Perspective

Future of uniportal video-assisted thoracoscopic surgery—emerging technology

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Uniportal VATS poses unique difficulties to the surgeon, mainly as a consequence of operating through a small single incision. The instruments in uniportal VATS have limited movement through the small incision. In addition, the approach to the surgical operating site is unidirectional, which may restrict vision and retraction, and unavoidably suffers from instrument fencing. Recent thoracoscopic technology in the form of a wide variable angled lens has to some extent improved these shortcomings. The development of an extendable flexible thoracoscope and wireless steerable endoscope (WSE) systems can further improve the visualization for surgery and reduce or even remove fencing between endoscope and instruments. New single incision access platforms both derived from Natural orifice transluminal endoscopic surgery (NOTES) and robotic surgery approaches are on the horizon. These may allow uniportal VATS to be performed through an even smaller ultra-minimally invasive incision, with improved vision, more freedom of movement of the instruments and greater precision. However, a number of problems remain to be resolved, including provision of a stable platform and payload, applied force limitations and equipment sterilization. Advances in uniportal VATS major lung resection techniques have not only challenged the surgeon to acquire new skills and knowledge, but at the same time have rekindled the collaborative spirit between industry and clinician in developing novel equipment and technology to push the boundaries of minimally invasive surgery. These technological improvements and innovations may improve operating efficiency and safety during uniportal VATS surgery.

Keywords: Cardioscope; Natural Orifice Transluminal Endoscopic Surgery (NOTES); robotic; uniportal; wireless steerable endoscope (WSE)

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Introduction

Although uniportal VATS has a history spanning over more than a decade, it is only in the past few years that more complex procedures and a strong desire by uniportal surgeons to further minimize surgical access trauma have spurred on rapid advances in VATS equipment. The potentially improved cosmesis together with patient demand have seen uniportal VATS quickly spread across the world (1). It can be extremely important in uniportal VATS, perhaps more than in other approaches, to use appropriate instruments with technology more suited to coping with the challenges of operating through a single small incision. The most obvious problems to overcome during uniportal VATS are instrument fencing, limited range and angle of vision through the thoracoscopy as well as the difficulty in executing the task with the instruments themselves. The current perspective will focus on certain areas of technological innovation, namely endoscopes and insertable operating platforms, that can help overcome the aforementioned challenges both in the present and in the near future.

