

Uniportal and single-incision video-assisted thoracic surgery: the state of the art

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Abstract

Over the past decade, uniportal video-assisted thoracic surgery (VATS) has evolved dramatically into a sophisticated technique capable of performing some of the most complex thoracic procedures. The idea of operating through fewer surgical incisions and, therefore, with potentially better cosmesis, less postoperative pain and paraesthesia, has led to uniportal VATS increasing in popularity worldwide. The uniportal approach demands instrument design to be better suited for operating with multiple instruments through a single small incision. Furthermore, the drive by surgeons and industry to develop novel, smaller, more specialized procedure-specific instruments for uniportal VATS to further allow reduction in incision size is relentless. Refinement of uniportal VATS instruments, angulated and narrower endostaplers, and improvements in video-camera systems, including 3D systems, and 120° articulating lens will make uniportal VATS major lung resection easier to perform and learn. In the future, we could see the development of subcostal or e-NOTES access, endorobotic arms that open and operate within the chest cavity, and cross-discipline imaging assistance for uniportal VATS procedures.

Keywords: DynaCT • Hookwire • Hybrid • Magnetic anchoring and guidance systems • NOTES • Robotic

INTRODUCTION

‘Intelligence is the ability to adapt to change.’

Stephen Hawking (1942–present)

Uniportal video-assisted thoracic surgery (VATS) has a history spanning over more than a decade and, more recently, has become an increasingly popular approach to manage thoracic surgical diseases. The potential advantages of reduced access trauma and better cosmesis, together with patient demand, have seen uniportal VATS spread across the world [1, 2]. A reflection of these trends can be appreciated in the literature, where 65% of all publications (in the English literature) relating to uniportal VATS were from the past 2 years, with roughly an equal representation from institutes in the East and West. Interestingly, one of the unexpected effects of this change in thinking and approach to VATS is the enormous craving for better equipment and technology to assist uniportal surgeons in accomplishing their task through a single small incision. This has led to rapid growth in communication and collaboration between thoracic surgeons and industry that has not been witnessed, perhaps since the leap from open thoracotomy to conventional VATS during the 1990s. The current review focuses on technological innovations of the present and those on the horizon, as well as providing a glimpse into the future of uniportal VATS.

EQUIPMENT

Uniportal VATS started from humble beginnings, with an initial report of uniportal VATS thoracic sympathectomy in 2000 [3]. Nevertheless, by pushing the boundaries of what might be possible with a uniportal approach, this initial report paved the way for the development of more complex uniportal procedures for an ever-increasing range of thoracic conditions. The development of 5 mm or even 3 mm needlescopic endoinstruments has allowed uniportal sympathectomy to be accomplished through a smaller incision. Apart from simply making equipment smaller or more slender to perform uniportal VATS, surgeons have thought of adapting or creating new instruments to accomplish these tasks. In the case of sympathectomy, the paediatric urological electroresectoscope has been modified to improve ergonomics and reduce fencing of instruments [4]. Along the same thinking, a more modern version would be to perform uniportal VATS sympathectomy with the Vasoview device, originally designed for endoscopic vein harvesting [5, 6].

With the announcement to the world in 2004 by Rocco *et al.* of their uniportal VATS wedge resection technique, the authors broke taboos about the possibility of performing lung resection through a single small incision [7]. Subsequently, the report of uniportal VATS pleurodesis quickly followed [8, 9]. Through the challenges associated with performing lung resection through

instruments with an unidirectional approach, novel ideas and equipment were recruited into the uniportal VATS surgeon's armamentarium, in this case rotator endoinstruments and flexible staplers. Furthermore, to limit the size of the single incision for minor lung resections, a Japanese group described the use of a thin puncture device with a loop retractor to hold the area for resection, whereas a Korean group has described their suture-lift method to a similar effect [10, 11].

