Review Article



# A glimpse of history: non-intubated thoracic surgery

**Alessandro Tamburrini[1], Tommaso Claudio Mineo[2]**

[1]Postgraduate School of Thoracic Surgery, [2]Department of Surgery and Experimental Medicine, Tor Vergata University, Rome, Italy

*Correspondence to:* Dr. Alessandro Tamburrini. Postgraduate School of Thoracic Surgery, Tor Vergata University, Policlinico Tor Vergata University Hospital, Viale Oxford 81, 00133, Rome, Italy. Email: alessandroptamburrini87@gmail.com.

**Abstract:** Thoracic surgeons in the modern era are expected to push the limits of their performances, limiting the invasiveness of operations and minimizing harm to the patients, keeping safety as the very first priority and benefiting from the constant scientific advances and technological developments. Minimally invasive thoracic surgery performed without use of general anesthesia, which seems to be the "end product" of this era, conveys instead a long, fascinating history of evolutions and revolutions. After World War I, the already established practice of chest operations on awake patients was furtherly implemented, reaching a peak in the 1950s when significant refinements in regional anesthesia techniques allowed pioneer surgeons to perform major thoracic procedures in spontaneously ventilating patients under epidural analgesia or by carefully developed multi-step nerve blocks. The introduction as a standard of practice of double-lumen endotracheal tube limited further developments in open surgery, but did not stop the ongoing evolution of thoracoscopy, the very first minimally invasive approach to the chest. Invented and popularized in the 1910s, thoracoscopy in awake patients for diagnostic and therapeutic purposes gained conversely widespread acceptance after the 1950s. It was extensively performed in most cases under local anesthesia and it can be rightfully considered the closest progenitor of modern minimally-invasive non-intubated surgery. The compelling affirmation on a large scale of video-assisted thoracic surgery (VATS) was the real game-changer in the 21st century, giving birth to a whole new idea of minimally-invasive. Shortly after its introduction though, the new pioneers in surgery developed a novel concept of "non-intubated" and "awake" thoracoscopic procedures, which are being continuously refined and implemented. From a dedicated investigational research program on "non-intubated" thoracic surgery, to complex chest operations under "non-general" anesthesia and to uniportal "tube-less" lobectomy, history of surgery is an ongoing and fascinating event, and past, present and future generations of thoracic surgeons are all part of it.

**Keywords:** Thoracic surgery; non-intubated; awake; tubeless

Received: 29 July 2017; Accepted: 16 August 2017; Published: 06 September 2017.
doi: 10.21037/vats.2017.08.12
**View this article at:** http://dx.doi.org/10.21037/vats.2017.08.12

## Introduction

The rapidly increasing technological developments and the growing importance of a patient-centered healthcare concept are the key features of thoracic surgery in the 21st century. In this setting, thoracic surgeons of the modern era are constantly encouraged to push the boundaries of their performance, aiming to minimize the invasiveness of surgical procedures while increasing effectiveness and safety as much as possible. Non-intubated, minimally invasive thoracic surgery seems quite rightly to be the "end product" of this modern era, embracing these concepts at its best. Nevertheless, non-intubated and awake techniques have instead been described since the early beginnings of thoracic surgery, and the aim of this article is to "catch a glimpse" of the fascinating history and evolution of non-intubated thoracic surgery. A brief summary of the most relevant historical steps is presented in *Table 1*.

## Early experiences in open surgery

At the beginning of the XX century, infectious diseases of

**Table 1** Relevant historical steps of non-intubated thoracic surgery

| | |
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| 1866 | A possible "very first" anecdotal report of thoracoscopy in awake patient |
| 1910s | Jacobaeus invents and popularizes thoracoscopy, performed under local anesthesia |
| 1920s | Eloesser and Sauerbruch perform major thoracic procedures with intercostal blocks |
| 1950 | Buckingham performs major thoracic surgery under epidural anesthesia |
| 1954 | Vischnevski performs various chest operations with intercostal, vagus and phrenic blocks |
| 1956 | Thoracoscopic pleural biopsies under local anesthesia |
| 1960 | Ossipov's 3,000 cases of thoracic operations with various techniques of local anesthesia |
| 1963 | Thoracoscopic talc pleurodesis under local anesthesia |
| 1975 | Thoracoscopic lung biopsies under local anesthesia |
| 1997 | VATS pneumothorax surgery under local + epidural anesthesia |
| 1998 | VATS pneumothorax surgery under sedation |
| 2000 | Tor Vergata "Awake Thoracic Surgery Research Group", first dedicated investigational program on non-intubated thoracic surgery |
| 2006 | Mineo's introduction of awake nonresectional treatment for pulmonary emphysema |
| 2007 | Open lobectomy and thymectomy in sedated, non-intubated patients |
| 2011 | Chen's first series of VATS lobectomies without general anesthesia and endotracheal tube |
| 2014 | Gonzalez-Rivas' first uniportal VATS lobectomy in non-intubated patient |
| 2016 | Over 1,000 cases of non-intubated thoracic surgery procedures by the Tor Vergata Group |
| 2017 | "Tubeless" thoracic surgery procedures |

