Università degli Studi di Napoli Federico II
Ph.D. Program in
Information and Communication Technology for Health
(ICTH)
XXXVI Cycle

THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Assessing the Feasibility of Remote Surgical Training (ReST) Using the da Vinci Xi System

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Ph.D. Thesis presented

for the fulfillment of the Degree of Doctor of Philosophy in Information and Communication Technology for Health (ICTH)

by

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October 2023

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Ph.D. Program in Information and Communication Technology for Health

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Candidate's declaration

I hereby declare that this thesis submitted to obtain the academic degree of Philosophiæ Doctor (Ph.D.) in Information Technology and Electrical Engineering is my own unaided work, that I have not used other than the sources indicated, and that all direct and indirect sources are acknowledged as references.

Parts of this dissertation have been published in international journals and/or conference articles (see list of the author's publications at the end of the thesis).

Napoli, July 16, 2023

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Lorenzo Spirito

Abstract

The research explores the feasibility and effectiveness of Remote Surgical Training (ReST) using the da Vinci Xi System, aiming to bridge the gap in remotely controlled training for robotic-assisted surgery. Unlike traditional mentoring, ReST allows tutors to assume control of the robotic instruments, providing real-time guidance to trainees during surgical procedures. The study was conducted at the Robotic Academy Intuitive Naples (RAIN) within the Antonio Cardarelli Hospital in Naples, Italy, from March 2021 to April 2023. The research team consisted of surgeons, engineers, tutors, trainers, potential trainees, human factors experts, and statisticians. Initially planned for 12 ReST tests and 12 control events, the study expanded to 15 tests and 15 controls. Surveys were developed for tutors, trainees, and trainers, assessing their experiences. The da Vinci Xi System was used for both ReST tests and control events, covering general urological, gynecological, and thoracic surgery. It's worth noting that during the tests at RAIN, surgeries were performed on pigs using the robotic system. ReST tests involved relocating the tutor's console to an adjacent room, connected to the robotic system via a cable. An environmental camera allowed remote monitoring, and audio communication utilized the da Vinci Xi System. Fifteen ReST tests were compared with fifteen control events where the tutor was physically present in the trainee's operating room.. The Global Evaluative Assessment of Robotic Skills (GEARS) tool demonstrated high internal consistency (Cronbach's $\alpha = 0.805$). There were no significant score differences between the control and test groups across GEARS dimensions (Mann-Withney test). Participants' perceptions indicated good agreement on aspects like session effectiveness and interaction quality. Trainees valued clear instructions and feeling comfortable. Tutors emphasized the importance of trainees following instructions carefully. The physical proximity of the tutor was consistently ranked as the least important aspect. ReST is feasible and as effective as traditional training, with high satisfaction levels. Trainees, tutors, and trainers supported the format's safety for patient application. Future research should explore advanced forms of remote training, including long-distance network connections. The possibility of remote collaboration within surgical teams, enabled by advanced technologies like 5G and 6G, holds promise.

Keywords: Remote Surgical Training, da Vinci Xi System, Feasibility Study, Robotic Surgery, Surgical Education, Training Effectiveness.

Acknowledgements

The comprehensive research outlined in this dissertation owes its inception and successful execution to the generous support provided by the Intuitive Foundation for the project titled "Remote Surgical Training (ReST), Guided by the expertise and leadership of Principal Investigator Guido De Sena, this pioneering study was conducted at the prestigious Robotic Academy Intuitive Naples (RAIN) within the A. Cardarelli Hospital, Naples, Italy.

Index

List of Acronyms

ReST - Remote Surgical Training

COVID-19 - Coronavirus Disease 2019

FDA - U.S. Food and Drug Administration

GTSS - Green Stanford Research Institute Telepresence Surgical System

AESOP - Automated Endoscopic System for Optimal Positioning

DARPA - Defense Advanced Research Projects Agency

ISDN - Integrated Services Digital Network

TR - Training event Reference

GEARS - Global Evaluative Assessment of Robotic Skills

AR - Augmented Reality

List of Figures

List of Tables

List of Symbols

µs - Microseconds

5G - Fifth Generation of Wireless Technology

6G - Sixth Generation of Wireless Technology

° - Degrees

α - Alpha (Cronbach's alpha coefficient)

