

# Asian perspectives in thoracic surgery: clinical innovation in Taiwan

Chao-Yu Liu<sup>1,2</sup>, Chen-Sung Lin<sup>2,3</sup>, Chia-Chuan Liu<sup>4</sup>

<sup>1</sup>Division of Thoracic Surgery, Department of Surgery, Far Eastern Memorial Hospital, New Taipei City, Taiwan; <sup>2</sup>School of Medicine, National Yang-Ming University, Taipei, Taiwan; <sup>3</sup>Division of Thoracic Surgery, Feng-Yuan Hospital, Ministry of Health and Welfare, Taichung City, Taiwan;

<sup>4</sup>Division of Thoracic Surgery, Department of Surgery, Koo-Foundation Sun Yat-sen Cancer Center, Taipei, Taiwan

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**Correspondence to:** Chia-Chuan Liu, MD. Division of Thoracic Surgery, Department of Surgery, Koo-Foundation Sun Yat-sen Cancer Center, 125 Lih-Der Road, Pei-Tou District, Taipei 112, Taiwan. Email: gcliu@kfsyscc.org.

**Abstract:** The development of minimally-invasive surgery of the thorax began in the 1990s, but not until the recent decade did we see dramatic improvements in patient care and refinement of technique. The current generation has witnessed the evolution from traditional thoracotomy, to a single-port, non-intubated thoracoscopic approach. The investigation of subxiphoid single-port, transumbilical approach, and natural orifice transluminal endoscopic surgery (NOTES) in animal model are also undergoing. In Taiwan, several talented young surgeons have vigorously devoted their ideas and innovations to this field, making the Taiwan surgical society vivid and prosperous. The desire to improve, and willingness to change are the foundation of those surgeons. Providing better patient care is their impetus to strive for improvement. This article provides an account of how minimally-invasive thoracic surgery has evolved in recent years, and what clinical innovations have been developed by the Taiwan surgical society.

**Keywords:** Lung cancer; segmentectomy; single-port; video-assisted thoracoscopic surgery (VATS); non-intubated; transumbilical; subxiphoid; natural orifice transluminal endoscopic surgery (NOTES)

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## Taiwan has thrived as one of the pioneers of modern thoracic surgery

The very first “thoracoscopic” surgery performed in 1910 by a Swedish doctor HC Jacobaeus, who put a rigid tube into the pleural cavity to exam the pleural surface. Not until the 1950s did advances in technology make it possible that images could be transmitted to a monitor, from which we can see inside the human body by holding a “camera”. A prototype of videoscope was thus born. The videoscope was initially applied in the field of gynecology to perform various procedures, and the first cholecystectomy was performed in 1987 by Dr. Mouret from France. Not until the early 1990s did video-assisted thoracoscopic surgery

(VATS), the creation of several “holes” in the chest wall to do a surgery, come into use in the surgical community. Since then thoracic surgeon in Asia has rapidly embraced this new technology, and became pioneers in the development of VATS procedures.

Taiwan is a vibrant and multicultural society of 23 million people. Medical development in Taiwan was greatly influenced by Japan in the early twentieth century, and by Western countries in the latter half of the century. As VATS technology burgeoned in 1990s, Taiwan was part of the leadership. Liu *et al.* (1) published the use of VATS for treating various thoracic diseases, including lobectomy, in 1993, and the same team published the first preliminary experience of thoracoscopic-assisted lobectomies in Taiwan (2) in 1995.

Although the instruments at that time were those used for conventional open surgery, and the techniques applied were those used for open surgery, it had paved the way for the development of thoracoscopic surgery in Taiwan.

Taiwan is an island of 36,000 km<sup>2</sup>, about the size of Maryland, USA, and has 19 medical centers. The frequent interflow of knowledge between centers, and unimpeded media attention, allows all new technologies to spread rapidly. The concept of minimally invasive surgery, which brings less access trauma, was soon embraced by surgeons on the island. Continuous refinement in the techniques has to be made in order to meet the higher demands of our people. In the 2000s, VATS became the mainstay of approach for treating various thoracic diseases in Taiwan. The penetration rate of VATS in the late 2000s was estimated to be more than 90%. In the past one and a half decades, the changes in the thoracic surgery have been revolutionary, especially in Taiwan, where our fellow thoracic surgeon have been aggressively developing minimally invasive procedures from many perspectives. From conventional three-port VATS to non-intubated, single-port anatomic pulmonary resections, Taiwan has been one of the pioneers of VATS. In this review, we will highlight some of the clinical innovation milestones of the Taiwan thoracic surgical society over the recent decade.