lungs and pleural space were the most common conditions thoracic surgeons had to deal with in their daily practice. Consequently, surgical procedures were mostly confined to simple evacuations of fluid collections and, as reported by American surgeon George J. Heuer (1), local anesthesia was already considered a safe and effective technique. The supposed highly detrimental effects of iatrogenic pneumothorax following thoracotomy was however a major concern, thus limiting the execution of more complex and challenging operations. For the latter indeed, general anesthesia was regarded as essential to prevent the inevitably fatal consequences of the pneumothorax created after opening the chest cavity in a spontaneously ventilating patient (2).

In this regard, World War I, a dreadful occurrence in the history of mankind, interestingly represented instead a landmark event in the evolution of awake thoracic surgery. During the great conflict indeed, it was noted how soldiers with large, even bilateral, open chest wounds, could eventually survive in absence of other vital injuries. These observations promoted in the following years a better understanding of respiratory pathophysiology and of the iatrogenic pneumothorax (3). In the 1920s, a renewed consciousness of surgeons together with the raising knowledge in the field of anesthetics, ultimately led to a more enterprising attitude towards awake thoracic surgery, so that increasingly complex operations started to be carried out under local anesthesia (4).

Prominent American thoracic surgeon Leo Eloesser electively performed major thoracic surgery procedures via large thoracotomies (including thoracoplasty) using multiple intercostal nerve blocks with novocaine as the only anesthetic technique (5). He stated that "*…Almost all operations upon the bony thorax should be done under local and regional anesthesia…*" (5), quoting among its advantages the prevention during the postoperative period of retained bronchial secretions, due to preservation of the cough reflex. Similarly in Europe, German surgeon Sauerbruch was successfully performing operations with the same intercostal nerve blocks technique (6). Three decades later, further scientific discoveries and advances in the anesthesiology practice, provided additional significant contributions to thoracic surgery in awake and spontaneously ventilating patients. Above all, refinements in regional anesthesia technique represented a mainstay, resulting in a more efficient control of pain and reflexes.

In 1950, Dr. Buckingham from Kansas City described his extensive experience of major thoracic surgery procedures performed under thoracic epidural anesthesia (7). He was the first surgeon to introduce this technique and, in over 600 cases, reported no cases of permanent nerve damage or depressed respiration (8). Only 2 years later in Russia, a sophisticated multi-step analgesia protocol was developed by soviet surgeon Alexander Vishne*vsk*y, consisting in the block of the phrenic nerves and the vagus nerves at the level of the neck, followed by extensive intercostals and

 

lung hilum blocks with up to 900 mL of novocaine. Phrenic nerve block was performed to avoid diaphragmatic motion during the operation, while the parasympathetic block was aimed at limiting the possibility of dangerous vagal reflexes, potentially triggered by surgical manipulation and iatrogenic pneumothorax (9). With this technique, Vischne*vsk*i performed over 600 operations including major lung resections, cardiac surgery and esophagectomies (10). His valuable work was carried on and refined by compatriot Boris K. Ossipov, who published in 1960 an impressive series of 3,265 thoracic surgery operations under local anesthesia over a period of 20 years (11). These notable experiences were ultimately interrupted after the development in the 1950s of the double-lumen endotracheal tube, introduced by Bjork and Carlens, which enabled to operate safely on a completely collapsed lung (12). The use of general anesthesia and single-lung mechanical ventilation rapidly became the gold-standard, leading to the birth of modern thoracic surgery. Therefore, local and regional anesthesia techniques were progressively abandoned and confined to a minor role in medical thoracoscopy for several decades.