p-value - Probability value

τX - Tau-X rank correlation coefficient

Chapter 1

Introduction and background

1.1 Introduction

In September 2001 Jacques Marescaux and his team, using Computer Motion's "Zeus" robotic surgery system, realized what they called Lindbergh Operation, i.e. the operator was at the console in New York and the patient to be subjected to cholecystectomy was in Strasbourg Hospital in France. The intervention was successful. The transmission of the signal by cable was possible thanks to the collaboration of Telecom France. However, the latency time of the transmission of the signal from the console to the patient cart was too long and therefore not compatible with a correct clinical practice. The project was hence abandoned. In December 2018 at RAIN (Robotic Academy Intuitive Naples) in Naples, Italy, the principal investigator of the ReST project had the intuition to use this surgery technique remotely for training purposes and passed it on to Intuitive training managers in the US and in Europe who were enthusiastic about it. Very few examples of remote robot-assisted surgery do exist. Among them, the Chinese experience published in January 2019 by Liu in China, using the animal model. He performed the first robotic telesurgery with 5G technology (www.china.org.cn/china/2019-01/20/content_74391295.htm).

Recently, Mischa Dohler, Chair of Department of Informatics of King's

College in London, UK, highlighted the importance of using remote robotics in the general field during his plenary presentation at the 2019 International Conference on Acoustics, Speech and Signal Processing.
At present, in the field of remotely controlled training for robotic-assisted surgery there are only mentoring and not training and tutoring experiences. Hence, the team wants to explore this opportunity. If we carefully analyze the existing literature in the field, we realize that in educational programs there is only mentoring, that is, the mentor sees and supervises what the trainee does by operating with the robotic system and suggests solutions but cannot intervene by showing how to do it in the proper way. Our educational program, on the other hand, provides that the tutor, in addition to suggesting how to do it, can take the command of the instruments to himself/herself and show the trainee how that surgical step should be performed. If in the past this intuition of ours had the purpose of facilitating the educational program and containing spending by using the tutor with smart working, today it has a fundamental relevance due to the CoViD 19 pandemic, which requires distancing and tries to limit travel. The motivations driving this study are multifaceted. First and foremost, the aspiration to bridge geographical distances and enable effective remote training in robotic-assisted surgery has been a driving force. Moreover, the ongoing COVID-19 pandemic has underscored the need for innovative solutions to maintain surgical education and training while adhering to public health measures such as physical distancing. Our unique approach, allowing tutors to not only guide but also physically demonstrate surgical techniques remotely, aligns with these motivations and aims to enhance the accessibility and effectiveness of robotic-assisted surgical training

In the first chapter, an introduction and background to the research context are provided. It begins with an overview of the history of robotic surgery, including past attempts to perform remote surgeries. The motivations driving the research are highlighted, including the importance of bridging geographical distances and the challenges posed by the COVID-19 pandemic. Furthermore, it explains how this research approach differs from traditional mentoring experiences, focusing on the tutor's ability to remotely take control of surgical instruments to directly demonstrate surgical techniques. In the second chapter, the methods used in the study are presented. It discusses the study's design, questionnaire development, and data analysis. It also mentions the candidate's role in the research, emphasizing their involvement in various research phases.In the third chapter, the results of the study are presented. Specifically, the analysis of data obtained through the Global Evaluative Assessment of Robotic Skills (GEARS) tool is discussed. This tool was used to assess the performance of trainees during training in both the control group and the Remote Surgical Training (ReST) group. The perceptions and priorities of tutors, trainees, and trainers regarding the surgical training experience are also examined. Finally, in the fourth chapter, the conclusions of the study are drawn. The promising feasibility and effectiveness of ReST as a training approach are emphasized, with a particular focus on the high level of trainee satisfaction. Possible future directions for research are also explored, including challenges and opportunities related to the evolution of technologies and healthcare policies. This structural approach provides a clear overview of the thesis's content and findings, guiding the reader through the research journey and culminating in exciting prospects for the future of surgical training and telemedicine.

The candidate's contributions spanned study design, questionnaire development, data analysis, and active participation in urological surgery sessions. Specifically, the candidate played a significant role throughout this study, contributing to various essential aspects of the research process, such as shaping the study's design, providing valuable input, and helping to develop the research methodology. Additionally, the candidate was closely involved in the development of the study's questionnaire, ensuring its thoroughness and relevance for data collection. During the data analysis phase, the candidate contributed to processing and interpreting the research findings, assisting in drawing meaningful conclusions based on the collected data. Moreover, the candidate was hands-on during all urological surgery sessions at RAIN, actively contributing to the surgical team's efforts and ensuring the smooth execution of procedures. His involvement in these sessions was a crucial part of the project's success, particularly in facilitating surgical training.