Another major milestone for uniportal VATS came in June 2010 in the form of the world's first uniportal VATS lobectomy, which was subsequently published in 2011 by Gonzalez-Rivas's group in A Coruña, Spain [12]. Interestingly, this landmark case was performed with a standard 10 mm 30° thoracoscope and operating theatre equipment. This report heralded a new era of uniportal VATS complex lung resection that included, in quick succession, uniportal VATS segmentectomy, pneumonectomy, bronchoplastic procedures, chest wall resection and pulmonary artery reconstruction [13–17]. The early results and safety of uniportal VATS lung resection were shown to be comparable with those of conventional three-port VATS [18, 19]. By pushing the boundaries of minimally invasive VATS lung resection, a revolution in technical and technological innovation, as well as radical thinking, was started.

Firstly, the types of double-hinged, narrow-shafted, VATS-specific instrument (Scanlan, Minnesota, MN, USA) began to expand rapidly. To accommodate the small incision associated with uniportal VATS, the double-hinge mechanism was redesigned so that the instrument shaft is even narrower, such as the Gonzalez-Rivas Dissector. In patients with small stature and in the Asian patient population, these changes are more than welcome, given the narrower rib spaces and smaller chest cavity that surgeons have to operate on. Endoscopic thoracic surgical instruments also underwent minor evolutionary changes, most notably shaft angulation or curvature (Karl Storz, Tuttlingen, Germany) to allow improved reach within the chest cavity, particularly for anterior chest wall adhesiolysis, and to reduce instrument fencing [20].

More than ever in the history of VATS, endostapler design has become the cornerstone of uniportal VATS major lung resection development. Variable angulated endostapler design has really been instrumental in allowing its use in uniportal VATS, where achieving the angles to staple the hilar structures has always been a challenge. The additional development of the 'curved tip' staple end, developed by Demmy *et al.*, allows the staple to pass through narrower gaps and more acute angles. Endostaplers that are electrically driven, such as the Powered Echelon Flex (Ethicon, Johnson & Johnson, New Brunswick, NJ, USA) and iDrive Tri-staple (Covidien, Mansfield, MA, USA), have been developed to improve stapling stability and, hence, produce a more secure stapling line. In uniportal VATS where instruments are in very close proximity to each other and often touching, reducing stapler movement during firing can result in less movement disturbance to other instruments. Future endostaplers, such as the MicroCutter XCHANGE 30 (Cardica, Inc., Redwood City, CA, USA) will be narrower, lighter and designed to function with more angulation, allowing surgery through a smaller surgical incision with larger degrees of freedom (DoF) for stapling.

Thoracoscopic manufacturers responded with the design of a variable 0–120° lens through a rotating prism mechanism (Endocameleon, Karl Storz, Tuttlingen, Germany) or by a deflectable 'bronchoscopic'-like scope tip (Endoeye, Olympus, Tokyo, Japan). The greater lens flexibility improves visibility in uniportal VATS when all the instruments and scope pass through a single small incision in a parallel manner, in particular, for surgeons on the learning curve and in difficult cases [21]. Furthermore, the

versatility and range of view afforded by these new generation scopes could minimize chest wall trauma by reducing the need for torquing at the wound [21]. An often recognized advantage of surgery performed through the robotic system is the unparalleled magnified 3D binocular vision when compared with VATS. Recently, advances in high-definition 3D vision through ever smaller thorascopes are significantly narrowing this gap. As uniportal VATS surgeons strive for improved ergonomics and smaller wounds, the thoracoscope remains one of the Achilles heel by occupying a large part of the surgical incision. Not only that, but the transmission and light cables associated with the present thoracoscope systems are often cumbersome. Some manufacturers have added in an angulated light cable adaptor so that the cable runs more parallel to the scope to minimize scope-instrument interference. Fortunately, innovators have seen the potential future of thorascopes without intertwining cables, with the prototype design of a wireless scope—the 'airscope' [22]. The system comprises a built-in light emitting diode illuminating light source and wireless antennae to transmit video images without any cables attached. Other ideas to eliminate the need to have any scope take up space at the surgical incision have been truly inspiring. Having a wireless 'capsule'-shaped micro-video-camera clipping on to the distal end of the endoscopic energy or stapling device is one idea; however, an immediate hurdle that poses a significant problem is the large degree of image instability as the device moves around [23]. An alternative would be to place one or multiple unattached 'remote' wireless video cameras into the thoracic cavity [24], which can be 'hung' onto the inside of the chest wall or held against the inner chest cavity by strong magnets, also known as magnetic anchoring and guidance system (MAGS) cameras [25] (Fig. 1). Although initially developed for abdominal surgery, ironically, MAGS might be more suited for surgery within the chest cavity because the rigidity of the chest wall provides more stability and less movement for magnetic anchorage when compared with the abdomen.