### From multi-port to single-port VATS

VATS, undoubtedly, is the most revolutionary change in thoracic surgery of this generation. Its benefit to patients of reduced surgical trauma has unanimously gained popularity worldwide, and its advantages over conventional thoracotomy have been proven in scientific studies. However, over the past decade, progress in minimally invasive techniques has been dramatic. The use of conventional VATS with three or four ports has been challenged with the use of fewer ports in the past decade. Although Gaetano Rocco reported the first use of a single-port technique to perform pulmonary wedge resections in 2004 (3), at that time physicians were hesitant to perform anatomical pulmonary resections because of concerns of feasibility and oncological outcomes. Not until the 2010s did the number of single-port VATS procedures increase exponentially (4). In Taiwan, Dr. Liu began performing three-port VATS in 2005, and modified their approach to two-port in 2007 (5). In 2010, they began performing single-port pulmonary anatomical resections and published their initial experience of lobectomies and segmentectomies of 19

patients (6). Soon, Liu's team published the first comparative study between single-port versus multi-port thoracoscopic major pulmonary resection for lung cancer (7). The non-inferiority of single-port thoracoscopic major lung resections was later confirmed by Dr. Han from Korea who published similar results (8). Other thoracic surgeons at different centers in Taiwan soon began performing single-port major pulmonary resections. Hsu *et al.* (9) published promising results of 121 single-port VATS major pulmonary resections from four centers in Taiwan, indicating that the single-port has been rapidly well-accepted by Taiwan's thoracic surgeons.

Today, single-port thoracoscopic major pulmonary resection has been proven to be at least comparable to conventional VATS in terms of feasibility and perioperative outcomes. However, the data of long-term oncological outcomes for lung cancer such as disease-free survival and overall survival are still awaited.

### Subxiphoid single-port VATS

As single-port VATS has become common in recent years, another modification of the single-port approach—subxiphoid single-port VATS—made its debut in the thoracic surgical community.

Postoperative pain and chronic chest wall paresthesia are a common complaint of patients who have undergone thoracic surgery. The reported incidence of chronic post-thoracotomy pain ranges from 11% to 80% (10), and there is no difference in the rate of chronic postoperative pain between endoscopic and open thoracotomy. Chronic chest wound pain is due to damage to, or compression of, intercostal nerves, and the transthoracic approach inevitably causes injury to intercostal nerves, especially the result of torque by instruments or trocars. The subxiphoid technique does not involve intercostal incisions, thereby avoiding potential injury to the intercostal nerves and subsequent intercostal neuralgia.

Historically, the subxiphoid approach has been used in mediastinal surgery (11). Hsu pioneered the thymectomy (12) and extended thymothymectomy for myasthenia gravis (13) using a subxiphoid approach. However, in 2005 Taniguchi *et al.* (14) reported the first use of a subxiphoid approach in lung surgery by doing a bilateral metastasectomy. As for anatomical pulmonary resection for lung cancer, CC Liu once again took the lead reporting the first novel technique of pulmonary lobectomy via a single 4-cm subxiphoid incision in August 2014 (15). This resulted in

a subsequent wave of investigation for the feasibility and comparative studies regarding subxiphoid single-port VATS for pulmonary surgery. Wang and his colleagues in Taipei performed the single-port subxiphoid approach for the treatment of spontaneous pneumothorax to highlight its benefit of reduced postoperative pain over a three-incision transthoracic approach (16). The feasibility of this approach was quickly been proven by Zhao *et al.* from China, who reported 105 cases of subxiphoid single-port VATS lobectomy in 2016 (17).