1.2 The advent of Robotic surgery

Robotic surgery has its origins in the history of laparoscopic surgery, which gained worldwide acceptance in 1986 with the introduction of the first video computer chip enabling image magnification and projection onto TV screens. This advancement led to a surge in laparoscopic procedures and spurred interest in exploring remote laparoscopy, eventually giving rise to the development of robotic surgical systems. One of the earliest systems, the Green Stanford Research Institute Telepresence Surgical System (GTSS), emerged in the 1980s under the leadership of Dr. Phillip Green at Stanford Research Institute. This system, resembling contemporary "master-slave" robotic surgical systems, included a remote operative site, a surgical workstation, and three-dimensional visualization of the surgical site. However, it had limitations, offering only four degrees of instrument freedom. In 1992, DARPA's involvement and funding accelerated the development of remote robotic surgery, leading to the creation of the Automated Endoscopic System for Optimal Positioning (AESOP) by Computer Motion, Inc. in 1993. After successfully performing the first remote tele-surgical procedure in 1994 on an ex vivo porcine intestine, Dr. Frederic Moll, a general surgeon who had founded and sold two companies developing laparoscopic tools, became interested. He, along with electrical engineer Robert Younge and Harvard MBA John Freund, established Intuitive Surgical Devices, Inc. (later renamed Intuitive Surgical, Inc.) in 1995. By 1996, they had adapted the GTSS model to incorporate the EndoWristTM technology, enabling seven degrees of wrist-like motion.

Over the next three years, Intuitive continued to improve its robot and registered with the Securities and Exchange Commission in 1998. By 2000, several groups were using the da Vinci surgical system with EndoWristTM technology for robotic prostatectomy, and it received FDA approval for this purpose in May 2001. As of December 2018, Intuitive Surgical had sold 4,986 da Vinci robotic surgical systems worldwide, with 3,196 systems installed in the United States. In urology, robotic surgery, particularly robotic prostatectomy, saw significant adoption following FDA approval in 2001. Urologists played a pivotal role in driving the adoption of robotic technology, making robotic prostatectomy the most commonly performed robotic oncologic procedure in the United States by 2003. The rapid adoption of robotic prostatectomy led to its use in other genitourinary oncologic procedures, including robotic partial nephrectomy in 2002, radical cystectomy in 2003, retroperitoneal lymph node dissection in 2006, and inguinal lymphadenectomy in 2009. The adoption of robotic technology in urology can be understood through Everett Rogers' "Diffusion of Innovations" model, which categorizes adoption phases into Innovators, Early Adopters, Early Majority, Late Majority, and Laggards. Widespread adoption required engagement from three key stakeholders: the surgeon, the hospital administrator, and the patient.

The involvement of surgeons plays a pivotal role in the adoption of medical devices, as their approval is essential for procedures to take place, regardless of patient and hospital administrator consent. The success of robotic prostatectomy can be contrasted with the challenges faced by laparoscopic radical prostatectomy adoption. While laparoscopic cholecystectomy achieved an estimated 80% market saturation within four years of its introduction in the United States in 1988, laparoscopic radical prostatectomy experienced a much slower adoption rate.

The first laparoscopic radical prostatectomy, performed by Schuessler in 1992, was followed by a scarcity of published cases until 1997, with only one case series from the same group. In this early series, the mean operative times for the first nine patients were exceptionally long at 9.4 hours. Subsequently, Guillonneau published a 65-patient case series in 1999, demonstrating improved operative times with a mean of 4.5 hours for experienced surgeons. However, the laparoscopic approach faced hurdles due to its steep learning curve. Competency was estimated to require between 200 and 750 cases, making it challenging for urologists to adopt this technique widely.

In contrast, robotic prostatectomy, facilitated by the da Vinci system with EndoWristTM technology, boasted a shorter learning curve. It took approximately 40 cases for surgeons to achieve operative times below 4 hours in robotic prostatectomy, making it more accessible to the average urologist compared to laparoscopy. Additionally, the EndoWristTM technology improved surgeons' ergonomics, reducing the incidence of neck and back pain. A study comparing musculoskeletal ergonomic parameters among open, laparoscopic, and robotic prostatectomy revealed that only 23% of surgeons experienced such discomfort when operating robotically, compared to 50% for open surgery and 56% for laparoscopic surgery.