APPROACH

Uniportal VATS represents a radical change in approach to lung resection compared with conventional three-port VATS. However, having a significant incision at the lateral aspect of the chest wall can be unsightly and result in chronic pain or paraesthesia, whatever the strategies to reduce the incision size and decrease the risk of intercostal nerve injury. Liu *et al.* [26] from Taiwan successfully performed the first uniportal VATS lobectomy via a subxyphoid approach for left upper lobectomy, which might reduce the risk of intercostal nerve injury and avoids the limitations imposed by narrow rib spaces. One of the obvious difficulties observed from the video is the transmitted pulsation from the heart to the VATS instruments during left-side surgery. Interestingly, an additional advantage of the subxyphoid approach is the ability to gain access to bilateral thoracic cavities to perform bilateral lung resections through a single incision [27]. From a purely aesthetic point of view, with the expected improvements in VATS equipment and smaller more angulated staplers in the future, a uniportal incision at the axilla might be another alternative to consider.

On a more experimental level, embryonic natural orifice transluminal endoscopic surgery (e-NOTES) through the umbilicus has been used as the uniportal approach to thoracic surgery. In 2013, Zhu *et al.* [28] reported their initial experience of e-NOTES for thoracic sympathectomy in patients with palmar hyperhidrosis.



Figure 1: Illustrated photo of a possible future for uniportal VATS, with either single or multiple remote wireless cameras placed inside the thoracic cavity giving multi-directional views, which can be secured or controlled by a magnetic anchoring and guidance system (MAGS). The thoracoscope and related cables might become obsolete (red cross).

The transumbilical approach used a 5-mm ultrathin flexible gastroscope to incise through the diaphragm to reach the operating site. Hot biopsy forceps were deployed to complete the thoracic sympathectomy. The 35 patients who received this procedure suffered no complications, and experienced less pain and higher satisfaction with the aesthetic results when compared with conventional needlescopic sympathectomy, without any delayed complications in any patient [29]. Such an approach might be adequate for performing simple thoracic procedures; however, a more sophisticated endoscopic platform will be needed for more complex thoracic surgery. Lately, flexible endoscopic platforms, such as EndoSamurai (Olympus, Tokyo, Japan) and Anubiscope (Karl Storz, Tuttlingen, Germany), have been developed for NOTES [30, 31] (Fig. 2). These endoscopic platforms are usually deployed through a steerable endoscopic overtube, and utilize three channels (two articulating, one nonarticulating) with specialized instruments. In the context of NOTES, a needle cautery is used to create a pathway through the natural orifice organ, and endoscopic graspers, cautery and clips can be allowed to perform the necessary surgery. The manoeuvrable instrument arms allow an impressive 5 DoF of movement for instruments, resulting in superb manual dexterity and ergonomics. Compared with the standard endoscope, these advanced platforms provide the operator with much greater control, and the ability to have traction and countertraction through a single endoscopic port. However, traversing the trachea or oesophagus to enter the thoracic cavity for NOTES of the chest might remain the territory of the most adventurous thoracic surgeon for a very long time.

