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Invited Overseas Guest Lecture

Next step in minimally invasive surgery: hybrid image-guided surgery☆,☆☆

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ABSTRACT

Surgery, interventional radiology, and advanced endoscopy have all developed minimally invasive techniques to effectively treat a variety of diseases with positive impact on patients' postoperative outcomes. However, those techniques are challenging and require extensive training. Robotics and computer sciences can help facilitate minimally invasive approaches. Furthermore, surgery, advanced endoscopy, and interventional radiology could converge towards a new hybrid specialty, hybrid image-guided minimally invasive therapies, in which the three fundamental disciplines could complement one another to maximize the positive effects and reduce the iatrogenic footprint on patients. The present manuscript describes the fundamental steps of this new paradigm shift in surgical therapies that, in our opinion, will be the next revolutionary step in minimally invasive approaches.

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There are no experts on the future – J Folkman, MD

Innovation needs time and pertinacity to build momentum and move forward. Breakthrough innovations can generate a chain-effect enthusiasm, leading to exponential and contagious evolutions, or can encounter skepticism and resistance. There are hundreds of examples of "bad predictions" given by otherwise highly skilled celebrities, demonstrating that a lack of vision on the future can affect opinion leaders at any time.

Lord Kelvin, Scottish mathematician and physicist, sentenced in 1897: "Radio has no future". Marshal Ferdinand Foch, French military strategist, said that "Airplanes are interesting toys but of no military value". Pierre Pachet, professor of physiology from Toulouse declared in 1872 that "Louis Pasteur's theory of germs is ridiculous fiction." Sir John Eric Ericksen, said in 1873 that "The abdomen, the chest, and the brain will forever be shut from the intrusion of the wise and humane surgeon."

Innovation in healthcare requires strict regulation and high sense of responsibility. Patient safety and quality of life are major issues and, for this reason, innovation in healthcare needs to be patient-centered in order to be effective.

The introduction of video-assisted minimally invasive surgery (MIS) by French surgeon Philippe Mouret, almost 30 years ago, was welcomed as "the second French revolution". The axiom of surgical intrusion was broken: thin instruments penetrating the body through small incisions replaced surgeons' hands and optical systems displayed a magnified view of internal anatomy on a screen.

The reduced intrusion of the MIS approach immediately proved to be beneficial when compared to traditional "open" surgery, with better postoperative outcomes in terms of reduced incision-related

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complications, such as infections, hernias, postoperative pain and also improved cosmetic results. Thousands of working hours have been gained by an earlier return to daily activities of patients after MIS.

However, the ability of MIS to respect fundamental oncologic principles of open surgery, for example in oncologic colorectal surgery, was heavily questioned. For this reason, justified by the principle of prudence, scientifically proven as a "misinterpretation of the future", the MIS approach took approximately 10 years, and 4 major clinical trials, from the first MIS procedures for colon cancer reported in the early 1990s, to be accepted as a valid approach in cancer surgeries [1–4].

Spectacular technological developments, such as energy-based surgical devices adapted to complex MIS procedures and high-definition cameras, have further stimulated the extension of MIS approaches to a variety of surgical procedures, across the majority of surgical specialties, given the well-grounded benefits for the patients.

Radiology and endoscopy also have been moving from purely diagnostic to more interventional approaches.

Impressive developments in imaging systems allow to visualize human anatomy with an incredible degree of precision and the interventional radiologist can more easily perform catheter-based or percutaneous image-guided treatments for pathologies which would have required a surgical procedure.

Similarly, the development of tools allowing for advanced flexible endoscopic procedures is changing the therapeutic approach. Gastrointestinal cancers in early stage can be effectively managed by endoluminal surgery, with oncological outcomes similar to those of complete surgical resections, and lower postoperative morbidity [5,6].

Combining the approaches of minimally invasive surgery, interventional endoscopy, and interventional radiology into a hybrid image-guided therapeutic modality, has the potential to increase the number of surgical conditions that could be managed with targeted non-invasive treatments and/or extend the inclusion criteria to cases exceeding therapeutic possibilities.

However, minimally-invasive surgery, interventional radiology and advanced flexible endoscopy techniques have specific challenges which must be overcome and require well-designed training modules to be proficient.

