Surgical Life
The Journal of the ASGBI

Number 59

A Message from the President

Mr Neil Welch

What a wonderful change as lockdown from COVID-19 is slowly relaxed, the amount of suffering from infection has diminished, the days are getting longer, and Spring is well and truly established. A marked change from the beginning of this year when I assumed presidency of ASGBI.

The step from Vice-President to President brought with it a feeling of imposter syndrome, as I looked at the previous Presidents and recognised that I stood "on the shoulders of giants". Iain Anderson did so much for the Association, and many of his labours are coming to fruition now. I would like to thank him for his vision, support, and encouragement to me personally, the whole team and the Association as a whole. During his term of office, the Association has appointed new directors to take forward new endeavours in Research, and Inclusivity, worked hard on the finances of our organisation together with the Board, and encouraged the establishment of the ASGBI Webinar Series which has been so well received by members. Unfortunately, we had to cancel our Centenary Congress last year, and many of us feel that we did not get the opportunity to celebrate his Presidential term as we would have liked. Maybe this year we will be able to find a time for a face-to-face celebration. For those of you who may not be aware, the ex-President still has some roles in the Association, and I am grateful for his continued efforts on our behalf.

This year we are going to have a virtual Congress “Future Surgery Reboot” in May from Tuesday 4th until Saturday the 8th. The programme is very exciting, and we are trying new approaches made much easier by the online nature of the Congress. These include online yoga breaks, sustainability and inclusivity sessions, and a Saturday devoted to surgical training. All the favourites are still there with short papers, medicolegal and pension discussions, a marvellous BJS Lecture from Prof Julio Mayol, and “a bad day on call”. Some of the content will be available pre-recorded online only, and the rest will be streamed live and then the recording available shortly afterwards for review or catchup via the Congress platform. All delegates will be able to access the Congress app for 6 months after the event to look at the sessions at your leisure. This flexibility is the advantage of a virtual Congress, but the downside is the potential loss of face-to-face contact, and networking with friends that makes ASGBI such a friendly Association.

We continue with our series of webinars, free to members, throughout the year and I heartily commend them. There is a range of topics and something for everyone. We are also supporting a Twitter journal club - try following @ASGBIEastMidsJC! The date for the Emergency General Surgery Symposium has been set so please reserve the 29th September in your diaries. The theme of “Surgery in the Developed World, Developing world, and Real world” promises to be exciting with a wider view of general surgical emergencies. As usual this will be free to members.

Each of our Board of Directors continue to develop their portfolio and I am very lucky to have such a group of vibrant, driven and enthusiastic executives, generating many new ideas, and establishing committees of members to support each portfolio. Please do get involved yourself and keep an eye open for our adverts of job opportunities. Everybody matters, and everybody counts. If you want to get involved but don’t know how, then contact me.

We are all ably supported by our secretariat and a big thanks to them for their input and flexibility. You are welcome to contact Bhav and she will deal with most queries herself or find the most appropriate exec board member to respond.

Recent developments have included our trainee group the Moynihan Academy, brainchild of Gill Tierney your exceptionally able Vice-President; a research committee led by Susan Moug, Director of Research; an EGS committee led by Sonia Lockwood, Director of EGS; and Inclusivity & Diversity committee led by Nuha Yassin, Director of I&D.

Our Regional Representatives continue to develop, innovate, and are a sounding board for what is happening across the regions. I would like to welcome new ASGBI regional reps Ms Frances Howse for South Central & Wessex, Mr Gordon Pereira for the West Midlands, Mr Himanshu Wadhawan for West Scotland, and Dimitris Damaskos for Scotland East. Many of previous reps have gone onto ASGBI Exec posts. Please feel free to contact your regional rep. regarding regional matters. Names are available on the ASGBI website.

ASGBI also has a new SAS Representative, and I welcome Fuad Abid who is passionate about improving the profile and recognition of SAS doctors nationally. I would also like to thank our previous rep Gazalla Safdar for all her assistance to ASGBI.

Vassilios Papalois (Director of Communications) has delivered a new Journal we have named “ASGBI Surgery” with the aim of providing a platform for the publication of short articles and case reports with a very quick but robust peer review process. This has only just started and although it cannot be considered to become a citable medical journal in PubMed for at least 2 years, it has attracted already 10 excellent submissions of which 8 are published. If you have something you want published, please contact Vassilios. “ASGBI Surgical Life” continues the pedigree of our predecessor “Journal of ASGBI” addressing current and professional issues. This Spring 2021 issue of “ASGBI Surgical Life” serves as a prelude to our virtual congress and we are truly delighted that Lord Ara Darzi is our Guest Editor leading a great team of surgical innovators who present their work.

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FROM THE EXECUTIVE

The pace of change seems so fast now with many new and exciting developments. However, the whole general surgical community are about to become deeply involved in managing our patients who may already have waited 2 years for an operation. There is a huge amount of thought being put into this from individual clinicians up to senior NHS managers in the relevant devolved nations. In the end it will all come down to staff to deliver care for our patients.

Hopefully, we will be able to incorporate some of the changes wrought by COVID, particularly around technology, and create a better environment for our patients and the whole NHS.

I wish you all the best, and hope to “meet” you at the Virtual Congress in May.

Best Wishes

Mr Neil Welch
President, ASGBI

ASGBI is truly saddened by the passing of its long serving patron HRH Prince Philip, Duke of Edinburgh. Our century old Association has been deeply humbled and honoured to have the patronage of the Duke over several decades. Through the Duke’s office ASGBI has been supported in many ways and was extremely fortunate to have HRH The Princess Royal open our 2015 International Surgical Congress in Manchester. HRH Prince Philip, Duke of Edinburgh will be remembered by ASGBI with reverence and affection. He leaves behind a surgical community that has greatly benefitted from his philanthropy.

Contents of the Journal of the ASGBI

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A Letter from the Editor

Professor Vassilios Papalois, ASGBI Director of Communications

Dear Colleagues, Dear Friends,

The virtual ASGBI 2021 Congress promises to be a world class event that will attract participants from all over the word and will facilitate a most productive exchange of views and ideas regarding the future of our vocation.

We have now established three issues of ASGBI SURGICAL LIFE, and the spring issue serves as prelude to our Congress. This year, the theme of the Congress is Future Surgery Reboot, and the special issue is in the same spirit. It is a great honour to have Lord Ara Darzi as our Guest Editor. Lord Darzi has pioneered and championed surgical innovation internationally and leads in this issue a team of great surgical innovators who present their cutting-edge research related to all aspects of modern surgical practice. The articles are like a time machine offering an amazing journey to the future! I would like to express my gratitude to Lord Darzi and all authors. Also, my special thanks to Mr Hutan Ashrafian and Dr Steve McAteer for their most precious contribution in the preparation of the Guest Editor Section.

The Guest Editor Section is complemented with a series of articles related to expert views on future surgery including an in-depth review of the most influential surgical papers of the first 20 years of the 21st Century. Try to have your own guess as to which they might be before your read the article!

This year, we were also delighted that we launched our new journal ASGBI SURGERY. The new journal aims to offer a forum to all surgeons to present short articles related to clinical work, research and innovation. The other important characteristic of the journal is that we have a very quick (2 weeks!) but robust review process performed by a top-class Editorial Board. We were delighted that we had 10 submissions so far; 8 of those are already published and 2 more are in the peer review process. We are about to initiate the process of making the journal citable. You are most cordially invited to submit your work and spread the word to your colleagues; this is a journal that belongs to the ASGBI community!

I would also like to pay tribute to the Colleagues who took over the role as our Social Media Editors since last summer: Cleo Kennington, Jonathan Epstein, Kamal Mahawar, Irene Bellini, Dimitrios Damaskos and, as of May 2021, Alan Askari. They have done a superb job to raise the profile of the ASGBI in social media and facilitate networking.

I am also delighted that we have invited ASGBI members to join the ASGBI Communications Committee aiming to enrich the team, offer them opportunity to introduce new ideas, do great work and get the credit. We sincerely hope that many ASGBI members will apply and work together to pave the way to the future!

COVID 19 has been a great challenge but it did not manage to curb our enthusiasm for learning and innovation. We are certain that the ASGBI 2021 Virtual Congress would be testimony to that and the Spring Issue 2021 of ASGBI SURGICAL LIFE would be a good companion in the endeavour to explore Future Surgery.

Last, but most certainly not least, my grateful thanks to Ms Vicki Grant, our Communications and Events Manager, for her truly outstanding work for this issue as well as for the whole ASGBI Communications portfolio.

Enjoy reading!

2021 Virtual Congres

Director of the Scientific Programme, Mr Christian Macutkiewicz

When I think about "Future Surgery", I think about two things; the 2021 congress in May, and the future direction of surgery which is so important now that we have to reflect, reset and recharge after the COVID-19 pandemic has wreaked havoc for so many of us.

The "Future Surgery Reboot" congress this year focuses on four main themes: #EverybodyMatters, Innovation & Robotics, Training & Human Factors, and our core subject of Emergency General Surgery. The congress addresses what is important in our future, looking after ourselves, our trainees and our patients, and showcasing what research and innovation has brought into our practice. We have World leaders in robotic surgery sharing their visions for the future and we have experts in hernia surgery sharing their experience in tackling the difficult decision-making and procedural aspects of complex abdominal wall hernias in the elective and emergency setting.

For the first time ever, we have decided to dedicate the last day of the congress to trainees and to the latest aspects of training. I think it is so important for us to listen and understand what the modern trainee needs, the changes to the curriculum, modern ways of working and to respond to their views on training. They are the future of surgery, and it is our duty to help them get the most out of training.

We are pleased to be able to bring together a COVID-19 Symposium showcasing the important collaborative research projects that have been published during the pandemic, and which have shown how practice has changed during this time. It's important to be able to reflect on these and to ensure we learn from our experiences.

As an HPB surgeon I'm pleased to see the innovation that robotics is bringing to the specialty. We are honoured to have one of the highest volume robotic HPB surgeons at the congress. We also have leaders in robotic colorectal and hernia surgery to share their vision on the future of robotics in surgery. I think this is an exciting innovation, and while I do not think every operation will become robotic, I think there is a very real indication for complex operations that require fine motors skills in a confined environment. It is important to ensure that we introduce the technology with appropriate robust mechanisms and training programmes to ensure that our patients get the best of treatment, not just because a surgeon can do it, but because it's the best thing for them and for our NHS.

Finally, I want to look ahead at how we recover as a surgical community and a country. With so many cancelled elective operations, we need to be innovative in how we tackle the backlog. Whilst the creation of high-volume low complexity centres will help to deliver the numbers of procedures necessary to address this, it is important that we do not forget that these will be excellent facilities for trainees to learn the craft and skill of surgery. The future of surgery is not only filled with exciting innovation, but also with a need to graft, train and look after one another.

Future Surgery REBOOT
ASGBI VIRTUAL CONGRESS 2021
4TH - 8TH MAY 2021

Future Surgery as reflected in the 2021 ASGBI Virtual Congress

Value is the future of surgery

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Professor Jeffrey B. Matthews defines surgical practice as "an accumulated wisdom mixing fact, opinion, and magical thinking, in unknown proportions"[1]. Fortunately, this combination has traditionally worked to make surgery an effective and safe solution for many serious conditions.

Over the last three decades, surgeons have been pursuing a more scientific approach to the utilization of knowledge for surgical decision-making. Evidence-based practice was defined by Sackett et al. as “the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients”[2]. Applied to surgery, it has resulted in numerous advances, although the utilization of the best evidence to make decisions on an individual who does not meet all the criteria used in a randomized clinical trial is an imperfectly defined process, even more so if we take into account the quantity and quality of the evidence available to answer complex questions.

Even in times of evidence-based practice like these, surgeons, healthcare professionals, and patients continue being affected by five common problems summarised by Muir Gray for healthcare systems:

1. Unwarranted variability in quality and results,
2. Harm caused by adverse events and errors,
3. Waste of resources used for interventions that add no benefit,
4. Inequalities and inequities due to the overuse of resources for those who need them the least and the underuse for those who need them the most,
5. Failure to prevent disease.

In order to successfully face the abovementioned problems, while tackling complex challenges like the current pandemic, healthcare systems must undergo a radical transformation. Surgery, as a part of them, should incorporate a new framework and start focusing on generating more value: better experience and outcomes that matter to patients at a reasonable cost[3].

Probably, this transformation will not occur as the result of incremental improvements, but rather by more radical innovation in three deeply interconnected fields: culture, business model, and technology.

Accelerated social change is being led by patients, who demand shared decision making to find ubiquitous and convenient solutions, by massive access to information and knowledge, and by powerful digital technologies widely available everywhere. Patients visit their surgeons’ offices and ask important questions, which cannot be answered with the best information and knowledge currently available.

Peter Drucker reminded us that “Culture eats strategy for breakfast”. If there is no change, we will get more of the same. Thus, we should start by creating integrated programmes that encompass the entire cycle of care in a systematic way, with networks engaging patients in conversations for decision sharing, which will transform informed consent into informed request. And the siloed organizational structure should be abandoned to redesign care delivery processes.

For business model innovation, value-based contracting should be implemented.

But first, an agreement on what value is must be reached, because there are different types of value for different stakeholders[4] within the system and all of them must be aligned:

1. Allocative value (policy makers and managers),
2. Technical value (surgeons and related healthcare professionals),
3. Personal value (individual patients)
4. Societal value (communities).

Consequently, effective surgical care should be provided to all those in need in the community based on the best available evidence (clinical trials and real world data) by networks designed to function safely for patients, healthcare workers and trainees, in order to improve outcomes that matter to patients and their communities. The stewardship culture for the appropriate use of resources (financial costs, time and CO2) must be embedded in those networks. All this is in complete alignment with recent developments, such as enhanced recovery after surgery (ERAS)[5], “Choosing wisely”[6], and advances in the definition and analysis of patient reported experience (patient reported experience measurements, PREMs) and patient reported outcomes (patient reported outcomes measurements, PROMs)[7].

Last but not least, innovative digital technologies should enable systems to increase both the precision and the accuracy of interventions (image-guided procedures, robotization, automation, artificial intelligence, etc) and to quantify value, based on advanced analytics of data collected from various sources. Although decision making will be more data based (7), technology should be smartly incorporated as part of reengineered processes to avoid the risk of depersonalization (neglecting human agency and experience), which occurred in the past because of the industrialization of healthcare. However, moving into data-driven value-based surgery faces several limitations, like any transformation process in this digital era: trust, data veracity, replicability and reproducibility.

In summary, surgical practice must evolve to meet the requirements of a rapidly changing society. Evidence-based surgery is necessary but not sufficient to successfully tackle the current challenges A new framework that incorporates cultural changes, new business models, real world data and digital technologies, that is, value based surgery, is very much needed

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Communication, relationships and therapeutic alignment: goals of Patient-Provider Care

Timothy M. Pawlik, MD, MPH, MTS, PhD, FACS, RACS (hon.)

Communication is critical to align patient and provider expectations around treatment goals and possible outcomes. The experience of cancer patients is profoundly stressful due to multiple ambiguities that can accompany the disease, including the uncertainty of treatment-related decisions. For patients considering surgery as a part of their cancer treatment plan, an ill-informed decision to undergo a major procedure can result in unwanted immediate and long-term outcomes that decrease the quality and duration of survivorship. Unfortunately, there is widespread evidence that patients with cancer may not have optimal communication with their providers. In fact, research suggests that surgeons rarely employ shared-decision making strategies, which may result in different goals of treatment, including patients believing that a surgical procedure has the potential to cure their cancer even when this goal may be highly unlikely. As such, patients and providers can have misalignment of therapeutic goals, with patients having a more overly optimistic view of their prognosis and the likely benefits of treatment. To improve patient-physician communication, surgeons should take a patient-centered approach to support and develop goals of care that contextualized patient values and wishes. Up-front candid discussions of the underlying disease and the rationale of treatment, including the risks and benefits of surgery, is necessary for patients to select a treatment option consistent with their goals. Equally important is that the treating physician understands the patient's goals of therapy and recognizes what is most important to the patient receiving care. Both parties need to articulate clearly their needs and expected roles in the decision-making process. A patient may not rationalize medical decisions in the same manner as his or her physician; as such, each patient may require a different set of information. The surgeon should therefore specifically elicit the patient's goals of care and understand how the patient's anticipated goals (e.g., cure, symptom relief) compare with the surgeon's own understanding of what surgery might achieve. Even if there is only one dominant option, presenting alternatives and explaining how some options may be incongruent with a patient's goals will allow the patient to remain active in the decision-making process. Eliciting patient perceptions of their disease process and revealing their primary concerns is perhaps the biggest challenge during these discussions. While shared-decision-making should be facilitated, conversations around surgical goals of care should also focus on relational (e.g., empathy, trust, understanding) instead of "just" transactional processes (e.g., communication). Using a relational lens may facilitate the conceptualization and measurement of dynamic and reciprocal processes that occur within the context of a patient-surgeon relationship (e.g. shared-decision-making) as opposed to more unilateral concepts (e.g. information exchange). Relational techniques capture multiple perspectives of the individuals engaged in the cancer journey (e.g. physician, patient, nurse, spouse, family members, etc.). As such, rather than reducing the patient-surgeon relationship to isolated variables such as "communication," a "relational lens" considers all the aspects of the patient-surgeon relationship and its dynamic processes.

Technological Innovations

Shirin Towfigh

In the late 1990's, I chose to specialize in minimally invasive surgery (MIS) because I was intrigued by technological innovations I was seeing in laparoscopic surgery. The beauty of MIS is that we are in a constant motion forward. Robotic surgery has been the next stage of MIS. Intuitive Surgical, Inc. (Sunnyvale, CA, USA), based in my home state of California, has been the most successful in promoting robotics in general surgery; its da Vinci system was first introduced in 2000. The da Vinci robots are quite expensive, bulky, and therefore robotic surgery is primarily practiced in first world countries. The next generation of robots will include the Ottava™ system by Johnson & Johnson and the Hugo™ system by Medtronic, both expected to launch within the next 2 years [Figure 1]. These platforms are expected to be lower in cost and therefore more amenable for use in outpatient surgery centers and smaller healthcare systems.

Figure 1. A peek at the Medtronic Hugo™ RAS, expected to launch in late 2022. (Source: https://newsroom.medtronic.com/static-files/4155d177-2af3-461c-a17e-027f967353a1)

3D printing is a technique that allows any object to be recreated exactly as digitally designed. This technology is being increasingly adapted to surgical implants. Examples include 3D printing of the sternum or the jaw to replace surgically made defects as a result of infection or tumor. Wider application of 3D printing is being applied to hernia mesh that are tailored to the patient's anatomy, reducing risk of mesh folding, tightness, erosion, or other mesh-related complications. The mesh can be embedded with various agents in the printing process, such as antimicrobials, contrast agents, and stem cells[1].

The use of magnets has integrated into surgical practice in various ways. Magnetic instruments, such as the Levita® (Levita Magnetics, Menlo Park, CA, USA), are able to perform intra-abdominal functions, such as to retract a gallbladder or liver, without requiring percutaneous access [Figure 2]. This reduces the number of incisions and perhaps improves surgical site outcomes and recovery[2]. The introduction of more than one magnetically controlled instrument may promote MIS to be even less invasive than today. Another application of magnetic technology is for endoscopic GI anastomosis.

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FEATURES

Dubbed to be a magnamosis, the "Harrison ring" (Magnamois, Inc., San Francisco, CA, USA) involves placing donut shaped magnets across two adjacent GI tracts [Figure 3]. The tissues between the magnets fuse and a fistulous tract develops as the entrapped tissue dies[3]. The magnets can make anastomoses via a less invasive approach, with potentially less cost and less long-term risks.

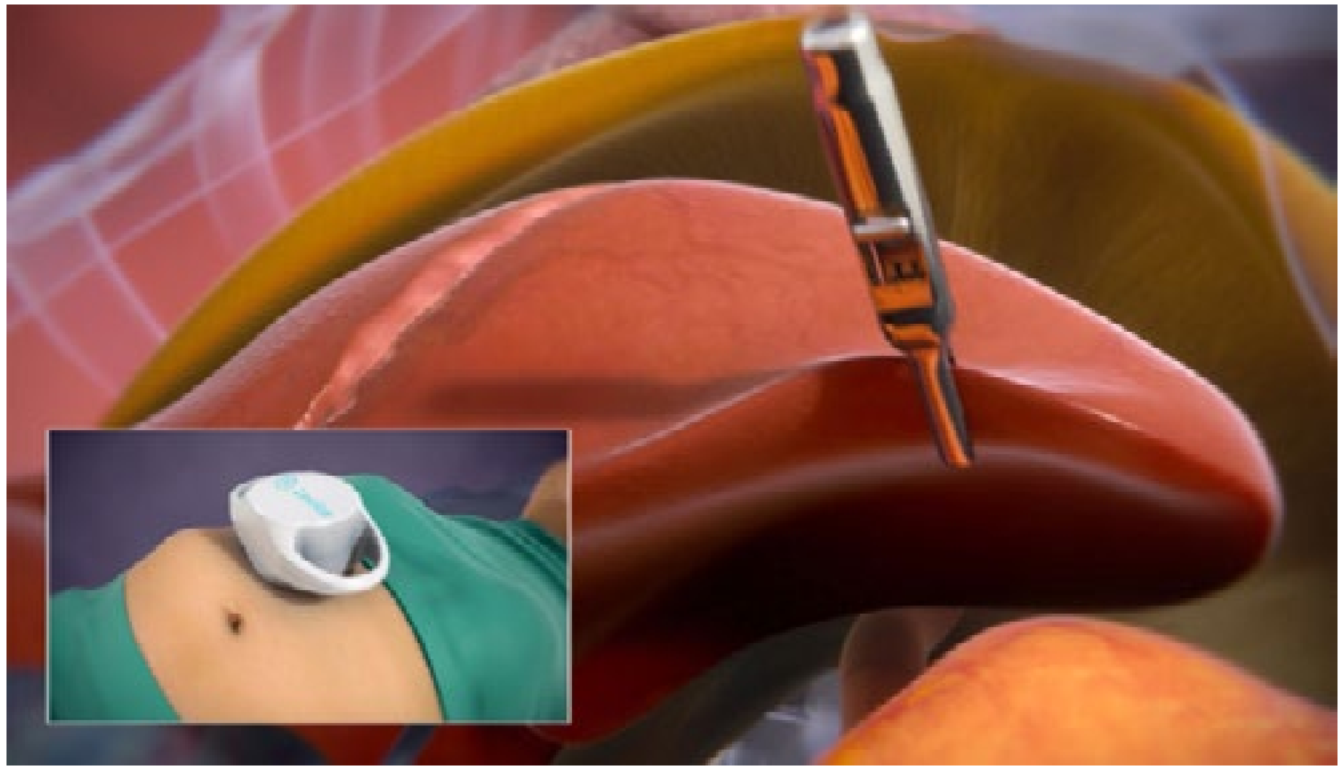

Figure 2. Use of magnetic technology to provide gallbladder retraction without a separate incision. (Source: https://www.magneticsurgery.com/news)

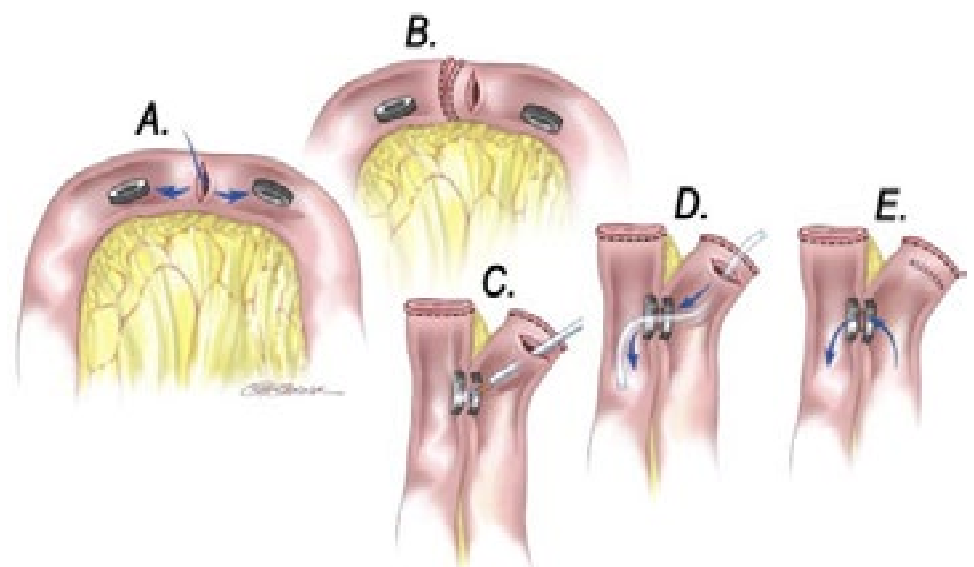

Figure 3. Magnetic compression has been shown to successfully create anastomoses. These magnets may be placed endoscopically. (Source: https://surgicalinnovations.ucsf.edu/project-portfolio/other-active-projects/magnamosis.aspx)

Finally, I believe that advances in imaging will offer the greatest innovations in general surgery. As we move toward less invasive procedures, we lose tactile sense but improve in visualization of our targets. As optics integrate more with our surgical environment, we will be able to perform more precise operations with the benefits of live directed image guidance or augmented reality[4]. Improvements in optics will allow us to visualize cancer cells at the cellular level, where they are otherwise non-palpable and not seen with standard imaging [Figure 4]. The addition of artificial intelligence will promote even safer and less invasive surgery.

In summary, the surgeon of the future will be less invasive, more precise, and less harmful to the patient of the future.

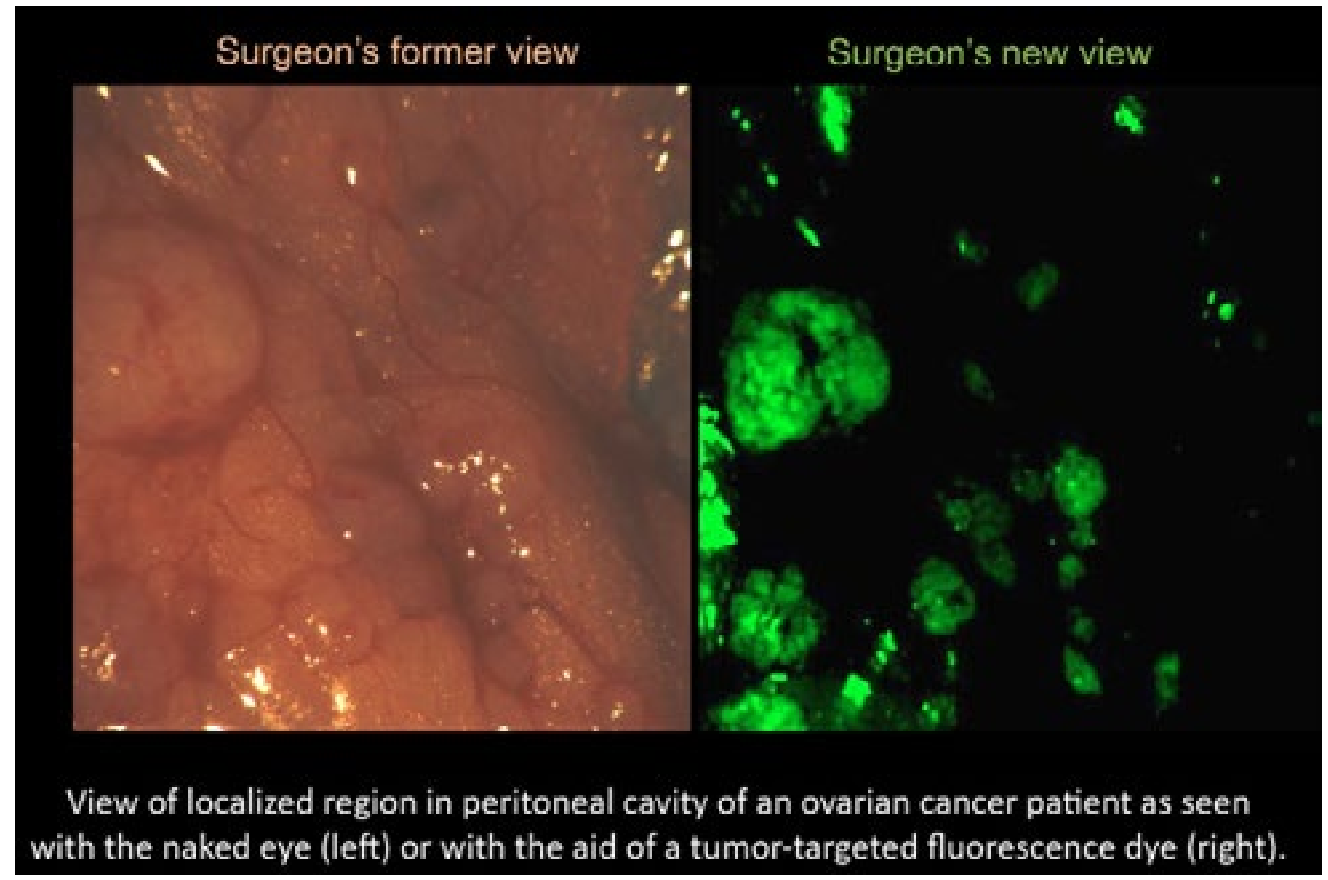

Figure 4. Use of in vivo optical evaluation to guide the surgeon during cancer surgery. (Source: https://www.chem.purdue.edu/low/research/tumor-targeted-dyes.html)

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The future management of anal fissure is primarily outpatient based

Tessa C Fraser and Katie LR Cross, Northern Devon Healthcare Trust, Barnstaple

An anal fissure is a linear tear in the squamous epithelium of the anal canal, distal to the dentate line. Although a benign condition, symptoms including painful defaecation and rectal bleeding significantly impact on quality of life and prompt urgent referral for colorectal opinion. A wide variety of treatment options exist and a sensible step-wise approach is recommended[1]. The Association of Coloproctology (ACP) is currently updating this position statement in conjunction with the European Society of Coloproctology (ESCP).

GPs effectively manage the majority of acute anal fissures with laxatives, analgesics and topical ointments to optimise blood flow - by relaxation of the smooth muscle cells in the internal sphincter and arteries. Evidence suggests that two months of topical treatment results in 63% healing with GTN, and 52% healing with Diltiazem ointments[2]. However failure or recurrence is not uncommon (up to 40%), and treatment with botulinum toxin (botox) is typically the next step, prior to consideration of more definitive surgery.

Traditionally, botox treatment is given in a surgical setting as part of a formal examination under anaesthetic (EUA) in theatre. Nonetheless, it is entirely feasible to inject botox in the outpatient setting. Although not a new concept, this is not yet widely practiced in UK. Our hospital has been running a specialist fissure clinic for 12 years. The clinic was set up with the aim of streamlining management through more efficient delivery of botox treatment, with the added benefit of significant cost saving.

A recent audit of 152 anal fissure patients attending this clinic between June 2016 – October 2020, found that 93 (61%) of patients were given botox treatment, 83% within the outpatient setting. For a significant proportion (67 patients), this was their definitive treatment. Outcomes in this group were good; 57% (35 patients) fully healed and 36% (22 patients) partially healed (defined as patients with fissures that intermittently heal and break down, but who do not want further medical input).

The benefits of this non-operative pathway are numerous, both for the patient and the wider NHS. The patient is simultaneously assessed and treated in one appointment; saving multiple hospital trips and reducing the overall duration of painful symptoms. The most obvious benefit for the NHS is financial. Outpatient delivery of botox in clinic costs £170 vs £1650 in theatre. However, the cost saving this represents is greater than the sum of individual patients treated, as several patients received multiple treatments. Although the evidence for multiple treatments is limited, this was often patient choice. Number of outpatient botox treatments per patient is demonstrated in Figure 1. Overall, non-operative management of patients related to the delivery of 116 outpatient botox treatments. This equates to a saving of £171,680. Furthermore, in the era of COVID the requirement for pre-operative COVID testing and self-isolation place an additional cost on treatment in the theatre setting.

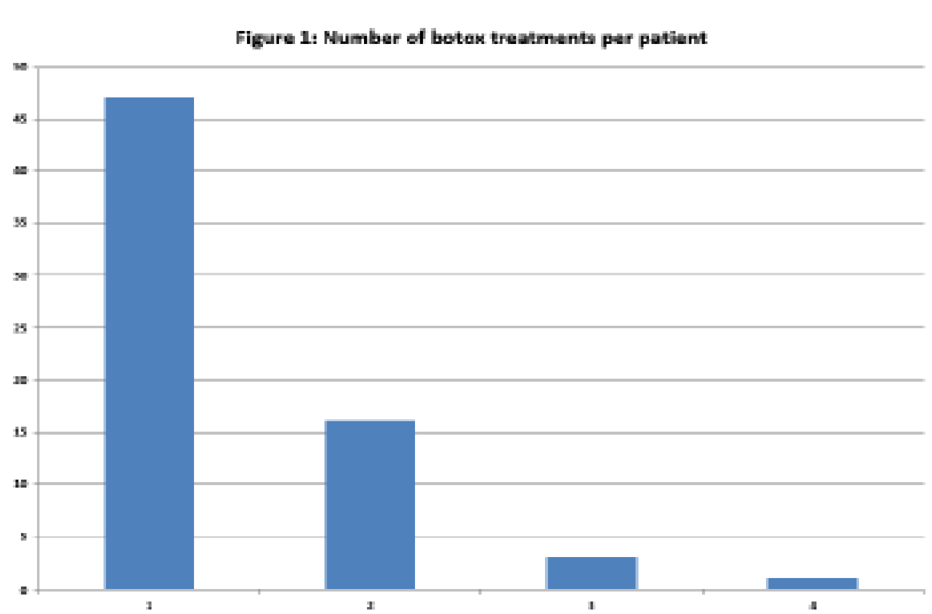

Figure 1: Number of botox treatments per patient

There remain a subset of patients that require a formal EUA for either diagnostic uncertainty or treatment for concurrent anorectal disease (haemorrhoids, abscess and/or fistula) or further dedicated fissure surgery, such as lateral sphincterotomy or anal advancement flap. In our service analysis, of the 16 patients given botox treatment in theatre; 9 patients underwent an additional procedure for a co-existing anorectal condition(s), and 7 underwent a simple diagnostic EUA along with delivery of botox. See Figure 2 for a breakdown of additional procedures performed. We reason that by treating patients in the outpatient setting where suitable, time and resources can be dedicated appropriately to these more complex cases.