The dominance of the da Vinci surgical system in the market was further solidified by the lack of significant competition before 2003. The only major competitor, the Zeus Robotic Surgical System from Computer Motion Inc., had limitations compared to the da Vinci, notably lacking the range of motion provided by the EndoWristTM technology. The Zeus system, approved by the FDA in 2001 for abdominal surgery, couldn't replicate the natural motions experienced in open surgery. Comparative studies, including one in a cohort of pigs by Gill, demonstrated significantly reduced operative times with the da Vinci compared to the Zeus. Consequently, more urologists gravitated toward the da Vinci over time, leading to the withdrawal of the Zeus from the market after Intuitive Surgical and Computer Motion's merger in 2003.

Following the initial adoption, subsequent innovations required less marketing effort and expanded the range of surgeries possible. These advancements included the introduction of the fourth surgical arm, dual consoles for teaching, high-definition imaging, upgraded systems with improved ergonomics (Si, Xi), and the development of the single-port surgical system.

1.3 Challenges and Opportunities in Robotic Surgery Training

The rapid expansion of robotic surgery in recent years has brought to the forefront important questions concerning the most effective modes of training for surgeons. Robotic surgery presents distinct challenges in training compared to traditional open or laparoscopic procedures. One significant challenge is the need for standardization in both the skills required for accreditation as a robotic surgeon and in the development of training curricula. However, evaluating the effectiveness of a given curriculum is a complex task. The conventional approach involves assessing "learning curves," which typically refer to the time or number of cases required to attain full proficiency in a specific procedure. However, as pointed out by Kassite et al., there is no universally accepted method for measuring these learning curves. Furthermore, factors such as patient outcomes, intraoperative complications, the skill level of the assisting surgeon and other team members, and the presence of a senior surgeon in the operating room are often overlooked in the literature on robotic learning curves. Another critical consideration is determining who should undergo training in robotic surgery. Is it a specialized skillset to be acquired after gaining experience in open and laparoscopic surgery, or should it be considered an essential component of a general surgeon's toolkit? This question is closely tied to the organizational structure of healthcare institutions. Some hospitals have dedicated robotic surgery teams comprising surgeons, nurses, and anesthesiologists who predominantly perform robotic procedures. This

specialization allows for a high level of expertise. In contrast, institutions lacking dedicated teams have reduced exposure to robotic surgery, making it challenging to maintain expertise and train new surgeons. Many argue that a sufficient case volume is necessary for effective robotic training and achieving a stable level of competence. Efficiency in surgical procedures is of utmost importance, and the need to minimize operating time adds a layer of complexity to training. Some robotic procedures are already time-consuming compared to open surgery. Thus, there is a delicate balance between the necessity to train operating team members and the imperative to maintain efficiency during surgery.
Robotic surgery also introduces a spatial separation between the lead surgeon at the console and other team members in the operating room, which may hinder effective teaching, particularly in terms of non-verbal communication. Financial constraints can be a significant barrier to training, limiting access to essential tools. Dual consoles, which allow a novice to operate under supervision, come at a substantial cost. The cost issue is a central concern in studies evaluating the utility and validity of surgical simulators. Furthermore, collaboration dynamics are altered during robotic procedures. The lead surgeon relies less on trainees for tasks such as retraction, reducing opportunities for active involvement. This reduced participation of trainees has led to robotic surgery being perceived as less conducive to resident training. Few studies have delved into the dynamics of training in the operating room during robotic surgery. One notable exception is Beane's research, which highlights how residents often acquire robotic surgical skills through a form of "shadow learning." This informal learning may not be entirely safe or effectively integrated into their formal training, potentially leading to situations where residents operate at the limits of their abilities with

limited supervision. Despite these challenges, robotic surgery presents two significant training opportunities within the operating room: the dual-console system and automatic video recording of procedures. The dual-console system, as seen in the da Vinci robotic surgical system, allows for proctoring. This means the lead surgeon can grant full control to the trainee, share control over two arms while retaining control over the third, or use pointers to guide the trainee through specific steps of the procedure. The didactic potential of these functions has been emphasized, with dual-console training enabling unique trainee-trainer dynamics that are not feasible with single-console robotics or even open surgery.