In minimally invasive surgery, the operative field is visualized through a 2D monitor which results in hand–eye disconnection and impaired depth perception. Additionally, the surgeon can't palpate tissues to appreciate the texture or a pulsating vessel.

Advanced endoscopic techniques, such as endoscopic submucosal dissections (ESDs), are largely underexploited, because they are considered very challenging with standard endoscopes [7]. The lack of effective traction and exposure and the need to use multiple instruments, lead to a prolonged operative time and to a non-negligible risk of perforation and bleeding [8,9].

Interventional radiology percutaneous therapies are challenged by organ motion during breathing and endovascular catheter-based approaches are limited by the reduced degree of freedom of catheters.

Challenges of minimally invasive techniques are being successfully addressed by the emerging discipline of computer-assisted therapies. Leveraging technologies from computer science and robotics to assist and augment performances of the physician, computer-assistance has brought medicine from the industrial age to the information age, as correctly predicted by Professor Richard Satava (University of Washington) in 1991.

1. Surgery meets aeronautics

Aeronautics developed models for error prevention and management that made the airplane the safest transportation mode. Surgical therapies of the information age take inspiration from aeronautics to strengthen the safety profile and analogies are becoming more and more apparent.

Just as aircraft pilots, surgeons, interventional radiologists and endoscopists have the possibility to train on specific virtual reality simulators [10,11] with an increasing degree of realism. Safety checklists are being used in the operating room to prevent adverse events. As a flight is very precisely planned, the surgical procedure can be planned and simulated on patient-specific virtual models [12] prior to being performed on the real patient. Aircrafts have a high level of computer assistance to enhance pilot accuracy, and new generation physicians will be assisted by image-based navigation systems and robotized effectors during the procedure (Fig. 1).

In a nutshell, computer and robotic sciences are progressively building a new paradigm, cybertherapy, which provides the physician with an

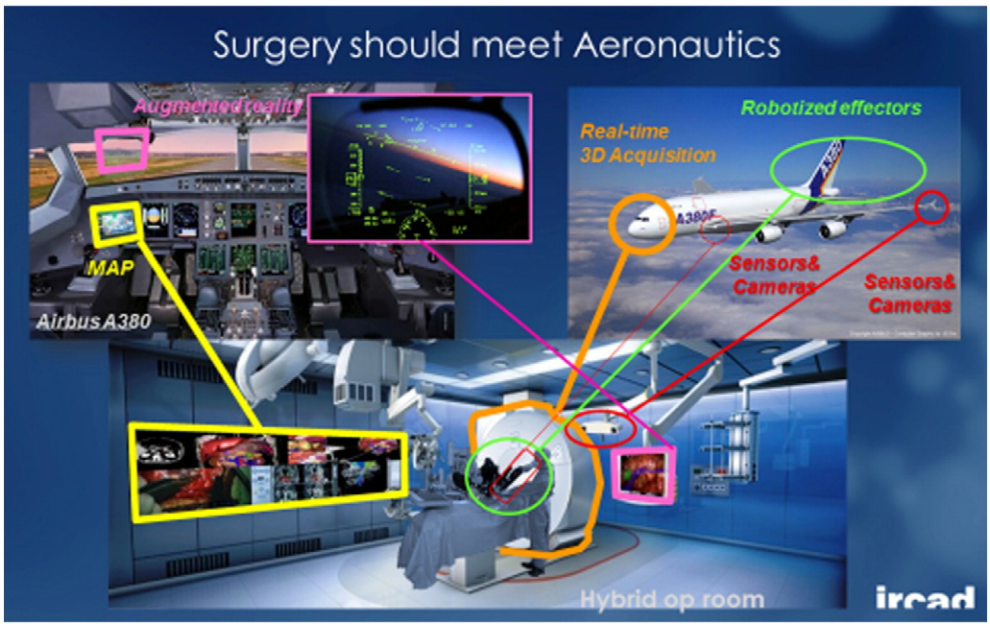

Fig. 1. Surgery should meet aeronautics. Analogies between aircraft cockpit and navigation systems with the hybrid operating room integrating imaging systems and robotized effectors.