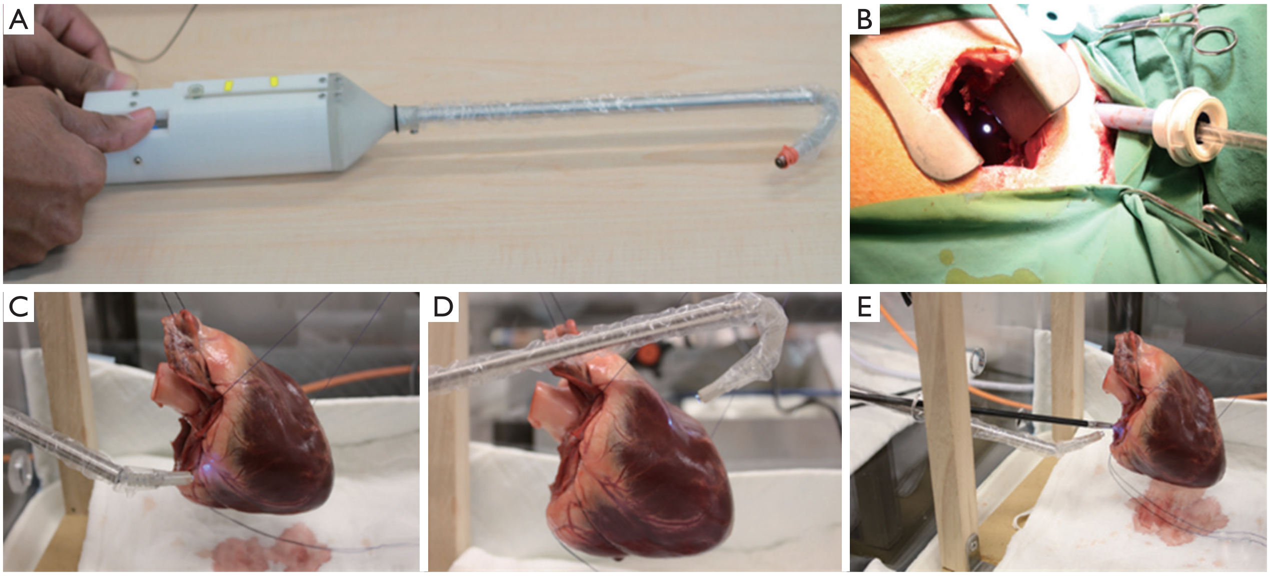


Figure 1 The cardioscope during testing: (A) the cardioscope prototype; (B) retroflexion of the cardioscope in an animal model of thoracic surgery; (C) the cardioscope operating at a short bending section; (D) the cardioscope operating at a longer bending section; (E) the cardioscope guiding other operating tools through a simulated uniportal approach.

Advances in thoracoscopy

In VATS, as in other endoscopic surgery, the quality of vision offered by the endoscope is of paramount importance. Most commonly used thoracoscopes have the classical rigid rod lens design with a beveled tip which defines the viewing angle. To modify the field of view (FOV), one has to steer the endoscope shaft or use an endoscope with a different viewing angle. These maneuvers can increase the chance of fencing between the endoscope and surgical instruments, which may prolong the surgical procedure while offering limited viewing angles. These challenges are more profound during uniportal VATS where all the instruments pass through one small incision in approximately the same direction. An endoscope with a distal flexible tip could reduce the chance of fencing between instrument and endoscope since the FOV could be modified by simply bending the tip section only without movement to the main body of the thoracoscopy (2). The EndoEye by Olympus (3) and the Cardioscope developed by Li *et al.* (4) are some examples. In the EndoEye, the distal flexible tip section, much like that of a flexible bronchoscope, can be angulated to over 100° with a variable lens angle adjuster, enabling the endoscope a wide FOV. However, the surgical site is often crowded and although the desired viewing angle may be achieved with the adjustable bending tip of the Endoeye, the tip itself can take up more room than a straight scope and cause obstruction to other surgical instruments. Therefore, the Cardioscope has been designed to further reduce collision of instruments and to improve visualization around tissue structures by not only having a flexible distal tip section but also an adjustable length to this flexible section, providing an even wider FOV (4). *Figure 1* shows the Cardioscope prototype being tested *ex vivo* and *in vivo*. Compared to the EndoEye, image quality of the current version of the Cardioscope is inferior. Further development is required to bring the Cardioscope to the operating theater.

One limitation of the conventional endoscopes is that the scope shaft occupies space within the uniportal surgical incision and interferes with other surgical instruments despite strategies to limit this (5). One approach to improve this is to develop a remote wireless steerable endoscope (WSE). At the start of the operation, the WSE is inserted into the thoracic cavity through the uniportal incision and magnetically anchored to the internal thoracic wall. The WSE transmits the video images of the surgical site to the monitor and the FOV is controlled by steering the WSE wirelessly. Thus, the WSE replaces the conventional thoracoscopy, with the main advantages of omitting the cables associated with endoscopes and not interfering with instruments at the surgical incision (6). *Figure 2* shows

