CHANGE VERSION TO SPANISH

NEXT STEPS IN MINIMAL INVASIVE SURGERY: NO SCAR & HYBRID IMAGE GUIDED SURGERY

Jacques Marescaux MD, FACS, Hon FRCS, Hon FJSES; Michele Diana MD.

Introduction: Minimally Invasive Surgery (MIS)

A radical shift in the practice of surgery has occurred with the advent of minimally invasive endoscopic techniques. The target organ is reached through small skin incisions through which low profile surgical instruments can be introduced. The working space is created by insufflating a controlled flow of carbon dioxide set to maintain a constant pressure. An endoscopic camera is introduced into the body's cavity and the vision of the operative field is transferred from the surgeon's direct view to a magnified and high definition optical system and displayed on a monitor. The reduced surgical insult ascribes unquestionable benefits to patients. Reduced postoperative pain, shorter length of hospital stay, earlier return to daily activities, reduced

morbidity rate and improved cosmetic outcomes represent the scientifically proven advantages of this approach as compared to conventional open surgery.

Nevertheless, MIS is not intuitive, and specific training is necessary to imbalance some unnatural requirements and to be proficient in laparo-endoscopic techniques, with a steep learning curve. The inherent challenges of the MIS approach may be summarized as follows: 1) the hand-eye axis is disjointed since the surgical field is visualized through a screen with incurred loss of visual drive of haptic proprioception; 2) the 2D vision offered by the flat screen results in a reduced depth of perception; 3) the angle of view is limited by the scope's zoom; 4) the "touch" sensation (tactile feedback) is very limited due to long low profile instruments and as a result, important information such as tissue stiffness, presence of a nodule or pulse of an unapparent vessel, is lost. Computer science and Robotics have been developing technologies which might improve MIS. Furthermore, a parallel development has occurred in the field of Interventional radiology and Endoscopy. A novel hybrid approach to surgical diseases may benefit from the convergence of surgery, endoscopy and interventional radiology in a hybrid treatment modality: the image-guided minimally invasive procedures. The main axes of this new paradigm build-up are briefly discussed.

1) Improve preoperative and intraoperative strategy

Computer science may provide the surgeon with a surrogate of physical palpation to correctly identify target structures, surgical planes and resection margins. In a nutshell, this allows to virtually navigating through the patient's anatomy. Virtual Reality (VR) is intended to be a realistic three-dimensional (3D) environment created by a computer system, in which the user is totally immersed and may interact through specific sensors and effectors. VR has an increasing number of applications ranging from multimedia entertainment, or training through VR simulators, and is becoming more relevant in the medical and surgical fields. Medical imaging is a specific area of application for VR. The 3D reconstruction of a Computed Tomography (CT) scan or a Magnetic Resonance Imaging (MRI) may enhance the ability to detect pathologies or understand anatomical relationships (1). VR medical software may elaborate a 3D virtual model of the patient from the Digital Imaging and Communication in Medicine (DICOM) format images. This 3D virtual model enables to navigate through the

patient's body and perform a virtual exploration, highlighting anatomical details which might be underestimated on a customary image (1,2). The virtual exploration can assist the preparatory stage of the surgical procedure through interactive and visual planning of strategy and simulation. Subsequently, during the intraoperative stage, the 3D VR model may be superimposed with real-time patient's images providing an enhanced navigation tool, highlighting target structures and anatomical variations through modular virtual organ transparency. The process of superimposing live images with synthetic computer-generated patient-specific images is defined as Augmented Reality (AR). AR may be obtained from preoperative images or in real-time in the operating room. The first clinical application of camera-based AR was performed by our group at IRCAD, involving 15 cases of laparoscopic adrenalectomy (3). In this setting, AR was able to guide the surgeon and assess the position of adrenal vessels and the location of the tumor with a maximum error of 2 mm. We then applied the same concept to minimally invasive liver resections (4), also taking advantage of the accurate resection volume computing offered by the VR-RENDER® software and the preoperative planning of the resection planes. Additionally, we have successfully used projector and video-camera-based AR to determine the correct position of parathyroid adenoma and for intraoperative navigation in more than 100 video-assisted minimally invasive parathyroidectomies. In digestive laparoscopic surgery, AR presents several challenges due to the respiratory motion and to the deformation of soft tissues during surgical manipulation. To overcome these issues, active research is currently underway to provide the laparoscopic surgeon with consistent, accurate and flexible patient-specific anatomical reconstruction with real-time enhancement of intraoperative images.

2) Improve minimal invasive access: Natural Orifice Transluminal Endoscopic Surgery (NOTES)

Natural Orifice Transluminal Endoscopic Surgery aims to further reduce the surgical trauma of MIS and the incisions-related morbidity. NOTES access to the peritoneal cavity is performed through incisions made in the hollow organs communicating with the external milieu (stomach, vagina, and rectum). Target organs are reached using flexible endoscopes or rigid instruments. At the Institute for Research into Cancer of the Digestive system (IRCAD), we have performed roughly 600 experimental NOTES procedures. Subsequently, the world first transvaginal NOTES cholecystectomy on a human being in 2007 (5) and right after the European first transgastric NOTES cholecystectomy. Although successfully completed, these procedures