Overall, the subxiphoid approach is a variant of single-port VATS, with theoretical benefits of reducing postoperative pain and chronic chest wall paresthesia. When there are bilateral pulmonary lesions, it allows assessment of the bilateral pleural cavities with a single incision, and avoids changing the position of patients as is needed in the transthoracic approach. However, the more data is needed to confirm the benefits of the subxiphoid approach.

### Non-intubated VATS

In ancient times, surgery had to be performed on patients awake without general anesthesia, let alone endotracheal intubation. Double-lumen endobronchial tubes allowing one-lung ventilation, introduced by Zavod in 1940 (18), provided the platform on which modern thoracic surgery development is based. General anesthesia with one-lung ventilation provides optimal conditions and space for safe and easy intra-thoracic surgical manipulation, and has been considered mandatory for most thoracic surgical procedures for more than a half century. However, the renaissance of non-intubated thoracic surgery in the recent years brought us back to old-school times, but in a whole different perspective.

Non-intubated VATS is another extension of the minimally invasive concept of thoracic surgery, and focuses from an anesthesiological perspective of to minimize the side-effects of intubated general anesthesia-related complications, such as residual neuromuscular blockade (19), airway trauma (20), ventilation-induced lung injury (21), impaired cardiac performance, and postoperative nausea and vomiting. In 2004, Pompeo and colleagues were the first pioneers to publish the feasibility of non-intubated VATS for the resection of pulmonary nodules (22). In 2007, Pompeo *et al.* (23) published the results of a randomized trial comparing the non-intubated technique versus general anesthesia with one-lung ventilation for the treatment of spontaneous pneumothorax. The results showed shorter

hospital stay and less procedure-related costs in the non-intubated arm, while providing an equivalent recurrence rate in the non-intubated group (23).

In Taiwan, Chen and his colleagues have employed non-intubated VATS since 2009. Before that, non-intubated technique procedures reported in the literature was limited to simple pulmonary procedures such as wedge resection of peripheral pulmonary nodules, empyema thoracis, and pneumothorax. The main concern was that the intense traction of the lung parenchyma and hilar manipulation, which may trigger a cough response, is inevitable in anatomical pulmonary resection and mediastinal lymph node dissection. The cough response, remarkable mediastinal swing, and the need for meticulous vessel dissection made the whole procedure intimidating during the early development of the non-intubated technique. Not until 2011 did Chen take the lead to report the first pulmonary lobectomy for lung cancer using a non-intubated technique (24). The combination of a sedative and intrathoracic vagal block enabled major pulmonary resections and mediastinal lymph node dissections to be performed with the same ease as with intubated general anesthesia (25). With accumulated experience, Chen *et al.* (26) reported the first largest series of non-intubated VATS in 2012 to prove the feasibility of this technique for various thoracic procedures including major pulmonary resections (26). Pulmonary segmentectomy, which requires a more detailed bronchovascular exploration, can also be performed in the non-intubated setting (27). Non-intubated VATS also can be applied in geriatric patients to provide improved postoperative pain control, a lower rate of throat sore, earlier resumption of oral intake, shorter length of hospital stay, and a lower complication rate as compared to intubated general anesthesia (28,29). These data generated a solid footing for further investigation of non-intubated thoracic surgery around the world.

### Natural orifice transluminal endoscopic surgery (NOTES) in thoracic surgery

In thoracic surgery, no matter how “minimal” the surgical wound is, there is concern of postoperative pain and paresthesia. This problem is caused by injury to the intercostal nerves during transthoracic approaches, which results in a variety of symptoms including pain, numbness, and paresthesia. The frequency of these complication ranges from 4% to 32% (30,31). The single-port transthoracic technique has minimized access trauma to only one intercostal space, and while the subxiphoid approach tries to

avoid intercostal spaces, is still requires passage through the sternocostal triangle and infrasternal angle (32). NOTES, the most recent advancement in minimally invasive surgery, offers a revolutionary idea for surgery. In NOTES, the operation is performed without a skin incision by using a natural body orifice to provide the access. It has been described as the next new surgical frontier with the advantages of being incision-free, aiming at early recovery time, less postoperative pain, and improved cosmetic outcomes (33).