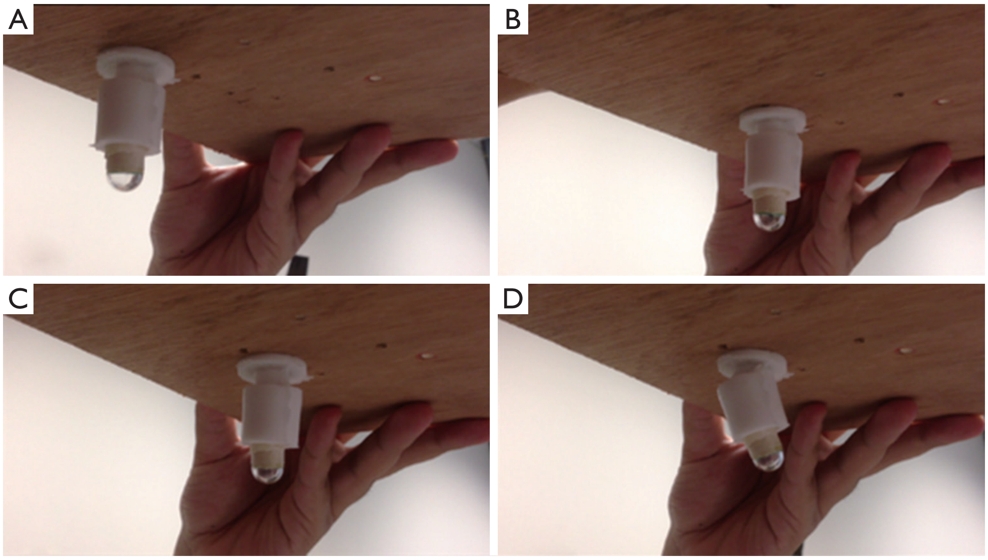


Figure 2 (A) Wireless steerable endoscope (WSE) prototype: the WSE is held against gravity by a magnet under a wooden plank mimicking attachment to the internal wall of a body cavity and is able to (B) slide; (C) axially rotate; (D) providing multiple viewing directions.

the WSE prototype. In this system, the wireless camera is hanging on a wooden plank, of which the thickness is equivalent to the average thickness of the chest wall. The prototype demonstrated good performance in sliding, rotating and providing multiple viewing directions and angles (*Figure 2*). Without occupancy by the thoracoscopy, the uniportal incision can potentially be smaller. In addition, since the WSE would be away from the operating tools, this would avoid fencing, leaving more space within the pleural cavity for use of other surgical instruments. This type of endoscope is not commercially available yet, however it is under development and currently being tested by the authors at their institute.

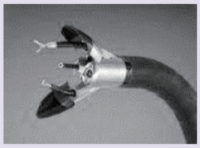
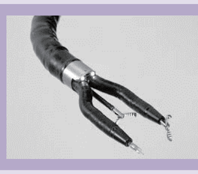
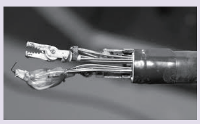
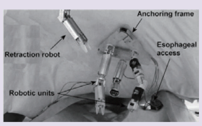
Alternate access

Natural orifice transluminal endoscopic surgery (NOTES) platform

Uniportal VATS has contributed to the growing interest in developing other forms of single access instrument platforms, such as NOTES (or embryonic-NOTES) and single incision robotic surgery, which may well have significant roles in the thoracic surgery of the future (6). In 2013, Zhu *et al*. reported their initial experience of e-NOTES transumbilical thoracic sympathectomy in patients suffering from palmar hyperhidrosis using a 5 mm ultrathin flexible gastroscopy. The procedure involved incision of the diaphragm to reach the operating site in the chest cavity and subsequent ablation of the sympathetic nerve. Such an approach may be adequate for performing very simple procedures, however a more sophisticated endoscopic platform is needed for more complex thoracic surgery.