showed all the difficulties of this revolutionary approach. To move the concept ahead, there is a need to focus on “the good indication” and “the good technology”. Concerning the indications, cholecystectomy has served almost as an experimental model, but there is no scope to develop complex technology for such application. Furthermore there is no benefit to violate a remote innocent organ. Optimal NOTES access could be within the organ of interest as the Per Oral Endoscopic Myotomy proposed by Inoue (6), or the transanal route for colorectal procedures as proposed by Leroy (7) and Sylla (8). The available endoscopic platforms are not suitable for complex NOTES procedures since 1) endoscopes lack of stability and cannot transfer the necessary force for traction and dissection, 2) the vision is « tubular » and not panoramic as in laparoscopy, 3) endoscopes lack of surgical triangulation, 4) stapling or suturing systems are not yet available. These are collectively the challenges for pure NOTES development. At IRCAD we are currently working, in collaboration with KarlStorz®, at the development of a novel surgical endoscopic platform (the AnubisScope® and IsisScope®) specifically conceived for NOTES. These prototypes are equipped with two 4.3 mm working channels and a tip that opens like a clam-shell. The working instruments (needle holder, grasper, diathermy hook) are manipulated with intuitive handles and the extremities exit the shaft of the scope in a triangulated fashion. Beside NOTES, these prototypes have been also adapted for the emerging field of endoluminal surgery for the minimal invasive treatment of early gastrointestinal cancers by Endoscopic Submucosal Dissection, rather than surgical resection.

3) Improve Robotics

Robotic technology offers additional solutions to facilitate MIS. The surgical robotic platform available on the market is the DaVinci®, by Surgical Intuitive: the surgeon is seated comfortably at the console equipped with a binocular camera that provides a stereoscopic, 10-fold magnified and high resolution view, uses a haptic interface that commands the instruments with a natural movement of the hands; the effectors exactly replicate movements into a precise and downscaled fashion and rule out physiologic tremors. An additional and unique feature of the robotic platform is the possibility to be remotely controlled: in one word, it enables “telesurgery”. Using a combination of high-speed fiber-optic connection with an average delay of 155msec with advanced asynchronous transfer mode (ATM) and the Zeus® telemanipulator in September 2001, we successfully performed the first transatlantic surgical procedure covering the distance between New York (United States) and Strasbourg (France). The event which was

considered the milestone of global telesurgery (9,10) was dubbed “Operation Lindbergh”. Our current aim is to develop miniature and lightweight surgical robotic platforms: the main prototype is a fully robotic version of the ISIS/ANUBIS®-Scope® that will be delivered by September 2012.

4) Next step: Image-Guided Hybrid MIS

Parallel to advances in laparoscopic surgery, advances in medical imaging and catheter based treatment led to the build-up of Interventional Radiology. Modern fluoroscopy, ultrasound, CT-scans and MRIs produce accurate images of the entire body. Interventional radiologists may treat a variety of pathologies, such as small liver tumor, by image guided thermal ablation. However, radiologists lack the training to perform complex surgical operations and flexible endoscopy, or manage post-operative patient care. Similarly, gastrointestinal endoscopy evolved from a diagnostic tool to an interventional discipline for intervention within the intestinal lumen, especially under the pressure of the NOTES brainstorm. Although gastroenterologists have the ability to perform no-scar endoscopic procedures, complex operations beyond the intestinal wall are impossible with current endoscopes due to the lack of integrated image guidance. Surgery, gastroenterology and radiology independently developed advanced techniques: combining the best aspects of these techniques to form a hybrid approach will lead to maximum benefits for patients. This new hybrid-approach paradigm would need a radical change in the OP room concept and organization to implement in a confined space an imaging tool (CT or MRI) and laparoscopic and endoscopic tools to perform targeted procedures.

The emerging of a novel physician typology requires a specific and systematic training to promote hybrid approaches. The IRCAD Strasbourg promoted a program which was labeled MIX-Surg to develop Image-Guided Hybrid surgery and to fundamentally change training, develop new continuing education modules and to educate those who enable the technology including engineers, scientists and other healthcare professionals to the next revolution in surgery.

Foto: Ph Eranian IRCAD

1. Nicolau S, Soler L, Mutter D, Marescaux J. Augmented reality in laparoscopic surgical oncology. Surgical Oncology 2011;20:189-201.
2. D'Agostino J, Diana M, Soler L, Vix M, Marescaux J. 3D Virtual Neck Exploration Prior to Parathyroidectomy. New England Journal of Medicine 2012.
3. Marescaux J, Rubino F, Arenas M, Mutter D, Soler L. Augmented-reality-assisted laparoscopic adrenalectomy. JAMA: the Journal of the American Medical Association 2004;292:2214-5.
4. Mutter D, Soler L, Marescaux J. Recent advances in liver imaging. Expert review of Gastroenterology & Hepatology 2010;4:613-21.
5. Marescaux J, Dallemagne B, Perretta S, Wattiez A, Mutter D, Coumaros D. Surgery without scars: report of transluminal cholecystectomy in a human being. Arch Surg 2007;142:823-6; discussion 6-7.
6. Inoue H, Minami H, Kobayashi Y, et al. Peroral endoscopic myotomy (POEM) for esophageal achalasia. Endoscopy 2010;42:265-71.
7. Leroy J, Cahill RA, Perretta S, Forgione A, Dallemagne B, Marescaux J. Natural orifice translumenal endoscopic surgery (NOTES) applied totally to sigmoidectomy: an original technique with survival in a porcine model. Surgical Endoscopy 2009;23:24-30.
8. Sylla P, Rattner DW, Delgado S, Lacy AM. NOTES transanal rectal cancer resection using transanal endoscopic microsurgery and laparoscopic assistance. Surgical Endoscopy;24:1205-10.
9. Marescaux J, Leroy J, Gagner M, et al. Transatlantic robot-assisted telesurgery.

Nature 2001;413:379-80.
10. Haidegger T, Sandor J, Benyo Z. Surgery in space: the future of robotic telesurgery. Surgical Endoscopy 2011;25:681-90.