## Minimally invasive thoracic surgery: from Jacobaeus to the modern era

In 1910, Swedish internist Dr. Hans Christian Jacobaeus used a cystoscope to inspect the chest cavity in patients with tuberculous pleural effusion, a procedure that he described as "thoracoscopy" (13). In reality, an anecdotal report of possibly the very first thoracoscopy traces back to 1866, as Irish physician Francis Richard Cruise performed an "examination of interior of pleura by endoscope" to monitor the therapy of an empyema in an 11-year-old girl (14,15). Nevertheless, Jacobaeus is rightfully acknowledged as the father of this technique and it is important to emphasize that he extensively utilized thoracoscopy in spontaneously breathing patients under local anesthesia. In the following years, this procedure grew wide acceptance in several European countries, initially for diagnostic purposes in pleural effusions, spontaneous pneumothorax, focal pulmonary diseases, diseases of the chest, mediastinal tumours, as well as anomalies of the heart and great vessels and thoracic trauma (16). Thoracoscopy became also of paramount importance in patients with tuberculosis, which were treated by Forlanini's artificial pneumothorax entailing collapse of the lung to control the infection (17). In his experience, Jacobaeus used thoracoscopy in awake subjects under local anesthesia in all those cases with pleural adhesions preventing the lung's collapse, as he performed lysis of adhesions by a thoracocautery introduced through a second entry ("Jacobaeus Operation") (18). Furthermore, thoracoscopy was described as a valuable option in the treatment of empyemas, spontaneous pneumothorax and hyperhidrosis (19-21), although maintaining its prominent role as a therapeutic procedure in tuberculosis disease for several decades (16).

After the 1950s, the advent of antibiotic therapy for tuberculosis and the progressive reduction of tuberculous patients in industrialized countries, highly restricted the therapeutic role of thoracoscopy (16). Notwithstanding, other pleuro-pulmonary diseases were becoming more important to thoracic surgeons and chest clinicians, so that the diagnostic applications and indications of thoracoscopy expanded greatly. In this regard, some of the most significant early experiences are worth to be mentioned. In 1956, Buchanan and colleagues (22) from Johannesburg were the first to report on the effectiveness of thoracoscopic pleural biopsies to investigate "idiopathic" pleural effusion in 71 South African mine workers, suspected to suffer from silicosis or tuberculosis. All the procedures were performed in awake and breathing patients, under local anesthesia, using two incisions (22). Few years later, Bergqvist and Nordenstein (23) reported a diagnostic yield for thoracoscopy of over 90% in patients examined for pleural effusions of either malignant or infectious etiology. In 1963, Roche and co-workers (24), were conversely the first group to report on talc poudrage during thoracoscopy to achieve pleurodesis in chronic, mainly malignant pleural effusions. The value of thoracoscopy for preoperative staging purposes in lung cancer was instead described by LeRoux, who investigated with this technique 139 patients prior to lung resection and found pleural metastasis in 82 of them (25). Brun *et al.* (26) published in 1975 a series of 93 consecutive cases of thoracoscopic lung biopsy under local anesthesia in spontaneously breathing patients.

Despite the role of awake thoracoscopy seems now rightfully confined to minor diagnostic procedures, mainly in the field of interventional pulmonology rather than surgery, its value as a mainstay starting point for the development of modern video-assisted thoracic surgery (VATS) and non-intubated video-assisted thoracic surgery (NIVATS) must be acknowledged (16). In the early 1990's, revolutionary technological advances resulted in the resounding birth of the modern era of VATS, and chest surgeons rapidly approached the rising age of minimally invasive thoracic surgery with great enthusiasm and

 

renewed passion (27). Two key technological breakthroughs led the minimally invasive revolution: the development of video-assisted cameras offering a magnified and panoramic view of the hemithorax compared to the previous tunnel-like view with direct vision and the availability of new dedicated endoscopic instruments like the linear mechanical stapler (28). The overwhelming impact of VATS among thoracic surgeons has substantially changed the clinical practice, becoming the gold standard for a vast majority of procedures. Minimally-invasive lobectomy for lung cancer has proved several advantages compared to conventional thoracotomy, including postoperative complications, chest tube duration, length of hospital stay, quality of life, systemic inflammatory response, recurrence rate and overall survival rates (29-34). Given the initial and conventional idea of VATS, general anesthesia with single-lung ventilation has been considered mandatory for the safety and feasibility of minimally-invasive thoracic operations for several years (35).