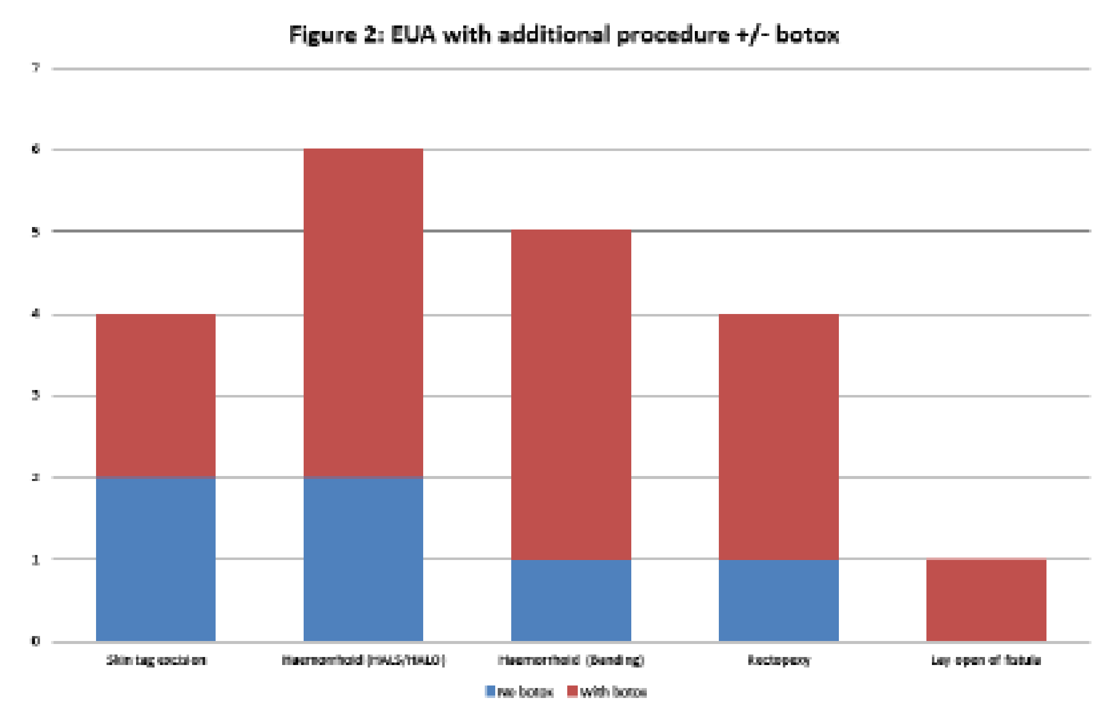

Figure 2: EUA with additional procedure +/- botox

Evidence supports lateral sphincterotomy as the best treatment option for healing and reduced recurrence of anal fissure[2]. This treatment strategy assumes the aetiology is high pressure sphincter tone. However, if a fissuerectomy is performed at the same time as the lateral sphincterectomy, it is unclear how much the fissurectomy itself contributes to healing rates. When managing more complex anal fissure patients, a particular concern is the association with anal fistula (approximately 5% in our data). The exact aetiology is not fully understood, but it has been suggested that fistula formation arises due to the bucket handle defect of the internal sphincter seen in anal fissure which enables abscess formation with subsequent fistulation[3]. Further inspection with EUA and laying open the low anal fistula with fissurectomy treats both the fissure and the fistula[4]. Fistula formation in anal fissures may occur with or without botox treatment. In our audit, 4 patients developed anal fistula after botox treatment, and 3 additional patients were treated for fistulae preceding or without any botox treatment. This highlights the complexity of co-existing anal disease and emphasizes the need for sequential treatment strategies. An alternative diagnosis (i.e. Crohns) should be considered in poorly healing fissures, whereby diagnosis and appropriate medical management improves healing but recurrence rates are high.

Within our unit, only small numbers undergo surgery. In just over four years, 12 anal advancement flaps and 1 lateral sphincterotomy were performed on 10 patients. These small numbers could be attributed to patients not wanting to risk higher rates of incontinence with sphincterotomy[5] and may partly reflect lack of access to benign operating time. Following our audit, we are pushing for higher prioritization of benign proctology with greater day-case operating and faster time to surgery. Notwithstanding their eventual operative management, 9 patients who underwent definitive surgery still received outpatient botox treatment. As such, they avoided the need for multiple surgical procedures with follow-up appointment and benefited from a more streamlined pathway leading to the decision to undergo dedicated fissure surgery earlier.

In our experience, the ability to deliver botox treatment in the outpatient setting has proven to be a valuable asset. We encourage this in the future management of anal fissure in the modern-day National Health Service (NHS). Not only is it proven to be cost-effective, but it also frees up surgical resources for operative management of complex cases. However, for this success to gain traction in the wider NHS the importance of high-quality management, along with appropriate resource allocation to benign proctology must be recognised by every Trust.

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Surgery and Surgical Research 2021: Learning from the past and looking ahead

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Introduction

In 1996, just before the rise of the new century, Richard Horton, the Editor in Chief of The Lancet, in one of his editorial commentaries, asked a very fundamental question: “Does surgical research have a future?”[1]. Indeed, at the time it was unclear whether outside the academic setting, research in a surgical career was considered essential, was prioritized, was highly thought of and appropriately conducted [1]. On the same year, Sackett DL et al, highlighted a new concept, known to every healthcare practitioner nowadays: Evidence Based Medicine (EBM) [2]. This concept revolutionized the practice of medicine in every field of medical practice, including surgery. Surgeons across the world came quickly to realize that the “art” and the “experience” of surgery should be combined with knowledge and scientific evidence produced and validated by research, for better results to be achieved[2].

Surgical research and EBM have radically transformed the practice of surgery during the 21st century and have completely changed the landscape. The amount of new knowledge and the advancements produced and made their way to clinical practice over the last 20 years is unprecedented. The big picture is also completely different. Almost every field of surgical practice has been subspecialized, services have been centralized and practitioners have been trained, updated and possibly re-trained in order to efficiently incorporate the new knowledge and technological breakthroughs available into clinical practice and to translate them into patients’ benefit. Thus, for most of us who practice surgery in the context of the modern NHS, the value of surgical research and EBM is given, and the question asked by Dr. Horton now feels outdated.

But as Winston Churchill once said: “Those that fail to learn from their history are doomed to repeat it.” So, what if we take a step back and given the advantage of the time passed, try to address Dr. Horton’s most fundamental question? Most importantly, what if we ask ourselves the very same question again today: “Does surgical research have a future?”

These are the questions that we will try to address here. Our primary objective is to overview the progress in the field of surgical research, summarize the top 20 most influential surgical journal articles in the 21st century and assess their clinical impact. Secondarily, we seek to identify the themes and the fields that these articles referred to as well as to foresee future trends in surgery and surgical research in these areas.

Methods

To address these objectives, we first identified all the scientific journals in the field of surgery since 2000 through the InCites archive of the Institute for Scientific Information (ISI)[3]. We acquired sequential benchmarking data on the volume (number of journals) and the impact of surgical research (number of citations and aggregate impact factor of surgical journals) compared to research in other scientific fields.

We then identified the top 5 journals in the field of surgery with the highest impact factor, per annum, for the last 20 years, using the Journal Citation Report, available from the ISI[4]. We searched the Web of Science archive and identified all the articles published in these journals since the 1st of January of 2000[5]. For every consequent year between 2000 and 2019 we identified one article per year; this was the most cited amongst all articles published in these journals on the same year. To identify these publications, we used the “times cited’’ function in the Web of Science search engine[5]. For an article to be considered eligible for inclusion in the present report the following criteria should be met:

1. The article should refer to a surgical topic.

2.The article should have been published in one of the top 5 most influential surgical journals (on the year of its publication).

3.The article should have had the highest number of citations amongst all articles published in the top 5 most influential surgical journals in the same year.

Data from the identified articles were extracted on:

1.The year and journal of publication.

2.The authors’ institution or the relevant scientific society and the country of origin. For international studies, the country of the leading institution or the country of the scientific society or the country of the majority of the authors was considered as the country of origin.

3.The number of citations.

4.The study type.

5. The field of surgery.

6.The article’s topic.

7.The most important conclusions.

8.The article’s recommendations on future research.

All data items were extracted in predefined data operation spreadsheets and synthesized qualitatively in order to address the study objectives outlined above.

Results

Expansion of surgical research in the 21st century

From the beginnings of the 21st century, surgical research has been expanded in volume and has become more impactful. As shown in Figure 1, the absolute number of scientific surgical journals has increased by 55%; from 136 in 2000 to 210 in 2019. Apart from the expansion in the volume of publications, the impact of surgical research is also greater today compared to 20 years ago. A 300% increase in the cumulative number of citations has been observed when the aggregate impact factor of surgical journals had a steady incremental rise, from 1.59 in 2003 to 2.56 in 2019.

Though, in order to better understand these numbers, it is crucial that we put them in context. According to the ISI, the volume of research publications in the field of surgery has been consistently high over the last 20 years. Among all the 235 different scientific fields (all areas of science considered), surgery ranked consistently between places 10 (in 2000) and 14 (in 2019), when the fields were ranked per absolute number of scientific publications[3]. When the different fields were ranked per aggregate impact factor of their scientific journals, surgery ranked between places 79 (in 2003) and 139 (in 2019) out of 235 scientific fields[3]. Medical oncology, a field with similar publication volumes to surgery ranked between places 10 (in 2003) and 16 (in 2019) out of 235 in fields in the latter ranking[3].

Figure 1A) The number of active scientific surgical journals since 2000. 1B) The cumulative number of citations for all articles published in scientific surgical journals during the last 20 years. 1C) Aggregate Impact Factor of all scientific surgical journals in the 21st century.

Figure 1A.

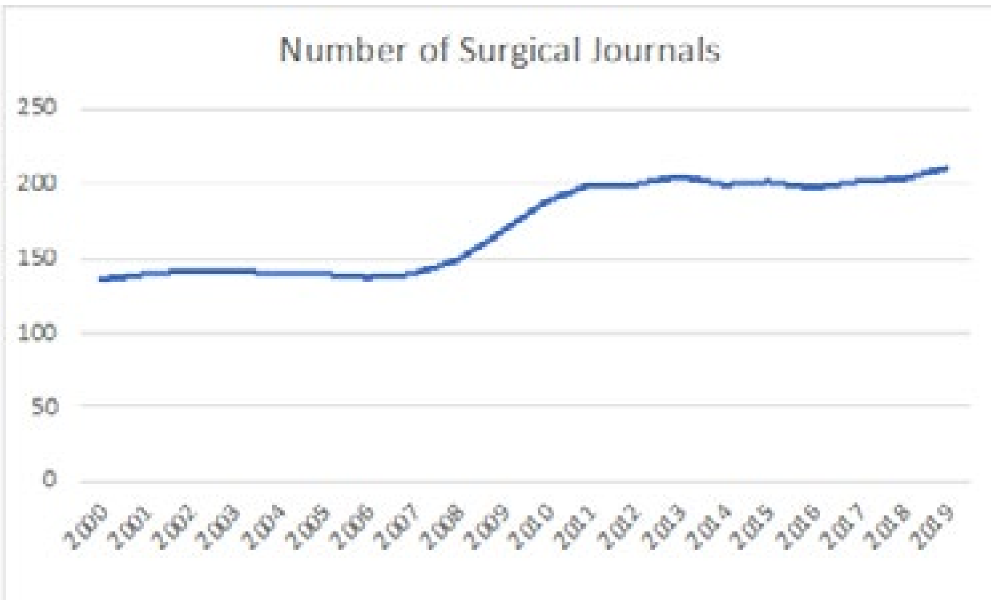


Figure 1B.

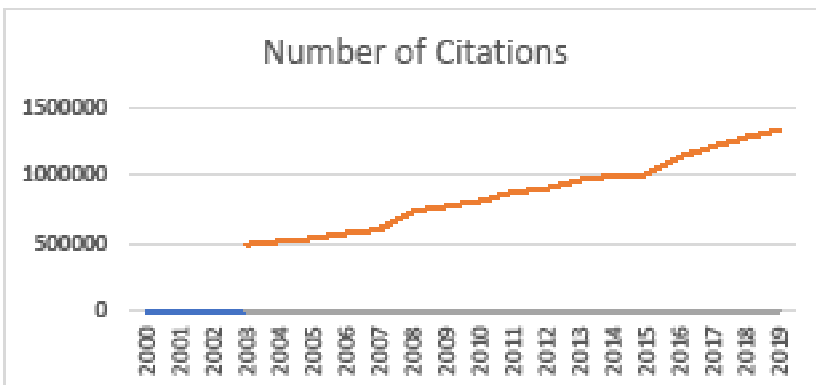
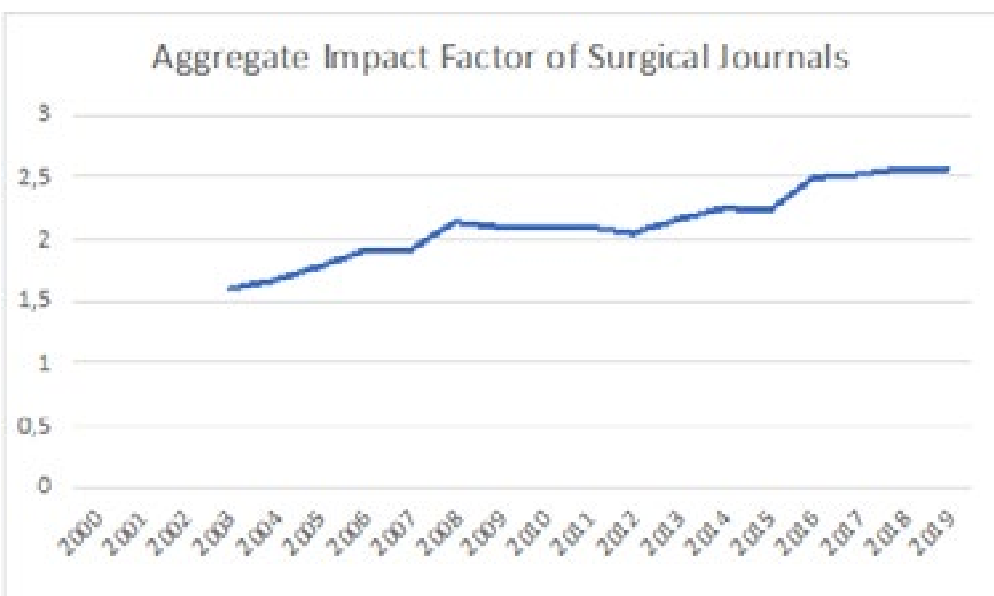


Figure 1C.



The most influential publications in the field of surgery in the 21st Century

To overview the progress made in surgical research, we identified the top 5 surgical scientific journals with the highest impact factor, per annum, for the last 20 years, using the Journal Citation Report, available from the ISI[4]. These journals along with the relevant impact factors can be seen in Table 1.

We then searched the Web of Science archive and identified all the articles published in these journals since 2000[5]. Our search returned 80,719 scientific publications. Among these we identified, the top 20 most influential surgical papers published between 2000 and 2019. These can be found on Table 2.

Table 3 illustrates the characteristics of these publications. With regard to the country of origin 45% of these publications came from the USA, 30% from Switzerland, 10% from the UK and the remaining 15% from other countries (Japan, Denmark and Canada). The most prevalent study types were Cohort Studies (45%), Consensus and Guidelines publications (40%), Randomized Clinical Trials (RCTs) (10%) and Review papers (5%). Out of 20 publications 10 (50%) referred to the field of transplantation, 5 (25%) to the perioperative care of surgical patients, 3 (15%) to the field of surgical oncology, 1 (5%) to the field of minimally invasive surgery and 1 (5%) to surgical education and training.

Table 1. The top 5 most influential surgical journals per annum (2000-2019)

Year	Surgical Journal with the highest Impact Factor (Impact Factor)	Surgical Journal with the 2nd highest Impact Factor (Impact Factor)	Surgical Journal with the 3rd highest Impact Factor (Impact Factor)	Surgical Journal with the 4th highest Impact Factor (Impact Factor)	Surgical Journal with the 5th highest Impact Factor (Impact Factor)
2000	Annals of Surgery (2.987)	American Journal of Surgical Pathology (4.369)	Transplantation (4.035)	Journal of Endovascular Surgery (3.276)	Journal of Vascular Surgery (3.114)
2001	Annals of Surgery (6.679)	Journal of Endovascular Surgery (3.487)	Transplantation (4.189)	American Journal of Surgical Pathology (3.491)	British Journal of Surgery (2.464)
2002	Annals of Surgery (6.573)	American Journal of Transplantation (4.040)	American Journal of Surgical Pathology (4.125)	Annals of Surgical Oncology (3.034)	Liver Transplantation (3.766)
2003	Annals of Surgery (7.947)	American Journal of Transplantation (3.698)	American Journal of Surgical Pathology (4.313)	Liver Transplantation (4.341)	British Journal of Surgery (3.773)
2004	Annals of Surgery (2.987)	American Journal of Transplantation (3.308)	American Journal of Surgical Pathology (4.650)	Annals of Surgical Oncology (3.433)	Endoscopy (4.874)
2005	Annals of Surgery (6.328)	American Journal of Transplantation (6.002)	Liver Transplantation (4.447)	American Journal of Surgical Pathology (4.377)	Endoscopy (4.872)
2006	Annals of Surgery (7.678)	American Journal of Transplantation (6.843)	Liver Transplantation (4.628)	American Journal of Surgical Pathology (4.144)	British Journal of Surgery (4.092)
2007	Annals of Surgery (7.448)	American Journal of Transplantation (6.433)	British Journal of Surgery (4.304)	American Journal of Surgical Pathology (4.183)	Endoscopy (4.166)
2008	Annals of Surgery (7.900)	American Journal of Transplantation (6.339)	Endoscopy (6.081)	British Journal of Surgery (4.921)	Journal of Neurology, Neurosurgery and Psychiatry (4.622)
2009	Annals of Surgery (7.900)	American Journal of Transplantation (6.433)	Endoscopy (5.345)	Journal of Neurology, Neurosurgery and Psychiatry (4.869)	JAMA Surgery* (4.325)
2010	Annals of Surgery (7.474)	Endoscopy (6.096)	American Journal of Transplantation (5.851)	Journal of Neurology, Neurosurgery and Psychiatry (4.791)	JAMA Surgery* (4.388)
2011	Annals of Surgery (7.492)	American Journal of Transplantation (6.394)	Endoscopy (5.210)	Journal of Neurology, Neurosurgery and Psychiatry (4.764)	British Journal of Surgery (4.606)
2012	Annals of Surgery (6.329)	American Journal of Transplantation (6.192)	Endoscopy (5.735)	Journal of Neurology, Neurosurgery and Psychiatry (4.924)	American Journal of Surgical Pathology (4.868)
2013	Annals of Surgery (7.188)	American Journal of Transplantation (6.190)	Journal of Heart and Lung Transplantation (5.611)	Journal of Neurology, Neurosurgery and Psychiatry (5.580)	British Journal of Surgery (5.210)
2014	Annals of Surgery (8.327)	Journal of Neurology, Neurosurgery and Psychiatry (6.807)	Journal of Heart and Lung Transplantation (6.650)	American Journal of Transplantation (5.683)	British Journal of Surgery (5.542)
2015	Annals of Surgery (8.569)	Journal of Heart and Lung Transplantation (7.509)	Journal of Neurology, Neurosurgery and Psychiatry (6.431)	American Journal of Transplantation (5.683)	JAMA Surgery (5.681)
2016	Annals of Surgery (8.980)	JAMA Surgery (7.558)	Journal of Neurology, Neurosurgery and Psychiatry (7.349)	Journal of Heart and Lung Transplantation (7.114)	American Journal of Transplantation (6.165)
2017	Annals of Surgery (9.203)	JAMA Surgery (8.498)	Journal of Heart and Lung Transplantation (7.955)	Journal of Neurology, Neurosurgery and Psychiatry (7.144)	Endoscopy (6.629)
2018	JAMA Surgery (10.668)	Annals of Surgery (9.476)	Journal of Heart and Lung Transplantation (8.578)	Journal of Neurology, Neurosurgery and Psychiatry (8.327)	American Journal of Transplantation (7.163)
2019	JAMA Surgery (13.625)	Annals of Surgery (10.130)	Journal of Neurology, Neurosurgery and Psychiatry (8.263)	Journal of Heart and Lung Transplantation (7.865)	Endoscopy (7.341)

*At the Time the journal was titled "Archives of Surgery"

Table 2. The top 20 most influential surgical publications in the 21st century

Year	Authors	Journal	Title
2000	DeMatteo RP et al [6]	Annals of Surgery	Two hundred gastrointestinal stromal tumors - Recurrence patterns and prognostic factors for survival
2001	Jarnagin WR et al [7]	Annals of Surgery	Staging, resectability, and outcome in 225 patients with hilar cholangiocarcinoma
2002	Seymour NE et al [8]	Annals of Surgery	Virtual reality training improves operating room performance – Results of a randomized, double-blinded study
2003	Brandstrup B et al [9]	Annals of Surgery	Effects of intravenous fluid restriction on postoperative complications: Comparison of two perioperative fluid regimens – A randomized assessor-blinded multicenter trial
2004	Dindo D et al [10]	Annals of Surgery	Classification of surgical complications – A new proposal with evaluation in a cohort of 6336 patients and results of a survey
2005	Epstein JI et al [11]	American Journal of Surgical Pathology	The 2005 International Society of Urological Pathology (ISUP) Consensus Conference on Gleason Grading of Prostatic Carcinoma
2006	Feng S et al [12]	American Journal of Transplantation	Characteristics associated with liver graft failure: The concept of a donor risk index
2007	Solez K et al [13]	American Journal of Transplantation	Banff '05 Meeting report: Differential diagnosis of chronic allograft injury and elimination of chronic allograft nephropathy ('CAN')
2008	Solez K et al [14]	American Journal of Transplantation	Banff 07 classification of renal allograft pathology: Updates and future directions
2009	Clavien PA et al [15]	Annals of Surgery	The Clavien-Dindo Classification of Surgical Complications Five-Year Experience
2010	Inoue H et al [16]	Endoscopy	Peroral endoscopic myotomy (POEM) for esophageal achalasia
2011	Lamb KE et al [17]	American Journal of Transplantation	Long-Term Renal Allograft Survival in the United States: A Critical Reappraisal
2012	Sellares J et al [18]	American Journal of Transplantation	Understanding the Causes of Kidney Transplant Failure: The Dominant Role of Antibody-Mediated Rejection and Nonadherence
2013	Feldman D et al [19]	Journal of Heart and Lung Transplantation	The 2013 International Society for Heart and Lung Transplantation Guidelines for mechanical circulatory support: Executive summary
2014	Haas M et al. [20]	American Journal of Transplantation	Banff 2013 Meeting Report: Inclusion of C4d-Negative Antibody-Mediated Rejection and Antibody-Associated Arterial Lesions
2015	Kirklin JK et al [21]	Journal of Heart and Lung Transplantation	Seventh INTERMACS annual report: 15,000 patients and counting
2016	Mehra MR et al [22]	Journal of Heart and Lung Transplantation	The 2016 International Society for Heart Lung Transplantation listing criteria for heart transplantation: A 10-year update
2017	Ljungqvist O et al [23]	JAMA Surgery	Enhanced Recovery After Surgery: A Review
2018	Haas M et al. [24]	American Journal of Transplantation	The Banff 2017 Kidney Meeting Report: Revised diagnostic criteria for chronic active T cell-mediated rejection, antibody-mediated rejection, and prospects for integrative endpoints for next-generation clinical trials
2019	Low DE et al [25]	Annals of Surgery	Benchmarking Complications Associated With Esophagectomy

Table 3. Journal Publications' Characteristics.

Authors, Year	Country	Study Type	Field	Topic	Number of Citations
DeMatteo RP et al, 2000 [6]	USA	Cohort Study	Surgical Oncology	Gastrointestinal Stromal Tumours (GISTs)	1683
Jarnagin WR et al, 2001 [7]	USA	Cohort Study	Surgical Oncology	Hilar Cholangiocarcinomas	848
Seymour NE et al, 2002 [8]	USA	Randomized Controlled Trial	Surgical Education and Training	Virtual Reality Surgical Simulation	1693
Brandstrup B et al, 2003 [9]	Denmark	Randomized Controlled Trial	Perioperative Care	Restricted Vs Standard post-operative Intravenous fluid administration	968
Dindo D et al, 2004 [10]	Switzerland	Cohort Study	Perioperative Care	Classification system for post-operative complications	14921
Epstein JI et al, 2005 [11]	USA	Consensus & Guidelines	Surgical Oncology	Prostate Cancer	1861
Feng S et al, 2006 [12]	USA	Cohort Study	Transplantation	Liver Graft Survival	1194
Solez K et al, 2007 [13]	Switzerland	Consensus & Guidelines	Transplantation	Renal Graft Survival	832
Solez K et al, 2008 [14]	Switzerland	Consensus & Guidelines	Transplantation	Renal Graft Survival	1450
Clavien PA et al, 2009 [15]	Switzerland	Consensus & Guidelines	Perioperative Care	Classification system of post-operative complications	4396
Inoue H et al, 2010 [16]	Japan	Cohort Study	Minimally Invasive Surgery	Oesophageal Achalasia	858
Lamb KE et al, 2011 [17]	USA	Cohort Study	Transplantation	Renal Graft Survival	564
Sellares J et al, 2012 [18]	Canada	Cohort Study	Transplantation	Renal Graft Survival	786
Feldman D et al, 2013 [19]	USA	Consensus & Guidelines	Transplantation	Mechanically Assisted Circulatory Support	743
Haas M et al, 2014 [20]	Switzerland	Consensus & Guidelines	Transplantation	Renal Graft Survival	676
Kirklin JK et al, 2015 [21]	USA	Cohort Study	Transplantation	Mechanically Assisted Circulatory Support	848
Mehra MR et al, 2016 [22]	USA	Consensus & Guidelines	Transplantation	Mechanically Assisted Circulatory Support	491
Ljungqvist O et al, 2017 [23]	UK	Review Article	Perioperative Care	Enhanced Recovery After Surgery	611
Haas M et al, 2018 [24]	Switzerland	Consensus & Guidelines	Transplantation	Renal Graft Survival	356
Low DE et al, 2019 [25]	UK	Cohort Study	Perioperative Care	Complications after oesophagectomy	136

Clinical impact of surgical research in the 21st Century

The 20 publications presented above outline impressive progress in surgical research in different topics and surgical fields. This progress had a certain impact in the practice of surgery in these fields that we are going to explore here.

Transplantation

Liver Graft Survival

Feng S. et al in their 2005 cohort study presented a liver donor risk index in an effort to quantify the risk of graft failure and to inform the decision of potential recipients[6]. They concluded that their index score can be used to inform the process of organ acceptance and they recommended that future research should focus on the interaction between donor risk index and recipients' risk factors to improve liver grafts' survival rates. Indeed nowadays, there is a plethora of scoring systems to predict graft survival[26]. Among these, models that combine donor and recipient characteristics (i.e. the donor-to-recipient model – DRM -) have been found to have greater accuracy in predicting long-term graft survival and are considered advantageous in informing the organ acceptance process[26]. Clinicians and patients have been able to take better informed decisions on the suitability of organs for transplantation and the selection of the appropriate recipients as a result of these advancements. 10-year liver graft survival rates have increased exponentially over the last 20 years from 57% in 2000 up to 83% in 2020[27-28].

Renal Graft Survival

Improving survival rates of renal grafts was possibly overall the most popular topic in surgical research over the last 20 years. The advancements on this field were tremendous. This progress was made possible by achieving a better understanding behind the pattern of graft failure (hyperacute, acute and chronic), the different causes (primary diseases, surgical complications, Antibody Mediated Rejection, T-cell Mediated Rejection, Polyoma Virus Nephropathy, nonadherence etc.) and most importantly by reaching expert consensus on how to best diagnose and treat those entities and communicating it to clinicians across the world[13,14,17,18,20,24]. 10-year renal graft failure rates have declined sharply over the last 20 years.

Mechanical Circulatory Support

Mechanical Circulatory Support is miracle of modern medicine coming from the past century. Despite the fact that the invention of ventricular assist devices can be traced back to the 1950s, approval by the regulatory authorities (i.e. Food and Drug Administration) was not granted up until the late 1970's. It was during the last 20 years that these devices were studied extensively, and guidelines were produced for the implantation of the devices either as a bridge therapy to transplantation or as a destination therapy for unfit heart failure patients[21-22]. Continuous research on the field has resulted in high survival rates for patients with ventricular assist devices (up to 80% 1-year and 70% 2-year survival)[21-22].

Perioperative Care

Standardizing reporting of perioperative complications was one the greater objectives of surgical research in the first 20 years of the 21st century[10,15,25]. The Clavien-Dindo classification, possibly the most popular publication in the beginning of the new century, gave us, the opportunity to credibly measure the incidence and the impact of post-operative complications[10,15]. This was the first step before the improvement of perioperative outcomes was made possible. Indeed, the impact of the implication of new perioperative interventions and clinical pathways, as the Enhanced Recovery After Surgery (ERAS) pathways, would not have been possible without having a standardized way of monitoring outcomes[23]. The introduction of ERAS pathways in different fields of surgery (colorectal, upper gastrointestinal surgery, transplantation etc.) has decreased the incidence of perioperative complications and the associated healthcare costs and increased the patients' satisfaction. ERAS can be considered one of the best applications of EBM in the practice of surgery[23,29].

Surgical Oncology

Surgical Oncology was possibly the most impactful field of surgical research during the first 5 years of the 21st century. Thereafter, things rapidly changed and oncological topics became less popular in surgical research. This could be partially due to the fact that advancements in medical oncology shifted the tide towards the expansion of the medical management in an increasing number of neoplasms.

For examples, De Matteo RP et al, in the beginning of the century investigated the management of Gastrointestinal Stromal Tumours (GISTs) and concluded that surgery alone is inadequate for their treatment[6]. They therefore suggested that future research should focus on the development of more effective adjuvant therapies[6]. Indeed, within the next 15 years through a series of RCTs, a tyrosine kinase inhibitor -imatinib- became the standard of care for the management of advanced/metastatic GISTs resulting in an impressive decrease in the mortality of patients with GISTs[30]. On the other hand, there are still certain neoplasms, as for example the hilar cholangiocarcinoma, where early research in the beginning of the century suggested that a more aggressive surgical approach is warranted[7]. Over the last 20 years, the role of surgery has been expanded in the management of hilar cholangiocarcinoma, incorporating new techniques and interventions (hepatectomy, liver transplant, vascular embolization)[31].

Minimally invasive surgery

Despite the fact that there was an evident increase in the use of robotics and other forms of minimally invasive surgery across the world over the last 20 years, only one publication from this field made its way to our list. This could be attributed to the fact that most of the studies in minimally invasive surgery are costly, require expertise and are therefore less reproducible. Thus, it is not a surprise that a relevantly simple and reproducible technique from the field of surgical endoscopy, the Peroral Endoscopic Myotomy (POEM), revolutionized the management of esophageal achalasia, decreased patients' perioperative morbidity and made its way to the top 20 most influential surgical publications[16].

Surgical Education And Training

The field of surgical training has traditionally been centrally placed in the life of surgical practitioners. The balance between the need for training for the novices and the safety of the patients has been extensively studied through the years. Progress in the field of surgical simulation with the introduction of Virtual Reality (VR) simulation in the early 2000s' introduced an alternative way of training that does not compromise patients' safety[8]. Nowadays, VR simulation is gradually been introduced in surgical training programs worldwide[32].

Trends in Future Research

In an effort to foresee future trends in surgical research we reviewed the abovementioned top 20 most influential surgical journal publications in the 21st century. Most importantly, we tried to identify the common features across them that could determine the characteristics of future influential surgical research studies. Here we outline the identified trends:

1. Emphasis on Transplantation: Transplantation is a miracle of modern medicine giving cure to patients with end-stage organ failure. Despite the impressive progress in transplantation research over the last 20 years, the rates of deceased and living solid organ donation and transplantation worldwide still remain low and the need for transplants is still to meet the demand. Widening access to transplantation is going to be a major objective for surgical research in the years to come. Equally, assessment and re-conditioning of organs prior to transplantation also has enormous potential to increase the pool of available organs and improve transplant outcomes.

2. Emphasis on reducing perioperative complications: a trend towards perioperative practice oriented studies with specific, attainable and reproducible methodology can be clearly foreseen in the abovementioned publications. This is likely to continue in the years to come, since there is a lot of ground to cover in order to reduce the existing disparities in surgical outcomes.

3. Incorporation of new technology: from surgical training to minimally invasive surgery, technological advancements as 3D printing, robotics etc. are likely to further advance the practice of surgery in the years to come[33].

Discussion

In the present study we systematically reviewed the progress in scientific research in the field of surgery, as well as the top 20 most influential surgical journal publications in the last 20 years. We found that the volume of research publications produced in the field of surgery over the last two decades was significant, but the impact and the quality of those publications was lacking behind particularly when compared to other biomedical fields. Despite this, the dissemination of research findings in clinical practice through guidelines and consensus statements was encouraging and enabled significant clinical progress.

Finally, we 've foreseen that transplantation, advancements related to clinical pathways and technology will be the main themes of surgical research in the years to come.

Having revisited Dr. Horton's question after 25 years, we believe that it is still relevant. Surgical Research had a future back then, and has also a future today. This will require surgical leadership, constructive collaboration, and more patient (and not career!) tailored, focused and meaningful original surgical research. It is the best way to maximize the impact of our vocation on patient care and the wellbeing of society.