Equipment used for NOTES can be categorized into two groups: flexible equipment and miniaturized devices (7,8). These devices, some of which are merely prototypes for NOTES, have their own advantages and disadvantages, which are summarized in *Table 1*. Flexible instruments have a bendable shaft and can conform to a natural orifice or lumen. These instruments currently dominate in the application of NOTES. The better known examples include the Cobra produced by USGI (9), Anubiscope by Karl Storz (10), the EndoSamurai by Olympus (11), the MASTER system from EndoMaster (12) and the Flex System from Medrobotics (13). Since the shafts of these instruments are flexible, positioning of the surgical arms may be less accurate and in general the system is less stable. Therefore, a recent improvement in the equipment has been the development of adjustable stiffness due to shape lock, which provides more stability. It is also desirable to have different effector operating arms and instruments that can be easily exchanged via instrument channels within the scope system, rather than having to retrieve the scope from the patient to change the effector or worse still

Table 1 Summary of the NOTES equipment

Equipment/prototype	Figures	Advantages	Weakness
Cobra (USGI Medical) (9)		▪ Shape lock ▪ Three independent arms	▪ Large diameter ▪ Fixed tools ▪ Difficult to manipulate ▪ Low precision
Anubiscope (Karl Storz/IRCAD) (10)		▪ Two movable triangulating arms ▪ Working channel for flexible instruments	▪ Limited triangulation ▪ Limited maneuverability
EndoSamurai (Olympus) (11)		▪ Two bendable arms ▪ Laparoscopic interface for bimanual coordination	▪ Requires multiple operators ▪ Limited maneuverability
MASTER (Endo Master) (12)		▪ Two arms with 4 degrees of freedom ▪ Standard dual-channel endoscope	▪ Large cap diameter ▪ Fixed end-effector ▪ Multiple operators
Flex System (Medrobotics) (13)		▪ High flexibility ▪ Two flexible arms	▪ Limited triangulation ▪ Slow motion ▪ Difficult to reposition
Endoluminal Robotic Platform (Scuola Superiore Sant' Anna) (14)		▪ Can be reconfigured inside the body ▪ Saves space	▪ Complex set up ▪ Tethered by wires for powering and image transmission

NOTES, natural orifice transluminal endoscopic surgery.

having fixed effector arms limiting the range of surgical instruments available to the surgeon. Another disadvantage of instrumentation in the current flexible platform set up is the limited triangulation between the scope and instrument arms due to the scope design and space confinement. Miniature devices, such as the Endoluminal Robotic Platform (14) by SSSA do not suffer from this problem (*Table 1*). The miniature robots are inserted into the body sequentially and are anchored and assembled at the surgical site. Compared with the flexible equipment, the miniature robots save space and avoid tool collision. However, the payload ability of these miniature robots is small and the implementation is very challenging. A hybrid approach would be recommended whereby the miniature robots provide imaging and assistance, while the main operation is performed by flexible instruments.

Robotic uniportal VATS

In contrast to the NOTES equipment, which usually has a flexible shaft, the instruments for uniportal robotic surgery mostly have a rigid shaft with a distal flexible section as the surgical arms (*Figure 3*). Examples of such systems include the da Vinci single site robot by Intuitive Surgical Inc. (15), the SPORT surgical system by Titan Medical Inc. (16), the SPIDER surgical system by TransEnterix (17) and the SJTU unfoldable robotic system (SURS) (18). The flexible surgical arms are positioned by the rigid shaft, which provides a stable platform, and its movement is controlled by wires, cables or 'tendons'. The instrument triangulation and