Several reports of NOTES have been published, including transgastric endoscopic cholecystectomy (34), tubal ligation (35), oophorectomy (36), gastrojejunostomy (37), partial hysterectomy (38), and splenectomy (39). However, due to the technical difficulty and lack of advanced instrument, no optimal NOTES approaches for the thoracic cavity have been developed. The negative-pressure environment of the pleural cavity which makes pleural space vulnerable to contamination is also a reason that the development of thoracic NOTES procedures has been limited. Most of the reports of NOTES for the thoracic cavity have been of animal models.

Liu and his colleagues in Taiwan, among the pioneers investigating the potential of NOTES in thoracic disease, have published their extraordinary studies of NOTES in thoracic surgery in animal models since 2010 (40). NOTES with a transvesical approach (41), transgastric approach (42), transesophageal approach (43) for thoracic procedures have been reported using animal models. The first successful approach to the thoracic cavity via a transtracheal approach was reported by Liu *et al.* in live canine model (44). However, significant intraoperative complications have prevented its development. Liu *et al.* modified transoral endoscopic surgery for thoracic surgical intervention. Lung biopsy and pericardial window creation were completed via a 12-mm incision over the vestibulum oris region. A comparative study of a transoral versus conventional thoracoscopic approach for thoracic intervention in a canine model was published in 2013 (45). The results demonstrated that the transoral approach is comparable to conventional thoracic surgery for lung biopsy and pericardial window creation in terms of safety and efficacy (45). However, a weakness of the transoral approach is the size of lung that can be removed is limited by the small incision at the vestibule oris region (46).

Later in 2013, Liu and his colleagues (47) adopted a transumbilical approach for thoracic intervention as an alternative of NOTES in a live canine model. The transumbilical approach, an evolving alternative to NOTES,

is also called embryonic nature orifice transumbilical endoscopic surgery (E-NOTES). With a small incision in the embryonal remnant, the umbilicus, it allows a surgical scar to be superimposed on an original natural scar; thus, no new incisional scar will be present. It also prevents the potential complication of intercostal nerve injury, neuralgia, and chronic thoracic pain. These potential benefits prompted their team to investigate a transumbilical access into the thoracic cavity.

The feasibility of transumbilical wedge resection of lung in a canine model was first published in 2013 (48). Further comparative studies of transumbilical wedge resection of lung and the conventional thoracoscopic approach were performed, with comparable results between the two approaches (49,50). In 2014, transumbilical lobectomy of lung in a canine model was reported (51). Although significant complications such as intraoperative bleeding were encountered, with further refinement and development of new instruments this approach has the potential to be feasible for major pulmonary procedures. With the endeavor made by Liu and colleagues, the information and valuable data gained from animal model have provided significant references for future clinical practice in human.

### Future perspectives of VATS development in Taiwan

Medicine is an ever-changing science, and Taiwan, in many ways, has been one of the pioneers. Generations of talented medical scientists have vigorously contributed to this field to make it innovative, safe, practical, and helpful to our people. In thoracic surgery, we have entered a new frontier where minimally invasive is a one-way road. In the past decades, we have witnessed the rapid change of the way we perform surgery: from traditional thoracotomy, to the multi-port thoracoscopic approach, to a one-port technique, and its variant subxiphoid approach. Another approach to minimizing trauma, intubated general anesthesia has also been modified to a sedative non-intubated technique in selected cases.

With the increasing use of low-dose computed tomography (CT) of the chest, more pulmonary nodules will be detected in the future, and more patients with small pulmonary nodules will require surgery. In the next phase, the concept of minimally invasive surgery will be expanded to include preoperative preparation (ex. the method of tumor localization), intraoperative procedures (ex. the type of surgical incision, non-intubated technique), and

postoperative care (ex. without a chest tube, no hospital stay). A new concept of tubeless thoracic surgery has been developed, meaning no endotracheal tube, no Foley catheter, no chest tube.

Although any new technology needs time to prove its equivalence or superiority over its conventional counterpart, the impetus of on-going innovation in Taiwan has never stopped. To the extreme, no skin incision, such as with E-NOTES or NOTES for thoracic disease will be the next realm to conquer.

*“The only thing that never changes is that everything changes.”* —Louis L'Amour

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### Footnote

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