, Plahouras J, Johnston BC, al. et. Virtual reality simulation training for health professions trainees in gastrointestinal endoscopy. Cochrane Database Syst Rev. 2018;8:CD008237.

36. Graafland M, Vollebergh MF, Lagarde SM, Van Haperen M, Bemelman WA, Schijven MP. A serious game can be a valid method to train clinical decision-

making in surgery. World J Surg. 2014;38(12):3056–62.

37. Kim Y, Hoon Lee J, Hyug Lee G, Hee Kim G, Huh G, Wook Hong S, et al. Simulator-based training method in gastrointestinal endoscopy training and currently available simulators. Clin Endosc [Internet]. 2023 [cited 2023 May 10];56:1–13. Available from: https://doi.org/10.5946/ce.2022.191

38. Vassiliou MC, Dunkin BJ, Marks JM, Fried GM. FLS and FES: Comprehensive Models of Training and Assessment. Surg Clin North Am. 2010 Jun 1;90(3):535–58.

39. Gardner AK, Ujiki MB, Dunkin BJ. Passing the fundamentals of endoscopic surgery (FES) exam: linking specialty choice and attitudes about endoscopic surgery to success. Surg Endosc 2017 321 [Internet]. 2017 Jun 21 [cited 2022 Sep 26];32(1):225–8. Available from: https://link.springer.com/article/10.1007/s00464-017-5663-1

40. Sullivan GM, Artino AR. Analyzing and Interpreting Data From Likert-Type Scales. [cited 2023 Oct 26]; Available from: http://dx.doi.org/10.4300/JGME-5-4-18

41. Mahmood T, Scaffidi MA, Khan R, Grover C. Virtual reality simulation in endoscopy training: Current evidence and future directions. [cited 2023 May 10]; Available from: https://dx.doi.org/10.3748/wjg.v24.i48.5439

42. Radhakrishnan U, Chinello F, Koumaditis K. Investigating the effectiveness of immersive VR skill training and its link to physiological arousal. Virtual Real

[Internet]. 2022 [cited 2023 Feb 14]; Available from: https://pubmed.ncbi.nlm.nih.gov/36405878/

43. Ericsson KA. Deliberate practice and acquisition of expert performance: A general overview. Acad Emerg Med. 2008 Nov;15(11):988–94.

44. Mascagni P, Spota A, Pizzicannella M, Laracca GG, Svendrovski A, Fiorillo C, et al. Democratizing Flexible Endoscopy Training: Noninferiority Randomized Trial Comparing a Box-Trainer vs a Virtual Reality Simulator to Prepare for the Fundamental of Endoscopic Surgery Exam. J Am Coll Surg [Internet]. 2022 Jun 1 [cited 2023 Feb 14];234(6):1201–10. Available from: https://journals.lww.com/journalacs/Fulltext/2022/06000/Democratizing_Flexible_Endoscopy_Training_.35.aspx

11. List of publications during the PhD time frame

-"Epidemiology of trauma admissions in a level 1 Trauma Center in Northern Italy: a 9-year study" Difino M, Bini R, **Reitano E,** Faccincani R, Sammartano F, Briani L, Cimbanassi S, Chiara O.

-"Trauma, alcohol and drugs misuse in car and motorcycle drivers:a prevalence study in a level one trauma center" Renzi F, **Reitano E,** Davanzo F, Chiara O, Cimbanassi S.

-“Avoiding immediate whole-body trauma CT: a prospective observational study in stable trauma patients” **Reitano E**, Granieri S, Sammartano F et al.

-“Impact of the COVID-19 outbreak on severe trauma trends and healthcare system reassessment in Lombardia, Italy: an analysis from the regional trauma registry” Giudici R, Lancioni A, Gay H…**Reitano E,** Bini R.

-“Predictive factors of ventilatory support in chest trauma” Fattori, S., **Reitano, E**., Chiara, O., Cimbanassi, S.

-“Traumatic limb wounds management: Efficacy of silver and hyaluronic acid-containing dressings” Schembari, E., Latteri, S., **Reitano, E.,** Russello, D., La Greca, G.

-“Nine year in-hospital mortality trends in a high-flow Level One Trauma Center in Italy” **Reitano E,** Bini R, Difino M, Chiara O, Cimbanassi S.

-“Current trends and perspectives in interventional radiology for gastrointestinal cancers” **Elisa Reitano**, Nicola de'Angelis, Giorgio Bianchi, et al.

-“Oral bacterial microbiota in digestive cancer patients: A systematic review” **Reitano, E.,**De’angelis, N., Gavriilidis, P., et al.