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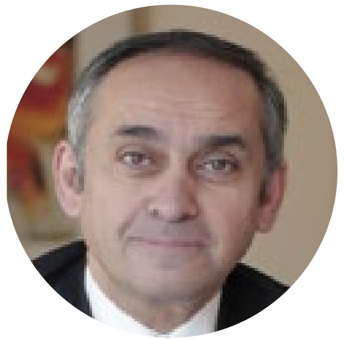
Future Surgery

Introducing our Guest Editor Professor the Lord Ara Darzi of Denham OM KBE PC FRS



Professor Darzi is Co-Director of the Institute of Global Health Innovation at Imperial College London and holds the Paul Hamlyn Chair of Surgery. He is a Consultant Surgeon at Imperial College NHS Trust and the Royal Marsden NHS Foundation Trust. Professor Darzi is non-executive director of NHS England, Chair of the Accelerated Access Collaborative and Co-Director of the NHS Digital Academy.

He is Fellow of the Academy of Medical Sciences and the Royal Society, Honorary Fellow of the Royal Academy of Engineering, and in 2020 was elected President of the British Science Association. His research portfolio is mainly in convergence science in areas of engineering, physical and data sciences in areas of robotics, sensing, imaging and digital technologies, and has over 1,350 peer reviewed publications.

In 2002, Professor Darzi was knighted, and in 2007 introduced to the UK's House of Lords as the Parliamentary Under-Secretary of State for Health. He has been a member of Her Majesty's Most Honourable Privy Council since June 2009 and was awarded the Order of Merit in January 2016.

Spearheading the Next Generation of Surgical Evolution

Professor the Lord Darzi of Denham PC KBE FRS FMedSci HonFREng

From our Halsteadian origins, surgery has continually been subject to a multitude of rapid innovations over the past hundred years but has seen vast strides in the 21st century. Surgeons no longer operate simply with their hands and a blade but have adopted a vast array of technologies ranging from haemostastic devices, anastomotic and stapling devices, intra-operative diagnostic tools and automatic closure devices. We are as much technologists as we are anatomists and the role of engineering in our day-to-day practice is likely to expand further. Our incisions can be smaller, our targets are more precise and there are mechanical and digital tools for nearly every step of our operations. The growth of minimally invasive vision systems and tools to operate in small spaces allowed our adoption of MIS technologies, which in turn heralded surgical robotics and the opportunities of long-distance tele-robotic surgery. More recently artificial intelligence and new imaging methods have been introduced into our practice and will likely herald the next generation of surgical evolution. The care and safety of patients remains our continued priority, and we can offer them more complex operations, with shorter hospital stays and better, more consistent outcomes. At the heart of our work however, evidence remains key and too often remains an ideal rather than actual day-to-day practice.

We remain a craft specialty, though our patients are being managed in clinical workflows that require our flexibility and open-mindedness to new approaches. Having like-for-like operations with more technology is not the only way forward, but a route in changing the whole patient journey will be most beneficial.

Our surgical healthcare will continue to shift towards establishing and maintaining good health, prevention and prediction of disease, early intervention and co-ordinated management of chronic conditions. Health and social care systems will need to address increasingly complex patient needs, including those living with multiple co-morbidities. Early intervention will become key including seeking to advance the ability to predict disease, risk stratification and earlier diagnosis. This may have potential implications for surgical treatment for example, in cancer, where improvement in prevention and early diagnosis may allow therapies other than surgery to become the preferred choice of treatment and increasingly complex care pathways, that integrate both medical and surgical treatments - with tele-medicine at its core. Surgery is currently used to treat advanced disease and takes place after the display of symptoms. In the future, surgery will potentially prevent – and not just treat – illness.

Innovation is also needed more than ever as we need to address the aftermath of latest pandemic where we have seen huge disruption in the ability to deliver basic surgical care arising from the necessary decision to cancel all non-emergency procedures and the reassignment of both personnel and resource to deal with the immediate care of patients with Covid-19. As of February 2021, around 4.7 million people were waiting for routine operations and procedures in England - the most since 2007.

Developments in automated digital appointments, clinical reviews and diagnosis will increasingly become the norm and robotics, artificial intelligence, genomics, and digital technologies promise a tantalising future, where healthcare is even less invasive and much more personalised.

We can expect even a greater application of minimally invasive surgery and robot-assisted procedures with the next generation of robots being more portable making them accessible to a larger number of patients. Nanotechnology will allow for less variation in surgical performance and even the possibility that skilled technicians undertaking procedures in place of a surgeon, and advances in imaging and simulation, including virtual reality and augmented reality, are already being used to complement surgical training and enable multidisciplinary teams to connect and specialist surgeons to support complex procedures remotely.

Developments in big data analytics and genomics will improve understanding of disease profiles, together with the continued use of artificial intelligence improve diagnosis and population-based risk assessment, and machine learning in preventing surgical errors by supporting surgical teams inside the operating theatre.

Operating theatres are likely to look different with greater integration of digital technologies and within this revolution we will also see a change in role for the surgeon, with the greater convergence at the interface of science and medicine and where other professional expertise, such as data analysts and engineers, integrate into surgical teams as the technologies become even more sophisticated.

In this special issue, we explore a selection of these emerging areas and core themes reflecting the future of surgery and new technological advances, developments in the use of data, AI, imaging, diagnosis and robotics, and disruptive technologies, focussing on areas of key importance to the surgical and support teams and I very much thank the authors for their insightful contributions. Whatever your speciality and pathological interest, surgery will continue to evolve with the increased momentum of digital and engineering breakthroughs. Whilst there will be uncertainty as to the which technology will offer the greatest future value, adopting these free of bias and with the best evidence will allow us to concentrate on what we do best, caring for patients with the most timely and appropriate operation to relieve them of disease.

Gaze Controlled Endoscopy

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What is Gaze Control

Gaze tracking systems offer the ability for users to move robotic devices by the direction of their gaze to effect hands-free control of devices[1]. Novel gaze control systems have been successfully trialled to control laparoscopic cameras. We present our application of an eye gaze control system to flexible endoscopy.

Why Gaze Control

Precision control

The remit of endoscopy as a minimally invasive therapeutic intervention is rapidly widening. Within the lumen malignant polyps that traditionally would have required colonic resection can now be removed by advanced endoluminal surgical techniques such as endoscopic submucosal dissection[2]. Natural Orifice Transluminal Surgery (NOTES) allows organs beyond the lumen to be accessed by an endoscope with the added benefits of shortened length of stay, reduced complications and improved cosmesis versus conventional surgery[3].

Such techniques are both mentally and technical demanding, requiring high precision control. Several novel endoscope control methods have been developed and trialled to help enable this precise control mainly involving remote manual control via joysticks[4]. Gaze control allows hands free control of the endoscope liberating the hands of the operator and reducing procedural workload.

Ergonomic in Endoscopy

Conventional endoscopy (using dials to steer and manual insertion) has well documented poor ergonomics with particular risk of upper distal musculoskeletal injuries[5]. Gaze control potentially reduces this risk.

Pandemic and Airborne Infections

Endoscopy is an aerosol generating procedure and the current pandemic has increased the risk to operators of COVID-19. Gaze control systems potentially allow the operator to be removed from the patient bedside which can both reduce the risk of exposure to airborne pathogens but also remove the need for restrictive personal protective equipment[6].

Gaze Control System

Robotic platform (Figure 1)

Two motor driven customised 3D printed gears were mounted on the control wheels of a gastroscope. The gastroscope was mounted onto a robotic arm with the flexible shaft of the endoscope placed on a guiderail.

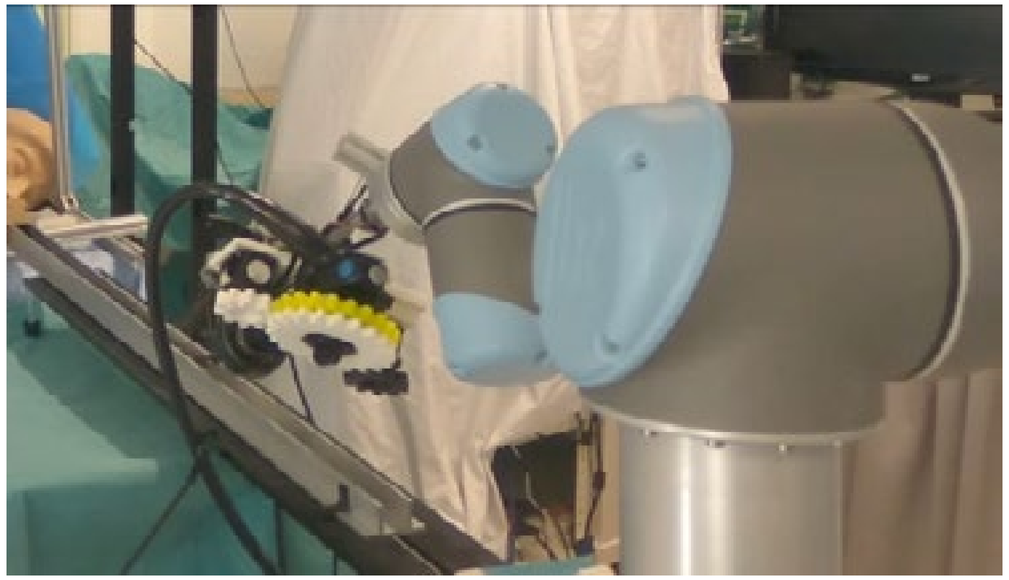

Figure 1. Robotic Platform

Gaze control system (Figure 2)

Gaze direction and head position were estimated by a custom gaze-contingent framework[7], based on eye tracking glasses, two RGB-D and four motion capture cameras. Further control was provided by a joystick controller.

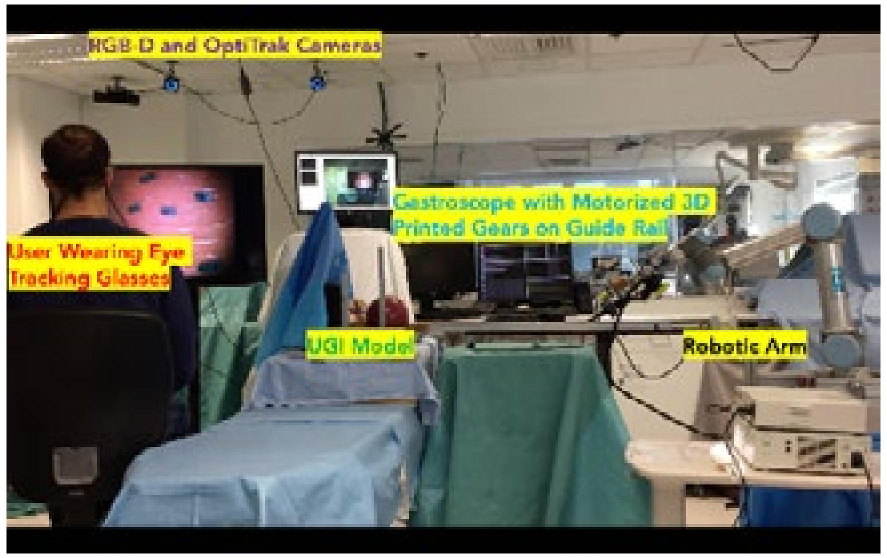

Figure 2. Overall Gaze Control Setup

User Interface

The operator sat in front of a 42-inch monitor displaying the endoscope view. The endoscope tip angulation was controlled by the direction of the operator's gaze in relation to the centre of the screen (following an initial calibration).

Tilting of the head actuated rotation of the endoscope. Insertion and withdrawal of the endoscope was controlled by pushing up or down on the joystick. Audible alerts such as "in" and "out" or "left" or "right" were produced by the system.

Gaze beyond the screen or pressing a button on the joystick paused the system.

Study Methodology

8 non endoscopists (no endoscopy experience) and 8 JAG accredited endoscopists completed simulated target location tasks in a spherical model and an anatomical UGI model using both the gaze control system and a conventional endoscope.

Objective measurements included time to complete task. Subjective measures included cognitive workload (NASA-TLX score [8]), usefulness/satisfaction (Van der Laan acceptance scale [9]) and ergonomics/usability (custom Likert 7 point scale).

Results

Non Endoscopists

Non endoscopists were significantly quicker at completing the tasks using gaze-control than conventional endoscopy in both tasks (Sphere Task - 3:54±1:17 vs 9:05±5:40 minutes, $p=0.012$, and UGI model task 1:59±0:24 vs 3:45±0:53 minutes, $p<.001$). Non endoscopists reported a significantly reduced workload versus conventional endoscopy (NASA TLX - 22.5±13.8 vs 80.6±11.3, $p<.001$).

Endoscopists

The inverse was true of the endoscopists who were significantly quicker with the conventional endoscope versus gaze control (Sphere task 1:24±0:39 vs 3:18±1:14 minutes, $p=0.002$, and UGI model task 1:27±0:20 vs 2:10±0:35 minutes, $p=0.006$). Endoscopists reported a significantly reduced workload using the conventional endoscope (54.2±16 vs 26.9±15.3, $p=0.012$)

Acceptance and Ergonomics of Gaze Control

All operators reported the gaze control system to be both useful and satisfactory to use on the Van-der Laan scale.

Endoscopists reported poor ergonomics in the eye gaze system in all domains as compared to the non-endoscopists who reported favourable ergonomics in all domains.

Discussion

Experienced endoscopists expressed a clear preference for conventional endoscopy as a control mechanism, however this is in the context of significant experience and thus familiarity with this system.

Those with no endoscopy experience interestingly reported a preference for the gaze control system with a corresponding quicker time which suggests that this may be a more intuitive system.

Although this study was a limited bench top trial this is an exciting signal that non manual gaze control may be a viable and beneficial control system. Further benchtop studies of the system with repetitive use, combination with simulated therapeutics and human feasibility trials will help determine if the eye gaze system can be a more intuitive adjunct to facilitate complex endoluminal and transluminal therapy.

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Versatility in Fluorescence Guided Surgery with the GLOW Camera System

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Background

Fluorescence Guided Surgery (FGS) is a novel and promising technique, whereby a contrast agent is used to demarcate targeted tissue and guide surgeons intraoperatively[1]. This is particularly useful in cancer operations where surgeons want to spare normal tissue[2] (neurosurgery, breast conserving surgery, etc.) or prevent damage to commonly injured structures[3] (e.g., ureters). FGS is becoming increasingly popular as it fulfils numerous pre-requisites for clinical translation[4], being safe (no ionizing radiation), user-friendly, cost-effective, and seamlessly blends into clinical workflow. So why has it not yet diffused into routine clinical practice? At present, there is a lack of specific targeted fluorophores, as the only European Medicines Agency approved drugs are passive in their mechanism of action and thus only applicable to a limited range of operations[5] (e.g. angiography, neurosurgery, urological procedures).

Given the vast potential of fluorescence guidance, the development of active fluorophores is rapidly evolving. Probes are being designed to target specific proteins in cancer, with 11 probes already undergoing clinical trials[6] (and hundreds more in pre-clinical trials). However, currently available fluorescence guided surgery systems (SpyPhi, Firefly, etc.) have not been developed with these new probes in mind, and furthermore are limited in the field-of-view which they can provide[7]. In view of addressing the technical challenges, our team has developed and tested a fluorescence imaging device with modular design, capable of accommodating a wide range of working distances and fluorescence probes.

2. Methodology & Results

The developed imaging device (Figure 1), uses interchangeable lenses and a beam-splitter to separate light into a colour and monochrome camera of high sensitivity with interchangeable fluorescence filters. Illumination is provided with the use of a Xenon light source with electronically controlled interchangeable filters. This system can be customized to facilitate imaging with different VIS-NIR fluorophores – available currently or in the future – by adjusting the corresponding excitation/emission filters (Figure 1a). The system is capable of being operated by a single user (Figure 1b) through its intuitive interface design (Figure1c).

The device performance was studied for the clinically approved and well-studied fluorescent agent Indocyanine Green11. Optimal excitation (bandpass, 500-750 nm) and emission (bandpass, 775-875 nm) were identified following ICG fluorescence spectroscopic measurements both in-vitro and ex-vivo Figure 2. Prior to clinical testing, the device was fully characterised with regards to its sensitivity to ICG fluorescence signals, working distance/ field of view coverage, and tested against a commercial analogue.

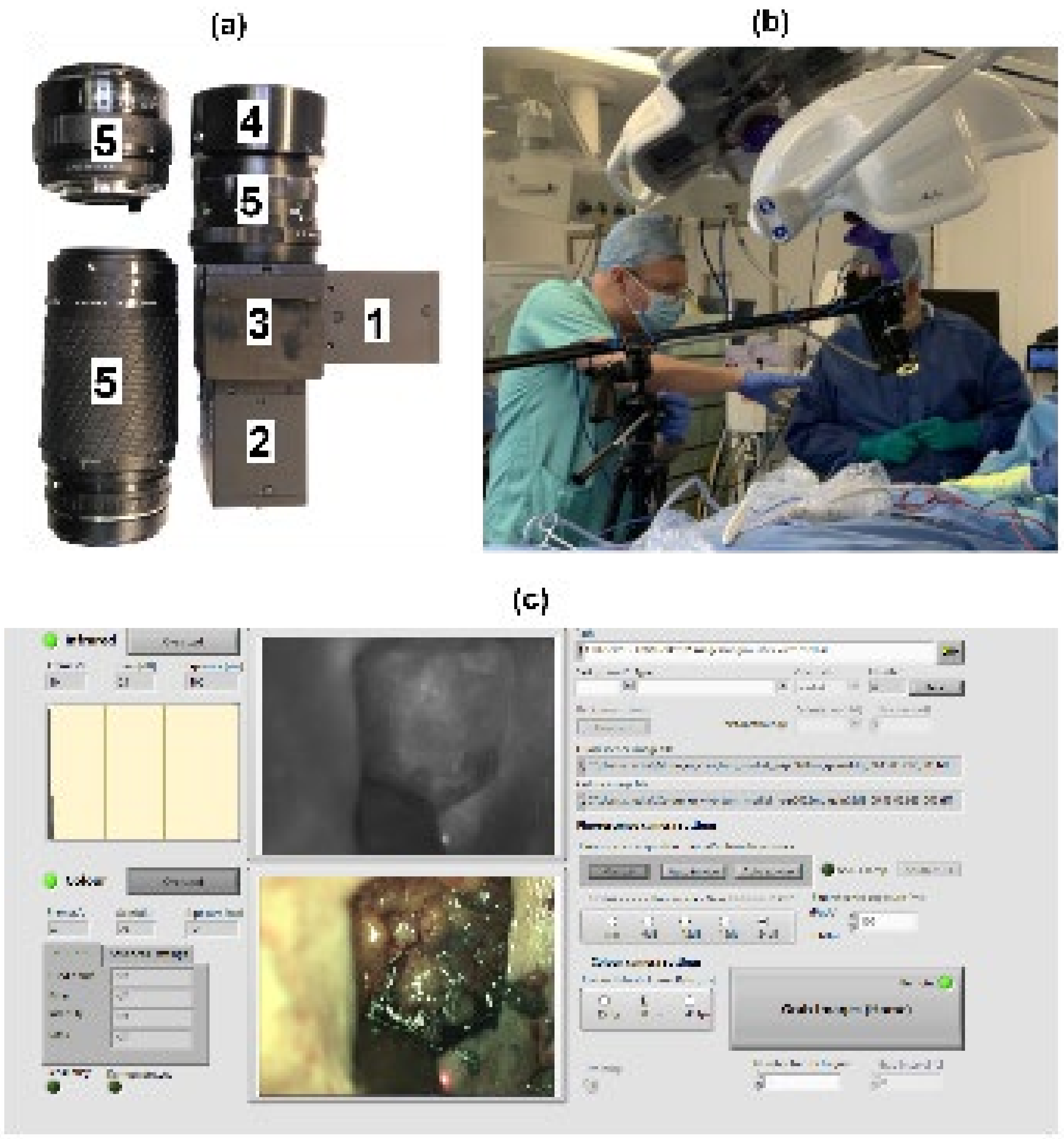

Figure 1. a) Modular GLOW setup for intraoperative tumour in-situ fluorescence imaging upon intravenous injection in BCS: 1) colour camera, 2) high sensitivity mono camera with built in interchangeable fluorescence filter 3) beam-splitter 4) illumination light ring connected to Xe lamp with interchangeable filters 5) interchange-able lenses, b) GLOW setup in operating theatre; c) clinician-oriented software interface.

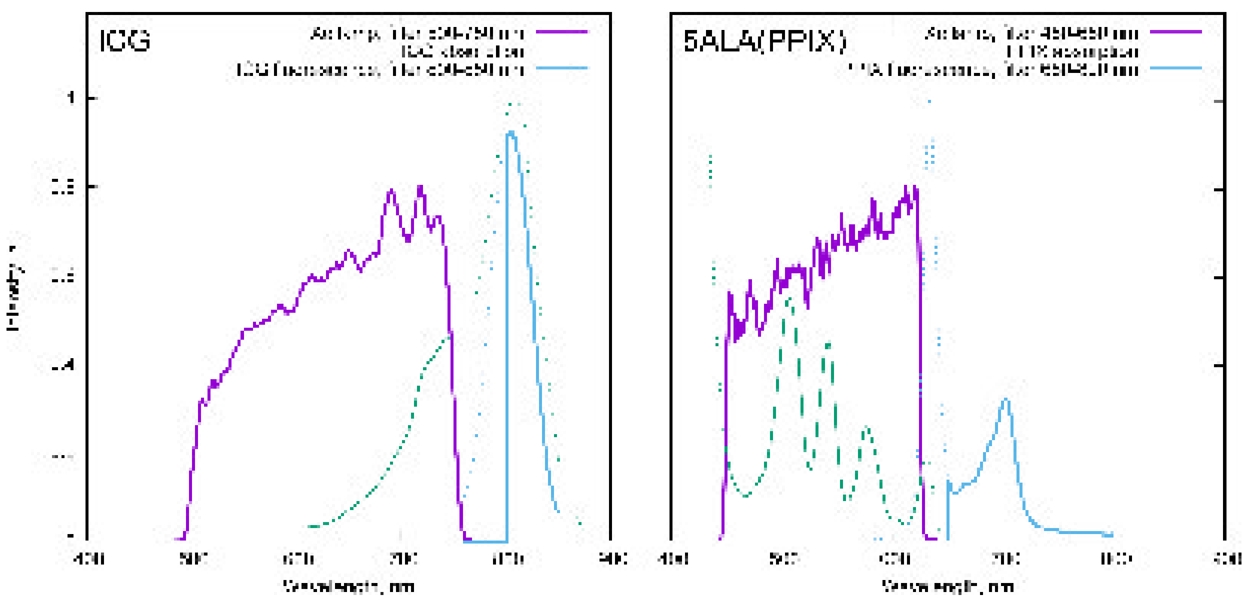

Figure 2 : Demonstration of GLOW setup adaptation for imaging with different fluorophores. ICG: spectrum of Xe lamp filtered in range 500-750 nm for simultaneous colour imaging/ICG fluorescence excitation with overlapping part of ICG absorption spectrum8 and ICG fluorescence spectrum in breast tissues. 5ALA (PPIX): spectrum of Xe lamp filtered in range 450-650 nm for simultaneous colour imaging/PPIX fluorescence excitation with overlapping part of PPIX absorption spectrum9 and PPIX fluorescence10, filtered in range 750-800 nm.

Experiment 1: Prototype development and performance characterisation

For the fluorescence sensitivity characterisation, ICG aqueous solutions at a concentration range of 1 to 100 10-9 M have been imaged to extract the signal to noise ratio:

SNR=(mean(fluorescence signal)-mean(background signal))/(standard deviation of background), at variable working distance close to the shortest acceptable distance between the patient and the camera (~10 cm) (Figure 3).

Working distance coverage and corresponding resolution have been measured with the help of a USAF 1951 (MIL-S-150A Standard). For every combination of aperture size, focal length and object distance of the lens, the corresponding optimal working distance, field of view and resolution have been calculated. The clinically relevant results are displayed in Table 1.

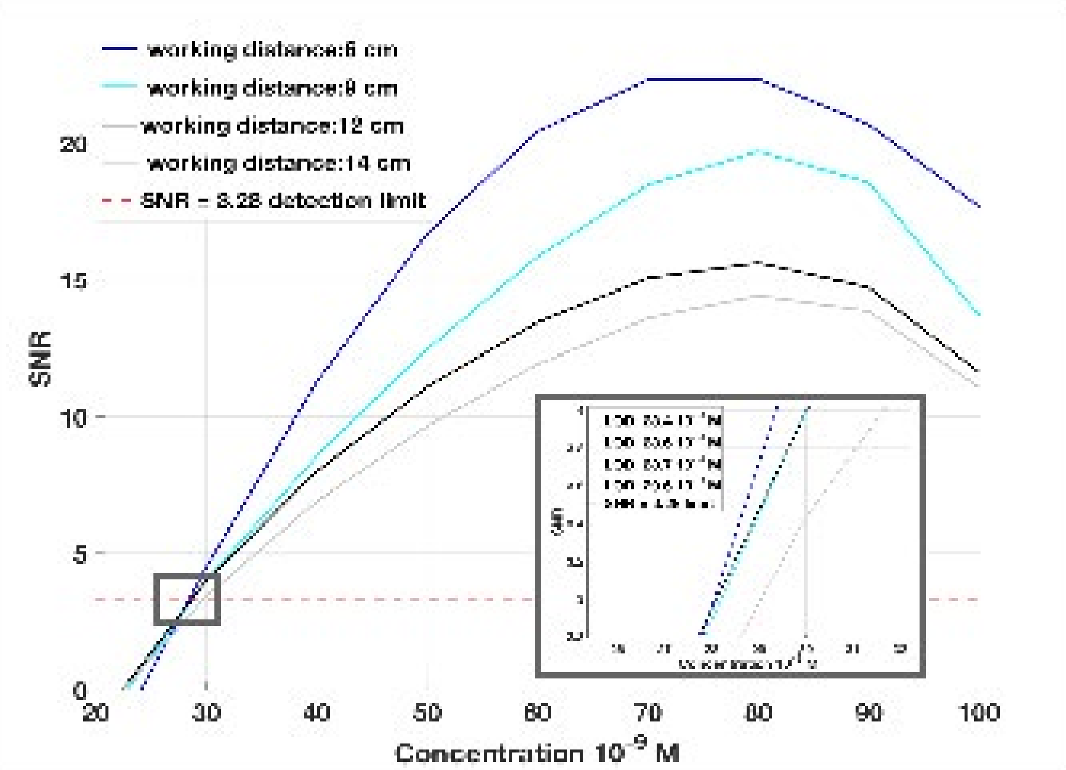

Figure 3: a) Sensitivity to ICG fluorescence characterized at different working distances. Limit of detection (LOD) is identified as the intersection point between curve and horizontal threshold of SNR=3.28 in line with Rayleigh's criterion. The magnification (grey rectangle) shows the LOD points of each curve.

Clinically relevant working distance range [cm] ±0.12	*Field of view (horizontal x vertical) [cm²] (±0.00, ±0.04)*	*Resolution [µm] (±2)*
10 cm~minimum allowable	3.1 x 2.2	40
30 cm~typical in surgery	**6.1 x 4.4**	**50**
56 cm~maximum in surgery	8.4 x 6.3	80

Table 1: Key-performance characteristics of the fluorescence imaging device. The standard error is also given in each column's top. The resolution reported here is the minimum detectable distance between adjacent features (measured in mm) on the USAF target for which the image contrast remains above 26.4 %, as defined by the Rayleigh criterion.

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The lowest ICG concentration that can be detected at a working distance of 14cm was 29.6 10-9 M or ~0.023 mg L-1 (the system's limit of detection) (Figure 3). The superiority of our system's performance (SNR=28) in detecting the expected in-vivo ICG signals (3.2 10-6 M or 2.5 mg L-1) is statistically significant ($p<0.001$) compared to that of the SpyPhi commercial system12 (SNR=12).

Also, as demonstrated in Table 1, the system is capable of high acuity at a wide range of working distances (10-56 cm), capable of distinguishing adjacent features as close as 50 µm at the clinically relevant working distance of ~30 cm.

Experiment 2: In-vivo feasibility study

The prototype was trialled in-vivo in 10 BCS patients (REC 18/LO/2018) to investigate feasibility as well as improving the hardware and software design.

12.5 mg ICG was administered intraoperatively once skin flaps were raised (thus exposing the tumour), and images were taken of the tumour in-situ (Figure 4), ex-vivo, and of the cavity post excision. After exclusion of five patients in which the specimen had healthy margins (tumour was >0.4cm deep), the ex-vivo images of five specimens were analysed to extract image texture metrics and detect the tumour boundaries in the image. The result of this preliminary analysis was compared to gold-standard histopathology to estimate the accuracy of the method in identifying cancer. The texture metrics: 'slope' and 'intercept', which are indicators of the images' spatial frequency content, have been found to be potentially useful in differentiating between cancer and healthy tissue[13].

Moreover, in this trial, the surgeons' feedback was used for iterative improvement of the software and user-interface, to develop a reliable and user-friendly platform that allows for single user operation. The developed interface is intuitive and supports advanced image processing including:

- optional full manual control

- automatic dark frame acquisition

- original flexible camera autoexposure algorithms, optimised for both in vivo and ex vivo imaging

possibility of image sequence recording with variable time lapse

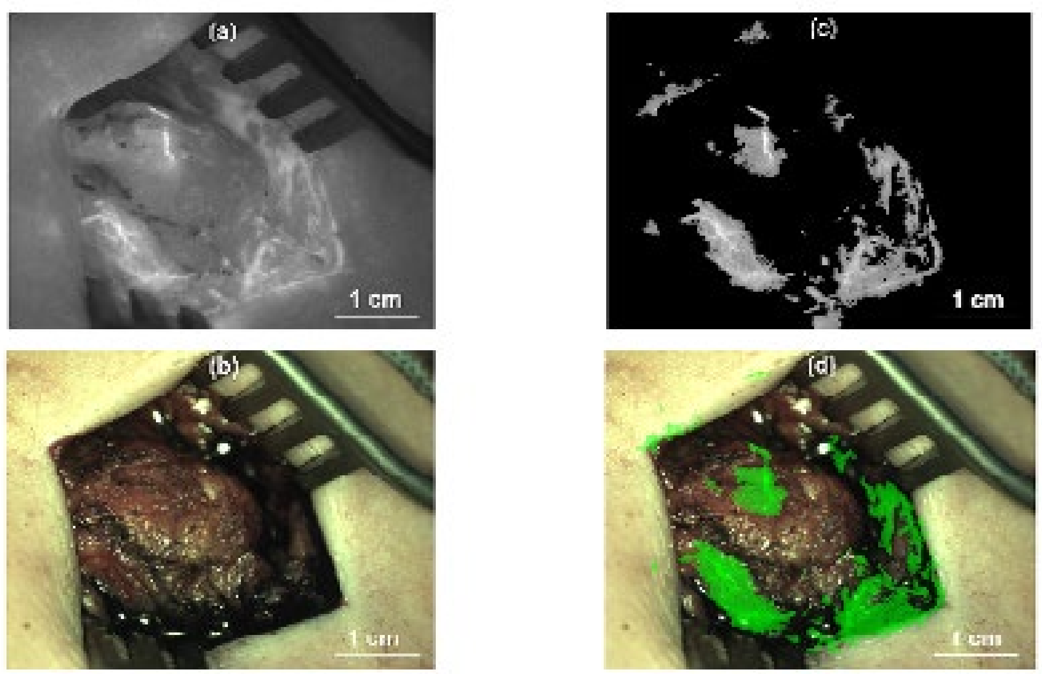

Figure 4: a) Raw fluorescence and b) colour image of the tumour in-situ, acquired with the device c) example of fluorescence image processing, where the pixel values below a global threshold are supressed to zero and d) the remaining fluorescence pixel values after the suppression are overlaid as a green pseudo-colour map on top of the colour image.

Discussion

FGS is a strong candidate in tackling the clinical need of real-time macroscopic tumour visualisation, empowering surgeons to make intraoperative decisions guiding patient treatment. However, commercially available systems which are restricted by filtration spectra and fixed lenses limit evaluations in new clinical interventions. In these trials, we have demonstrated that our system has higher sensitivity to fluorescence, improved resolution when compared to commercially available systems, and is ready for in-vivo applications due to its intuitive design.

Being able to detect the expected ICG concentration of 3.2 10-6 M opens up the potential of using a smaller dose of the fluorophore to the patients. This has both direct patient safety and cost implications, which in the case of cytotoxic and expensive immunotherapy agents (i.e. cetuximab-800/ panitumab-800), as the side effect profile is substantial and dose-dependent, one could improve tolerability through a reduced dose[14].

As required for the majority of surgical applications[4], our system can cover a wide range of working distances with sub-mm resolution. At the clinically relevant WD range, we achieve superior resolution compared to commercial competitors (Table 2)[7]. These encouraging results push the boundaries of using FGS as a macroscopic visualisation tool.

Although the system is sensitive to in-vivo fluorescence, high tumour diagnostic accuracy - a key pre-requisite for clinical adaptation- was not achieved when ICG was used as contrast agent. This result is consistent with current literature15 where accuracy in the context of ICG is low as this fluorophore does not actively target tumour cells. However, the image texture metrics 'slope' and 'intercept' of the images' spatial frequency content analysis could be potentially useful in detecting tumour location. Therefore, in future studies we will aim to: a) investigate the diagnostic accuracy of the system in an additional 40 patients using ICG and b) modify the camera for its use with the fluorophore protoporphyrin IX in another 40-patient trial (Figure 2) (19/LO/0927).