1.4 Remote surgery

Telesurgery represents a departure from traditional surgical procedures, where the surgeon operates in close proximity to the patient. In telesurgery, the surgeon operates from a remote console while the robotic system remains in direct contact with the patient. Advanced communication technology facilitates real-time control of endoscopic cameras and robotic arms, providing the surgeon with immediate feedback. This innovative surgical approach serves multiple purposes, including eliminating the need for patients and their accompanying persons to undertake unnecessary travel, reducing the overall financial burden associated with medical care, and ensuring access to high-quality surgical expertise regardless of geographical location. The journey of telesurgery began as an innovative concept and gradually evolved into a transformative reality in the realm of surgical care. It can be traced back to NASA's exploration of providing medical treatment to astronauts in space during the 1970s. A pivotal moment in the evolution of telesurgery was the development of endoscopes and video computer chips, enabling laparoscopic surgery and the magnified projection of images on television screens. These advancements laid the foundation for remote surgical interventions. In the late 1980s, visionaries like Scot Fisher and Joseph Rosen envisioned telepresence surgery using robotic systems. This vision led to the creation of computer-assisted surgical tools, eventually giving rise to modern robotic surgical systems. Notable developments include the ZEUS Surgical System and the da Vinci Surgical System. The da Vinci system, in particular, gained prominence due to its 3D immersive camera and advanced robotic arms. To make telesurgery feasible, addressing communication latency between the surgeon's console and the surgical robot was crucial. Studies demonstrated that a time lag exceeding 150–200 milliseconds could be detrimental. The world's first telesurgery, the "Lindbergh Operation," conducted in 2001, showcased the potential of remote surgery. Professor Jacques Marescaux in New York successfully performed a cholecystectomy on a patient in Strasbourg, France, using the ZEUS system and advanced telecommunications. Since then, telesurgery has witnessed continued global adoption and advancements.

Telesurgery also finds application in telementoring, enabling highly skilled surgeons to provide real-time guidance and technical assistance during surgical procedures. However, despite the significant technological advancements in telesurgery, its widespread integration into clinical practice still faces barriers that necessitate identifying and addressing limiting factors.

1.5 Telementoring

At the heart of surgical education lies the ability to safely guide and mentor trainees through various medical procedures. Telementoring, an integral component of telemedicine, has emerged as a means to achieve this mentorship remotely. It encompasses two essential facets: Teleproctoring and Telestration.

Teleproctoring hinges on the connection between a mentor and a trainee through a specialized interface. This interface relies on two fundamental components: a digital platform and a connection linking both sites. Over the years, the modes of connectivity have evolved significantly. Initially, teleproctoring relied on technologies like ISDN and dedicated trunk communication lines. Subsequently, dedicated fiber optic channels were introduced, offering faster bandwidth and reduced lag times. Cable networks made strides as well. Local internet connectivity played a crucial role, making telemedical communications practical and cost-effective. Today, with the advent of 5G technology, wireless internet networks have achieved unprecedented data transfer speeds, significantly enhancing telementoring experiences. Moreover, mobile cellular networks and satellites have effectively supported various forms of telemedicine with minimal connectivity lag. In tandem with these advancements, digital platforms tailored for teleproctoring and telestration have emerged to facilitate effective two-way communication between mentors and trainees. Examples include the ConnectTM platform by Intuitive Surgical Inc. and the ProximieTM telemetry system developed collaboratively in Boston, London, and Beirut. These platforms allow mentors to virtually scrub in, guiding trainee surgeons through every aspect of a procedure, including incision sites and anatomical landmarks. Studies have illustrated the effectiveness of these systems. For instance, ConnectTM was used to mentor 55 robotic prostate and renal surgeries, with results showing effective telestration and similar outcomes in terms of blood loss and operative times compared to non-telementored cases. Surgeons and trainees reported higher satisfaction rates, and mentors preferred remote interaction. Similarly, the Proximie platform demonstrated comparable perioperative outcomes between telementored and on-site cases during Aquablation procedures for Benign Prostatic Obstruction. Telestration adds a new dimension to telementoring by allowing mentors to illustrate surgical steps directly on the operative screen. This capability enables trainers to telestrate their operative thoughts, highlighting crucial structures and anatomical landmarks during procedures. This interactive approach significantly enhances the telementoring experience. However, the introduction of the Da Vinci robot marked a significant advancement, enabling remote surgeons to manipulate more equipment and perform full telerobotic surgeries. Notable milestones include remote nephrectomies using the Da Vinci system and a laparoscopic renal cyst ablation in 2002. In 2020, the Da Vinci system was used for 1.25 million procedures, highlighting its growing popularity. Other competitive systems have since entered the market, such as Senhace, Revo-I, Versius, Avater, Hinotori, and the Hugo RAS, with ongoing human trials and promising advancements in the telerobotics sector. While telementoring and telerobotics hold great promise, they also face several challenges. Patient and physician acceptance, licensure and liability issues, costs, safety concerns, ethical considerations, and workflow changes are among the hurdles that need to be addressed. Notably, malfunctions of robotic systems and internet instability can lead to complications during procedures.