-“Centralization of Major Trauma Influences Liver Availability for Transplantation in NortherItaly: Lesson Learned from COVID-19 Pandemic” Altomare M, Chirici A, Virdis S…**ReitanoE.** Cimbanassi S.

-“Current trends in the diagnosis and management of traumatic diaphragmatic injuries: Asystematic review and a diagnostic accuracy meta-analysis of blunt trauma” **Reitano E**, Cioffi S, Airoldi A, Chiara O, La Greca G, Cimbanssi S.

-“Negative Pressure Wound Therapy for the Treatment of Fournier’s Gangrene: A Rare Case with Rectal Fistula and Systematic Review of the Literature” Altomare M, Benuzzi, L., Molteni, M., … **Reitano E**…Sesana G, Cimbanassi S.

- “Gut Microbiota Association with Diverticular Disease Pathogenesis and Progression: ASystematic Review” **Reitano, E.,** Francone, E., Bona, E., Follenzi, A., Gentilli, S.

-“Surgeons’ attitudes during laparoscopic appendectomy: do subjective intraoperativeassessments affect the choice of peritoneal irrigation? A spin-off analysis from the REsiDENT-1 multicentre prospective observational trial” Cioffi S.P.B., Granieri S, Scaravilli L, … **Reitano E**…Vignati B.

-“Elective surgery system strengthening: development, measurement, and validation of thesurgical preparedness index across 1632 hospitals in 119 countries” Glasbey, J.C., Abbott, T.E., Ademuyiwa, A.... Mushawarima, T **(collaborative group participation)**

-“Predictors of Mortality in Bicycle-Related Trauma: An Eight-Year Experience in a Level One Trauma Center” **Reitano E,** Cioffi SPB, Virdis F, Altomare M…Cimbanassi S.

-“In-Hospital Predictors of Need for Ventilatory Support and Mortality in Chest Trauma: AMulticenter Retrospective Study” **Reitano E,** Gavelli F, Iannantuoni G, Fattori S et al.

-“ Increasing Trend in Violence-Related Trauma and Suicide Attempts among PediatricTrauma Patients: A 6-Year Analysis of Trauma Mechanisms and the Effects of the COVID19 Pandemic” Maina C, Cioffi SPB, Altomare M, Spota A.. **Reitano E.**et al.

-“Time for a paradigm shift in shared decision-making in trauma and emergency surgery? Results from an international survey” Colabianchi L, Del Mas, Agnoletti V,..**Reitano E**, Pizzocaro E

-“Partial Hepatic Vein Occlusion and Venous Congestion in Liver Exploration Using aHyperspectral Camera: A Proposal for Monitoring Intraoperative Liver Perfusion” Famularo S, Bannone E, Collins T. **Reitano E,** Diana M**.**

-“Educational Scoring System in Laparoscopic Cholecystectomy: Is It the Right Time to Standardize?” **Reitano E,** Famularo S, Dallemagne B, …Mutter D.

-“Detection of post-traumatic abdominal pseudoaneurysms by CEUS and CT: A prospectivecomparative global study (the PseAn study)—study protocol” Virdis F, Cioffi SPB, Abu-Zidan F, **Reitano E,.**Cimbanassi S.

-How much is enough? A surigical perspective on imaging modalities to estimate function andvolume of the future liver remnant before hepatic resection” Milana F, Famuaro S, Diana M, Mishima K, **Reitano E…**Torzilli G

-“Deep sedation versus orotracheal intubation for endoscopic sleeve gastroplasty (ESG):preliminary experience” **Reitano E,** Riva P, Keller D,…Perretta S.

-“Contrast-enhanced ultrasound (CEUS) in the follow-up of abdominal solid organ trauma: an international survey prior to the PseAn study” Santolamazza G, Virdis F, Abu-Zidan F, Cioffi SPB, **Reitano E,** Altomare M…Cimbanassi S.

-“The burden of the knowledge-to-action gap in acute appendicitis. Cioffi SPB, Altomare M, Podda M, Spota A, Granieri S, **Reitano E**…Cimbanassi S.

-“ Dynamic magnetic resonance imaging (dy-mri) evaluation of the impact of endoscopic sleeve gastroplasty (esg) on gastric structure and function in morbid obesite patients” **Reitano E,** Quero G, Berardo A…CImbanassi S.

-“ A prospective observational study on minimally invasive surgery skill acquisition across novice levels” **Reitano E,** Riva P, Keller D, Badessi G..Perretta S.

-“2023 WSES Guidelines for the prevention, detection and management of Iatrogenic UrinaryTract Injries (IUTI) during Emergency Digestive Surgery” de’Angelis N, Schena CA, Marchegiani F, **Reitano E**….Catena F.