Device	*Working distance [cm]*	*FOV (h x v) [cm]*	*Resolution [µm]*	*Sensitivity to contrast agent [nM]*	*Adaptable to fluorophores*	*Gain setting/ room light correction*	*Full Manual Control*
GLOW system	10-56	3.1 x 2.2 – 8.4 x 6.3	40-80	29.6 (ICG)	YES	YES/YES	YES
LAB-Flare (Curadel)	**30-45**	**0.9 x 0.8 – 25.3 x 25.3**	**50-600**	**NA**	**Only 85-735 & >781 [nm]**	**YES/NO**	**Partial**
Spy Elite (Novadaq)	~30	10 x 14	NA	~5 (IRDye 800CW)	Only 825-850 [nm]	NO/NO	NA

Table 2: Comparison of the GLOW system's technical specifications against those of the commercially available devices7. FOV – field of view

Conclusion

FGS is a strong candidate in tackling the clinical need of real-time intraoperative macroscopic tumour visualisation as it is patient-safe, user-friendly, cost-effective and provides seamless integration with the clinical workflow. Since FGS is still in its infancy, it is limited in its clinical applications by the performance limitations of existing camera systems and the availability of targeted fluorophores. To address these issues, we have developed an imaging platform for fluorescence guided surgery with higher fluorescence sensitivity, better resolution and flexibility in choice of diagnostic fluorophores (as compared to commercially available systems). Iterative testing and design optimization through laboratory, in-vivo, and ex-vivo studies, enabled the development of a functional user- and problem-oriented prototype. Through facilitating interchangeable illumination/ acquisition filtration and adjustable lenses, a wide range of contrast agents and working distances/ scales can be accommodated, thus enabling the application of this system well beyond breast cancer surgery.

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Consent/ethical approvals

Ethical approval has been obtained for our previous1 and current2 work ('GLOW') which covers the intraoperative testing of fluorescence and fluorescence combined with multispectral devices, respectively:

[1] Study short title: Real time tissue validation using NIR fluorescence imaging: Surgery.

IRAS ID: 222629, REC reference: 18/LO/1362, Date study commenced: 08/10/2018, Date study ended: 25/10/2019

[2] Study short title: GLOW -Guiding Light Optimising Wide local excisions

IRAS ID: 260633, REC reference: 19/LO/0927, Date study commenced: 09/03/2020, Planned study end:07/2022

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Cognitive workload measurement using wearable sensor technology in surgery

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1. Introduction

Reducing the risk of human error remains an endeavour of daily surgical practice with ongoing research activity to improve the optimisation of patient safety and minimise preventable harm in the operating environment[1,2]. This paper aims to briefly describe the role of cognitive workload measurement in the surgical setting using wearable sensor technology and use of the emerging technological trend in multimodal physiological sensor data synchronisation and fusion.

2. Background

2.1 Technical and non-technical skills in surgery

The operating room is a high-risk and dynamic environment centred around the delivery of safe patient care. Non-technical skills such as teamwork, leadership, communication and decision making are equally as important as the technical surgical skills demonstrated by a surgeon such as dexterity and economy of movement. Errors or adverse events in the surgical environment can be related to any of these aforementioned factors as well as related elements such as organisational structure, patient-related factors and work or personal-related stressors[3]. The intra-operative stress experienced by a surgeon due to environmental factors such as distraction or procedural complexity have also been associated with impaired performance[4,5].

The impact of non-technical skills on surgical performance and patient outcome are well recognised and have led to the development of multiple training programmes to assess and cultivate these cognitive skills[6–9].

2.2 Cognitive workload

Cognitive workload is a concept first defined by Sweller in 1988 and describes the allocation of cognitive resources or working memory that is imposed by a task[10,11]. Cognitive overload occurs when the demand on cognitive workload exceeds the working memory capacity of an individual when performing a task[12]. The negative impact of cognitive overload is increasingly being recognised in the healthcare setting[13,14]. However, the measurement of cognitive workload, a subjective physiological construct with measurable autonomic physiological responses, remains elusive and continues to be an area of interest particularly in the surgical environment where the impact of cognitive overload can result in significant patient morbidity.

Current methods used to measure cognitive workload in the surgical setting are either subjective or objective in nature. Subjective measurements, including questionnaire and self-reported measures such as the Surgical Task Load Index, take place retrospectively[15]. Their use is limited in the real-time setting and are subject to recall bias. A greater emphasis is now placed on objective physiological measures of cognitive workload which has the potential to be used in real-time to allow immediate changes to the operating environment to reduce cognitive burden.

Frequently used objective measures include heart rate variability (HRV), electroencephalography (EEG), functional near infrared spectroscopy (fNIRS) and pupil studies[16–21]. Recordings of these measurements are typically analysed retrospectively. However, with increasing developments in machine learning and computer processing power, specifically artificial neural networks, there is scope to analyse these measures in real-time to provide live measures of the cognitive workload. In addition to this, the development of sensor technology has made wearable sensors a relatively low-cost, non-intrusive and readily available method to accurately measure physiological parameters.

3. Pupil studies to measure cognitive workload

Pupil studies have demonstrated a reliable and non-invasive method to calculate cognitive workload[22]. The use of pupil or gaze studies is well documented in the context of skill assessment and surgical training[23]. However more recently, the role of pupil and gaze studies in the measurement of cognitive load with respect to surgery is growing. A review of current published literature has identified that pupil metrics (pupil diameter, change in pupil size), gaze studies (gaze entropy, fixation number) and blink frequency have shown correlation with cognitive workload and task complexity in surgery[24–26].

There is a new drive to integrate data captured from a multimodal source of physiological data to assess the cognitive workload of surgeons whilst operating [27,28]. We aim to further explore this new area of interest, particularly focusing on the relationship and synchronisation of multimodal wearable and distributed sensor data including pupil metrics and the measurement of cognitive workload in a surgical setting (Figure 1 and 2).

Figure 1. Demonstration of laboratory use of **ble sensors to measure physiological parameters**

Figure 2. Example use of wearawearable sensors

4. Challenges

One of the key technological challenges remains identifying and implementing an appropriate method to synchronise data from a diverse range of multiple sensors used to measure various physiological parameters such as heart rate and pupillometry. In addition to this, a validated computerised system using neural networks is required to be able to analyse, demonstrate and potentially predict cognitive workload in real-time.

The benefits of cognitive workload measurement also need to be clearly demonstrated to facilitate adequate stakeholder involvement from the surgical team and patients in order to appropriately justify the measurement and/or recording of sensitive and personal data. The ethical and data protection implications of individual physiological parameter recordings must also therefore be taken into consideration and comply with local and national data protection laws and guidelines with informed consent. The development of an artificial intelligent network will also potentially require the storage and analysis of 'big data' retrieved from sensor recordings from surgeons across multiple sites which also poses inherent challenges that must be addressed in the long-term.

5. Future applications

The ability to successfully synchronise and fuse sensor data from multiple sources simultaneously and in real-time to measure cognitive workload has a number of future applications in surgery. The development of a multimodal sensor network would be able to provide a platform whereby mental workload can be measured and assessed under various high intensity scenarios in a simulated setting, for example emergency trauma surgery or a patient deteriorating on the operating table, to help develop skills to manage cognitive overload. A further application in surgical training may also include the use of this system during surgical training cases whereby a trainer can monitor the cognitive burden experienced by a trainee during a case and offer assistance during episodes of raised workload which may otherwise go unrecognised.

Future developments may also entail integration of captured sensor data into a smart operation theatre that is able to automatically detect periods of raised workload and make automated changes to the operative environment to help reduce this. The use of real-time cognitive workload measurement can also be applied to include the multidisciplinary team involved in the operating theatre, such as the anaesthetic and scrub teams. Amalgamation of team data in real-time would provide an overview of mental workload in the theatre and help to predict when human error is more likely to occur during episodes of cognitive overload. The early recognition of these phases therefore acts as an indicator to alter the theatre environment to avoid unnecessary risk.

6. Conclusion

There is a need for accurate and real-time measurement of cognitive workload in surgery to improve surgical performance and overall patient safety in the operative setting. The measurement and synchronisation of multimodal sensor data shows promise with the development of artificial intelligence neural networks together in combination with advances in wearable sensor technology. Further development in this area shows the potential for integration of this technology in future surgical practice in training, assessment and real-life settings to improve patient safety in the operating room.

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Quantifying Hypoxia with Diffuse Reflectance Spectroscopy for Advanced Prognostication and Real-Time Response Monitoring in Rectal Cancer

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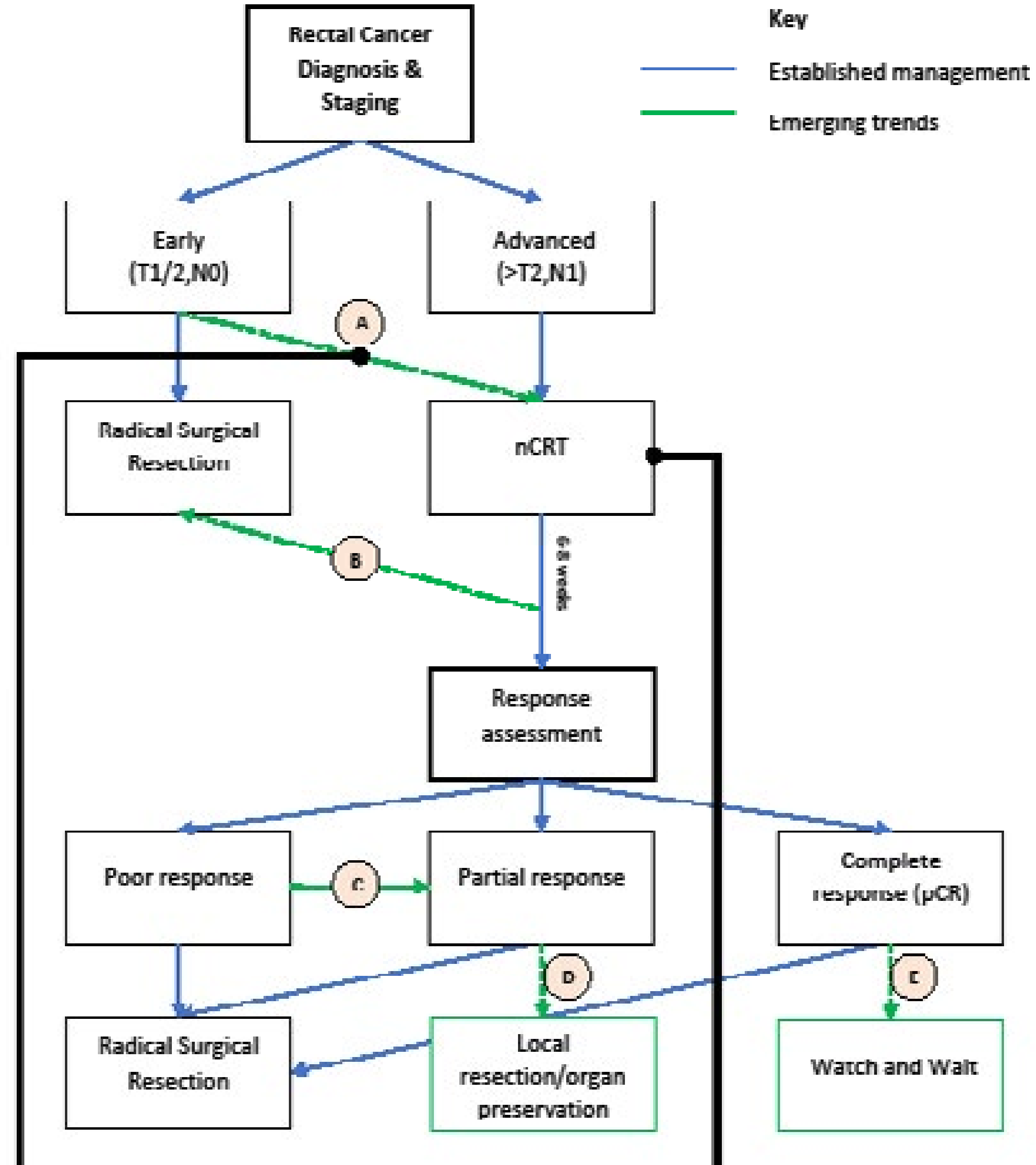
Introduction

A quiet revolution is occurring within the realm of rectal cancer (RC) management: neoadjuvant chemoradiation therapy (nCRT), once of modest impact, is changing the way we manage RC[1]. Following Habre-Gamma's pioneering work[2], there is great international interest in the phenomenon of pathological complete response (pCR). Occurring in 15-30%[3] of RCs exposed to nCRT, pCR describes the finding of no residual tumour on histopathological analysis following surgical resection. The requirement to proceed with surgery in this patient subset has been questioned, and is the focus of two large ongoing randomised trials – STARTREC[4] and TRIGGER[5] – investigating the safety and efficacy of 'local excision with organ preservation' and 'watch and wait' policies, respectively, following nCRT.

The lure of major rectal surgery avoidance is strong, particularly for those with risk enhancing co-morbidities. However, barriers remain to endorsement of this strategy by key health bodies[6]. First, it should be recognised that a significant proportion (20%) of tumours progress, or fail to regress, in spite of nCRT, meaning that any delay in proceeding with surgery whilst nCRT is completed may paradoxically increase the likelihood of distant metastasis. Second, success has been recorded for the early T1/T2N0 tumours, a group not normally offered nCRT. There is therefore a moral disquiet in offering nCRT to a patient with a good prognosis if the tumour is surgically resected. Third, the timing of re-assessment following nCRT is arbitrary and disputed: whilst the tumour may still be present at eight weeks, it may not be at twelve. Thus, the requirement is clear: patient selection and prediction of pCR is paramount if we are to avoid undesirable outcomes and unnecessary delay from this novel strategy, particularly for patients where surgery is inevitable. Further, an ability to accurately monitor response to nCRT would enable a dynamic decision process and personalised tailoring of therapy (figure 1). Below we describe the existing techniques for prognostication and real-time response monitoring (including their limitations), discuss the important role played by oxygen deficiency (hypoxia) in tumours, and introduce diffuse reflectance spectroscopy as a tool that may provide opportunities for advanced response monitoring and prognostication through minimally invasive assessment of oxygenation.



Box 1. Prognostic methods

Method	Limitation
Tumour characteristics	Overlook tumour microenvironment [7]
Gene/protein biomarkers	Lack accuracy and commonality [8]
MR imaging	Limited predictive value [10]
Metabolomics	Emerging field [11]
Anaemia	Non-specific [12,13,14]
Degree of tumour hypoxia	Poorly measured at present

Box 2: Response monitoring

Method	Limitation
MR Imaging	Single point in time [17]
CT imaging	Inferior to MRI
PET imaging	Inferior to MRI
Endoscopy	Misses heterogeneity [16,17]
CEA	Non-specific [16]
DRE	Unreliable [16]
Tumour re-oxygenation	Poorly measured, under-studied

Figure 1: Simplified management algorithm of RC, highlighting the requirement for advanced prognostication and response monitoring in accordance with emerging trends. Advanced prognostication (A) would identify early tumours (not normally offered nCRT), which may respond to enable organ preservation (D) or W&W (E), and conversely identify advanced tumours which may not respond to nCRT and thus require immediate surgery. Continuous response monitoring would facilitate early identification of failure to respond and the need to proceed with surgery (B). as well as allowing time for a poor (C) or partial (D) responder to respond. thus avoiding major resection. Boxes (1) and (2) summarise the current methods and associated limitations of current prognostication and response monitoring. and highlights the potential role of tumour hypoxia assessment.

Present Methods for Predicting and Monitoring Response to nCRT

Predictive nomograms[7] using patient and tumour features (such as circumferential resection margin (CRM) involvement and distance from the anal verge) have been used to predict nCRT responses with promising, and yet inadequate, accuracy. Therefore, for an accurate prediction, a deeper knowledge of the tumour microenvironment and mechanism of chemoradiation resistance – including the underlying transcriptional, proteomic and genomic changes – is required. The solution seemed to lie in the discovery of a novel molecular biomarker based on individual or collective gene expression profiles. Research and resource has been invested heavily into this mission, and yet despite some promising individual findings (figure 2), none have reached the accuracies required for routine clinical use[8]. The difficulties, notwithstanding the inherent complexities of radiation oncobiology, appear to be threefold. First, multiple studies have focussed on differing end points (e.g. pCR, tumour regression grade), timings of response assessment, and regimes and types of chemoradiation. Second, significant intratumoural heterogeneity means that a single, or serial, pre-treatment biopsy(ies) is/are likely to be futile, since the same tumour could harbour different genetic mutations in a neighbouring, but unbiopsied, area. Third, there is little agreement or overlap between the various published genetic/molecular biomarkers. Indeed, many markers are investigated in isolation without interpretation of a unifying molecular pathway. Poynter et al[9] attempted to address this by performing a network analysis of key molecular biomarkers and pathways involved in RC radiosensitivity, mapping and statistically analysing the relative importance of each. Here, the ontologies of 'stress response' and 'cellular metabolism' demonstrated the greatest potential. Nonetheless, the future appears challenging and uncertain for genetic and molecular profiling in relation to predicting response to nCRT. Subsequently, investigators have looked to imaging, untargeted metabolomics and pre-treatment haemoglobin as predictive biomarkers (figure 1, box 1) – but with similarly non-conclusive results[10,11,12,13,14]. Therefore, this predictive field remains ripe for exploration.

The gold standard method to assess tumour response following nCRT is MRI imaging, which can accurately identify CRM involvement and involved surgical planes[15], and, increasingly, identify pCR more accurately than other methods[16] (figure 1, box 2), including endoscopic inspection for residual disease[17]. MRI imaging assesses four tumour components: (i) downsizing (physical size of tumour); (ii) downstaging (stage of tumour); (iii) regression (degree of fibrotic transformation); and (iv) specific patterns of morphology, such as texture analysis. Whilst the value of MRI imaging is clear, it suffers limitations: an inability to detect residual tumour post nCRT induced tumour fragmentation; notoriously inaccurate involved lymph node detection; and difficulties in differentiating between fibrosis and residual tumour. However, perhaps the greatest drawback of MRI assessment is that it is performed at, somewhat arbitrarily, a single point in time, usually 6-8 weeks following nCRT. As discussed above, it is likely that some of these tumours would continue to regress, but the multidisciplinary team (MDT) is often left with a binary decision: progress with surgery or deferral of surgery (watch and wait). Whilst repeat MRI imaging is possible, it is time consuming, costly, resource intensive and rarely done in practice. There is therefore great appeal in a device or biomarker which can provide real-time, continuous feedback of tumour response to enable a more dynamic, personalised management.

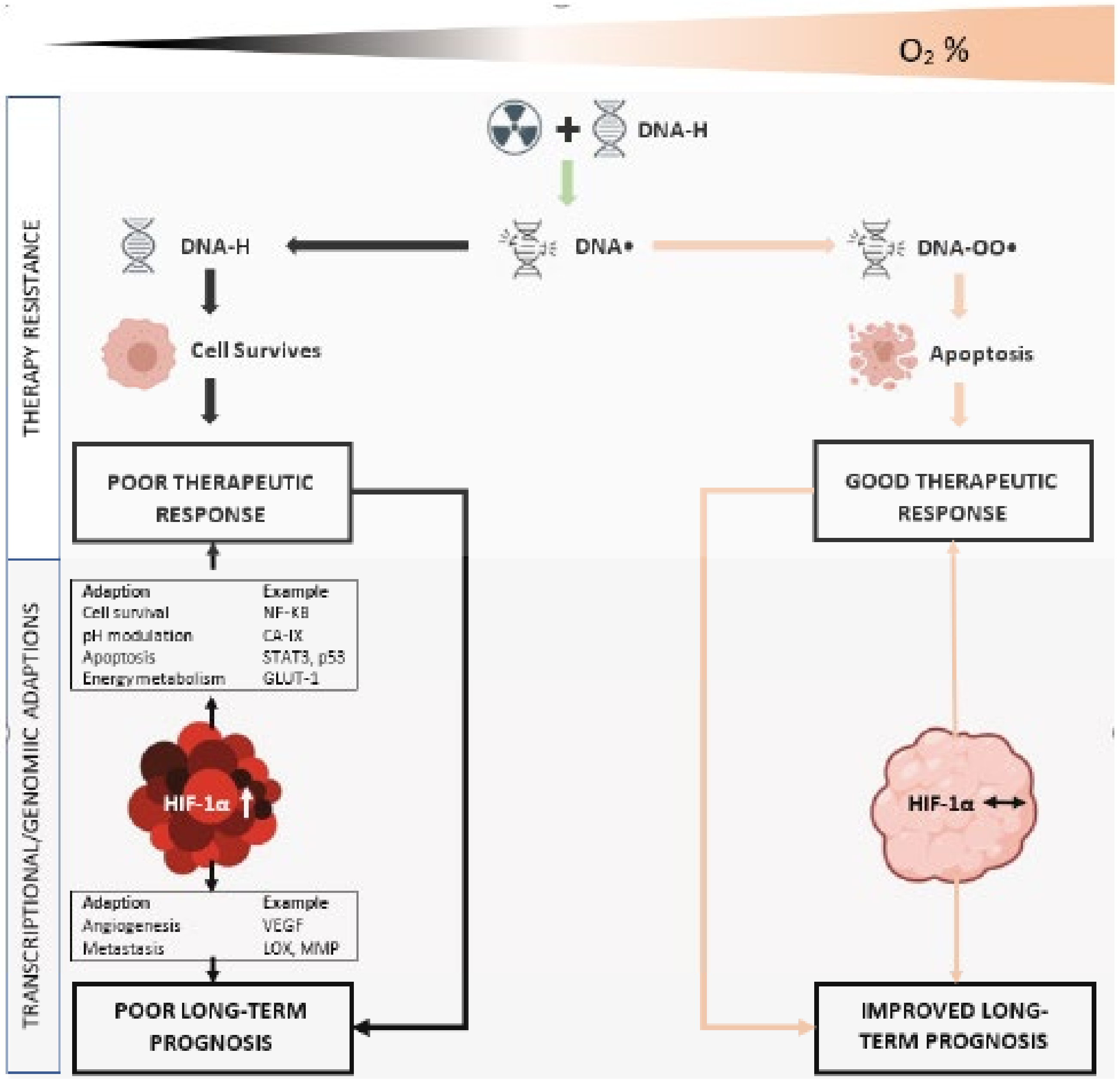


Figure 2: Schematic simplification highlighting the importance of oxygen in the radiobiological process and the hypoxia-induced transcriptional, genomic and proteomic alterations leading to poor therapy response and poor overall survival. HIF, hypoxia inducible factor; GLUT-1, glucose trasporter-1; LOX, lysyl oxidase; MMP, matrix metalloproteinase; NF-kB, nuclear factor of kappa-light-chain-enhancer of activated B cells; p53, tumour protein 53; STAT3, signal transducer and activator of transcription 3; VEGF, vascular endothelial growth factor; CA-IX, carbonic anhydrase 9. Ionising radiation impacts directly with DNA, resulting in ionization damage, DNA•. This can easily be repaired to its original state (DNA-H), but the presence of oxygen fixes the damage into a permanent state through the formation of a peroxy radical (DNA-OO•). Hypoxia results in the upregulation of HIF-1α, a master transcriptional protein with numerous downstream regulatory genomic and proteomic effects, leading to enhanced cell survival, invasion, metastasis, and consequent poor overall survival.

Tumour Hypoxia: A Primary Cause of Chemoradiation Resistance

The role of tumour hypoxia in therapy resistance is well known. Hypoxia is common to all solid tumours and is independent of tumour size, stage, grade and histology[18,19]. It is the inevitable consequence of a tumour's rapid growth, demanding metabolism, and disorganised, inefficient vasculature. Thus, cells situated over a certain distance (typically 100-150 Ҵm) from a functional blood vessel are prone to chronic (>24h), diffusion limited, hypoxia[20]. Solid tumours are also prone to episodes of transient vessel occlusion leading to periods of acute hypoxia (<24h). The result of these confounding mechanisms is a cyclical, heterogeneous map of tumour hypoxia, further complicated by varying rates of oxygen consumption between cellular components.

The compensatory mechanisms employed by tumours, and indeed the absence of oxygen itself, hinder the ability of all treatment modalities, including radiotherapy, chemotherapy, and more recently, immunotherapy[21]. The role and availability of oxygen in the radiobiological process is critical. Radiation induces apoptosis by directly or indirectly generating double stranded DNA breaks. The oxygen fixation hypothesis describes how, in the presence of oxygen, ionising radiation causes the oxidation of free radicals to DNA[22], thus causing irreparable damage[23]. The irreversible nature of this oxidation process is vital: without it, cells can affect DNA repair and avert cell death (figure 2). So important is this oxidative effect, that 2.5-3.0 times the dose of ionising radiation (IR) is required to achieve the same effect in the absence of oxygen – the so-called oxygen enhancement ratio[24]. The presence of tumour hypoxia is not binary; rather it exists on a gradient of oxygen pressures. Radiobiological hypoxia, the level at which the effect of IR is limited in a manner described above, occurs at ≤3 mmHg (0.4%). However, other biological phenomena can occur at less severe levels of hypoxia, and therefore anything below normoxic states can affect negatively affect therapy response[25].

The consequences of hypoxia on resistance extend beyond the aforementioned oxygen induced DNA damage. Up/down regulation of over 100 genes are known to be involved in a cell's drive for survival and adaption to hypoxic conditions. Central to their regulation is the master transcription factor, hypoxia inducible factor 1 (HIF-1)[26]. The far-reaching effects of HIF-1 are beyond the scope of this review. However, it is important to note that the downstream regulation of a number genes, exemplified in figure 2, affect apoptosis, glycolysis, angiogenesis, and the cell cycle to enhance a cell's survival capability.

The clinical consequence of tumour hypoxia is therefore poorer overall survival, disease free survival, and locoregional contro[27]]. Recognising this, clinicians have been attenuating the effect of hypoxia, primarily with hypoxic modification or with hypoxia activated pro-drugs. Some success has been made in such modification[23], particularly for head and neck cancers[28]. However, triumph has been limited by our inability to accurately measure and map tumour hypoxia in a non-invasive, practicable, and reproducible fashion. Achieving this will enable the selective application of hypoxic modification and potentiate the use of targeted radiotherapy, thus paving the way for precision oncology in RC.

There is also the potential to use changing levels of hypoxia for advanced tumour response monitoring. The notion of re-oxygenation following radiotherapy, first proposed by Withers et al, describes how tumours become progressively re-oxygenated over a course of fractioned radiotherapy via processes of: reduced oxygen metabolism, improved circulation, tumour shrinkage, and migration of cells from hypoxic to aerobic conditions[29]. There is strong supportive experimental evidence[30] and clear clinical demonstration[31] of this, albeit via indirect positron emission tomography (PET) measurement with hypoxic tracers. Thus, this process of re-oxygenation, if measured accurately and dynamically, could prove revolutionary in tumour response monitoring.

Measuring tumour hypoxia: where are we now?

The measurement of tumour hypoxia can be divided threefold. The first category is the direct quantification of the amount of oxygen in tissues using polarographic needle oxygen electrodes, now commonly referred to as Eppendorf electrodes. This methodology is accurate and enabled the fundamental link to be realised between tumour hypoxia and poor outcomes[32,33,34,35,36]. Unfortunately, the technique is invasive, user-dependant, impracticable for inaccessible tumours, and can be incapable of differentiating irrelevant necrosis from treatment-decisive severe hypoxia.

The second category is the use of hypoxic markers/tracers which reduce or bind to metabolic components under hypoxic conditions and can be identified on subsequent imaging (e.g. PET) or immunohistochemical staining (e.g. Pimonidazole staining). The most promising of these is PET imaging following injection of a radiotracer – e.g. 18F-Fluoromisonidazole (18F-FMISO) or 18F-Fluoroazomycin-Arabinofuranoside (18F-FAZA) – which diffuses into cells and, under hypoxic conditions only, binds to intracellular macromolecules. Notably, non-uptake of 18F-FMISO has been correlated with better outcomes and overall survival in gliomas, head and neck, renal and breast tumours (although not in rectal cancers due to non-specific uptake in the surrounding normoxic tissues)[37]. PET imaging has also been used to map tumour hypoxia, with consequent planning and application of intensity modulated radiation therapy (IMRT), in which higher doses of radiation are directed to hypoxic regions[38,39] – so called dose-painting. Unfortunately, PET imaging is plagued by several limitations, the most significant of which is the quantification of hypoxia. Whilst a high uptake is assumed to equate with heightened hypoxia, it may represent slow clearance from normoxic cells. Conversely, low uptake could indicate lower hypoxia, or rapid clearance from normoxic cells. Radiotracer uptake and perfusion differ between tumour types, radiotracer sub-category, and most problematically, areas of the same heterogenous tumour. Thus, the time from radiotracer injection to static imaging greatly influences the hypoxic readout, exposing this technique to considerable inaccuracy.

The third category involves the indirect method of measuring biological processes which are known to affect or result from hypoxia, such as gene or protein expression (which are discussed above). This category also contains indirect imaging techniques, such as Dynamic Contrast-Enhanced (DCI) and Blood Oxygen Level Dependant (BOLD) MRI imaging, which provide information on tumour dynamics and perfusion. Whilst both have shown promise, they provide qualitative, rather than the required quantitative, information on hypoxia.

Therefore, whilst these techniques have shown potential, each is associated with limitations preventing its adoption into routine clinical use. It can therefore be seen that the required device or imaging technique needs to: (i) differentiate accurately between hypoxia/anoxia/necrosis; (ii) be non-invasive (to the tumour); (iii) allow serial measurement to account for hypoxic heterogeneity over space and time; (iv) be sensitive to hypoxia levels relevant to therapy resistance; and (v) reflect cellular, rather the vascular, oxygenation.

The Future of Measuring Tumour Hypoxia: Opportunities Provided by Diffuse Reflectance Spectroscopy

Diffuse reflectance spectroscopy (DRS) involves the study of light and its impingement on biological tissues. Specifically, light can either reflect off the surface in a specular fashion or diffuse into a tissue, whereupon it is partially absorbed and elastically scattered. The term 'elastic' refers to the light's retention of energy, and consequent maintenance of wavelength, between each scattering event. Therefore, the study of a tissue's absorptive and scattering properties, and the degree at which individual wavelengths are backscattered across a spectral range, allows the quantification of otherwise invisible cellular properties. This technology is suitable for assessing a tissue's oxygenation profile due to the differing absorption profiles of oxygenated and deoxygenated haemoglobin. There is a wealth of evidence demonstrating how this can be done in a qualitive, quantitative, and reproducible fashion[40,41], (figure 3). Further, despite the apparent complexities of DRS, the required hardware is relatively simple. The typical components used are: a light source; a fibre-optic probe to deliver and retrieve the light; and a spectrally resolved detector (spectrograph) to determine the intensity of the light at each wavelength of interest. The result is a technology which is low cost and ideal for miniaturisation, with even implantable devices having been developed (figure 3)[42]. There are many in vivo examples of how DRS can be used to accurately assess, for example, bowel and cerebral perfusion and ischaemia [43,44,45,46,47]. Further still, the role of DRS is not limited to the assessment of oxygenation. Quantification of various intracellular components (e.g., nuclear enlargement) has meant that DRS has been used for the early detection of dysplasia and carcinoma in many organs. Specifically, within the realm of colorectal cancer, DRS has been used to detect signatures of early dysplastic transformation in colonic polyps[48,49]. Of note, Avila-Rencoret et al are working towards a 'robotic-assisted cartography of the colon'[50], where DRS probes and robotic scanners are mounted onto a conventional endoscope (figure 3) to enable large area mapping of the colon for early detection of pre-malignant polyp transformation.

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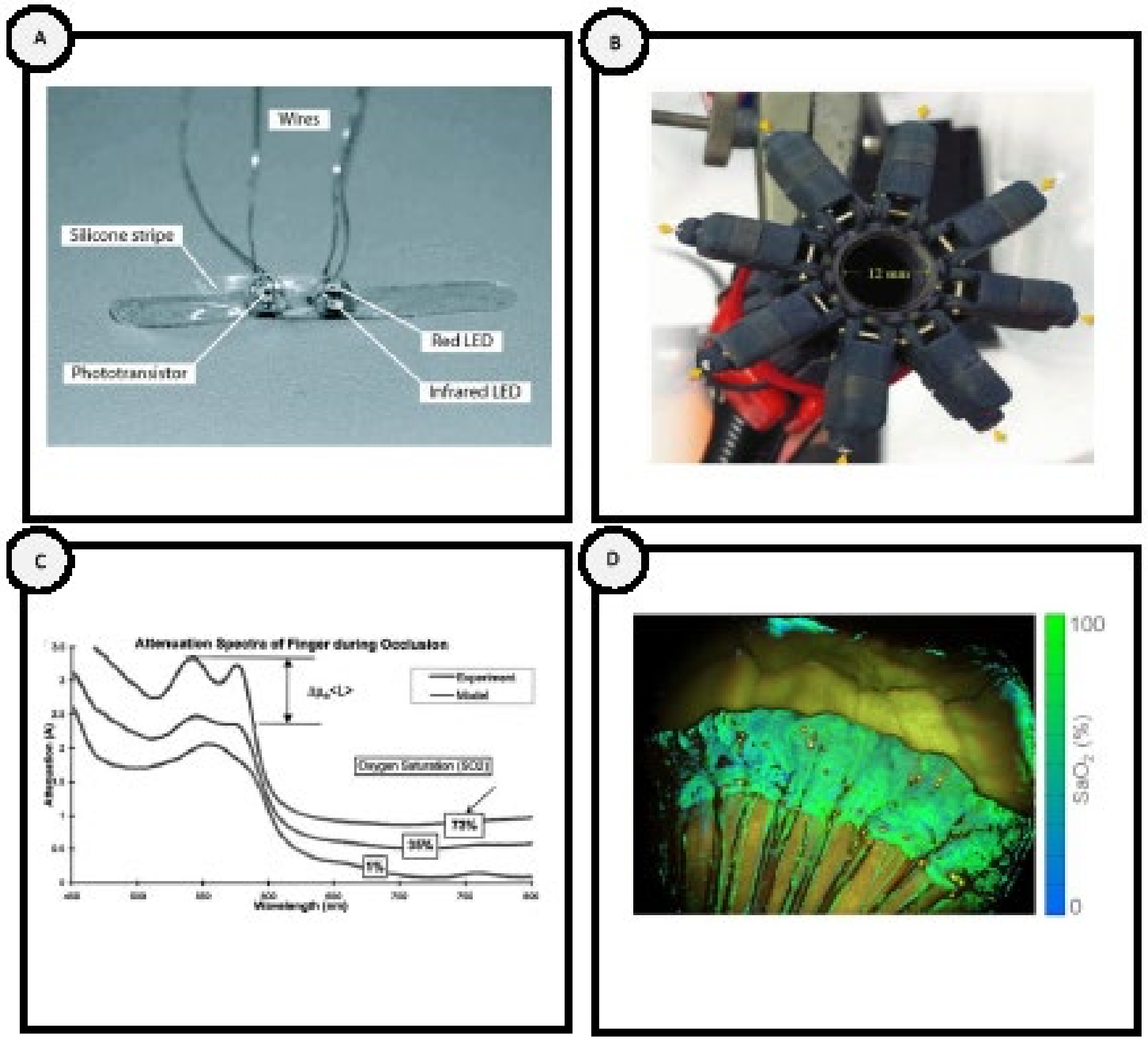

Figure 3: Diffuse Reflectance Spectroscopy (DRS) sensing devices and output: (A) Prototype of an implantable pulse oximeter, measuring 40mm x 4 mm x 0.2mm; (B) Example of how DRS probes can be mounted onto a conventional flexible endoscope, as performed by Avila-Rencoret *et al* in 'working towards a robotic cartography of the colon'; (C) Example of diffuse reflectance spectral data in relation to differing tissue oxygenations; (D) Images of perfused bowel obtained from a DRS probe mounted to a high resolution surface laparoscope [47]. Images (A), (B) and (C) have been reproduced with permission from [42], [50] and [41]

DRS represents an extremely promising technology with a proven ability to assess tissue oxygenation, and an evolving ability for carcinogenic assessment, which can be deployed using minimally invasive tools. It seems logical that a DRS probe could either be delivered via an endoscope for regular assessment of tumour hypoxia, or, more ambitiously, as an implanted device to give real-time, continuous feedback on cyclical and heterogenous hypoxia. It is reasonable to premise that such a device could provide feedback on tumour size, invasion, and the presence of the aforementioned tumour fragmentation post nCRT. Notwithstanding the challenges that remain (including issues relating to the effect of space and pressure at the probe-tissue interface[51]), DRS holds very real potential to enhance our understanding and management of tumour hypoxia in rectal (and other) cancers.