The current DaVinci robotic system has been around for over a decade. Despite offering excellent visual feedback and robotic arm dexterity and precision, it is undeniable that multiple ports are required. Although performing robotic surgery through

specialized single-incision laparoscopic surgery (SILS) ports is possible with computer-compensated movements to overcome the difficulties associated with instrument crossover, robotic SILS is probably the limit for the current system design in terms of minimizing surgical access trauma. The main reason for this limitation is simple; essentially the robot is 'outside' of the patient. To move forwards into a higher realm, the whole robotic approach needs to be revised. To perform complex robotic thoracic surgery through a single small incision, the robot's 'shoulders', 'arms' and 'head and eyes' must move inside the thoracic cavity. There are currently two promising systems, the Insertable Robotic Effector Platform (IREP) developed by Columbia University, USA [32], and the KidsArm System developed by MacDonald Dettwiler Space and Advanced Robotics, Ltd, in partnership with Centre for Image-Guided Innovation and Therapeutic Intervention (CIGITI) at Hospital for Sick Children in Toronto (Fig. 3). The IREP has a diameter of only 15 mm and a cylindrical profile. After entering the thoracic cavity, the device opens up inside to reveal the head and eyes, shoulders, arms and hands of the robot. The IREP offers dual arm dexterous operation with submillimetre accuracy, 3D visualization and automated instrument tracking. The total number of actuated DoF of the IREP is 21. These include seven actuated DoF per dexterous surgical arm, three actuated DoF for deploying and controlling the pan/tilt of a 3D vision module, two actuated DoF for each gripper and two DoF are used for axial insertion of each dexterous arm. Tissue manipulation, retraction and suturing can accurately be done with up to 2 N of force with an amazing positional accuracy of 0.25 mm or less, potentially allowing even microsurgical procedures to be performed. The platform has multimodal use including energy and drug delivery and suction achieved through the use of tubular access channels within each surgical arm. In



Figure 2: Flexible endoscopic platforms, (A) EndoSamurai (Olympus, Tokyo, Japan) and (B) Anubiscope (Karl Storz, Tuttlingen, Germany).

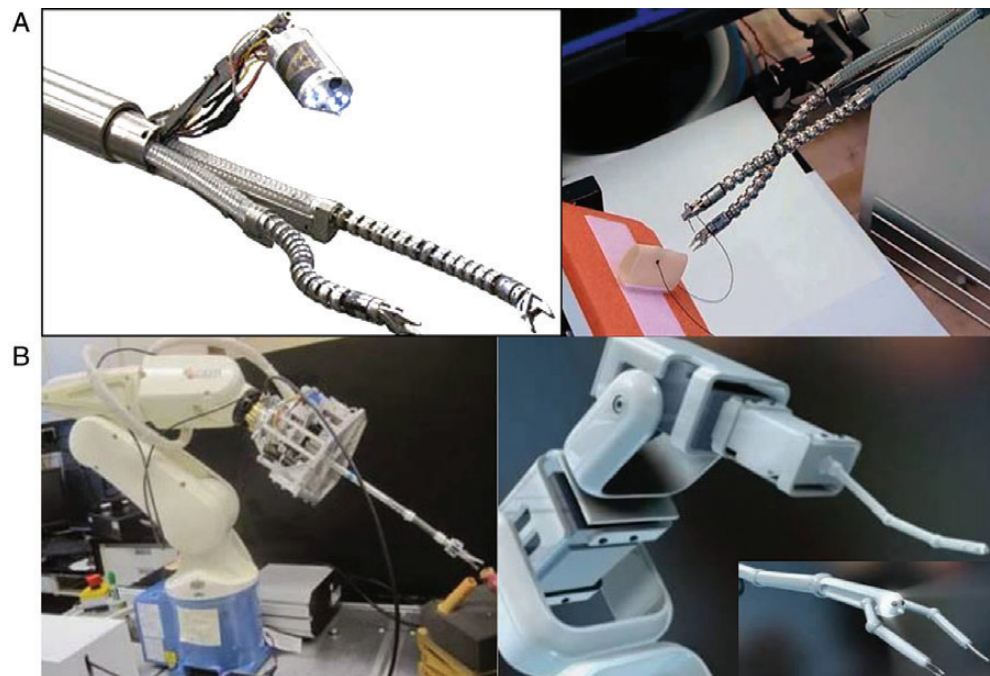


Figure 3: Insertable robotic platforms, (A) Insertable Robotic Effector Platform (IREP), (B) KidsArm system [photos by courtesy of Columbia University, and Centre for Image-Guided Innovation and Therapeutic Intervention (CIGITI), Toronto, Canada, respectively].

the IREP, certain minor technical considerations still need to be ironed out, such as the limited 60° rotation of the wrist, which might hinder suturing efficiency. Nevertheless, these systems will be the next generation of surgical robots that will totally transform and redefine minimally invasive single-incision thoracic surgery.