## "Awake" and "non-intubated" VATS: pioneers and evolutions of the XXI century

The developments and implementation of minimally-invasive techniques has produced undeniable benefits to patients undergoing thoracic surgery procedures, and VATS has become an established and widely recognised standard of care (36). However, surgical technique itself, cannot be considered the only constituent of a "successful" operation, as the role of anesthesia in surgery is of paramount importance as well. Albeit being initially deemed mandatory for VATS, the use of general anesthesia with selective lung ventilation is nevertheless well known to potentially cause a number of adverse effects including an increased risk of pneumonia; an impaired cardiac performance with a decrease in myocardial blood flow and left ventricular function; possibility of residual neuromuscular blockade and postoperative ventilator dependency; a composite ventilator-induced injury with barotraumas, volutrauma, atelectrauma and biotrauma; the development of atelectasis in both the dependent and the nondependent lung; and a non-negligible risk of major airways and vocal cords injury (37).

Based upon these acquaintances, in the early 2000's at Rome, Tor Vergata University one of us (TCM) established a pioneer investigational program of thoracic operations performed without the employ of general anesthesia and one-lung ventilation (3). Small case series on videothoracoscopic treatment of pneumothorax under local + epidural anesthesia (38) or sedation (39) had already been reported by two distinct Japanese groups, but the Tor Vergata project must be considered a true landmark, being specifically designed and purely dedicated to investigate and refine techniques, indications, and physiopathological knowledge of thoracic surgery procedures under non-general anesthesia and avoidance of endotracheal intubation. The Tor Vergata group published the first randomized series of lung resections for solitary nodules performed under sole epidural analgesia in fully awake and cooperative patients, demonstrating not only safety and feasibility, but also significant advantages compared to the control general anesthesia group in terms of hospital stay, nursing care and patients satisfaction (40). Strongly supported by lead investigator and academic coordinator Mineo, the Italian group attained several historical steps since the development of this dedicated program, with multiple aspects of surgery being investigated and elucidated. A number of thoracic diseases were approached with continuously evolving diverse anesthesia protocols, from "awake and alert" to "non-intubated and mildly sedated". The group performed metastasectomy (41), surgery for pleural diseases (42,43), approached mediastinal masses (44) and interstitial lung disease in high-risk patients (45), also extensively evaluating the systemic impact of non-general anesthesia (46,47). Another cornerstone result was the introduction by Mineo's group of a newly conceived awake nonresectional therapeutic option in the treatment of emphysema patients, a subgroup at undeniable increased risk of general anesthesia (48). In the years, a member of this distinguished group illicitly took advantage of some data for personal reasons and forged their scientific rigour, which has always instead been observed incorruptibly by the original awake team. In over 15 years, starting with epidural anesthesia in conscious and fully alert patients ("awake") for more straight-forward procedures (49), moving to more complex operations in mildly sedated but spontaneously ventilating patients ("non-intubated") (50), the official Tor Vergata "Awake Thoracic Surgery Research Group" has recently reached a milestone achievement of over 1,000 "tubeless" procedures, making this series one of the widest in the world (51).

The encouraging and convincing results in terms of safety, feasibility and reduced morbidity had the effect of a stone thrown in a pond… Several groups progressively started to perform "awake" and "non-intubated" VATS for an increasing number of thoracic diseases, implementing the techniques, providing advances and developments and

 

establishing new protocols and standards (52-56). In 2007, Al-Abdullatief and co-workers (57) showed the possibility of performing major thoracic surgery procedures, including lobectomy and thymectomy, in awake or mildly sedated patients, even via thoracotomy and sternotomy. Chen *et al.* from Taiwan reported the first preliminary series of 30 non-intubated thoracoscopic lobectomy in 2011, with fewer anesthesia-related complications, reduced morbidity and shorter hospital stay compared to a control intubated group (58). The following year, the same group published a series of nearly 300 non-intubated VATS lung resections, including segmentectomy, lobectomy and wedge resections, advocating feasibility, effectiveness and safety (59). Wu and colleagues (60) evaluated the feasibility of elderly patients (age ranging from 65 to 87) undergoing lobectomy, which showed comparable safety profile with control group, and opened up the possibility of non-intubated VATS on the old age group. Some technical refinements and "surgical tips" which have been progressively introduced in recent years are worth to be mentioned. One of the main drawbacks of non-intubated procedures is the cough reflex, which can impair patient's immobility during the operation and jeopardize. The frequent lung traction and the intense hilar manipulation required when performing awake anatomical lung resections particularly, can trigger this cough reflex and several attempts to counteract it have been proposed (61). Ipsilateral stellate ganglion block was advocated by Al-Abdullatief *et al.* (57), while Guarracino *et al.* (62) described the preoperative inhalation of aerosolized lidocaine. Chen's group instead have routinely performed intraoperative thoracoscopic vagal block, and it has been proved effective on cough reflex suppression without causing hemodynamic instability and allowing to safely perform even segmentectomy (59,63). In some other cases, incremental intravenous fentanyl has been used instead of vagal block to decrease cough suppression duration (64). In terms of monitoring conscious sedation instead, bispectral index has recently entered the anesthesist's armamentarium, and it is highly recommended for evaluation of sedation level and advanced judgment of sedation depth (61).