Conclusion

The role of nCRT within rectal cancer is rapidly expanding, and the era of organ preservation, watch and wait, and major rectal cancer surgery avoidance is upon us. With this has come an urgent need to predict those who are likely to completely respond, and an equally pressing requirement for real-time response monitoring to enable personalised treatment protocols.

Whilst the importance of hypoxia in chemoradiation resistance is undisputable, the medical profession has failed to capitalise on this discovery due to the inherent difficulties in measuring it in a meaningful manner. However, with the ongoing development of sensing and imaging tools based on DRS, we reach an exciting stage where we can potentially exploit tumour hypoxia to enhance cancer management. In turn, this may enable the introduction of precision oncology through improved prognostication, real-time tumour response monitoring and accurate three-dimensional mapping of hypoxia, thereby enabling effective deployment of hypoxic modification, high-dose targeted radiotherapy and other personalised treatments.

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Helping Surgical Patients to Make Better Choices: The Intersection Between Behavioural Economics and Artificial Intelligence

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Introduction

Delivering personalised and precise consultation remains a core aim of surgical practice; whether it is related to lifestyle modifications, medication compliance or chronic disease management[1]. A key component of this initiative is the tailoring of clinical advice to meet the needs of the individual patient. Despite the efforts of surgical care providers, deleterious health behaviours that can lead to negative consequences and increased health resource utilisation still persist. Underpinning these behaviours and patient decisions are factors such as time constraints, cognitive limitations and knowledge deficits[2]. As described by the bounded rationality theory, the interplay of these factors influences how patients make decisions and leads some to opt for less desirable behaviours[3]. This context for this decision making, or choice architecture, forms a central principle of Behavioural Economics (BE)[4]. This field aims to investigate these determinants of decision-making behaviour. Using this understanding, BE enables the development of interventions, or nudges, to prompt people towards particular desired actions, whilst maintaining their choices. Over the past decade, healthcare has made a concerted effort to leverage these lessons to improve the health behaviours of populations. Whilst these initiatives have had some success, such as opt-out procedures for organ donation, they are often reliant on examining how populations use common biases to derive a choice[5].

Surgical practice, however, often requires a greater delivery of, as well as adherence to, individualised information. Born from this need of personalisation, is the emerging concept of 'personalised choice architectures,' which sits at the intersection of behavioural economics and artificial intelligence (AI)[6].

Pre-Operative

One area of pre-operative care in which personalised nudges hold substantial promise is in the field of screening. Cancer screening forms a significant component of the diagnostic pathway for breast, cervical and colorectal cancer. Despite this, in all three programmes, there are significant disparities across the UK, with breast cancer coverage having declined 2.7% in the past decade[8,9]. As such, there has been considerable research to address these trends. These include using behavioural-science informed interventions, for example emphasizing the consequences of missed appointments (known as loss-framing). These tools, however, have had variable success[10]. One reason for this is that novel interventions, for feasibility purposes, are often developed amongst smaller groups. These samples may not represent all the factors influencing screening behaviours in the whole population[11], thus impacting the widespread effectiveness of the nudge. Using AI algorithms, however, it could be possible to segment individuals according to how receptive they would be to particular messages based upon medical, socio-demographic and psychometric data[12]. This would enable the delivery of personalised nudges tailored to an individual's context. As a result, the optimum message to enable an individual to choose to undertake a screening test would be delivered. This ultimately, could improve screening rates, even amongst traditionally low-uptake groups. Furthermore, the dynamic nature of this process means that if an individual's circumstance changes between screening cycles, the messaging would also automatically adapt, unlike the traditional static interventions currently being used.

Peri-Operative

Whilst patients are, for the most part, reliant upon healthcare professionals to undertake clinical decisions and provide care in the inpatient setting, there is increasing importance placed upon the concept of shared decision making[13] (SDM). SDM is a model that encourages healthcare professionals to collaborate with patients in making joint decisions in settings in which evidence-based options are provided in a tailored patient centric approach. SDM is aimed to respect a patient's subjective weighting of values, inherent biases and the importance that they place upon specific treatment outcomes. The model is of particular importance in discussions related to surgical consent, where it has been noted by several studies that the care received does not align with patient preference. The use of personalised choice architectures, in which material regarding surgical procedures is tailored towards patient's core value set as well as their health literacy, would provide nudges that help achieve decisions that constitute both good patient care and patient preference[14]. AI systems which have the ability to process datasets incorporating patient reported outcomes measures, patient demographic data and choice of operation would be able to provide personalised and dynamic decision aids that depict more accurate expectations about the risks and benefits associated with different treatment options.

Post-Operative

Unplanned post-operative readmission has long been a marker for poor care, and has significant financial implications for health services[15]. Rates of readmission vary significantly, with patient, surgical and hospital factors all associated. Remote monitoring sensors to facilitate discharge are now garnering increasing support following major surgery, including cardiac bypass and aortic aneurysm repairs[16]. Whilst their use remains in its infancy, some studies have shown these sensors can potentially reduce healthcare utilisation[17]. Their adoption, however, is limited by several issues including their effect on patient anxiety, and how the data they provide can affect clinical decision making[18]. Personalised choice architectures may help overcome these problems and utilise this wealth of data to improve surgical outcomes. AI models can be used to process the large volumes of clinical data the sensors derive in real-time, whilst factoring in aforementioned covariates such as type of operation. The data would, in effect, be able to algorithmically determine the likelihood of an individual deteriorating or needing readmission based upon their current status. If integrated with booking systems, this could enable an appointment of appropriate urgency to be automatically scheduled. This would give an opportunity for the surgeon to intervene prior to the deterioration, making it easier to triage these patients. Moreover, if undertaken for patients responsive to default options, a pre-booked appointment would act as a nudge to attendance. In both circumstances, whilst patients are being nudged into particular choices (e.g., to attend a pre-fixed appointment, or avoid re-attendance), their ability to act outside of this scope is not affected.

Conclusion

In 2014, the National Information Board (NIB) published Personalise Health and Care 2020, which set out a route to achieve personalised care through aims such as the provision of 'real-time digital information on a person's health and care by 2020'[19]. Personalisation, however, is not just about collecting individualised data, but the way in which that data is used to derive care options. Underlying biases in how these options are weighed, could have significant consequences such as delaying a cancer diagnosis, or unnecessary readmissions to hospital. Iteratively improving AI systems, however, may enable surgeons of the future to understand, and automatically act upon a single patient's choice architecture.

Whilst, this impact would be invaluable, currently, these aims are not possible. As with many AI-based systems, the ability to make predictive models requires the availability of large, good quality dataset which contain pertinent variables[20]. Whilst, healthcare produces vast amounts of data, much of this remains in digital silos which preclude interoperability. Furthermore, there needs to be an understanding of what data would be relevant, and how to collect it. As mentioned, decision-making is impacted upon by biases, cognitive stresses, as well external factors. Feasibly ascertaining these metrics in sufficient volume to develop algorithms may prove difficult. An appreciation of the ethical implications raised through intervening in personalised choice models, not least with respect autonomy, is also needed[21]. While patients are given the freedom of choices, whether personalisation crosses into coercion would need to be carefully considered[22]. If these limitations could be addressed, however, the promise of personalised nudges, could become a crucial surgical tool for the future.

Author Contributions

AA and VS equally conceptualized the piece, undertook data collection and manuscript writing. Both are considered first authors. HA, SRM and AD undertook revision of the manuscript.

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Depth estimation to support minimally invasive tumour excision education and robotic surgical vision using convolutional neural networks.

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Introduction

Minimally invasive surgical intervention includes various surgical approaches ranging from laparoscopic, endoscopic and robotic surgery that requires, dexterity, stereoscopy and precision being advantageous for safety and improved recovery times over traditional open surgical approaches.[1, 2, 3-7] Neurosurgery is one such specialty that has embraced the minimally invasive approach through micro-neurosurgery over several decades, however the specialty is yet to fully adopt robotic surgery in the United Kingdom, which necessitates advanced judgement of depth.[8-15] Scene depth estimation is also necessary for augmented reality to aid 3D perceptual registration of preoperative models unto organs intraoperatively.[16-19]

Depth perception is the ability to perceive the world in 3-dimensions, crucial in everyday life to avoid injury, but also required in any surgical specialty being a necessary skill for all practicing surgeons. It remains a critical pre-requisite to facilitating effective and safe intraoperative surgical practice over a narrow surgical corridor in minimally invasive neurosurgery.[3,20,21] However, no set methods to facilitate objective depth training exist in medical school, neither do we have objective methods of providing feedback for judging depth intraoperatively.

Recent efforts in depth perception studies have been focussed on adopting artificial intelligence, computer and robotic vision methodologies, and their ability to allow the intraoperative robotic platforms to judge and estimate tissue depth.[3,20,21] However, from the medical education perspective, newer methods of objective depth perception and estimation also necessitate exploration to support the trainee's practical minimally invasive surgical knowledge and skills development. This is particularly crucial when we are looking to introduce robotics into future curricular in most surgical subspecialties.

If one was to ask an experienced surgeon how far an object is in front of their field of view during intraoperative excision of a lesion, they might not have an exact numerical answer, but rather have developed an intuitive ability to estimate depth and accurately gauge the distance due to years of experience based on familiarity with anatomical landmarks. The problem is that communicating distance across to a trainee does require objective cues to guide operative practice and learning experience.

The aim of this work is to find a suitable architecture for depth estimation. We hypothesised that just like random search for neural network optimisation having enough random connections during the training process would enable the network to learn the most optimal connections to provide suitable architecture in the end. Here we describe a novel encoder decoder artificial intelligence algorithm for depth estimation and depth perception based on deep convolutional neural network encoder-decoder architecture summarised in Figure 1. We then test the proof of concept on mono-ocular videos of publicly available glioblastoma multiforme excision videos to estimate depth for the surgeon.

Methods

For this purpose, we focus on the generation of random architectures which are combined with a photometric loss function to evaluate their performance on depth estimation. This enables us to optimise monocular and stereoscopic depth estimation by selecting the random architecture with the best performance. A photometric loss function is introduced which adopts perceptual and adversarial losses estimated at multiple scales, efficiently.[22] The randomly generated networks are trained in a self-supervised manner, using stereo data similar to Godard et al.[22] To deal with stereo we concatenated information from left and right camera frames and fed it as an input to the model. Training was done on dataset from partial nephrectomy surgery performed using DaVinci Robotic platform available at the Hamlyn centre.[23] The minimum and maximum depth range was (10mm – 200mm) selected by the authors because ground truth depth was not available.

Qualitative validation of image frames was extracted from anonymised intraoperatively recorded videos of partial nephrectomy surgery performed using DaVinci Robotic platform and before qualitatively testing it on minimally invasive non-robotic assisted glioblastoma excision procedure freely available online and performed by an expert surgeon to estimate both monocular and binocular depth within the operative scene.[24]

Results

Monocular depth

The ability for the model to characterise monocular depth demonstrated a mean Structural Similarity Index (SSI) of 0.745 (± SD 0.69), which was superior to some of the standard architectures for depth estimation presented previously in the literature. The results were superior to previously reported architectures like ELAS (improvement of 44.7% percent difference), SPS (improvement by 30.65%), basic (improvement by 29.2%) and recently the Siamese autoencoder networks (improvement by 20.9%) see Table 1.23,25-27

Stereoscopic depth

We also applied model on stereo depth estimation. The network was able to characterise stereo depth by demonstrating a mean SSI of 0.744 (± SD 0.069).

Methods	ELAS[26]	SPS[27]	Basic [25 23]	Siamese[23]	Model A(mono)	Model A(stereo)
Mean SSI	0.473	0.547	0.555	0.604	0.745	0.744
SD SSI	0.079	0.092	0.106	0.066	0.075	0.069

Table 1. SSI measurements for the depth image reconstruction, compared with previously available architectures.

Figure 1 and 2 **demonstrates the network applied to robotic surgical data (Figure 1) and qualitatively tested on unseen minimally invasive glioblastoma resection data (Figure 2).**

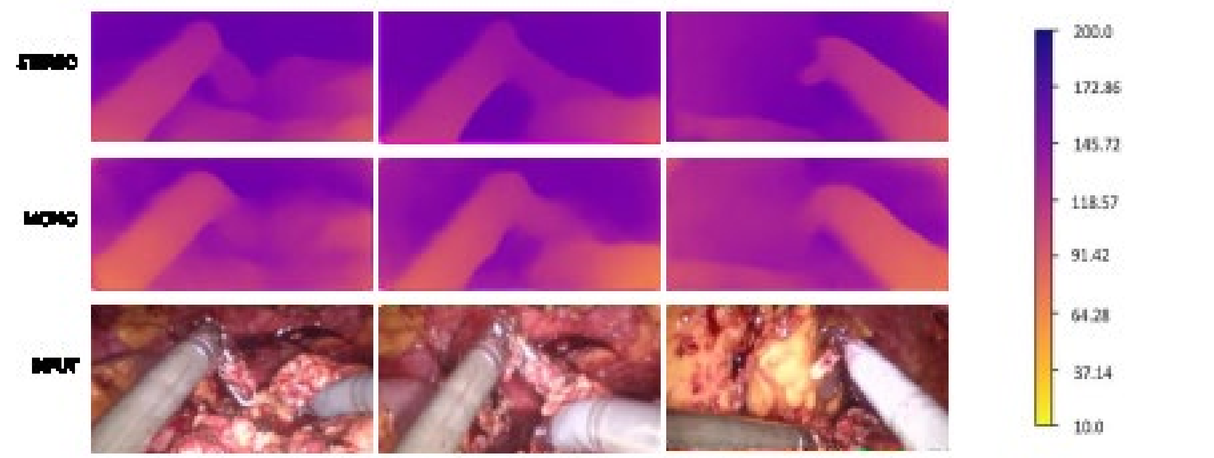

Figure 1 Illustrating applying the depth perception network to prediction qualitatively on minimally invasive vigo partial nephrectomy surgery performed using DaVinci Robotic platform. The minimum depth range was selected by the authors because ground truth depth was not available.

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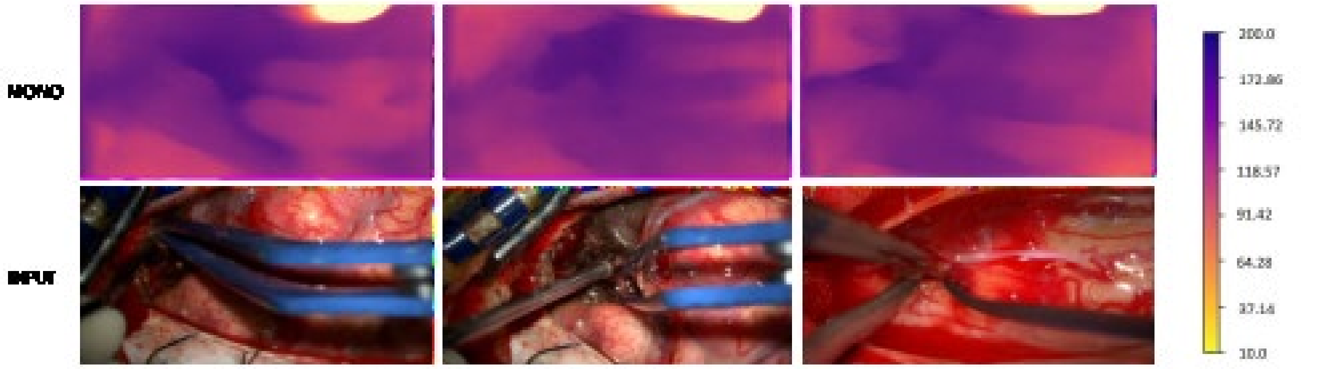

Figure 2 The monocular depth perception network to qualitatively predict intra-operative minimally invasive neurosurgical educational videos freely available online demonstrating excision of a glioblastoma multiforme.[24] The minimum depth range was selected by the authors because ground truth depth was not available.

Discussion

Depth perception and the ability to effectively estimate distance remains a crucial skill that a surgeon must possess to facilitate intraoperative spatial cognizance. Depth can be stereoscopic or monocularly judged. The lack of depth perception can have harmful safety implications leading to accidents during minimally invasive surgical interventions and robotic surgery. With the margin of error being so narrow across a narrow surgical corridor for neurosurgery and most surgical specialties, misjudging the location of structures can result in intraoperative harm to the patient and accidents.

Expectedly trainees are usually projected to have acquired these skills inherently and be equipped with it before considering a career in any surgical specialty. With modernising medical careers accelerating the need for trainees to decide early upon a career in surgery most usually have little experience and practice available to them if they are considering a career in surgical practice. Current education methods do little to facilitate depth perceptual practice or account for inherent medical conditions that could affect depth perception, hence simulation has been considered as the potential solution. However, post-graduate assessment and education to improve depth perception and estimation can also be challenging with trainees practicing this skill requiring objective feedback which may also be problematic, because there are very minimal systems available to facilitate this. Objective appreciation of depth in tandem with real-time operative depth feedback will be desirable, but little exist to facilitate this. A fully functional system like this can be integrated into the operative and robotic minimally invasive system for trainee development.

Artificial intelligence has gained significant global interest and application within the medical and surgical fields with a myriad of models being developed and applied across all subspecialist fields. The application of machine learning for depth perception research has also gained widespread. Convolutional neural networks and other deep neural network architectures have been developed to good effect at helping robots estimate depth. Others have used a Siamese autoencoder and a spatial transformer, with good comparable results to other commercially available depth estimation algorithms like ELAS and SPS (Mean of 0.604 ± 0.066 SD).[1,2,23,25-27] Comparatively, our network showed a 20.9% higher Structural

Similarity Index (Mean 0.745 ± 0.075 SD) to a recently reported Siamese network of mean of

0.604 (± 0.066 SD) but as high as 44.7% improvement in depth estimation compared with ELAS. The intended application is as described to facilitate depth perception for both surgical education and robotic vision.

Future work

The ability to estimate the depth of instrument tips in the operative scene and proximity of instruments in the surgical field is a useful next step for evolving this network to provide objective safety metrics for depth estimation and combination with automated tool tip segmentation.[28]

Conclusion

Encoder-decoder architectures can be effective for depth estimation to provide objective characterisation of depth for minimally invasive surgical education characterised on glioblastoma resection. We show that a convolutional neural decoder encoder network can be feasibly deployed for objective depth estimation with superior structural similarity index of 0.745, which is up to 44.7% better than models like ELAS.

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Deep convolutional neural networks for robotic vision-based estimation of the probe-tip to tissue distance in surgical Confocal Laser Endomicroscopy

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Introduction

Real-time in-situ histology promises to offer surgeons the ability to make quick decisions about various pathologies resolving inherent impasses for intraoperative surgical resections of tumours.[1] Clinically identifying the right resection margins, or differentiating between normal and abnormal tissue all contribute to improved clinical outcomes for patients undergoing surgery.[2-8] As such, it is believed that having real-time ability to delineate between various tissue types at specific morphological time-points can allow for characterisation of the tissue itself and facilitate optimal resection to improve clinical outcomes.

Many methods have been proposed to allow in-situ histology including probe-based laser confocal endomicroscopy (pCLE).[2-10] pCLE offers an approach for optical biopsy to histologically section the cytoarchitectural nature of tissues offering an added advantage of being a compact in-situ non-destructive imaging technique.[9] The probe can be used as an intraoperative surgical instrument adjunct with utility in multiple surgical areas including general and neurosurgery.

The challenge is that the optimal probe distance is highly variable among tissue types with an added caveat that tissue surfaces are uneven and highly variable. Tissue deformation due to cardiorespiratory motion also affects the probe-tip to tissue distance in-vivo. We therefore sought newer approaches to identifying the optimal probe-tip to tissue distance. This work investigates this using deep convolutional neural networks to identify the optimal probe-tip to tissue distance for acquisition of high-resolution images with the overall aim of vision-based distance estimation for autonomous robotic scanning.

Methods

Ex-vivo experiments

Ex-vivo experiments involved imaging of bovine gastrointestinal tissue; scalpel-cut into 2cm x 2cm squares, stained with 0.1% Acriflavine for one minute and washed with distilled water for another 30 seconds prior to imaging. The tissue surface was covered with a thin layer of transparent cling film plastic. This method kept the probe-tip clean between experiments, creating a constant 30µm probe-tip to tissue distance.

Probe-based confocal laser endomicroscopy (pCLE)

Image acquisition was performed using a CellVizio 488nm wavelength pre-clinical pCLE probe (Mauna Kea Technologies calibrated and run using ImageCell software (version 3.8.2)) and an additional custom-built image capturing and pre-processing scripts written in Python (version 3.6) and MATLAB (MathWorks version 2019b) to facilitate batch image processing. Images were acquired from the pCLE probe at a frame rate of 12 frames per second (FPS) to reduce the size of the files and to speed up image-processing.

Probe-to-tissue distance

The probe itself was clamped to a motorized robotic stage (Motorized XYZ Translation Stage 8MT173-30XYZ, STANDA 8SMC5-USB micro-step controller running XIMC library and XiLabs MATLAB controller software version 1.17). MATLAB 2019b (MathWorks) was used to control the movement of the robotic stage with 1.25µm step precision. The stage was connected to universal service bus (USB) ported micro-controller and programmed to step down in 2.5µm steps over a range of 250µm and then recorded both the timestamp and step distance using a custom-built script.

Computer Vision

Image processing was achieved using custom-built software to extract, calibrate and exclude images that had no pixel values. The optimal frame of focus was found by using a combination of no-reference Blur metrics. We achieved this by applying the Gaussian Derivative, Crete-Roffet and Brennar's gradients as shown in Figure 1. Histogram equalisation is a process that recalibrates an image's histogram from a gaussian distribution, flattening it into a uniform histogram. It is commonly used for standardising contrast adjustment across a series of images and we applied this technique to our dataset before using the images as input to the neural network.

Deep Convolutional Neural Network Algorithmic Design

The structure of the multi-layered convolutional neural network was a 32-layer 2D convnet layer with pooling, 64-layer 2D convnet layer with pooling, 128-layer convnet layer with pooling and a 256-layer 2D convnet layer. The deep convolutional neural network filter was trained on endomicroscopy images for distance regression estimation to identify the distance when the image comes into focus. A train test split of 80:20 was applied to split the videos into 80% for training and 20% for testing. L1 and L2 regularization were applied to solve overfitting, Stochastic Gradient Descent (SGD) for optimization. We used the Huber loss for loss function and R Squared for evaluation of final model accuracy.

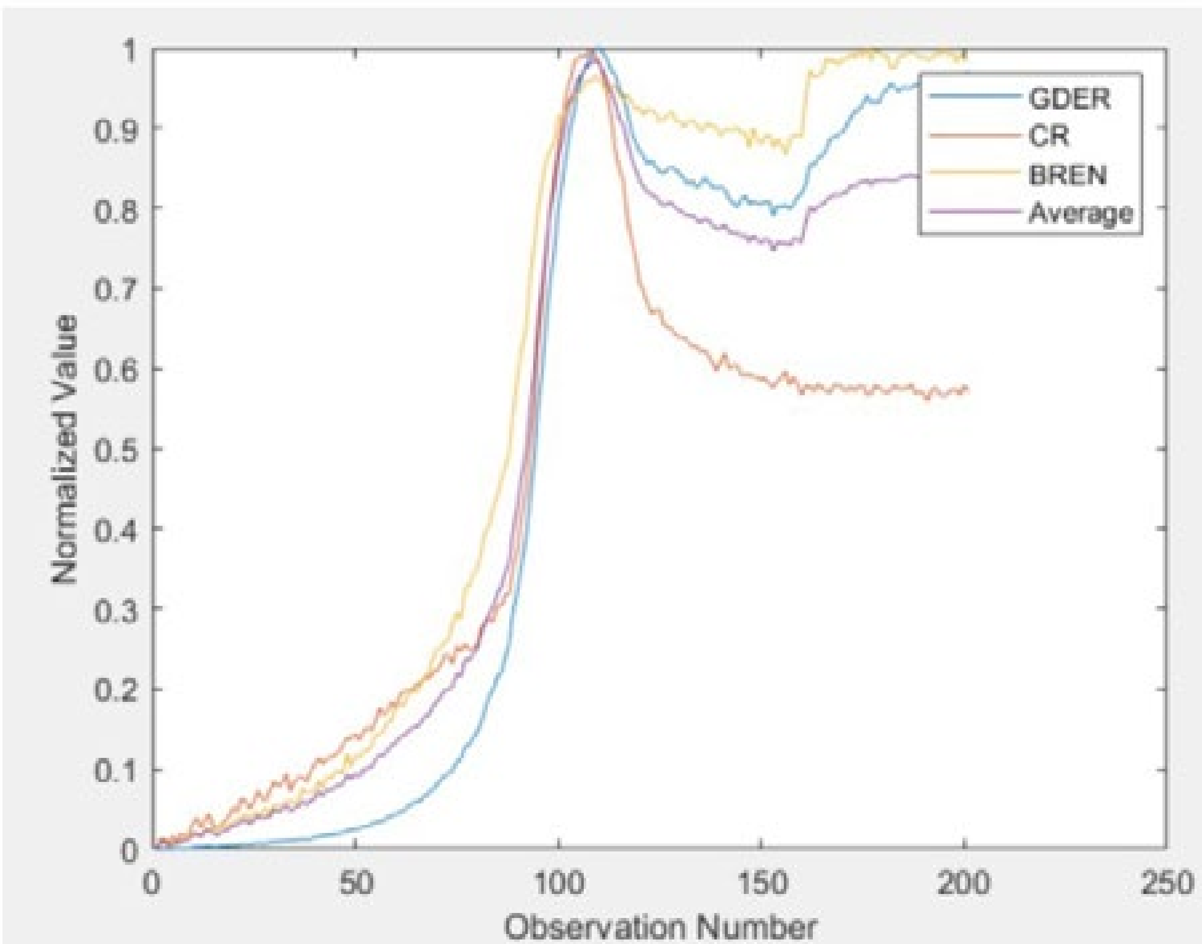

Figure 1. Illustration of the evolution of normalized blur metrics (Gaussian Derivative, Crete Roffet and Brennar's Gradient) and their average by observation number for a single experiment.[11]

Image Processing

Figure 1 demonstrates the peak normalised value centred on observation number of 110 for experiments performed on the pCLE data cleaning to identify optimal images for training and deep learning. Figure 2 shows the final image post histogram equalisation and highlights the contrasting features within the image at a probe tissue distance of 0 micro-meters where probe is in contact with the tissue surface. Figure 3 shows the optical sections demonstrating vitiligo distributions as useful areas of brightness for an algorithm to locate and learn as demonstrated. Figure 4 illustrates histogram equalisation which demonstrated that beyond the optimal point of focus, the image quality first degrades and then improves making it challenging for the algorithm to learn imaging features.

Deep Learning Accuracy

Initial training performance of the deep convolutional neural network showed a performance of 89% achieved following additional optimisations of enlarging the image training range.

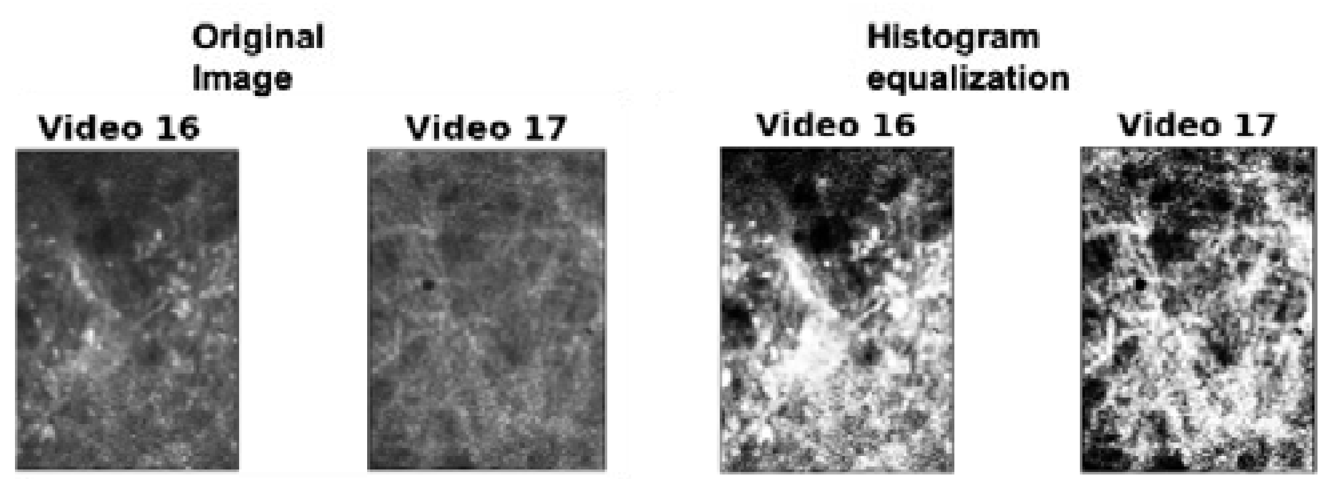

Figure 2. Figure 2 Image tiling of the original image before and after histogram equalisation. The final image post histogram equalisation highlights the contrasting features within the image at a probe tissue distance of 0 micro-meters where probe is in contact with the tissue surface.

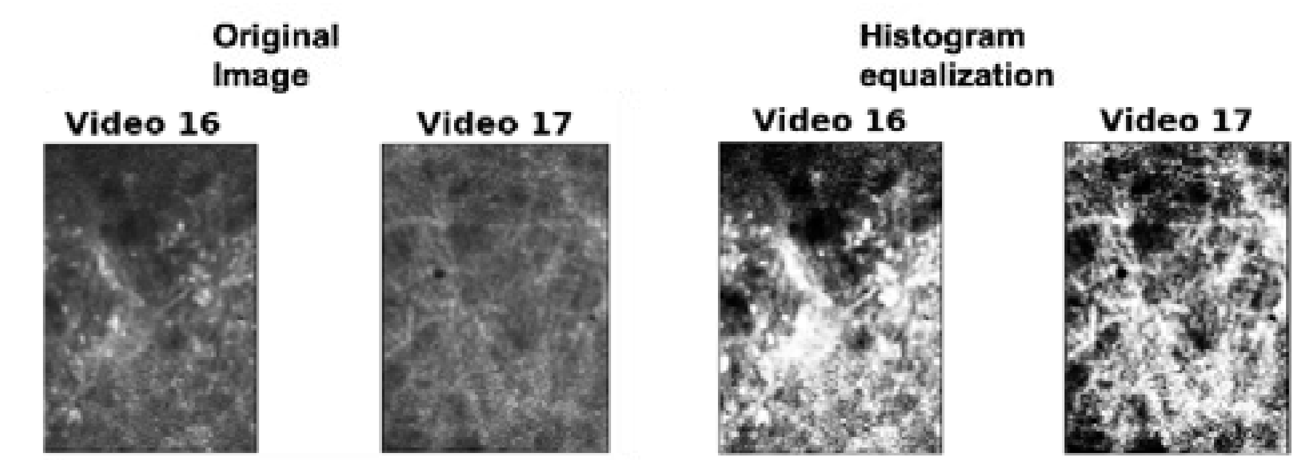

Figure 3. Morphological vitiligo distributions of pCLE imaging dataset demonstrated at a single probe distance where the image slowly approaches focus as zoomed in the red circle.