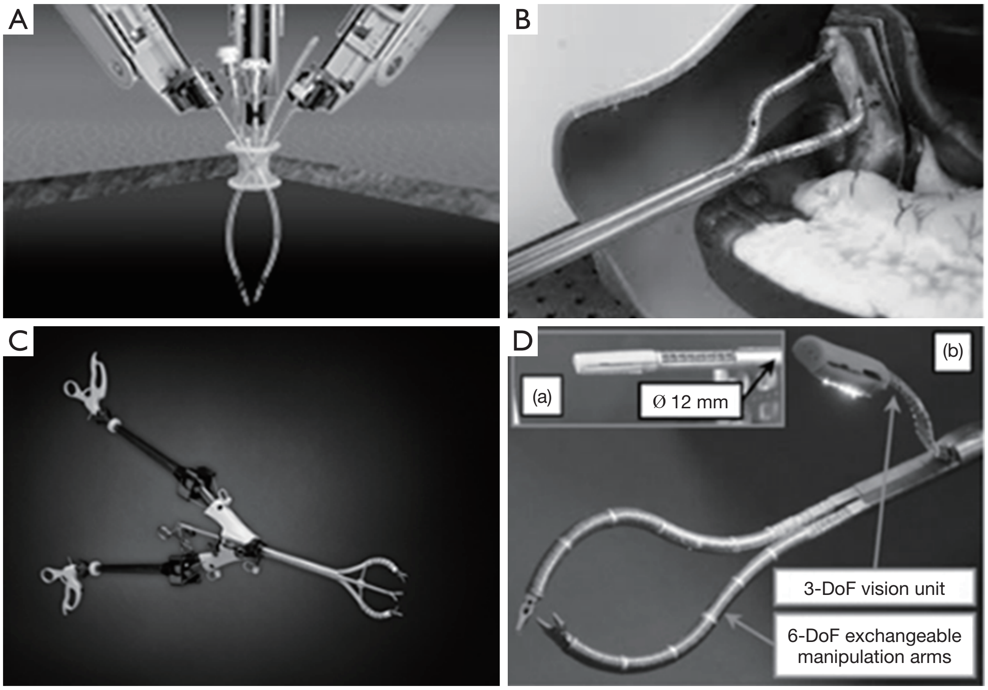


Figure 3 Examples of Single Port Access Surgery Equipment. (A) da Vinci Single Site Surgical Robot (15); (B) Titan Surgical Robot (16); (C) Spider surgical system (17) and (D) SJTU unfoldable robotic system (18).

dexterity of these systems are much improved and superior compared to the previous NOTES equipment as the distal flexible section usually contains multiple bending segments. However, this makes the actuation unit much more complex and system reliability can be problematic. Meanwhile, the payload ability of these systems or the force the instrument arms can exert for surgical tasks remains limited. The development of novel flexible mechanisms could help to simplify the robot system while preserving the advantages of reachable workspace and dexterity of the surgical arm inside the body cavity (19,20). Also, stiffness control (20) of the flexible surgical arms could help to increase the payload ability as well as adapt the surgical arm to various tasks.

For both NOTES and single port access surgery, cauterization is frequently used for tissue cutting. This not only lightens the payload requirement of the surgical arms but is also one of the main methods of achieving hemostasis. However, the smoke cloud generated within the confined surgical environment often affects thoracoscopic image quality and operative progress. Therefore, smoke evacuation should be considered in developing such systems. Another common problem is the sterilization of the surgical arms and cameras in these robotic systems. Each surgical arm contains numerous movable complex components which can make proper sterilization difficult, costly and time-consuming. Conventional sterilization by autoclave could impair the mechanical strength of the wires and damage the electronic component. A further challenge relates to instrument replacement, which is inevitable in surgery. In these robotic systems, the flexible surgical arm, as mentioned above, is steered by numerous motors and cables. Since the actuation unit is integrated into the surgical arm, the sterilization becomes more difficult and the cost of replacement of each arm is much higher.