Evidence-based validity for non-intubated thoracic surgery did not take long to appear as well. Deng *et al.* (65) recently published a large meta-analysis also entailing four randomized trials, asserting safety and feasibility of the technique. In this regard, it is important to point out that these are surprisingly striking evidences, after only less than two decades from the introduction of a conceptually new procedure combining both surgical and anesthetic changes in approach. Dedicated anesthetic teams are also implementing the evidence, and the Papworth Group (United Kingdom) recently conducted an elegant case-matched analysis, focusing specifically on the advantages (shorter anesthetic time, shorter hospital stay and reduced oxygen requirements) of a non-intubated compared to an intubated group for thoracoscopic procedures (66).

Perhaps one the most striking event in the latest history of non-intubated thoracic surgery has been its association with the other pillar innovation of XXI century: single-incision (uniportal) VATS. Introduced by Migliore *et al.* (67), who first reported in 2001 on 37 patients operated for different thoracic diseases using a single trocar to enter the chest and to perform the planned operation, the technique gained increased popularity with its implementation by Rocco and co-workers (68), who published in 2013 his experience of a decade entailing over 600 procedures with low morbidity, low mortality and short hospital stay. The single-incision approach raised however to absolute worldwide dissemination and fame thanks to uniportal champion Diego Gonzalez-Rivas (69). Following their first single-port thoracoscopic lobectomy in 2010 (70), Gonzalez-Rivas and his group from La Coruna implemented the technique extensively and rapidly, and were soon able to perform very complex and technical demanding anatomic lung resections with a single incision, including lobectomies with chest wall resections, sleeve resections, pulmonary artery reconstruction and segmentectomies (71-74). The milestone operation, single-port uniportal VATS lobectomy in non-intubated patient was finally performed by Gonzalez-Rivas in 2014 (75), reaching the goal of possibly the least invasive operation for a major lung resection and ultimately raising the question whether uniportal non-intubated VATS could become the actual future of thoracic surgery (76). As a very (so far) final step, one must mention the ultimate concept of "tubeless" surgery, entailing in Gonzalez-Rivas' case series a uniportal VATS lobectomy in complete absence of a tracheal tube or even laryngeal mask, central line, urinary catheter or epidural (77), while for Li *et al.* (78) the resection of small pulmonary nodules in spontaneously ventilating patients, without tracheal intubation, without urinary catheterization, and without post-operative chest drain placement.

## Conclusions

From the XVIII century to the 1950s, thoracic surgery has been performed in awake and conscious patients, with

 

prominent surgeons investigating and implementing the expertises around this technique, ultimately aiming to perform progressively more complex operations causing minimal harm to patients. As we often witness in history, awake surgery suffered from the phenomenon of forgotten knowledge, having been initially discovered and used successfully before being forgotten and subsequently rediscovered, advanced and readopted several decades later. The XXI century "awake", "non-intubated" , and "tubeless" thoracic surgery, all derive from the same desire of innovation arising from the constant willingness of chest surgeons to expand their horizons in implementing the natural transition towards "true" minimally invasive. We are certainly living in an interesting era… and from such a complex and fascinating past, and with such an engaging present, the future of non-intubated, minimally invasive thoracic surgery is only waiting for us to be built.

## Acknowledgments

*Funding:* None.

## Footnote

*Provenance and Peer Review:* This article was commissioned by the editorial office, *Video-Assisted Thoracic Surgery* for the series "Non-intubated Thoracic Surgery". The article has undergone external peer review.

*Conflicts of Interest:* Both authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/vats.2017.08.12). The series "Non-intubated Thoracic Surgery" was commissioned by the editorial office without any funding or sponsorship. The authors have no other conflicts of interest to declare.

*Ethical Statement:* The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.



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doi: 10.21037/vats.2017.08.12
**Cite this article as:** Tamburrini A, Mineo TC. A glimpse of history: non-intubated thoracic surgery. Video-assist Thorac Surg 2017;2:52.

 