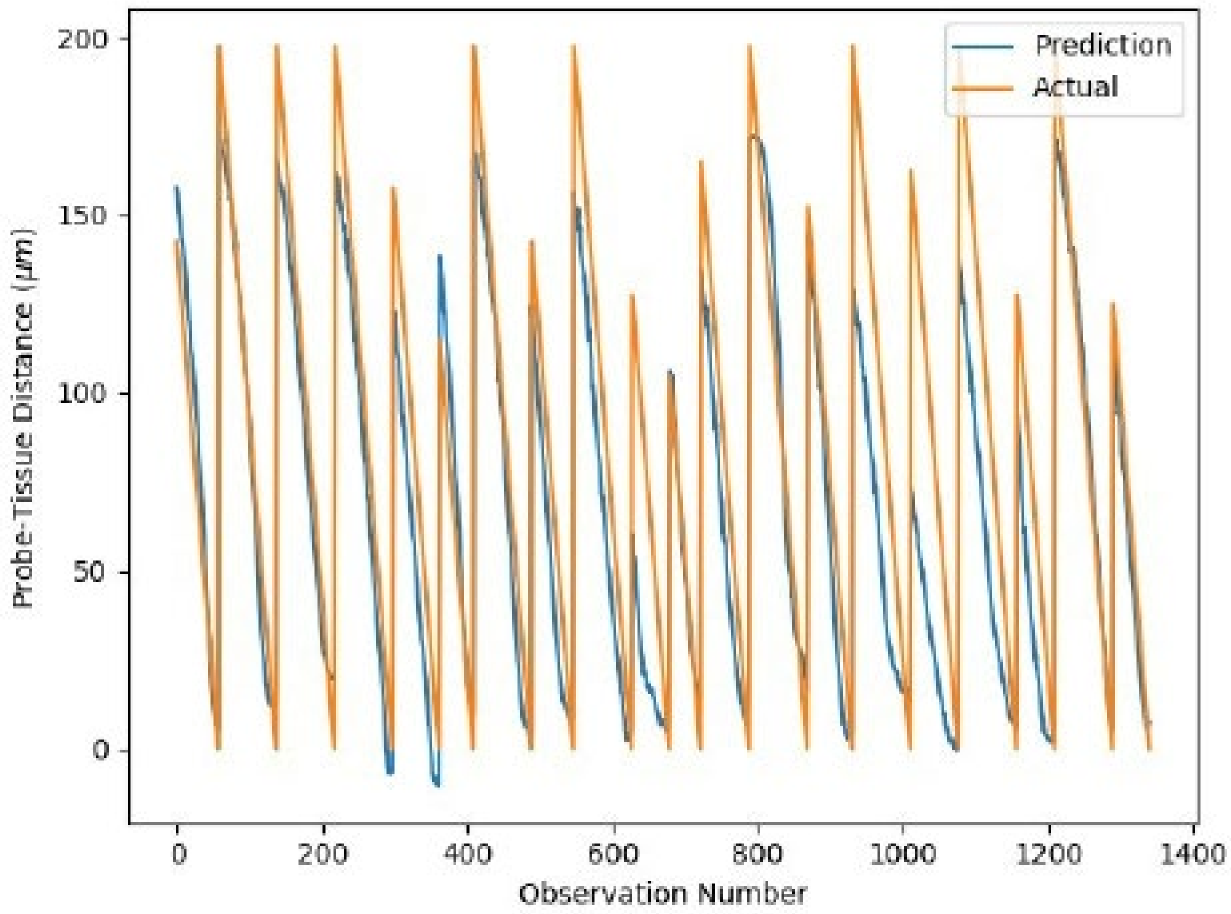

Figure 4. Results showing actual vs predicted probe tissue regression. The orange line is the actual probe-tip to tissue distance from the experiments we performed. The blue line represents the model prediction of prove-tip tissue distance. Each trough suggests the end of the experiment with peaks signifying the beginning. The current prediction accuracy was calculated as 89%.

Discussion

The explosion of interest in artificial intelligence has uncovered unique applications for surgical specialties as well specifically in GI surgery and neurosurgery.[12,13] Computer vision and robotics in image-guided intervention are areas reaping the benefits of machine learning. Multi-modality imaging for data acquisition to microscopically capture excision margins and tissue microarchitecture have required leveraging techniques like pCLE allowing for realtime in-vivo and ex-vivo characterisation. Many other authors have leveraged it for in-situ imaging of carcinomatosis and surveillance endoscopies.[14,15]

This technique is still in its infancy and requires additional image processing and characterisation. Disadvantageously, pCLE probes have a limited field of view (FOV) typically in the range of 0.24–0.6mm and hence the ability to generate larger cross-sectional consecutive scanned sections of the tissue surface is needed in order to stitch them together as mosaics. For high quality image acquisition, the optimal probe-tissue distance must be set at 0-100micrometers with an applied force of ≤100 mN.

This work used machine learning to identify the optimal distance of optical sectioning performed on gastrointestinal tissue. For pCLE, recurrent feature learning and other methods have been demonstrated.[5,12,16-19] In our study, the optical sections demonstrated vitiligo distributions as useful areas of brightness for an algorithm to locate and learn as demonstrated in Figure 3. We also adopted techniques like histogram equalisation which demonstrated that beyond the optimal point of focus, the image quality first degrades and then improves making it challenging for the algorithm to learn imaging features as shown in Figure 4.

A deep neural network was capable of detecting and differentiating distance with a 89% accuracy without any additional optimisations. This is a promising area for further exploration and the network will benefit from additional architectural enhancements to improve accuracy.

Future Extended Work

Additional optimisations and comparison with newer machine learning networks will be of benefit and will augment this study further. We were also limited by data quality hence more datapoints will also improve the algorithm ability to regress distance with better accuracy.

Conclusion

Morphological architectures are noticeable in pCLE images of porcine gastrointestinal tissue and can be identified at various probe-distances from the tissue surface. Deep learning can feasibly facilitate accurate predictions of optimal probe-tissue distance estimation that can bring pCLE images into focus however, further studies are necessary to characterise these architectures and fully delineate them. Additional architectural enhancements may be necessary for a deep convolutional neural network to improve its accuracy for judging probetissue surface distance.

Acknowledgments

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Recent technological advances and challenges for the future landscape of minimally invasive surgery.

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Introduction

Minimally invasive surgery (MIS) is a set of techniques that enable surgeons to operate on a patient with reduced trauma thereby improving recovery time and limited scarring. Surgery is a complicated task, requiring skilled surgeons operating with tools that extend their dexterity and reach to the region of interest. Within the past 5 years there have been great strides in innovation in applications of computer assistance and robotics to minimally invasive surgery, building upon the initial uptake in the field roughly 3 decades ago. Robotic and minimally invasive surgery have introduced new benefits and challenges to the operating room, the latter of which are being identified and addressed[1]. The benefits of MIS have begun to be revealed within the past two decades, as less trauma to the patient means shorter recovery times, less pain, scarring, and a lower infection rate[2]. This essay presents three different areas of MIS in which computer assistance and technology are innovating. It also describes how each example can apply in practice.

Software

While hardware such as surgical instruments and cameras may be limited by available space, software tools for MIS handle a different set of challenges. Recent developments in artificial intelligence (AI) and training programs for minimally invasive surgery present innovative and effective ways of teaching MIS techniques. Additionally, standardisation of MIS robotics platforms brings uniformity to the burgeoning field.

Machine learning (ML), or more broadly AI, combined with surgery does not instantly strike confidence in those that hear of it. The technology is not at the stage where a computer program autonomously performs a procedure. Instead, the application is in tandem with surgeons, assisting them with their work or learning from it. In Setti et al., training data is acquired from multiple sources during a teleoperated robotic surgery. This work is part of a project called the Smart Autonomous Robotic Assistant Surgeon (SARAS, saras-project.eu). While not inherently using AI, this work demonstrates significant progress towards advanced robotic minimally invasive surgery (R-MIS). Leporini et al., collaborators on the platform, conducted extensive validation tests on the system to rank its performance in comparison to their reference standard, the da Vinci IS1200 (Intuitive Surgical Inc., Sunnyvale, CA). This smart robot assistant will be able to help surgeons in a limited but productive capacity during surgery. As is the case in other robot manipulation or computer vision tasks, this robot is trained on actual data. Table 1 summarises the characteristics of artificial intelligence studies.

User interface innovations work to streamline the interaction between human operators and technology. ML methods may be applied to this task[4], but sometimes they are not necessary[5]. Classification and detection algorithms have applications both in and out of the medical research setting. ML-based methods are especially useful in scenarios where tactile feedback in traditional open surgery would be used, such as sensing tissue deformation or lumps in tissue. Tonutti et al. present an ML system for modelling tissue deformation in real time, which offers improved tracking compared to other systems.

Training software is another avenue for innovation in MIS. One application of AI to this is with reinforcement learning, a type of machine intelligence where an agent learns a policy for completing a task.

The better choices it makes to minimise error, the greater the reward it receives. This method resembles the way that biological organisms make decisions; good choices are rewarded, bad choices are disincentivised. This machine learning technique can learn policies for controlling surgical systems, learning from skilled surgeons as well as other reinforcement learning agents[7]. Developing robust surgery agents is not only helpful to new surgeons, but for the new avenues of research and application where these models may be used. With feedback systems to be implemented more broadly in robotic surgery tools, applying learning models to surgical procedures could produce massive data sets for data analysis and ML applications. AI is especially applicable in tasks that seem straightforward to humans but require more nuance when attempted by a learning agent. In Thananjeyan et al., a deep reinforcement learning agent is developed to learn optimal policies for holding gauze taught to enable precise cutting of shapes. In the effort of reducing the cognitive load on surgeons, this paper presents a next step for more automation in the operating theatre. Staff availability is another issue that is being addressed with technological innovation. Userfriendly and handsfree human-computer interface technology such as gaze tracking are being used to control robots to act as "robotic scrub nurses"[9]. As the hands of a surgeon are precious, gaze tracking and other handless-controlled technology is conducive to a more seamless workflow. Figure 1 shows a simplified pipeline of how AI could be integrated into surgical practice.

Study	Technique	Year	Novelty
Power et al [4]. IEEE International Conference on Robotics and Automation	Continuous Hidden Markov Model (CHMM).	2015	Haptic control of RMIS system with ML agent learning from demonstration.
Tonutti et al [6]. Artificial Intelligence in Medicine	Artificial neural networks (ANN) and support vector regression (SVR).	2017	Developed patient-specific deformation model for tumour tissue.
Tan et al [7]. IEEE Robotics and Automation Letters	Deep RL.	2019	Implements RL agent for observing and learning surgical procedure.
Thananjeyan et al [8]. IEEE International Conference on Robotics and Automation (ICRA)	Deep RL.	2017	Improved agent learning of material manipulation policies in complex cutting task.

Table 1: Characteristics of AI studies

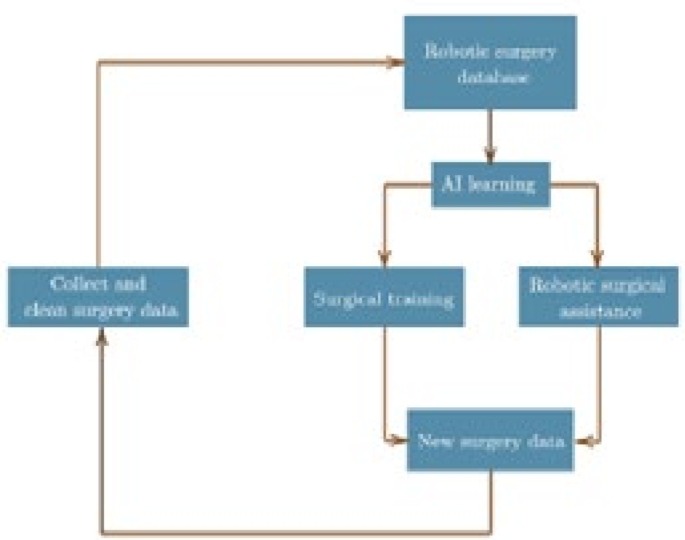

Figure 1: Flow diagram depicting steps for using AI assistance in robotic surgery.

Imaging

In open surgery, acquiring images or a real-time view of the surgical site is trivial. In MIS, however, there is the desire to create as few lacerations to the patient as possible. Therefore, improving imaging technology for MIS applications is very important for improving surgical experience, duration and patient outcomes. A summary of imaging studies is provided in Table 2. There are two key challenges in imaging and visualisation for MIS: Loss of depth perception and loss of tactility, two important sensory inputs a surgeon uses constantly. To compensate, recent advances try to restore this absence of visual or haptic cues with software and hardware solutions.

Currently, views are provided by HD cameras that are introduced laparoscopically to the region of interest. The camera feed is provided to the surgeon on a screen. This translation of the patient in 3D to a 2D image removes depth from the image, making it more difficult to navigate the space and understand the topography. Two emerging technologies for visualisation are augmented reality (AR) and virtual reality (VR). These technologies allow digital assets to be applied to the real world, or the creation of an entirely different environment, respectively. In the operating setting, AR is being used to visualise patient data for the surgeon. In De Paolis & De Luca, a system is developed for overlaying interior patient anatomy on top of the patient and for assisting guidance of an ablation tool to a region of interest. This application of AR is useful because it reduces the cognitive load and switching time for the surgeon, who would otherwise need to repeatedly look at a screen away from the work area for a view of the operation region. Also, it can provide the preoperative data and surgery planning data to the surgeon, visualising the areas that need to be incised, ablated, removed, preserved, etc. Another emerging technology is mixed reality (MR), whereby virtual assets can be viewed in real time in the real world, and manipulated just as you would with physical objects. One of the most established MR platforms is the HoloLens (Microsoft Corporation, Redmond, WA). The HoloLens has been used to improve the in-theatre experience for surgeons and present endoscopic data in a more ergonomic way[11]. Given the speed at which hardware and computation power improves, future iterations of the HoloLens would minimise cost and size, while improving performance, making the technology even more fitting in a surgical setting. This mixed reality technology is also applicable to real time data, providing the surgeon wearing the device with an "X-ray vision" of the inside of the patient. The system was liked by users and improved their task performance score[12]. Figure 2 depicts a possible future operating theatre scene, outfitted with advancements to improve surgeon capabilities and performance.

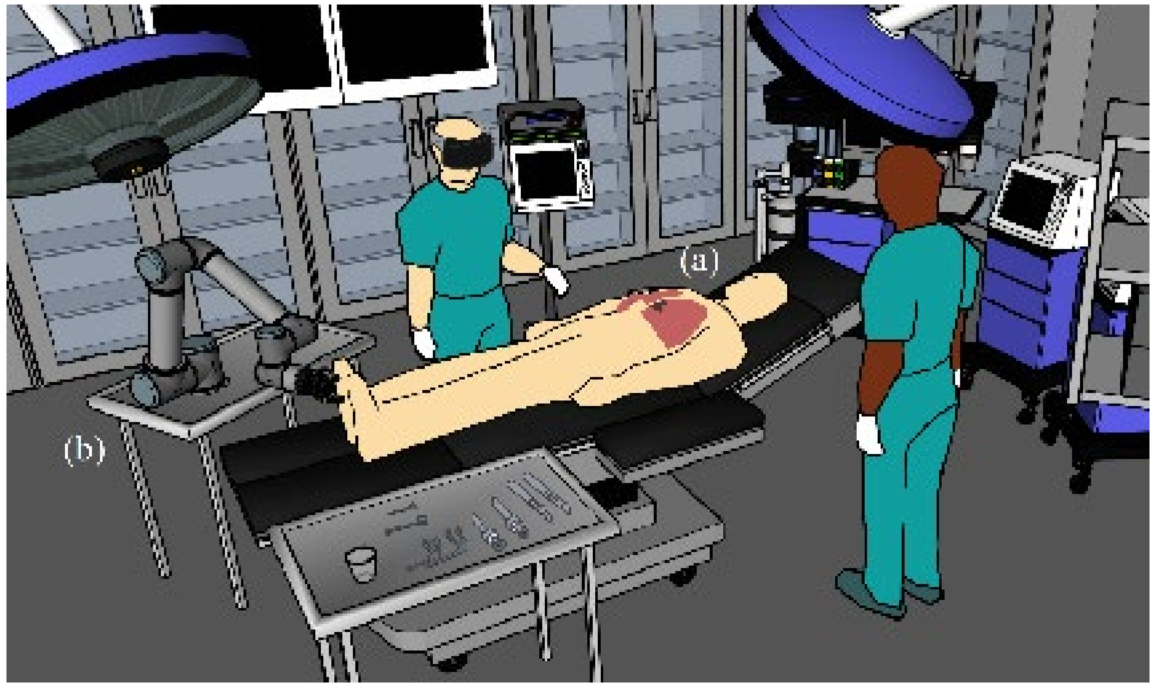

Figure 2: Operation theatre augmented with technology presented in this paper: AR view of diseased lung (a) and a smart robot assistant (b). Illustrated using SketchUp.[13]

The other form of sensing lost in MIS is the tactile connection surgeons have with the instruments and the operating region. In robotic or assisted MIS this connection is lost or diminished almost entirely because the surgeons' hands are at the controls of the instruments, farther away from the operating region. Haptic systems for MIS present multiple challenges, as it is difficult to develop a compact, sturdy system which can still be sterilised with other medical instruments. As found by Koehn & Kuchenbecker, haptic feedback functionality is not a universal solution and may provide aid to surgeons based on their experience level. Additionally, the VerroTouch system developed and validated by Bark et al aimed to rectify the issues common in haptic feedback systems, and Koehn & Kuchenbecker provide a thorough follow-up regarding user feedback of the system.

The VerroTouch system provided haptic as well as audio feedback, the former of which receiving most of the positive feedback from study participants, while audio feedback well less well received [16]. There were participants who did not want feedback on their tools, as they did not feel they needed the assistance, or have enough experience to acquire the feedback visually. Similarly, haptic feedback has been shown to aid early learning of surgical techniques for unexperienced participants; however, it is not necessarily helpful after a certain learning threshold has been reached[16]. Haptic feedback may be one augmentation to surgical technology that is not necessary in all stages and across all surgical disciplines. Implementation thereof must consider not only the cost and technical challenges, but the input of those who will be using the technology.

Study	Imaging Method	Year	n	Participants	Novelty
De Paolis & De Luca [10]. Medical & Biological Engineering & Computing	AR	2019	2	Surgeons.	High image tracking accuracy (2 mm).
Janabi et al [11]. Surgical Endoscopy	MR	2020	72	Surgical novices (n=28), intermediate level (n=24), and experts (n=20).	Achieved shorter procedure length, and the majority (n=89%) of participants provided positive feedback on using the system.
Qian et al [12]. Medical Image Computing and Computer Assisted Intervention	AR	2019	25	Users, some experienced with augmented reality (n=2).	Achieved low visual tracking error (4.6 mm), high visual update rate (n=34.8 Hz) over different point cloud sizes. Users preferred AR system.
Koehn & Kuchenbecker [14]. Surgical Endoscopy	Haptic	2015	20, 94	In first experiment, surgeons (n=10) and non-surgeons (n=10). In the second experiment, surgeons (n=68) and non -surgeons (n=26).	Majority (n=96%) of users preferred haptic feedback and said it would be a useful option in surgery.
Bark et al [15]. Surgical Endoscopy	Haptic	2013	2	Surgeons.	High (82%) number of movements yielded haptic feedback for the user.
Zhou et al [16]. Surgical Endoscopy	Haptic	2012	20	Novice subjects (no prior laparoscopic experience)	Haptics group learned at a faster rate than no-haptics group. Haptics group had faster average task completion time.

Table 2: Characteristics of imaging studies

Robotics

The introduction of robotics to MIS has enabled surgeons to work in tight spaces with more dexterity and precision than in non-assisted MIS [17]. As one of the most well-known surgical robots, the da Vinci surgical robot features small instruments which can articulate almost as well as the human hand. Still, it does not currently have haptic feedback, AR/VR functionality, or AI agents, but it serves as a solid foundation upon which these advances are being designed. Robots, much like AI, have been entering the medical field at a steady rate. Still, they are not as frequently found in clinical use than in research settings. R-MIS technologies have not yet become as cost effective or uncomplicated to learn as conventional surgical tools, and it is this and the small amount of empirical study and evaluation of said technologies which explains their absence from most operating theatres around the world[17]. Cardiac surgery is one surgical discipline which has changed since the introduction of MIS and R-MIS technologies. Operative outcomes from robotic heart valve surgery have been incredibly promising with significant reductions in scarring, hospital stay durations, recovery times, and increased patient satisfaction, among other improvements[18]. However, as is the case with many new technologies (especially in medicine), success in controlled instances does not mean the technology is ready to be used on the population at large. Since the application of R-MIS is limited in volume, it is not yet possible to objectively compare it to its alternative, open surgery.

Hardware innovations in R-MIS enable surgeons' greater control of their instruments as well as improve navigation in the operation region. Ranzani et al. propose a soft robot for navigating around organs, able to move them out of the way if necessary. By leveraging granular jamming, a technology for controlling the stiffness of a structure with small particles, they were able to stiffen part of the robot while the rest of it could still articulate. The application of this to MIS is great as such a system could be introduced laparoscopically and navigate within the body, removing the need for clamps and retractors to move or offset tissues. Another feature being explored is modular robotic manipulators, whereby the length and features of the manipulator can be customised to suit the surgical task[20]. Modular robotics appear often in subdisciplines such as swarm robotics and aerospace engineering innovation. Modularity of tools is not a common focus in surgical instrument design, but it is an important aspect of instrument applicability. Well-designed instruments with many uses (determined by changeable modules) would be more cost-effective than single-use, single purpose instruments. Figure 3 below is a concept rendering of an advanced MIS system featuring variable stiffening, making it easier to accomplish targeted surgical tasks with a wide range of tools.

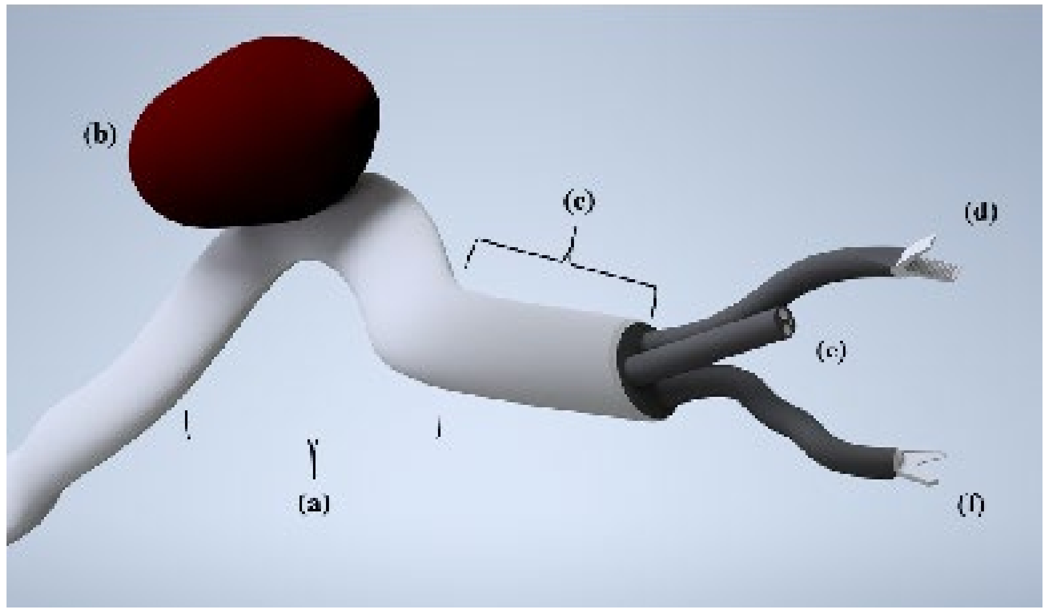

Figure 3: Robotic manipulator for MIS applications, featuring variable stiffening (a) and flexible (c) portions for retracting tissue (b). The tube structure can deliver small tools such as a clinch gripper (d), stereo camera (e) and insulated scissors (f). Modelled using Inventor.[21]

One very important aspect of all medical technologies, for MIS in particular, is the minimisation of trauma to the patient. Advances such as articulated endoscopes, used in natural orifice translumenal endoscopic surgery (NOTES) and single incision laparoscopic surgery (SILS), enable surgeons to use minimal incisions and navigate areas that were previously too complex to reach without many laparoscopically inserted instruments[22]. However, even in insufflated abdomens, introducing the same vision instruments is not always as reliable due to light source placement difficulty and inadequate leverage for manoeuvrability[23].

Di Lorenzo et al. used a magnetic control mechanism to position a camera module through the abdomen wall. The camera was coupled with an internal motor and LED array and allowed for introduction to the operation region via trocar. This technology reduces procedure invasiveness and allows for better viewing within the surgical region.

Conclusions

This paper describes multiple technological advances in minimally invasive surgery. It goes on to present examples of how these technologies can be applied in practise, as well as where they may go in the future. As is the case with all new technologies, thorough testing and evaluation is required. The standard for new medical instruments is quite high, which creates a difficult barrier to entry for many new techniques. For these technologies to rise in popularity and ubiquity they need to be evaluated, which is difficult to accomplish if they are totally novel and unfounded technologies in the medical field. Thus, a vicious cycle has formed around MIS innovation. Despite this there are still many new innovations taking place around the world, slowly pushing the discipline into the future and into the forefront of medical technology.

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The Future of Prehabilitation

Nigel Noor

Patients who are admitted to a hospital to undergo a surgical procedure expect to be better off after the intervention than before. Surgical intervention, however, causes a physiological insult which results in an initial decline in patients' function from which they must recover. Minimising this decline in function is therefore key to improving outcomes. The role of postoperative rehabilitation is widely accepted part of the surgical pathway, with well-established Enhanced Recovery After Surgery (ERAS) protocols[1] now common place. ERAS protocols are focused on the intraoperative and postoperative phases of the hospital stay and offer restorative rehabilitation with the aim of returning the patients' function towards their preoperative baseline. ERAS protocols have been shown to measurably improve postoperative outcomes, including length of stay, re-admission, and complication rates.[2] Prehabilitation, by comparison, is a relatively new and evolving concept in patient care which is rapidly gaining acceptance.

Prehabilitation utilises the time before surgery to optimise the patient's wellbeing and improve their functional capacity to better withstand the stress of surgery.[3-5] The prehabilitation window begins from the time of the patient's diagnosis and continues up to the time of surgery. Some patients have neoadjuvant therapies during their prehabilitation period which may provide an overall survival benefit, however, this is often at the further cost to the patients functional capacity immediately prior to surgery.[6]

Across the literature, current prehabilitation regimes have displayed significant heterogenicity in their composition. Physical activity is a core component seen across all studies however more recently there is a growing evidence-base to support a more multimodal approach. This Includes addressing modifiable risk factors such as alcohol and smoking consumption as well as nutritional and psychological interventions.[7] Trials have been conducted on high risk surgical patients from a range of surgical specialities, including thoracic, oesophagogastric, colorectal, hepatobiliary, bariatric, urological and orthopaedic surgery. Prehabilitation programs have been shown to both improve cardiovascular fitness pre and post surgery[8-10] and reduce some post-operative complications.[11,12]

The majority of existing prehabilitation programs have been developed to be delivered either in a hospital outpatient clinic or home-based setting with both seen as conveying certain benefits over each other. Indeed, some programs provide a combination of both hospital outpatient clinic and home-based settings. In hospital-based programs group sessions involving multiple patients are easier to facilitate which can provide the benefit of comradery between the patients and efficiency in delivering interventions to multiple patients simultaneously. However, the move towards centralised surgical services has led to patients being drawn from increasingly large geographical areas meaning that home-based programmes have logistical benefits for patients who can avoid excessive travelling. It is therefore more acceptable for the frequency of exercise interventions prescribed to be higher for patients in a home-based program. Some research projects have also described utilising exercise laboratories, rehabilitation centres and community facilities to deliver prehabilitation programs which have similar advantages and drawbacks as hospital-based programs.

Supervision of patients undergoing exercise interventions varies significantly between different studies with 45% programs offering no supervision or measurement of adherence to the exercises prescribed.[13] Of the remaining studies the supervision varied from a single follow up session to three sessions lasting an hour each conducted weekly during the prehabilitation period. Across prehabilitation studies, and exercise intervention studies more broadly, there is no consistent way to assess adherence to exercise.[14] The assessment of adherence within home-based exercise programs frequently utilised patient self-reporting in diaries with weekly follow-up phone calls. The challenges of encouraging patients to undertake exercise, accurately recording participation and ensuring that patients are completing their exercises correctly are more difficult in a remotely supervised programme. A previous study of a home-based exercise program demonstrated an average adherence of 64% to the prescribed exercise.[15] Adherence to home-based exercises is often lower than supervised programmes[16] and exercise participation during chemotherapy is particularly challenging.[17]

For exercise interventions to remain effective throughout a patients prehabilitation program the patients progress should regularly be assessed. Patients can be trained to self-monitor and self-regulate their exercise intensity using the Borg scale rating of perceived exertion (RPE). Borg's RPE scale is a widely used and validated scale that has been shown to accurately correspond to intensity measured by maximum heart rate (HRmax) in many different populations.[18-20] (Figure 1) However, as a self-reported measure, it is inherently prone to measurement bias and a preliminary study found that over 60% of RPE measurements made by patients during prehabilitation were overestimates of the actual achieved intensity measured by achieved heart rate.

Borg's Rating of Perceived Exertion (RPE) Scale

Perceived Exertion Rating	Description of Exertion
6	No exertion; sitting and resting
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Figure 1: Borg scale of Rating of Perceived Exertion (RPE)

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There are potential pitfalls which need further consideration with the expansion of prehabilitation programs into mainstream practice. As the effectiveness of prehabilitation services are acknowledged there is the possibility that these services may fall victim to their own success. The rapid expansion of prehabilitation services may result in capacity issues as the number of patients utilising these services exponentially increases. Healthcare systems globally are increasingly dealing with a greater demand for surgical interventions on an aging and comorbid group of patients which will further increase the demand on the service. Coupled with the centralisation of some surgical services the additional travel may limit the accessibility of these prehabilitation services with patients in some cases being required to travel long distances to centralised tertiary centres. This burden of travel may also reduce the amount of time available to patients to undergo exercise.

The changing face of Surgical Care in 2020 resulting from the SARS COV-2 pandemic has highlighted the need to minimise hospital attendances, particularly in patients with cancer, who may also be undergoing neoadjuvant chemotherapy and are immunocompromised. Home-based prehabilitation exercise programs are beneficial as they avoid the above risks, but their effectiveness is dependent on the patients' adherence to the prescribed physical exercises.

The Future of prehabilitation within surgery will involve augmenting existing home-based multimodal prehabilitation programs with technology. Wearable "fitness tracking" technologies incorporating sensors which monitor activity and physiological parameters are now pervasive leading to a rapidly expanding commercial industry worldwide with a market size valuation of USD 37.10 billion in 2020 and a projected compound annual growth rate of 15.9% from 2020 to 2027.[21] Wearable technologies have been shown to be both feasible and insightful in the perioperative setting.[22] Significant investment has been made in this technology increasing functionality, reliability and aesthetics opening up the potential for use in a healthcare setting, Yet little work has been done so far to demonstrate their use in prehabilitation.

eHealth technologies are already widely used by patients with 72% of internet users saying they looked online for health information of one kind or another within the past year72%[23] and 69% of adults regularly tracking a health indicator like weight, diet, exercise routine, or symptom.

Combining wearable fitness trackers and eHealth technologies into prehabilitation programs has the potential to improve patient participation, particularly in remotely supervised home-based programmes. The accurate assessment that the wearable fitness tracker devices record of the exercise intensity undertaken eliminates the current limitations of patient self-assessment and reporter bias. Utilising e-health technologies simplifies feeding back data to patients and clinicians to better assess exercise intensity and monitor the frequency that they are achieving their target activity leading to improved exercise behaviour and consequently improvement in the response to prehabilitation. The ability to better quantify adherence will improve the understanding of the effects of pre-operative exercise and therefore enable a more scientific and directed approach to the future development of prehabilitation. Work is underway to explore the use and define the role of wearable fitness trackers and e-health technologies in prehabilitation.

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Quantification of Upper Limb Morbidity after Breast Cancer Surgery with Wearable Activity Monitors: The BRACELET study

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Breast Cancer

Breast cancer is one of the most common cancers in the world. There has been an improvement in survival rates over the recent decades due to advancement in screening and treatment.[1] Many of these treatments are associated with long term complications such as reduced range of motion, lymphoedema and pain which may last months to years after treatment completion.[2] There are misconceptions that upper limb dysfunction (ULD) will resolve over time without intervention and this has caused an inadequate monitoring of ULD in breast cancer survivors (BCS).[3] Even though national and international guidelines state that rehabilitation should be provided to oncology patients, rehabilitation services are often not integrated into the breast cancer services.[4,5] Research on survivorship should be focused on reducing complications associated with breast cancer treatments which subsequently will improve patient's quality of life. Increasing awareness about the impact of ULD has led to further work into identifying those who are more at risk of developing the morbidities which warrant early intervention.

Validated tools to measure upper limb dysfunction

The validated tools to measure upper limb dysfunction in breast cancer survivors are mainly subjective such as questionnaires which rely heavily on recalls and they are prone to bias.[2,6-8] There are objective measures such as arm volume and goniometry[2,9], but they may not reliably capture the functional morbidity and provide poor comparison between patients.

Wearable activity monitors (WAMs)

Recent technological advances have allowed us to use wearable activity monitors (WAMs) to monitor and collect objective data about patients in a non-invasive and non-obtrusive manner in a free-living environment. WAMs are being utilised in oncology trials to investigate the relationship between physical activities and outcomes.10 Increased in physical activities have positive outcomes towards quality of life, complication rates and hospital length of stay.[8,11,12] Although the relationship between objectively measured upper limb activities and complication rates of patients with breast cancer have not been elucidated, higher physical activities maybe associated with improved quality of life.[13,14] WAMs have the potential to capture a more reliable and objective measure of physical function, which might help to better delineate the recovery process.

We would like to assess the feasibility of using WAMs to objectively monitor upper limb functional recovery after different types of breast cancer treatments. Even though WAMs are widely available commercially and being used in research in healthier populations and some oncology trials[10], there is limited data on how to integrate the use of WAMs in order to track recovery after different types of breast and axillary surgeries. Furthermore, most of the available trials in the literature are concentrated on the general activity and step-counts of breast cancer patients.[15,16]

The WAMs that we use in our study is a triaxial accelerometer developed by Open Lab, Newcastle University (Figure 1). Patients are identified from theatre and multidisciplinary meeting list lists and assessed for eligibility. Breast cancer patients undergoing breast and axillary surgery are approached for recruitment and patients who have a movement disorder (e.g. Parkinson's Disease) or those using a mobility device or aids, inadequate comprehension of the paperwork or unable to provide informed consent are excluded from the study.