Chapter 2

Methods

2.1 Overall study design

The research took place at the Robotic Academy Intuitive Naples (RAIN), located within the Center of Biotechnologies at the Antonio Cardarelli Hospital in Naples, Italy. In the months of March and April 2021, our research team convened multiple times to strategize our approach for investigating the feasibility and effectiveness of Remote Surgical Training (ReST). This diverse team consisted of surgeons, engineers, tutors, trainers, potential trainees, human factors experts, and statisticians. Initially, we decided to conduct 12 ReST tests and 12 control events. However, we later expanded this to 15 tests and 15 control events. To assess the outcomes of our research, we developed three distinct surveys: one for the tutor, one for the trainee, and one for the trainer. These surveys were administered at the conclusion of each event. Our chosen robotic surgical system for both ReST tests and control events was the da Vinci Xi System. The surgical procedures encompassed various aspects of general urological, gynecological, and thoracic surgery. Control events followed a similar structure to the TR 300. In these control events, the trainee and the tutor each operated from their respective consoles within the same robotic operating room, supervised by a specialist trainer. For the ReST tests, we maintained the didactic protocol of the TR 300 but with a key difference: the tutor's console was situated in an adjacent room within the same operating block. To maintain connectivity, a long cable linked the tutor's console to the robotic system. Additionally, an environmental camera in the robotic operating room, remotely controlled by the tutor in the adjacent room, facilitated visual monitoring. Audio communication relied on the da Vinci Xi System. Following each ReST test and control event, the tutor, trainee, and specialist trainer promptly completed the designated survey, submitting their responses in real-time through a platform prepared by our team of statisticians. To gauge the trainee's performance, supervisors present in the robotic operating room, coupled with recorded interventions by the trainees, utilized the Global Evaluative Assessment of Robotic Skills (GEARS).

2.2 Statistical methods

In this study, several statistical methods were employed to analyze the data. Firstly, the internal consistency of the GEARS tool was evaluated using Cronbach's α coefficient to assess the reliability of the tool overall and separately for the control and ReST groups. To compare scores between these groups, the Mann-Whitney test was used across different dimensions of the GEARS tool. The degree of agreement in perceptions between tutors and trainees was measured using the weighted Cohen's κ coefficient, particularly for statements related to the training session. Additionally, to determine the most important aspects of the training, a consensus ranking was established for both tutors and trainees using the Kemeny's axiomatic approach. These statistical methods provided a comprehensive analysis of the research findings, aiding in the assessment of reliability, group comparisons, agreement between participants, and the identification of training priorities.

Chapter 3

Results

3.1 GEARS Tool Evaluation in ReST Tests vs. Control Events

In our study, we conducted a total of fifteen ReST tests, which were meticulously compared with fifteen control events. Our assessment of the GEARS tool's internal consistency revealed a high level of reliability, with an overall Cronbach's α coefficient of 0.805. For the control group, this coefficient stood at 0.837, and for the test group, it was 0.768.
Utilizing this robust and consistent tool, we calculated an overall score for each trainee by averaging their performance across all seven domains. Our analysis revealed no statistically significant difference in scores between the control and test groups (Mann-Whitney test, p-value = 0.595). Furthermore, within each dimension of the GEARS tool, there were no noteworthy distinctions between the scores assigned to trainees in the control group versus the test group (Mann-Whitney test, with a minimum p-value of 0.074 for the "Autonomy" dimension and a maximum p-value of 0.683 for the "Use of third arm" dimension). Details of these test results for all dimensions are presented in Table 3.1 for reference.

Table3.1. Mann-Withney test

Dimension	U statistic	p-value
Depth	96.00	0.512

Perception		
Bimanual Dexterity	124.00	0.653
Efficiency	84.00	0.250
Force sensitivity	97.00	0.539
Autonomy	151.00	0.106
Robotic Control	69.00	0.074
Used of Third arm	102.00	0.683