ADJUNCTS

The minimally invasive approach of single-port VATS might result in less surgical access trauma, and opens up opportunities to further reduce hospital stay and fast-track patients postoperatively. In 2010, Rocco *et al.* described the feasibility of performing single-port VATS

middle lobe wedge resection for a pulmonary nodule in an 'awake', nonintubated and non-mechanically ventilated patient. The operation was performed under mild sedation, single-shot epidural regional anaesthesia, and bronchoscopically guided Fogarty balloon placement into the middle lobe bronchus to facilitate collapse at the target lobe [33]. The same group in the subsequent year used a similar 'awake' technique to perform single-port VATS for spontaneous pneumothorax [34]. The concept of ambulatory thoracic surgery, particularly facilitated by the single-port technique, might further evolve and provide favourable cost and length of hospitalization implications.

One of the criticisms of uniportal VATS lung resection is the difficulty in palpating and assessing tumours through a single small incision usually positioned at the mid-thoracic region. For small tumours and those with low solid component, lesion identification might prove to be even more challenging. Rocco *et al.* [35] recently described the successful use of intraoperative articulating ultrasound probe to identify small nodules during uniportal VATS lung resection. The use of other adjuncts, such as preoperative computed tomography-guided hookwire localization of the lung mass, can help the surgeon to identify the culprit lesion. In selected cases, hookwire localization might also allow the uniportal VATS incision to be minimized [36]. Nevertheless, the time between hookwire localization performed at the radiology department and subsequent surgery should be limited because of the possibility of pneumothorax, and to decrease the risk of hookwire dislodgement. The recent development of advanced multimodality image-guided operating room (AMIGO) use in different surgical specialties has opened up new possibilities. Although AMIGO has been widely utilized in many medical specialties, particularly cardiology and vascular surgery, its use in minimally invasive thoracic surgery, also known as image-guided VATS (iVATS), was only first reported in 2013 by Prof. Raphael Bueno's group at Harvard University, Brigham and Women Hospital, Boston. In the subsequent year, the group at The Chinese University of Hong Kong,

Hong Kong became the first to pioneer AMIGO image guidance for uniportal (single-port) VATS (iSPVATS) (Fig. 4). Essentially, the application of AMIGO in VATS is twofold. Firstly, the hookwire insertion and uniportal VATS surgery can now be performed in one room, reducing the risks associated with patient transfer and delays, such as pneumothorax, hookwire displacement and discomfort. There could also be cost benefits with less transfers and porter use, and time savings. In addition, if the hookwire migrates or dislodges, a DynaCT scan can rapidly and conveniently be done to reinsert the hookwire or relocalize the lesion. Secondly, for those lesions for which it might not be feasible to insert a hookwire because the lesion is either too close to major thoracic vessels or not accessible by a percutaneous approach, a real-time on-table scan can be performed to localize the lung lesion for resection and potentially provide additional information on resection margins. In the future, with the development of radiolucent instruments, it might be possible to perform thoracic imaging and iSPVATS simultaneously in the AMIGO, further improving resection accuracy and safety.

CONCLUSION

Uniportal VATS brings with it unique challenges to overcome that will require an evolution in surgical approach, technological reinventions, technical adjuncts and perhaps advances in robotics. The difficulties in deciding which approach or technology to apply to a particular patient might require even more discretion. As the great Italian Renaissance artist Michelangelo (1475–1564) once said, 'The greatest danger for most of us is not that our aim is too high and we miss it, but that it is too low and we reach it.' The recent rapid developments in uniportal VATS have led us to re-define the *status quo* and to push the boundaries of minimally invasive thoracic surgery.



Figure 4: Advanced multimodality image-guided operating room used to perform image-guided video-assisted thoracic surgery (A), the adjacent control room (B) and in this case uniportal (single-port) video-assisted thoracic lobectomy (C).

Conflict of interest: none declared.

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