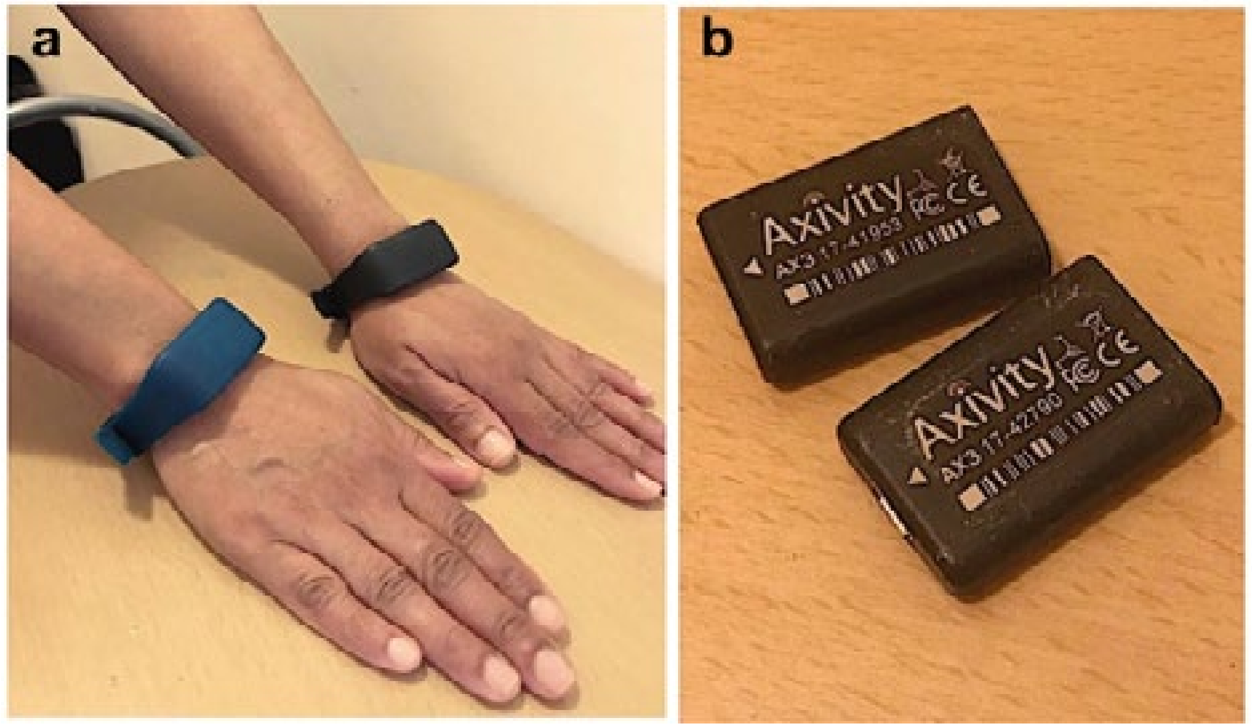

Figure 1(a): WAMs (Axivity AX3) worn on both wrists. (b): Axivity AX3 logging accelerometer.

Recruited patients are required to wear the WAMs on both wrists at least 24 hours prior to surgery and up to 14 days post-operatively. They are also required to complete the Disability of the Arm, Shoulder and Hand (DASH) and EuroQol5D (EQ-5D) questionnaires pre-operatively and at one week post-operatively.

Our pilot data (n=20) shows that regain of function was seen from day one to day 14 after surgery with greatest increases (Figure 2) was seen between day one and two ($p<0.05$). The recovery plateau was seen on day seven (Signal vector magnitude (SVM)= 66). There was also a significant difference between operated and control (non-operated) arm where there was a significant greater activity in the control arm compared to operated arm in both week one and two ($p=0.001$) with a 15% average disparity between the arms (Figure 3).

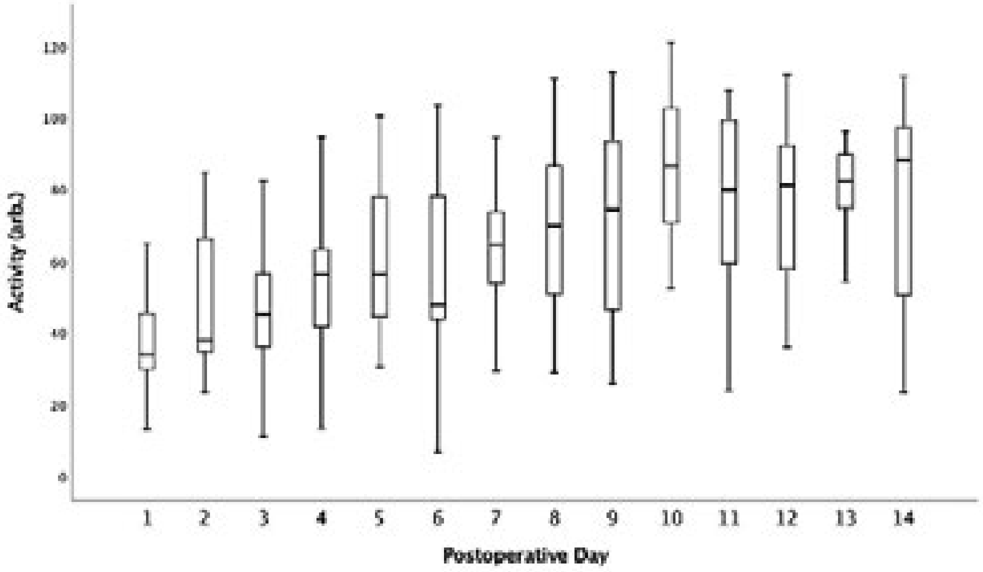

Figure 2: Post-operative physical activity (i.e. operated and control arms SVM combined).

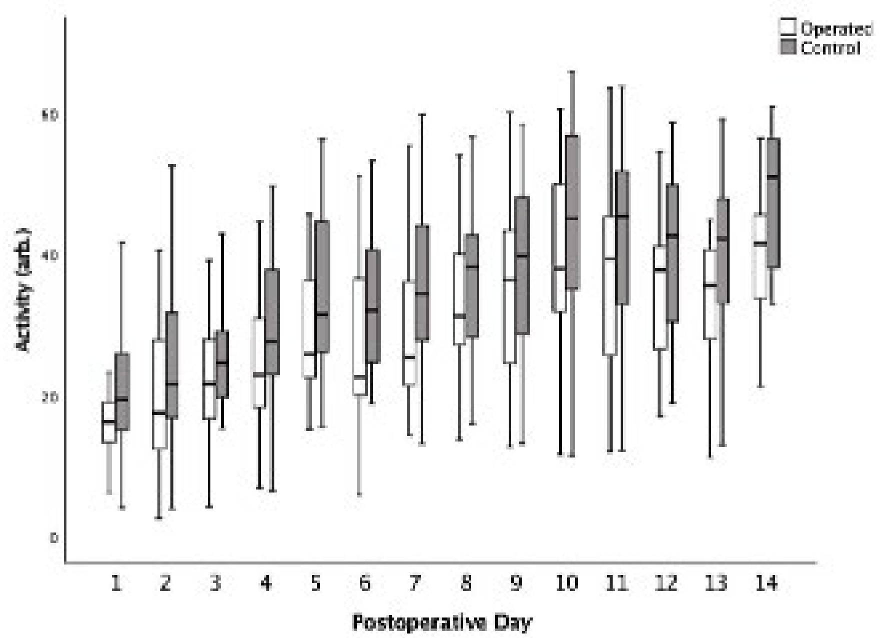

Figure 3: Disparity between recovery in operated vs control arm movement activity over 2 weeks postoperatively. (N.B: All patients right handed except for 1, 7:9:4 R:L:BL operations).

Based on the preliminary data, WAMs can be used to achieve a continuous objective assessment of patients after breast cancer treatment. This information would help better inform patients of expected recovery times, and aid clinicians in making decisions about treatment options especially when there is equivalent oncological outcome.

The NHS incurs a huge economic burden due to complications related to breast cancer treatments. This research project will enable us to provide further objective insight into the magnitude of this burden and the differences in post-operative morbidity caused by different types of breast cancer treatments. This work will also act as a baseline for future work in which WAMs might be used to support feedback-enabled prehabilitation and rehabilitation. By quantifying and characterising upper limb morbidity, a screening tool can be developed to identify patients at risk of developing upper limb complications or needing further support. Sensor-enabled interventional programmes to encourage physical activity have been used in many different patient populations including stroke[17], peripheral vascular disease[18] as well as breast cancer.[19] Tracking patient's upper limb activities can be integrated into an enhanced recovery care plan to motivate patients to take control of their care guided by their personalised activity goals. This could be a gateway to improvement in patient management with the utilisation of technological solution to improve outcomes and quality of life of BCS and could potentially be cost-saving for the NHS.

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Artificial Intelligence in Mammography and Breast Cancer Screening

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1 in 8 women will be diagnosed with breast cancer during their lifetime and breast cancer is associated with an estimated 11,500 deaths per year in the United Kingdom (UK). Mammographic breast screening aims to find these cancers in their early stages, where treatment is more likely to be successful, thus improving survival. An estimated 2.14 million women underwent breast screening in the UK in 2018 in the National Health Service Breast Cancer Screening Programme (NHSBSP). Breast screening units face significant current and future challenges, as radiological workforce shortages are predicted, highlighted by the 2019 Royal College of Radiologists Report. This pressure on breast screening services may be compounded if the invitations for routine screening were to be extended to women aged 47 to 73, as suggested by the Age X trial[1]. Breast screening in the UK is also struck with other hurdles such as clinician fatigue, lack of screening uptake, taskforce backlog and administrative errors leading to missed invites or recall. In the last year, the COVID-19 pandemic has had a significant negative impact on breast screening, due to cancelled or missed screening appointments.

> "The U.K. radiologist workforce is now 33% short-staffed; without more consultants in training and better staff retention and recruitment, the shortfall will hit 43% by 2024."
>
> Clinical Radiology UK Workforce Census 2019 Report

Image 1: Excerpt from Radiology Report - 2019

An artificial intelligence (AI) based breast screening analytic tool can ease the radiological and workforce burden of routine mammographic screening and offer a safe, cost and time-effective solution to futureproof the NHSBSP. Imperial College London, Royal Surrey County Hospital, Cancer Research UK and Google Health (McKinney et al, Nature Jan 2020) outlined an artificial intelligence system created by Google Health[2], that was trained to evaluate anonymised mammograms from a large representative dataset of 76,000 women from the UK and a large enriched dataset of more than 15,000 women from the United States of America (USA). In the UK, the mammograms came largely from the Cancer Research UK's OPTIMAM dataset, collected from St George's Hospital London, the Jarvis Breast Centre in Guildford and Addenbrooke's Hospital, Cambridge. The efficacy of this AI model was then evaluated on de-identified mammograms of more than 28,000 women and this produced a 5.7% and 1.2% reduction of false positives in the US and UK, respectively. A reduction in false negative rates of 9.4% and 2.7% was also observed in the US and UK, respectively. The model performed better than a single radiologist in both the US and UK. The AI system also maintained a non-inferior performance and reduced the workload of the second reader by 88%, when assessed during a simulated double-reading process that is currently used in the UK. Thus - AI, in the form of an independent second reader can help mitigate the limitations of screening mammography within the NHSBSP.

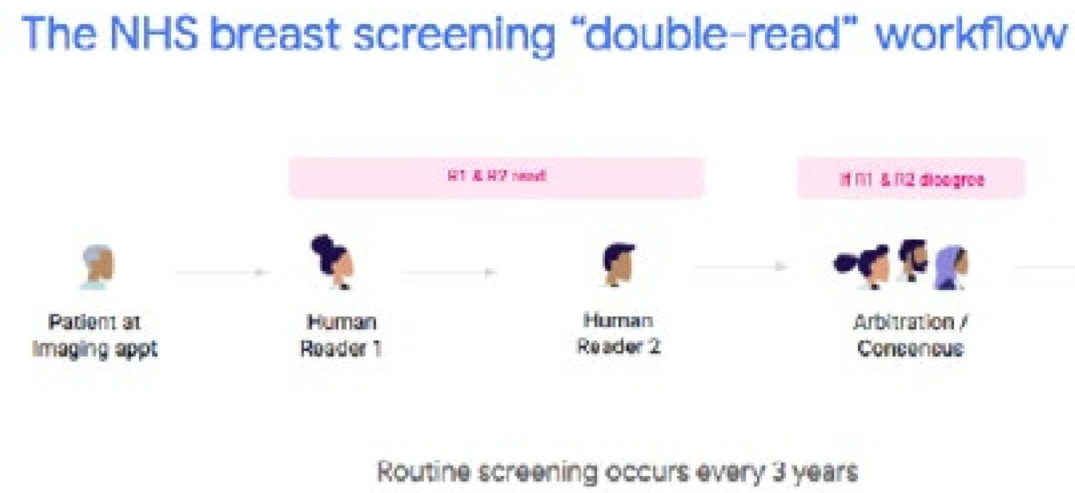

Image 2: NHS Breast Screening Workflow

As we look to the future, the next steps of this clinical-industrial-academic partnership are to assess the diagnostic accuracy and technical feasibility of AI-enabled systems within double-read breast screening radiology workflows, and whether an AI system can act as a second reader and be seamlessly integrated within the NHSBSP. This would result in a double-read mammography workflow, where the AI-system would work 'silently' as the second reader, alongside a reporting consultant radiologist. The overall aim of such integration would be to create a safe, robust and accurate AI system that would achieve patient impact at scale, whilst alleviating some of the existing workforce burdens. However, there are several key issues which will need to be addressed as part of the review of feasibility of this model. The introduction of an AI-enabled tool alongside a human reader will require further evaluation to assess the impact on screening workflows and human factors. The technical integration of an AI-based tool with existing ageing IT infrastructure poses a serious challenge. This integration may also highlight certain confounders such as reader bias or automation bias, which will affect the future use of AI-based screening tools. An important facet of the rollout of AI-based screening modalities is to ascertain public and patient thoughts, perceptions, ideas and concerns around its use. This is crucial, as meaningful engagement of lay participants is vital in the development of an AI-based tool that meets the needs of the screening programme, radiologists and patients alike. With technological advances, it may be possible for the AI-based to 'continually learn' as the diversity of its database of images increases, and this may be particularly useful for its application in screening for patients with risk factors for breast cancer, such as increased breast density and a family history of breast cancer. This may also be extended to high-risk patient groups who undergo surveillance screening annually. Future AI-based tools may also be extended and designed to take into account individual patient factors such as age, previous history of breast disease, previous mode of breast intervention and details of family history, in addition to being able to undertake a review of historical mammograms for the same patient as part of its diagnostic algorithm.

Successful integration of an AI-enabled mammographic screening tool can be a leap forward to revolutionising point of care provisions and access for our patients in the one-stop breast clinic. Whilst the current focus has been on AI-enabled diagnostic tools, this deep learning can be extrapolated to introduce new interventions based on mammographic assessment. Future one-stop breast clinics may entail a comprehensive AI-integrated mammographic and clinical assessment, followed by AI-enabled radiological intervention, such as performing core or stereotactic biopsies and placement of marker clips, which is usually completed by a breast radiologist. This may enhance patient experience and improve clinical and radiological throughput. A further future possibility is the successful use of AI-enabled breast diagnostics within more complex imaging modalities such as Magnetic Resonance Imaging (MRI) and tomographic assessment. A challenge that AI-based breast screening tools face is inter-user variability and/or technical variability, which may be a significant hurdle in its use for ultrasound-based assessment, thus limiting it to the other modalities highlighted above.

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AI-based breast screening tools provide an exciting and effective opportunity to fill NHS unmet need, whilst providing significant benefit to patients, the NHS and the wider population in the years to come. It is important that additional steps are taken to futureproof the NHSBSP – these may include investing and upgrading in technological infrastructure, rationalising screening demand and retention and support of the radiological and allied care workforce.

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Ethical Challenges of Artificial Intelligence in Surgery

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The increasing availability of data has seen a surge in the adoption of artificial intelligence (AI) across healthcare[1]. Surgery is no exception; the operating room offers a diverse range of datasets including video data, kinematic data, sensor data, and physiological data. The potential applications of AI in surgery are broad, ranging from automation of surgical processes[2], to performance assessment tools[3], to risk prediction models[4]. The allure of novel technology coupled with potential advantages such as improved clinical outcomes, better surgical education and reduced cognitive load on the surgeon has led to significant hype amongst the surgical community. However, such hype can lead to the overshadowing of the wider ethical implications of adopting this technology into the operating room which is dependent on the acquisition, sharing and processing of vast amounts of potentially personalised data.

Potential harms caused by AI systems
Bias and discrimination – AI systems such as surgical risk predictors are built upon existing data, and have the potential to reinforce pre-existing discrimination and inequality
Denial of individual autonomy – AI systems such as decision support systems can lead to difficulty in deeming accountability
Non-transparent outcomes – due to the black-box nature of many machine learning algorithms employed in surgical AI systems, it can be difficult to interpret how algorithms come to their decisions
Invasion of privacy – surgical AI systems are dependent on the use of vast amounts of personalised data which threatens the privacy of subjects
Loss of social connections – the power of AI to automate processes can cause loss of human-human interactions both for patients and surgical teams
Unsafe or poor quality outcomes – surgical AI systems can lead to unsafe or poor quality outcomes through low quality datasets, poor model design or failures in their deployment

Table 1: Examples of potential harms of surgical AI systems adapted from [5]

Guidance can be taken from the implementation of AI across different industries. The field of AI ethics has emerged as a response to the potential harms of AI systems (Table 1). It has been defined as 'a set of values, principles, and techniques that employ widely accepted standards of right and wrong to guide moral conduct in the development and use of AI technologies.'[5] The Alan Turing Institute has named 4 key pillars with respect to the design and use of AI systems: fairness, accountability, sustainability, and transparency. While these pillars provide a framework for surgical AI systems to abide by, the unique environment of the operating room as well as the nature of decisions that future surgical AI systems may have to contend with poses specific ethical issues. Four key areas of concern are presented below:

Privacy

AI is dependent on the input of often personalised data in order to train its models. Data which may be fed to AI algorithms range from imaging data to details of a patient's medical background from their electronic health record to geographical data from remote sensors. Such information can be used to build up a thorough picture of a patient which threatens their privacy. While anonymisation of this data is a fundamental step for the majority of these applications, there are legitimate concerns that patients could be subsequently reidentified[6]. Moreover, surgical AI may not have to contend with the privacy of surgeons alone but also the wider surgical team. Future AI systems may involve the recording of all intraoperative proceedings for the purpose of decision support systems or error detection methods.

It is unclear how surgeons may react to a culture where their every move may be scrutinised and how this may influence their behaviour. Will surgical teams be able to opt out of such systems and what will be the implications if they do so? What is clear is that surgical AI systems will challenge beyond the privacy of patients but also those who choose to use them.

Consent

The basic premise underpinning the consent process is that consent needs to be informed for it to be valid. However, AI systems are dependent on the collection of vast datasets and it is often not possible to define the final applications of such data. Consenting a patient for data collection where future applications are unknown calls into question how truly informed that consent can be. Even where the purpose of such data collection is clearly defined, it is unclear whether the general population have sufficient knowledge of AI to be able to consent. For surgical AI systems to flourish, education must not only be provided to patients but also to surgeons who must be able to explain clearly what data will be collected and with whom it will be shared. Finally, the consent process must extend to the wider surgical team who also have rights to their own data.

Public trust

The vast majority of the public are supportive of AI applications in healthcare, believing that it will drive better healthcare and increased efficiency**7**. However, there is often an assumption that data will remain within the NHS despite data in reality often being shared with commercial organisations. Though partnerships with these commercial organisations are often necessary for the development of AI due to their specialist knowledge and resources, historic failures of data management[8] within these partnerships have damaged public trust. Efforts must be made to ensure the development of AI applications are transparent with public involvement at all stages.

Law

Surgical AI systems are evolving rapidly; the law is unable to keep pace. The international nature of AI requiring datasets to be shared across borders is not only a technical challenge but also a legal challenge as data sharing laws vary by country with no overarching international law. Moreover, the ownership of intellectual property is unclear under the law. Healthcare providers may not often have experience in partnering large commercial companies and must protect themselves and more importantly their patients' data. Defining fair and equitable partnerships between healthcare providers and industry is a priority in order to avoid a potential imbalance in power. Finally, once surgical AI systems are deployed, we must determine lines of responsibility for potentially failing algorithms.

Conclusions

The challenges of deploying AI systems in the operating room are not solely technical. Efforts are being made in order to define the key ethical issues and future clinical, technical and organisational research goals ahead of this next era of surgical technology[9]. Those working at the interface of surgery and AI must not be short-sighted and must anticipate the ethical challenges of bringing this technology into clinical practice.

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The future of surgery: digital alerting and remote monitoring

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Remote monitoring allows people to live at home rather than in expensive hospital facilities through non-invasive digital technologies (such as wearable sensors) which collect health data, support health provider assessment and clinical decision making.[1]

Alerting mechanisms, generated following recognition of clinical deterioration, allow for appropri-ate subsequent action. Varying forms of alerts have been reported, including transmission to a mobile device; automated emails generated to a healthcare professional; video consultation; in-teractive voice responses; or web-based consultations.[2] Moreover, alerts can be relayed to pa-tients through audible alarms (figure 1).[3]

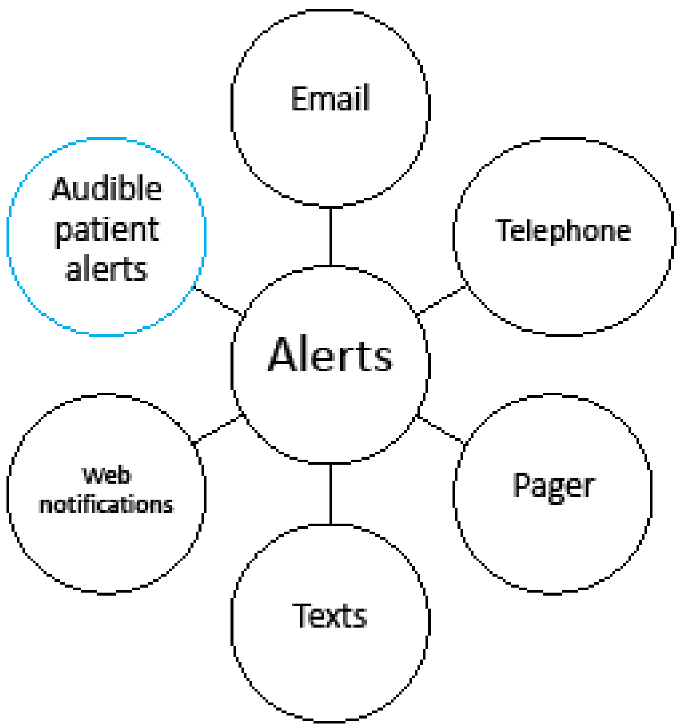

Figure 1: alerting mechanisms

A recent meta-analysis demonstrated a 9.6% decrease in hospitalisation.[4] The effects of alerting on hospitalisation, however, were noted to differ in medical and surgical cohorts. Differences were most striking when comparing studies with individuals suffering from chronic medical condi-tions (e.g., COPD, heart failure) compared to the acute surgical cohorts with shorter follow-up pe-riods.4 However, the literature remains conflicted with studies low in quality with short follow-up timeframes.[5,6]

One study reported that avoidable hospitalisation increased by a factor of 1.35 for each additional chronic condition and 1.55 for each additional body system affected.[7,8] Clearly, a cohort with signifi-cant chronic disease burden is particularly susceptible to recurrent hospitalisations and, while digiti-sation may play role in changing healthcare delivery, hospital departmental factors (e.g., seniority of clinician reviewing, busyness of department, community service delivery) and external factors (e.g., patient education and activation, behavioural insights towards digitisation, social support available) are likely to significantly contribute and may impact widespread deployment of novel digital technologies.[9]

A reduction in hospital length of stay by 1.04 days was noted with remote monitoring, favouring digital alerting.4 This is likely a result of earlier recognition of deterioration resulting in prompt clini-cal review and treatment administration; a recent systematic review concluded that digital alerts similarly reduced hospital length of stay in cases of sepsis by 1.3 days.[10]

The relationship between all-cause mortality and digital alerting systems is unclear.[4] This may be due to the nature of quality of published studies. Few studies would be deemed as high quality and older studies may utilise obsolete telemonitoring platforms.[4,11–13] One study, using the Health Buddy telemonitoring platform, has since become obsolete.[11] Early iterations of digital alerting and telemonitoring platforms may suffer significant pitfalls, preventing successful use.

Digital alerting mechanisms have not shown to reduce visits to emergency departments.[4] Earlier recognition of deterioration should prevent presentation to emergency departments and inpatient hospitalisations with non-urgent reviews scheduled for outpatient visits. Despite this, no change in overall outpatient or clinic visits was reported.[4] Further randomised trials for specific medical co-horts and conditions may address the benefit of digital alerting in affecting outpatient visits. Addi-tionally, research capturing emergency department visits, (scheduled and unscheduled) outpatient visits, and hospitalisations would be vital in addressing whether workloads can be altered through digitisation.

The current literature has several limitations based on the methodological heterogeneity and overall study quality. The paucity in high quality, robust, literature limits the conclusions that may influence clinical practice. Observational trials are prone to selection biases, particularly pre-post implementation designs, which can be theoretically confounded by longitudinal changes in healthcare provision. Moreover, integrated feedback loops and responses to alerts are likely to feed into the Hawthorne effect,[14] an additional source of bias.

Further research to answer several important questions is required. First, the optimal alerting fre-quency; a range of remote monitoring schedules have been trialled including continuous, daily, office working hours (Monday–Friday), and weekly.4 This diverse methodology expectantly influ-ences response time variation with potential for missing early signs of acute deterioration. Studies with less intense monitoring schedules may be suited for a cohort of individuals less prone to acute deterioration, regardless, a 'window of opportunity' presents itself for missing clinical deterioration in less frequent schedules. Second, the team members to alert and the nature of alert to use. Alerts are frequently generated when pre-established thresholds, often tailorable, are breeched or for concerning responses to symptom questionnaires, although audible alarms to alert patients, empowering individuals to contact their responsible physician for further assessment have also been trialled.[15] It is unlikely that one type of alert will be suitable for all individuals but further work identifying the most rapidly acknowledged and actionable alerts is required, including the explora-tion of alerts sent to individuals alongside healthcare professionals.

In conclusion, digital alerts used in remote monitoring seem to reduce hospital length of stay, mor-tality, and may reduce hospitalisations. Digital innovation has the capacity to change current healthcare provision, particularly in this pandemic era. Large, robust, multicentre, randomised tri-als studying digital alerting mechanisms in a varied cohort of individuals is needed. Trials should seek to optimise different alerting protocols to better understand successful alerting protocols, guiding future widespread implementation not only within secondary and tertiary care settings but, importantly, in community settings, as implementation of new technologies within the home environment has potential to revolutionise healthcare delivery.

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AI-Guided Surgical Resection in Neurosurgery Using Intraoperative Ultrasound

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Background

The main goal of surgical oncology is to achieve complete resection of cancerous tissue with minimal iatrogenic injury to surrounding healthy tissue. Surgery on tumours residing within the brain is particularly demanding. Furthermore, the prognosis for patients afflicted with such tumours remains very poor, with high costs to the patient, relatives, society and the economy[1]. There is evidence that increasing the extent of tumour resection substantially improves overall and progression-free survival in highgrade gliomas[2]. The current standard of care for resectable cases is that of neuronavigation based on preoperative MRI, which allows the surgeon to localize tumours when planning the surgical incision and craniotomy, and intraoperative use of 5-aminolevulinic acid (5-ALA)[3]. Unfortunately, neuronavigation based on preoperative imaging is of limited use intraoperatively, due to the increasing impact of brain shift as the operation progresses (ie. once the dura has been opened, cerebrospinal fluid and/or cyst fluid draing and tumour removed). In addition, fluorescence imaging using 5-ALA does not inform of residual tumour volume or function, and only identifies fluorescing tumour immediately apparent in the surrounding tissue, without consideration of tumour hidden due to an irregular resection cavity.

Intraoperative MRI permits assessment of tumour removal during the surgery. However, it interrupts the surgical workflow, requires changes to infrastructure, and is prohibitively expensive for many centres. Another imaging modality which has been used in neurosurgery is intraoperative Ultrasound (iUS). This permits multiple image acquisitions, and minimally augments operative time[4]. It also allows precise visualization of vital structures, real-time progression of tumour resection, and management of immediate complications, such as haematoma. It is user friendly, widely available, portable, and a pragmatic, cost effective alternative to iMRI. Furthermore, it does not require any change to theatre set up or infrastructure. However, the interpretation of iUS data is challenging for three main reasons. First, it is strictly examiner dependent, leading to considerable inter-observer variability. Second, it requires a certain amount of training and confidence to perform the 3D examination satisfactorily. Finally, imaging and spatial resolution can change depending on the US machine used. The most critical technical difficulties arise with tumour margin identification. This can be open to different interpretations, and pathological tissue can be easily confused with surrounding healthy brain structures. Hence, automatic tissue characterisation on iUS images, based on a database of previously annotated data by expert physicians, would support the surgeon in establishing diagnosis and guide surgical resection.

Methods

In this work, we formulate the brain tissue characterisation task for tumour detection as a semantic segmentation problem without the requirement of any pre-processing or postprocessing on the iUS images. Our proposed framework is built on a backbone architecture similar to Res U-net[5], which is used to characterise each pixel on an iUS image as "tumour" or "healthy". To enhance the performance of the above model and give more emphasis during the segmentation on regions of interest on the iUS images, two soft attention modules have been designed and fused with the FCN architecture, namely, the gated mixed-attention and the gated residual-attention modules. These modules have been incorporated in the backbone architecture to build two different networks, the Mixed-attention U-net (MAU-net), which incorporates mixed-attention in the long skip connections, and the

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Residual-attention U-net (RAUnet), which uses residual-attention in the short skip connections.

For training, we use an asymmetric loss function based on the Fβ function[6], which can prevent our network from being severely biased towards the larger class, which in our work is the "healthy" tissue class. The parameter β controls the weights for false positives and false negatives. Theoretically, larger β values in our loss function give more emphasis to decrease false negatives, and can therefore achieve better performance in terms of precision-recall trade-off.

The validation of the proposed tissue classification framework is based on iUS data collected during brain tumour resection procedures at Charing Cross Hospital, Imperial College London, UK. A new generation US machine, the Toshiba Aplio 900, was used to capture iUS videos, which were exported into image sequences and cropped to exclude the logos on the screen frame. Our dataset includes iUS images from three patients with Glioblastoma (GB) tumours. Two cases (Case1 and Case2) are highgrade GB, while Case 3 is a low-grade GB. To avoid in our dataset repetition of similar images captured from the same viewpoint, the iUS data from each case has been sampled to keep only distinct images. The images from Cases1 and 2 have been used in our experimental results to train our modes while, Case3 has been used as an unseen case for testing. The image resolution is 687x692 for Case1, 679x562 for Case2, 300x300 for Case3. Our current dataset is limited, as a small number of cases underwent surgery using the above US machine, which has just been recently introduced in our clinical department for improved data quality.

Table 1: Quantitative comparison of state-of-the-art and proposed segmentation architectures. Main values are mean and standard deviations in brackets. c-e: cross entropy.

Models	Global Accuracy	Mean Accuracy	Mean IoU	Weighted IoU	Mean BF
Semantic segmentation methods in literature					
U-net (Weighted c-e)	0.6814 (0.0432)	0.6592 (0.0472)	0.4764 (0.0641)	0.4865 (0.0616)	0.3056 (0.0328)
GAU-net (Dice loss)	0.6951 (0.1831)	0.7037 (0.1623)	0.5292 (0.2352)	0.5257 (0.2449)	0.3220 (0.0291)
SegNet (Weighted c-e)	0.7284 (0.0711)	0.7173 (0.0749)	0.5610 (0.1008)	0.5661 (0.0985)	0.2733 (0.0560)
FCN-8 (Weighted c-e)	0.8381 (0.0432)	0.8392 (0.0487)	0.7216 (0.0653)	0.7224 (0.0637)	0.3645 (0.1010)
Proposed architectures					
sRAU-net (β=1)	0.8622 (0.0025)	0.8639 (0.0039)	0.7573 (0.0042)	0.7579 (0.0040)	0.4242 (0.0136)
uRAU-net (β=1)	0.8646 (0.0108)	0.8697 (0.0081)	0.7613 (0.0169)	0.7611 (0.0175)	0.4285 (0.0297)
MAU4-net (β = 2)	0.8694 (0.0109)	0.8754 (0.0091)	0.7689 (0.0173)	0.7685 (0.0177)	0.4465 (0.0159)
MAU3-net (β = 0.5)	**0.8782 (0.0105)**	**0.8832 (0.0086)**	**0.7827 (0.0169)**	**0.7825 (0.0174)**	**0.4676 (0.0204)**

Ground truth segmentation maps were generated by expert neurosurgeons using the dedicated software Mimics, Materialize. Segmentation results were cross-checked between surgeons for validation.

The performance of our proposed framework has been compared to state-of-the-art semantic segmentation networks including the U-net[7], FCN[8], SegNet[9] and the GAU-net[10]. In our work, the implementation suggestions of the original papers for the above networks were followed. The first three networks have been trained with the weighted cross-entropy loss function in our experiments. The GAU-net has been trained with the Dice loss function as suggested in[10].

To evaluate the performance of the compared segmentation methods, five different metrices have been selected namely, global accuracy, mean accuracy, mean Intersection over Union (IoU), Weighted IoU and boundary F1 (BF) score[11].

Results and Discussion

The quantitative comparison with the baseline methods shown in Table 1, verifies that our proposed models outperform all the baseline methods and provide a 22.4% improvement to U-net and 4.4% to FCN, the best performing baseline model. RAUnet and MAU-net achieved the highest scores for all of the performance evaluation metrices. Besides, the standard deviation of the performance evaluation scores for our networks are lower than for the compared networks which verifies that not only they have superior but also more consistent performance.