3.2 Assessment of Perceptions and Priorities in Surgical Training

The survey contained a series of questions to evaluate how trainees, tutors and trainers perceive the surgical session. A series of questions were the same for both tutors and trainees. The aim was to assess whether there were any differences in the perceptions of these two actors during the training session. The response scale was ordinal with categories “strongly disagree”, “disagree”, “agree”, “strongly agree”. The degree of “agreement” between the statements of the tutors and the trainees who participated in the same session was measured through the weighted coefficient Cohen’s k. There was significant agreement between tutor and trainees in assuming that the session made surgical teaching/training easy (p-value = 0.004), that the tutor could follow the trainee (or the trainee felt followed by the tutor) adequately in his/her tasks (p-value = 0.011) and that the quality of interaction between tutor and trainee was good (p-value = 0.014). There was general agreement between tutors and trainees in perceiving that the trainee applied tutor’s instructions promptly versus instructions sent to trainee were clear (for both actors the proportion of answers that are equal at least to “agree” is as high as 100%), even if the Cohen's k was not significant. Also, in investigating other aspects ("*My function was effective in achieving trainees' learning objectives*" versus "*This session was effective in achieving my learning objectives*" and "*I felt the need to have the trainee close by*" versus "*I felt the need to have the tutor close by*") there was not a not significant "agreement" between tutors and trainees. In the first case the response distributions are really similar, whilst there is a remarkable difference in the answers in the second case. It is worth noting that not necessarily the answers have to be similar between tutors and trainees and between the same class of actors between control and ReST group. The "similarity" of the answers given by the same class of actors between control and ReST group has been measured through the Spearman correlation coefficient (minimum -0.4, maximum 1.00). The trainers agreed that the atmosphere for learning was adequate in both test and control groups. They declared that the quality of interactions between tutor and trainee was even better in the test group than the control group. According to the tutors and trainers this format can certainly be replicated on real patients. Although basically of the same idea, the trainees express some greater perplexity about it. The overall degree of satisfaction about the training experience was at least high for tutors and trainers. For the trainees, in only one case the degree of satisfaction has been declared low in the test group (see Figure 3.1).

External observers of the ReST test noted that the remote tutor often used the environmental camera to closely follow what was happening in the robotic OR.

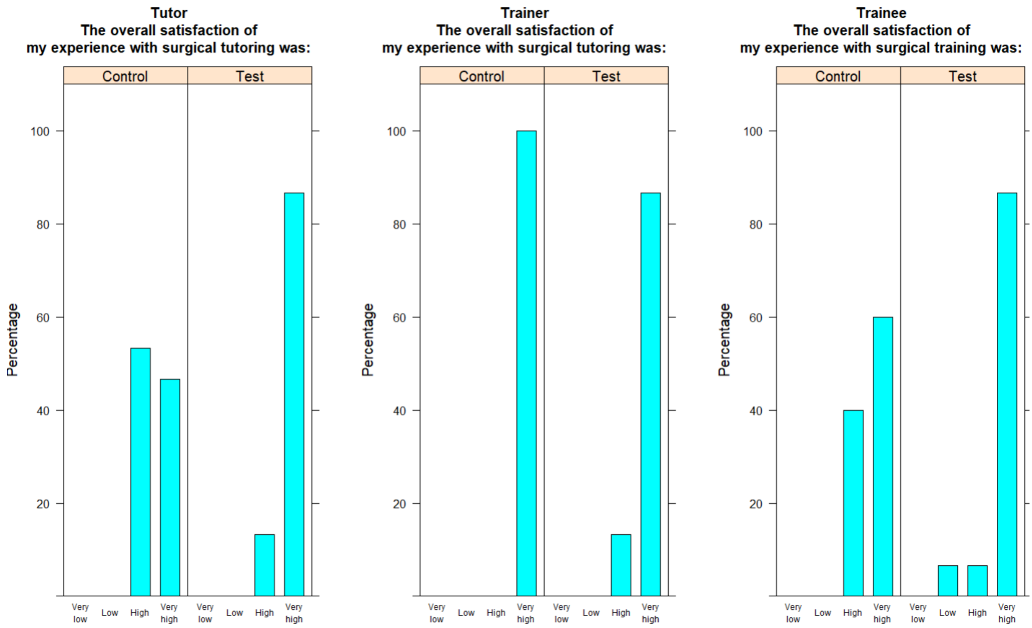

Figure 3.1. Satisfaction levels declared by Tutors, trainers and trainees partitioned by control and test groups

In Table 3.2, which presents the tutors' rankings, the results show that, across the entire sample, tutors considered the trainee's ability to follow their instructions carefully as the most crucial aspect of the training. In the control group, tutors prioritized having a sense of connection with the trainee as the immediate key factor, followed closely by the trainee's ability to follow instructions. However, in the ReST group, tutors placed the highest importance on the trainee's ability to follow instructions carefully, indicating a shift in priorities.

Table 3.3 outlines the trainees' rankings. In the overall sample, trainees ranked the clarity and understandability of the tutor's instructions as the most vital aspect of their training experience. Interestingly, this priority remained consistent in both the control and ReST groups. The second-highest ranked aspect for trainees in both groups was having the tutor follow them in their tasks. These results suggest that trainees highly value clear communication and guidance from their tutors, regardless of the training format.