Conclusions

Endoscopes with ultra-high maneuverability, such as the Endoeye and Cardioscope, can potentially provide better vision of the operating field for the surgeon, while minimizing interference with other instruments co-sharing the single incision. WSE systems may be the ultimate solution for fencing between endoscope and instruments and can further decrease the size of the uniportal wound. Furthermore, the insertion of several endoscopes within the pleural cavity would allow an unprecedented panoramic view of the whole operating space. NOTES and single incision robotic platforms will become the next generation of tools for performing uniportal VATS, allowing the endoscope and 'hands of the surgeon' to be inserted into the chest cavity through an even smaller incision and enable operations with greater precision. Technology is evolving rapidly at a pace that we have never seen in the past. The present article only touches on certain aspects of endoscope development and insertable surgical platforms. The future development, refinement and success of uniportal VATS will to a large extent depend on advancing technology that will allow ever more complex procedures to be done through smaller incisions and with greater patient safety and satisfaction.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Ng CS, Lau KK, Gonzalez-Rivas D, et al. Evolution in surgical approach and techniques for lung cancer. Thorax 2013;68:681.
2. Ng CS, Wong RH, Lau RW, et al. Single port video-assisted thoracic surgery: advancing scope technology. Eur J Cardiothorac Surg 2015;47:751.
3. Endoeye by Olympus (visited on 24th, Oct. 2015). Available online: http://medical.olympusamerica.com/products/endoeye
4. Li Z, Oo MZ, Nalam V, et al. Design of a Novel Flexible Endoscope-Cardioscope. Available online: http://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=2483640
5. Ng CS, Wong RH, Lau RW, et al. Minimizing chest wall trauma in single-port video-assisted thoracic surgery. J Thorac Cardiovasc Surg 2014;147:1095-6.
6. Ng CS, Rocco G, Wong RH, et al. Uniportal and single-incision video-assisted thoracic surgery: the state of the art. Interact Cardiovasc Thorac Surg 2014;19:661-6.
7. Ren H, Lim CM, Wang J, et al. Computer-assisted transoral surgery with flexible robotics and navigation technologies: a review of recent progress and research challenges. Crit Rev Biomed Eng. 2013;41:365-91.
8. Vitiello V, Lee SL, Cundy TP, et al. Emerging robotic platforms for minimally invasive surgery. IEEE Rev Biomed Eng 2013;6:111-26.
9. Bardou B, Nageotte F, Zanne P, et al. Design of a telemanipulated system for transluminal surgery. Conf Proc IEEE Eng Med Biol Soc 2009;2009:5577-82.
10. Dallemagne B, Marescaux J. The ANUBIS™ project. Minim Invasive Ther Allied Technol 2010;19:257-61.
11. Spaun GO, Zheng B, Swanström LL. A multitasking platform for natural orifice translumenal endoscopic surgery (NOTES): a benchtop comparison of a new device for flexible endoscopic surgery and a standard dual-channel endoscope. Surg Endosc 2009;23:2720-7.
12. Phee SJ, Kencana AP, Huynh VA, et al. Design of a master and slave transluminal endoscopic robot for natural orifice transluminal endoscopic surgery. Proc Inst Mech Eng C. Mechanical Engineering Sci 2010;224:1495-503.
13. Flex® Robotic System: Expanding the reach of surgery®. Available online: http://medrobotics.com/gateway/flex-system-int/
14. Ashok PC, Giardini ME, Dholakia K, et al. A Raman spectroscopy bio-sensor for tissue discrimination in surgical robotics. J Biophotonics 2014;7:103-9.
15. De Vinci Single-Site Instruments by Intuitive Surgical. Available online: http://www.intuitivesurgical.com/products/davinci_surgical_system/da-vinci-single-site/
16. The SPORTTM Surgical System by Titan Medical Inc. Available online: http://www.titanmedicalinc.com/
17. SPIDER Surgery Demonstrating the Potential of Flexible Laparoscopy. Available online: http://www.transenterix.com/technology/spider/
18. Xu K, Zhao J, Fu M. Development of the SJTU Unfoldable Robotic System (SURS) for Single Port Laparoscopy. IEEE/ASME Transactions on Mechatronics 2015;20:2133-45.
19. Li Z, Du R. Expanding workspace of underactuated flexible manipulators by actively deploying constraints. In: Robotics and Automation (ICRA), 2014 IEEE International Conference on; 2014 May 31-June 7; Hong Kong, China. Hong Kong;2014:2901-6.
20. Li Z, Feiling J, Ren HL, et al. A Novel Tele-operated Flexible Robot Targeted for Minimally Invasive Robotic Surgery. Engineering 2015;1:73-8.

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