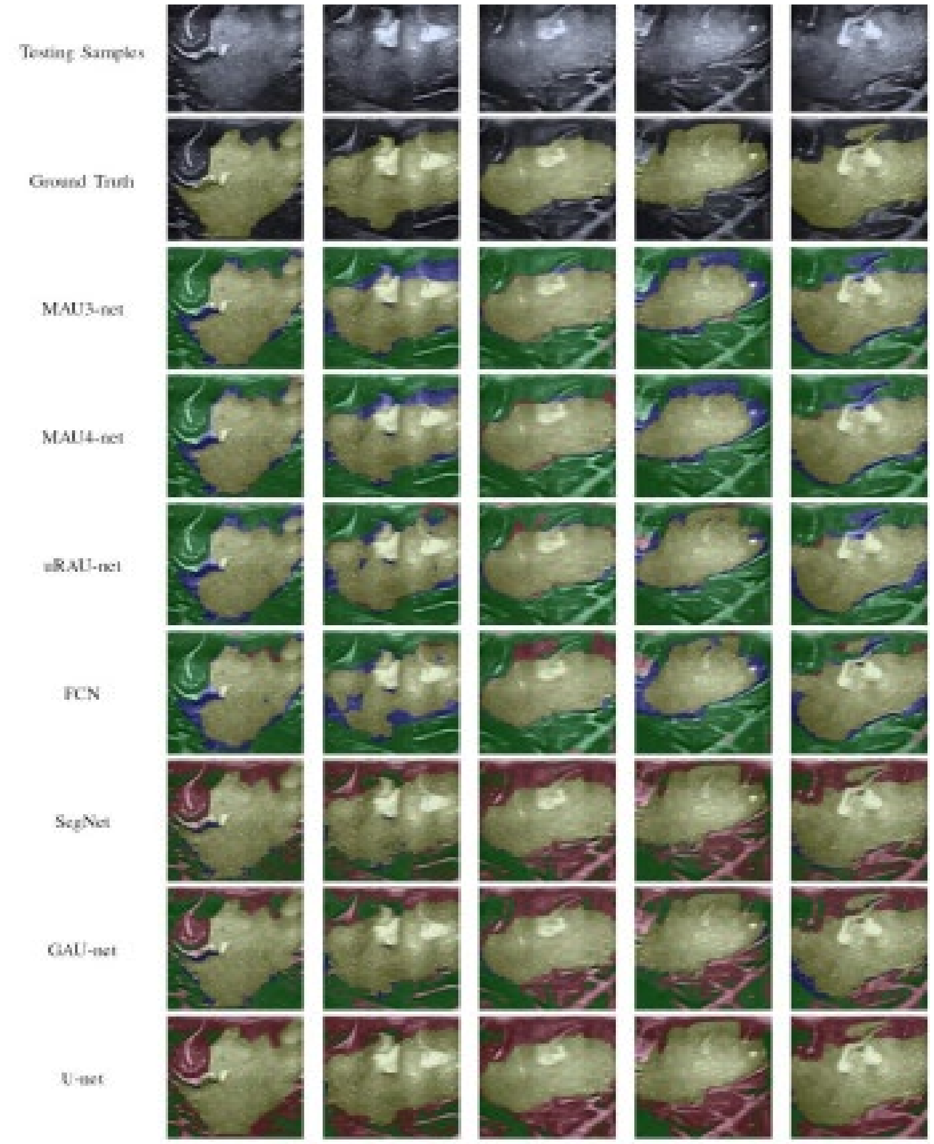

Figure 1: Qualitative comparison between the state-of-the-art and the proposed architectures, yellow: true positives; red: false positives; green: true negatives, blue: false negatives

As shown in Fig. 1, although the U-net identifies the area of the tumour adequately, it also detects many false positives. This verifies our initial motivation to introduce the soft attention to enforce the network to focus on salient areas and suppress the false positive detections. The attention modules included in the GAU-net improved significantly the segmentation result compared to U-net, but there are still many false positive detections. The performance of the SegNet seems visually comparable to GAU-net. Among all of the baseline segmentation networks, the FCN seems to perform the best, however, it results in more false detections compared to our proposed RAU-net and MAU-net models in all testing samples, especially the second and third sample.

Our segmentation results were also reviewed by the expert neurosurgeons who generated the ground truth segmentation. They confirmed that the proposed networks tend to correctly identify the tumour areas while suppressing false positive detections, which can prevent iatrogenic injury.

Conclusion

In this paper, a deep learning-based semantic segmentation framework enhanced with attention modules has been proposed for tissue characterisation during brain tumour resection using iUS data. The proposed attention modules help the network to reduce the interference from non-tumours structures which share similar intensity with tumours. The quantitative and qualitative performance evaluation analysis verifies the superiority of the proposed models compared to state-of-the-art segmentation frameworks. Future work will focus on extending our iUS database and enhancing the proposed model with more tissue classes.

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Ethical approval

All studies on human subjects were performed according to the requirements of the local ethic committee and in agreement with the Declaration of Helsinki.

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Endomicroscopic Tissue Characterisation with Few-Shot Learning for Intraoperative Diagnosis Support in Neurosurgery

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Background

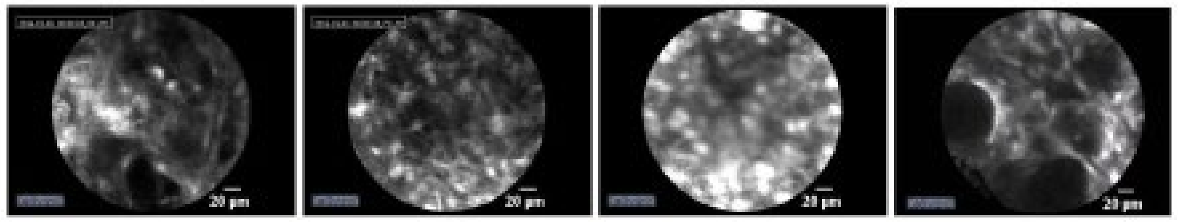
Complete resection of brain tumours is more demanding than for any other organ system. Brain cancer is the 8th most common cause of cancer deaths in the UK[1] and it has the highest Average Years of Life Lost (AYLL) of all common tumours, just over 20 years[2]. More children and adults under 40 die of a brain tumour than from any other cancer. Current state-of-the-art technologies used to facilitate brain tumour identification such as neuronavigation[3], iMRI and fluorescence imaging[4] have significant limitations intra-operatively or can not provide complete tumour identification.

Biophotonics techniques such as probe-based Confocal Laser Endomicroscopy (pCLE) have enabled direct visualisation of tissue at a microscopic level, with recent pilot studies suggesting it may have a role in identifying residual cancer tissue and improving resection rates of brain tumours[5]. However, the interpretation of endomicroscopic information remains challenging, particularly for surgeons who do not themselves routinely review histopathology. Also, even among experts, the diagnosis can be examiner-dependent, leading to considerable inter-observer variability. Automatic tissue characterisation with pCLE, based on a database of previously annotated data by expert physicians with diagnosis confirmed by histology, would support the surgeon in establishing diagnosis and guide autonomous robotic tissue scanning to focus locally on pathological areas. The main challenge to such tissue characterisation is the quality of the pCLE data which is prone to degradation during scanning due to debris on the tissue surface or motion instability of the imaging probe. In addition, there is significant intra and inter class variability in the appearance of pCLE images.

Recently, deep learning has gained a lot of attention for the design of computeraided diagnosis (CAD) systems for brain tissue characterisation [6]. These architectures enable the learning of data-driven and highly representative image features for efficient tissue state classification. However, a large set of data is required to train these models which could be a limitation for systems focusing on the analysis of in vivo data captured intraoperatively. To overcome the lack of large training datasets, few-shot learning techniques can be adopted as they can learn to classify medical data even when only few training examples are available for each class.

Method and Data analysis

In this work, we propose a few-shot learning framework to assess the diagnostic value of pCLE images and classify them into four different brain tissue states namely, Glioblastoma tumour, Meningioma tumour, Astrocytoma WHO III and healthy tissue, as shown in Fig. 1.



(a) Healthy (b) Astrocytoma (c) Glioblastoma (d) Meningioma

Figure 1: Sample frames of pCLE data.

The aim of the data quality assessment is to remove from the pCLE dataset, images which do no to carry significant diagnostic value due to motion artifacts or imprecise probe-tissue contact. This assessment is done in two stages. At the first stage, images with Shannon entropy lower than a predefined threshold are rejected as they do not contain sufficient information for tissue characterisation. At the second stage, the Deep Nearest Neighbour Neural Network (DN4)[7] is used to classify images which survived the first quality assessment stage, as "diagnosticable" or "nondiagnosticable". An example of "non-diagnosticable" pCLE data is shown in Fig. 2.

Figure 2: Sample frames of "non-diagnosticable" pCLE data.

The DN4 classifier consists of an embedding module which uses Convolutional Neural Networks to learn local image descriptors. Then, an image-to-class module is used to measure the similarity between a query image and each image class. For this purpose, the k-Nearest Neighbour based on cosine similarity is employed. The above two modules are trained in an end-to-end manner. During training, a support set S is created which contains few labeled samples for different image classes. Given a query set Q, the classifier is trained to classify each sample in Q according to the support set S. In the test stage, the learned model is used together with a support set to classify a query image. In this work, the DN4 model has been enhanced by constraining the support and query sets not to contain data from the same patient to avoid bias. The pCLE data with high diagnostic value are further processed for tissue characterisation while the "non-diagnosticable" data are removed from our dataset as shown in Fig. 3.

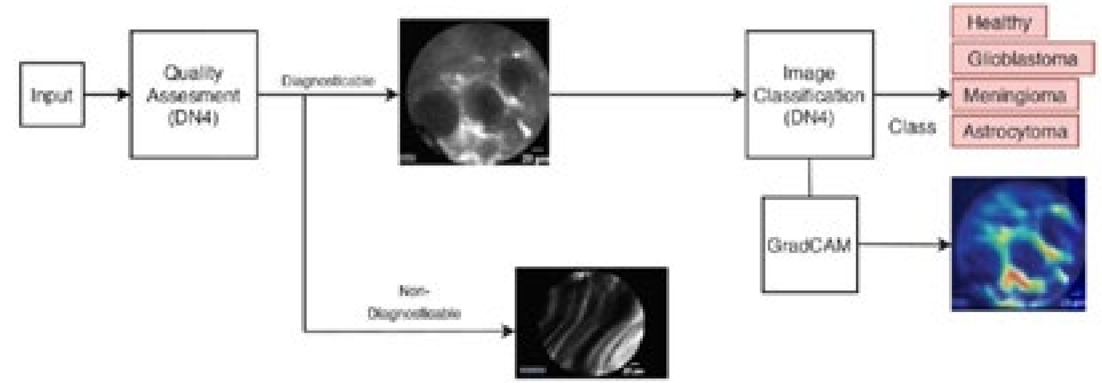


Figure 3: Outline of the proposed tissue characterisation framework.

To characterise brain tissue, a DN4-based architecture is designed to classify pCLE images into the tumour and healthy tissue states defined above. To improve the classification performance, a more detailed data representation is estimated by increasing the number of filters in the convolutional layers comprising the embedding module of the DN4 architecture. Similar to the quality assessment model above, the support and query sets of the proposed classification model do not contain data from the same patient.

The tissue characterisation framework proposed in this work is based on the analysis of ex vivo and in vivo pCLE data of brain tissue, collected using a classic diagnostic endomicroscopic system during brain tumour resection procedures at the Department of Neurosurgery, Cologne Medical Center in Germany. The ex vivo dataset described in[6] contains Meningioma and Glioblastoma brain tumours. In vivo data was collected using Indocyanine Green (ICG) as contrast agent and was classified into Glioblastoma, Meningioma, Astrocytoma WHO III and healthy brain tissue by expert histopathologists. Each in-vivo pCLE video represents one tissue state and our dataset includes 6, 20, 9 and 27 videos of Glioblastoma, Meningioma, Astrocytoma and healthy tissue, respectively, resulting in 27472 frames in total.

To train the diagnostic quality assessment model, the ex vivo pCLE dataset with Glioblastoma and Meningioma images is first used to learn an efficient data representation on a large and high-quality dataset. We then capitalize on the strength of few-shot learning which allows the classifier to adapt to new classes with minimal training. For the training of the tissue characterisation model, only the in vivo data which has survived the quality assessment process is further used for training, validation and testing without using videos from the same patient on multiple sets to avoid bias.

Results and Discussion

The performance of the proposed diagnostic quality assessment model has been validated on a set of 382 "non-diagnosticable" images selected from the in-vivo Glioblastoma-Meningioma dataset and on all the images from the ex vivo dataset which are considered as "diagnosticable". Further validation has also been done on 4534 "diagnosticable" images from the in vivo dataset. The performance evaluation results in Table 1, verify the ability of the model to identify data of high diagnostic quality and reject images of low diagnostic value. The data quality assessment process led to the rejection of 34.3% of the in vivo data and resulted in 37.5% improvement in the classification accuracy as shown in Table 2. The proposed tissue characterisation framework classifies endomicroscopy data into three brain tumour and healthy tissue, achieving 96.20 % accuracy which is also verified in the confusion matrix shown in Fig. 4.

Table 1: Performance Evaluation of the Diagnostic Quality Assessment Model

Data	Avg. Accuracy	Precision	Recall	F1-score
Ex vivo	93.44	88.78	98.45	93.38
In vivo	84.35	77.68	98.40	86.03

Table 2: Classification performance improvement for in vivo Glioblastoma/Meningioma data due to the rejection of low diagnostic quality data

Data	Avg. Accuracy	Precision	Recall	F1-score
Without quality assessment	62.36	62.38	62.38	62.38
With quality assessment	99.82	98.68	100	99.83

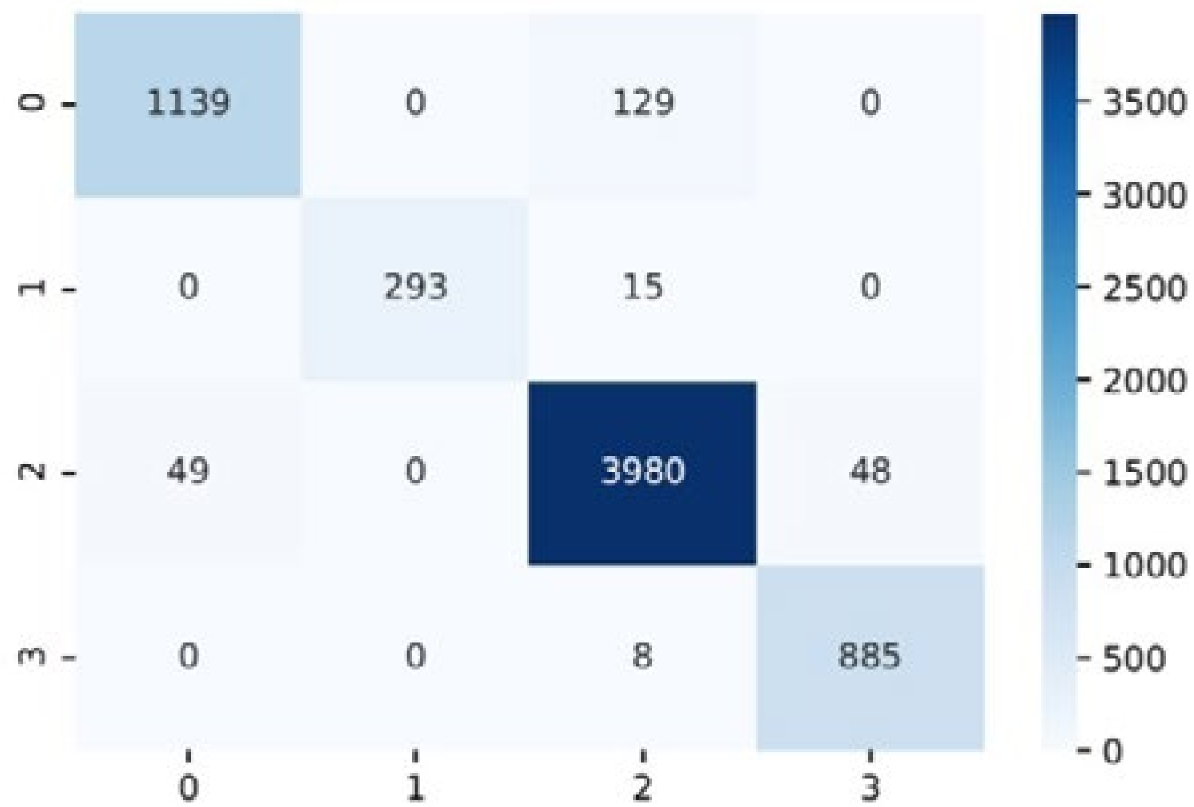


Figure 4: Confusion Matrix of the Tissue Characterisation Model (0: Astrocytoma III, 1: Glioblastoma, 2: Healthy, 3: Meningioma)

Conclusion

In this paper, a tissue characterisation framework based on few-shot learning has been proposed to classify endomicroscopy data of brain tissue into three types of tumour and healthy tissue. Images with low diagnostic value due to motion artifacts or imprecise probe-tissue contact, are eliminated improving the tissue characterisation accuracy by 37.5%. The performance evaluation study has shown that the proposed framework achieves 96.20% accuracy on the classification of in vivo pCLE data.

Acknowledgements

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A gaze-based robotic scrub nurse: Reporting on surgeon/scrub nurse experience on ex vivo bowel hand-sewn anastomosis

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Introduction

Recent UK legislation is paving the way for increased funding within artificial intelligence across all sectors to continue its position as a global frontier within this area[1,2]. Previous notable examples of this include assistive robotic devices (ARD) like the da Vinci® which have increased in use across the past two decades since inception in 1997[3]. Favourable patient benefits compared to conventional approaches, such as reduced intraoperative blood loss, post-operative pain and hospital stay have shown the promise and potential of ARD within surgery[3]. In this work we study another surgical application of ARD to develop a robotic scrub nurse (RSN) which is based on the surgeon's gaze alone in delivering surgical instruments. Previous examples report on robotic nursing systems based on hand gestures and verbal user commands, such as the Gestonurse and HERMES VRI, respectively[4-5]. ARD offers the surgeon an "extra hand" and can free up the human scrub nurse (HSN) to execute more tasks. We report on the usability and acceptability of our RSN and explore their impact on intraoperative communication taxonomy.

Methods

Training surgeons conducted ex vivo segmental resection of animal colon and completed a handsewn anastomosis. Participants were asked to wear eye-tracking glasses (ETG). The ETG in combination with RGB-D motion sensors and cameras which are mounted on the theatre ceiling, yield the gaze direction in 3D space based on a gaze-contingent framework[6]. Surgical trainees (ST) selected desired instruments by fixing their gaze on a screen displaying a set of instruments, to signal the RSN to pick it up and transfer it. A traffic light sequence was initiated once the surgeon visually "locked in" on the desired instrument (red, amber and green, the latter to initiate RSN deployment with the selected instrument). The task with the assistance of a human scrub nurse (HSNt) versus the task with the assistance of robotic and human scrub nurse (R&HSNt) was compared. Task load (NASA-TLX) and technology acceptance (Van der Laan's) scores were collected. Performance metrics including task duration and completion rates were compared. Communication between the HSN and surgeon was stratified into task related, social and gratitude, and analysed. Qualitative feedback was collected immediately after each experiment.

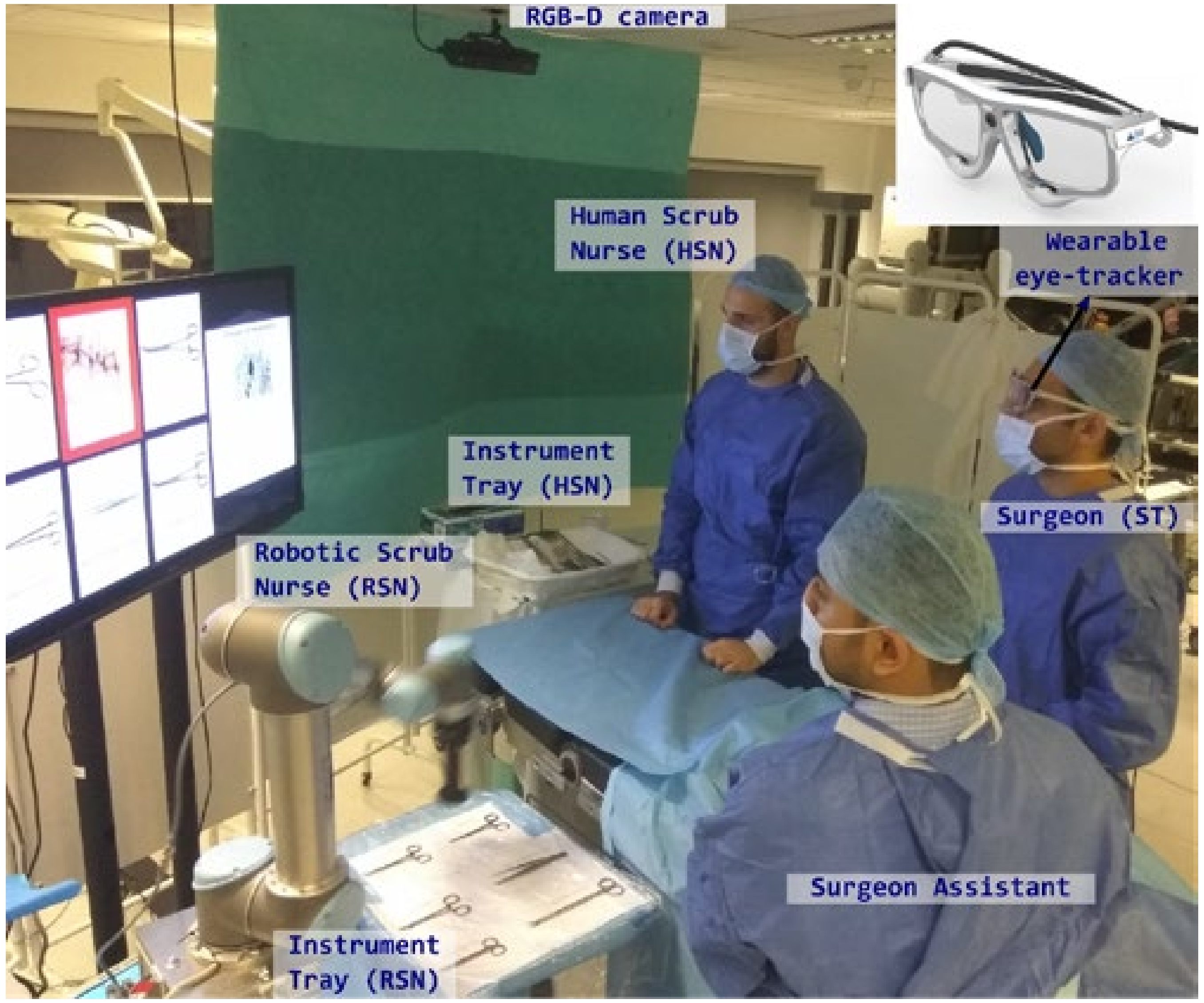

Figure 1. Experimental setup.

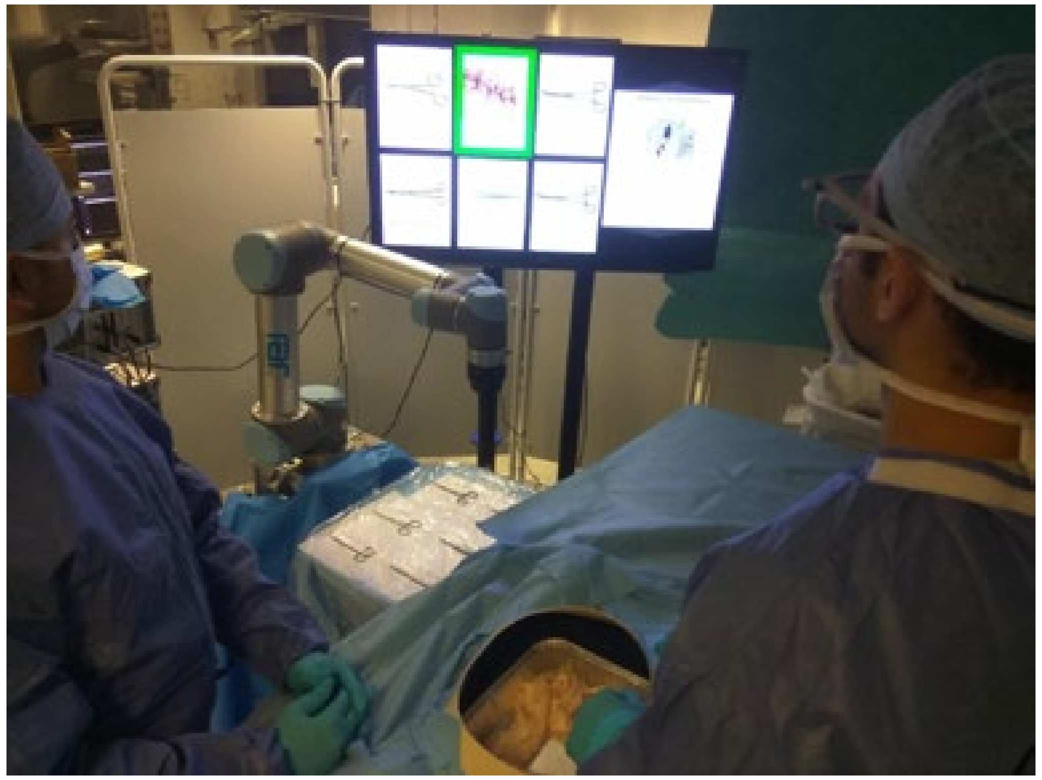

Figure 2. Instrument selection.

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Results

Overall, there were 10 ST participants (7 male and 3 female). NASA-TLX feedback for ST on HSNt vs R&HSNt demonstrated no significant difference across temporal, physical and mental demands. Importantly, there was no significant difference on task performance (p=0.526). ST reported significant frustration during R&HSNt (22±10.6 HSNt vs 51.5±19.3 R&HSNt, p=0.012). HSN reported a significant difference (39.9±19.6 HSNt vs 24.6±15.9 R&HSNt, p=0.017). Frustration remained unchanged (p=0.833), whilst mental, physical demand and effort showed significant differences in favour of the R&HSNt. Comparing ST vs HSN using RSN showed significant difference (57.5±14.2 vs 24.6±15.9, p<.001), in so showing reduced HSN demands.

All participants were novel to this experimental RSN. 100% of tasks were completed in both experimental set ups. Van der Laan's scores were positive overall in using the RSN. ST participants reported a usefulness score of 0.5±0.73 and satisfying score of 0.43±0.74. ST feedback toward the RSN was that the system was likable 0.4±0.84, useful 0.5±1.08 and pleasant 0.8±0.79. There was a neutral ST response when questioned about RSN desirability 0.1±0.99. HSN feedback reported a usefulness score of 0.76±0.92 and satisfying score of 0.78±0.79. HSN feedback demonstrated the RSN was likable 0.6±1.26, useful 0.7±1.42 and pleasant 0.9±0.99. RSN was perceived to be desirable 0.7±0.82. Overall, comparison between ST vs HSN when using the RSN showed no statistically significant difference in technology acceptance parameters; p=0.491 for usefulness and 0.32 for satisfaction. Overall responses were positive in ST and HSN groups.

Overall operating time showed no statistical difference; 22:35±6:30 [16:02, 37:17] minutes vs 26:04±4:50 [20:18, 34:35] minutes (HSNt vs R&HSNt, respectively), p=0.074. No significant change was found upon comparison of gaze behaviour across both tasks including fixation frequency and duration. Communication was classified as task-related, social and gratitude. Significance was demonstrated mainly due to task related communication 34.3 HSNt vs 16.8 R&HSNt, p=0.008. Upon comparison of the two tasks no significant difference was found with gaze behaviour such as average fixation rate and duration, except for pupillometry measurements where pupil diameter was significantly larger during the HSNt compared to the R&HSNt task. Lighting conditions were identical. Overall, no significance was demonstrated in task interruptions upon comparison of HSNt vs R&HSNt p=0.84; examples include wrong HSN or RSN instrument delivery or need for RSN system recalibration due to problematic gaze fixation. Social and gratitude related communication were not significantly different, whilst expectedly task related communication was significantly different in favour of the HSNt.

Discussion and Conclusion

We describe our initial findings about the use of eye tracking based RSN. This allows the surgeon unrestricted mobility intra-operatively. User feedback proves much promise, supported by non-inferior metric performance and acceptability in concept. ETG is a promising modality in combination with verbal and hand gestures in future systems. This enables the team "a third hand", negate human-human sharps transfers (prevalent in at least 7% surgeries), and empower nursing experience in active surgical assisting. The integration of RSN which undoubtedly will evolve and integrate in the future enables a rethink in principles relating to effective crew resource management. Often scrub nurses have invaluable experience which offers additional assistance intra-operatively, causing a paradigm shift in thinking towards HSN job roles in the future in comparison with other developed healthcare systems such as the USA. This experience utility may be of value for patient safety, clinical performance and enable a likewise reproach in trainer leadership, whereby they can take a "step back" to enable training surgeons increased operative opportunity, adopting principles of Lighthouse Leadership as used within cardiac arrest resuscitation with enhanced patient outcomes[7]. Inherently, there is some frustration by ST due to reliance on gaze alone, and moving forward further work is needed to integrate hand gestures, verbal and gaze based RSN to improve practicality and system related task interruptions.

Finally, integrating the use of eye tracking whilst allowing the user natural movement in an unrestricted fashion, has future implications on potential use for real time pupillary measurements, established to reflect user concentration, task cognitive demands, and fatigability.

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Giulio Anichini is a post CCT neurosurgeon at Imperial Healthcare NHS Trust and Research Fellow at Imperial College of London. He qualified in Medicine (2007) and got his CCT degree in Neurosurgery (2013) at University of Rome “Sapienza”. During his training, he won a Research Fellowship in Skull Base Surgery at New York Cornell University (20112012 and 2013). He has worked in Scotland (Aberdeen Royal Infirmary) and London (Imperial Healthcare NHS Trust) for most of his post CCT career. His clinical experience ranges from intra-cranial surgery to trauma and spinal degenerative disease, with a specific focus on neuro-oncological and skull base surgery. His research is mainly focused on brain surgical anatomy, neurophysiology of the grey and white matter, and developing new technologies in neurosurgery.

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Alexander Cairns is a junior doctor in London with a special interest in surgery.

Sophie Camp

Sophie Camp studied Medicine at the Royal Free and University College Medical School, following her first degree in Experimental Psychology at Corpus Christi College, Oxford, and a PhD at the Institute of Neurology, Queen Square, London. She entered Neurosurgical training in 2007, on the London (North Thames) rotation, and in 2015 she was awarded an NIHR Academic Clinical Lectureship working specifically in neuro-oncology. She was appointed as a consultant neurosurgeon at Imperial College

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Dr Vadzim Chalau is a Research Associate in the Hamlyn Centre for Robotic Surgery and the Department of Surgery and Cancer at Imperial College London. His expertise covers the development of optical equipment, statistics and computational modelling with focus on medical applications.

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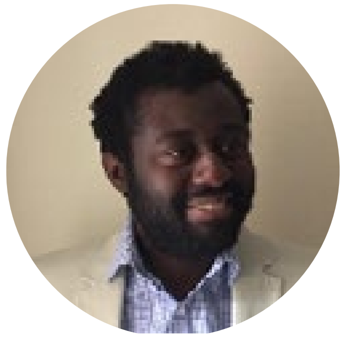

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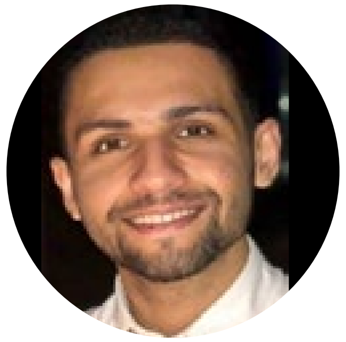

Ahmed Ezzat is an academic general surgery registrar at Imperial College with a background in human factors and applied ergonomics. He is interested in the study of robotics within surgery as well as machine learning in tissue cancer diagnosis to facilitate better performance and improved patient outcomes.

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Teddy Fletcher is a post-ST6 general surgical registrar and clinical research fellow under Professor Darzi at Imperial College London. He has a specialist interest in both colorectal and trauma surgery. Teddy is based at the Hamyln Centre for Robotics & AI where he is developing an implantable sensor for measuring rectal tumour oxygenation using diffuse reflectance spectroscopy to enable advanced prognostication and response monitoring.

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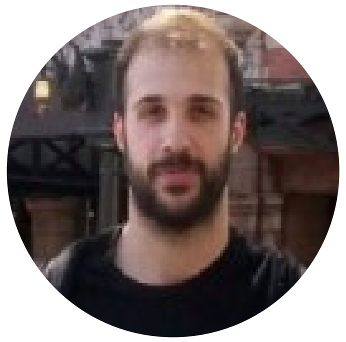

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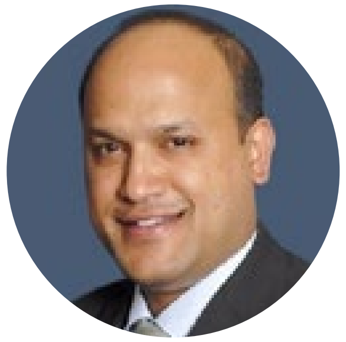

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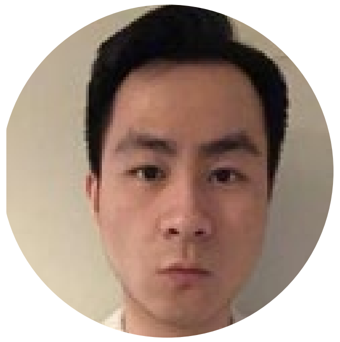

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The Journal of the Association of Surgeons of Great Britain and Ireland (JASGBI) is a regular publication that has evolved from the previously named Newsletter. It aims to publish material of topical or general interest to members of the Association, which will promote and advance the reputation and functions of the Association to a wider professional audience.

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- Historical articles of interest and relevance to surgeons.
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