The averaged τX rank correlation coefficient values provided at the end of each table represent the level of agreement among the participants regarding the importance of each item. In general, these coefficients indicate moderate to good agreement on the relative importance of various aspects of the training, with some differences observed between the control and ReST groups.

Table 3.2. Tutors' rankings

Tutor	**Rank**	**1**	**2**	**3**	**4**	**5**	**Averaged τ_X rank correlation coefficient**
Whole sample	Item	The trainee can follow my instructions carefully	I can take over the commands at the right moment	I have feeling with the trainee	I feel comfortable	The trainee stands close to me	0.5133333
Control group		The trainee can follow my instructions carefully	I have feeling with the trainee	I can take over the commands at the right moment	I feel comfortable	The trainee stands close to me	0.3866667
ReST grou		The trainee can	I can take over	I have feeling with	I feel comfortable	The trainee	0.680000

p		follow my instructions carefully	the commands at the right moment	the trainee		stands close to me	

Table 3.3. Trainees' rankings

Trainee	**Rank**	**1**	**2**	**3**	**4**	**5**	**Averaged τ_X rank correlation coefficient**
Whole sample	Item	The instructions of the tutor are clear and understandable	The tutor follows me in my tasks	I feel comfortable and autonomous	The tutor takes over the commands at the right moment	The tutor stands close to me	0.3933333
Control group		The instructions of the tutor are clear and understandable	The tutor follows me in my tasks	The tutor takes over the commands at the right moment	I feel comfortable and autonomous	The tutor stands close to me	0.3733333
ReST group		The instructions of the tutor are clear and understandable	The tutor follows me in my tasks	I feel comfortable and autonomous	The tutor takes over the commands at the right moment	The tutor stands close to me	0.426667

Chapter 4

Conclusions

Our investigation into Remote Surgical Training (ReST) has yielded compelling insights into its feasibility and effectiveness when evaluated through the Global Evaluative Assessment of Robotic Skills (GEARS) tool. Notably, we found no significant differences in outcomes between ReST and traditional training methods, particularly when considering trainees with similar backgrounds in both control and test groups. This discovery underscores the potential of ReST as a valuable training approach.

One notable aspect of our findings is the consistently high or very high levels of satisfaction reported by trainees regarding their surgical training experience. Moreover, the interactions among tutors, trainees, and trainers were generally rated as positive for both control and test groups. Surprisingly, the physical proximity of the tutor was deemed the least important factor in the training process.

Additionally, trainers consistently reported that the training atmosphere was conducive to effective learning. Both trainers and tutors expressed confidence in the safety of the ReST format, even on real patients, with some exceptions.

While our results highlight the promise of ReST, they also shed light on areas for improvement. Notably, trainees expressed a desire for more robotic tools and resources to enhance their training experience.

Looking ahead, our findings strongly support further investigation into more advanced forms of remote training. One promising avenue includes exploring testing scenarios that involve cable or wireless network connections over long distances, as well as potentially relocating trainees during TR 100 sessions. Such innovations have the potential to significantly reduce the time and costs associated with training, making surgical education more accessible.

One particularly intriguing aspect of our study is the favorable opinion of tutors and trainers regarding the possibility of replicating the ReST format on patients. However, this also raises complex questions about the responsibilities of operating surgeons and proctors, whether remotely displaced or physically present in the same operating room. While the concept of remote robotic surgery may find application in exceptional situations, such as war zones, its integration into routine clinical practice may hinge on the evolution of technologies like 5G or 6G. These advancements could enable seamless remote collaboration between senior surgeons and the surgical team, heralding a new era in surgical education and practice.

In conclusion, our research not only validates the potential of ReST but also prompts us to explore innovative avenues in surgical training and practice. The future holds exciting possibilities for remote surgical education, and we are at the cusp of transformative changes in the field.
In the future, augmented reality (AR) and wearable equipment are expected to play a significant role in telementoring. Devices like Google Glass and Microsoft HoloLens have shown promise in remote telementoring, and further trials are needed to assess their efficiency. Policy-wise, health policies need to evolve to regulate and promote telemedicine effectively. Licensing between different states remains a major challenge, and unified policies for cross-border medical practices are still lacking. Other issues include reimbursement controversies and patient data privacy. Telemedicine, particularly telementoring and telerobotics, has the potential to transcend geographical boundaries in healthcare. Despite challenges, it

offers numerous advantages, including improved patient care, enhanced training opportunities, cost-effectiveness, and resilience in times of pandemics. As technology continues to advance and regulations evolve, the future of telemedicine looks promising.

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