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Modern Imaging Technology in Video-Assisted Thoracoscopic Surgery

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Abstract

Since its original inception in the early 20th century, thoracoscopy has undergone rapid advancement thanks to technological innovations. In this article we will go through some of the modern innovations in imaging technology such as the next generation of thoracoscopes, visual displays, 3D technology, intraoperative imaging techniques as well as the use of nanotechnology (ICG & Quantum dots) to help map the spread of neoplastic disease.

Keywords: Modern Imaging Technology; Surgery; 3D technology

Introduction

Video assisted thorascopic surgery (VATS) is primarily used in the diagnosis and management of pulmonary, pleural, esophageal and mediastinal pathology. The approach is a well-established minimally invasive technique that uses a thoracoscope to visualize the surgery and is performed through small port incisions avoiding the need for a thoracotomy [1]. In contemporary practice the most common setup utilizes a high definition camera, thoracoscope, specialized adjuncts (stapling devices and diathermy electrodes) along with two monitors which are used to monitor the surgery [1]. One lung ventilation is crucial for pulmonary resections in VATS. Gas insufflation is not normally required and operating space is obtained by collapsing the affected lung. This minimally invasive approach has slowly gained popularity: over the past two years alone the number of lobectomies conducted for primary neoplastic lung conditions has approximately doubled from 7.0% to 13.8% [2]. When compared to open thoracotomy procedures, VATS consistently show fewer complication rates, reduced hospital stays and superior perioperative outcomes which helps to explain its increasing use [3]. To build on these successes the VATS approach has evolved with technological innovation and there has been a stepwise reduction in the number and size of incisions with a gradual shift in approach from the classical 3 port VATS to single port instrumentation [4].

Development of VATS

In all VATS procedures the quality of vision is of paramount importance as the entire procedure is done through limited incisions. The quality of the image primarily depends on the thoracoscope being used, the resolution of the display and the quality of the light source. The thoracoscope not only gives the surgeon an unrivalled opportunity to view the thoracic cavity closer than ever before, but also offers viewing angles not even possible by open surgery. The ability to focus in on details gives the surgeon an opportunity to carry out fine surgical tasks in otherwise difficult to reach areas.

Conventional thoracoscopes have been either 10mm or 5mm in diameter with either a 0^{o} or 30^{o} angulation [5,6].

However, the ever-increasing trend of smaller and more advanced technology has led to the development of needlescopic instruments and the use of high definition imaging [6]. Needlescopic instruments are usually either 2mm or 3mm in diameter and have developed in an attempt to reduce postoperative pain and scarring. They are rarely used in modern practice mainly due to several limitations including a reduction in visual fields, inadequate strength and the need to create a second port in order to obtain biopsies [7,8]. The feasibility of needlescopic VATS was demonstrated in a retrospective study. The study combined both a needlescopic and non-intubated method to surgically resect peripheral lung nodules from 46 patients [8]. They were able to demonstrate that needlescopic VATS was a safe alternative to the more traditional VATS for the diagnosis and management of peripheral pulmonary nodules [8,9]. However, eight patients in their study required extension of the original 3mm incision due to either a primary lung cancer (requiring a lobectomy), pleural adhesions or difficulty in resecting/locating the nodule [9].

In order to further improve viewing angles within the thoracic cavity and reduce torqueing of the scope at the incision site, companies have developed wide angled rigid thoracoscopes along with variable angle technology allowing a viewing angle anywhere between a 0^{o} and 120^{o} [5,6]. This along with the development of technologies which allow distal tip articulation (Endoeye Flex, Olympus) further increases viewing angles and gives unparalleled views of the whole thoracic cavity [10].

Despite the improvements in viewing angles and image quality the thoracoscope still remains tied down by cables and wires. This not only reduces the ability of the user to steer the device but also poses a risk of desterilizing the operative field and infection. The development of the next generation of thoracoscopes will mainly be focused on the wireless transmission of video signals in order to overcome these barriers [6]. Research groups have also explored the idea of using a remote camera attached to the chest wall, held in place and controlled by a magnetic anchoring guidance system (MAGS) [6,11,12]. MAGS instruments classically consist of an external magnet which steers an internal intracorporeal device which is normally a camera [6,11,12]. They come with the advantages of a large viewing angle, reduced fencing and greater functional space within the port incision [11]. However, there have been several problems reported with the use of these devices including: the fact that all the intracorporeal devices developed so far have not been wireless, device decoupling in obese patients and increased difficulty in cleaning the camera lens during intraoperative use [11]. These systems are likely to undergo a period of development and evolution in order to overcome some of these barriers.

Future instrument designs are also likely to focus on integrating the thoracoscope into the surgical instrument itself in order to further minimize instrument fencing and the number of surgical incisions required to successfully complete the procedure [6]. However, combining functionality in this way is likely to come with additional drawbacks such as an implicit increase in the instrument diameter requiring larger port incisions.

Development of 3D VATS

The main disadvantage of VATS procedures is the loss of depth perception and tactile feedback when compared to open procedures. This leads to an increase in cognitive load that compounds the inherent challenges in minimally invasive surgical procedures. This was confirmed in a study conducted by Dan et al, where EEG data was used to objectively calculate the cognitive load index in 17 patients [13]. Participants were split into two groups; one completed the VZ-Brace paper folding test using 2D video, whilst the other group used a 3D digital avatar with identical content. The results showed that the cognitive load index associated with the visual processing of the 2D video was higher than that of 3D virtual environment [13].

In an attempt to overcome some of these barriers associated with the traditional 2D VATS there has been adoption of three-dimensional imaging by using either specialized glasses or dedicated autostereoscopic displays. The advantages of these technologies lie in their ability to restore depth perception and thereby allowing improved grasping, suturing and dissection during surgery [6].

Current 3D VATS systems consist of passive polarising techniques which rely on polarization glasses in order to recreate a 3D image [14]. They depend heavily on the users positioning themselves accurately with respect to the screen in order to achieve optimal viewing. When 3D VATS was first introduced in the early 1990's, trials reported frequent adverse effects such as considerable mental fatigue [15]. However, this is thought to have been due to outdated endoscopic equipment with low resolution displays [16,17]. A more recent trial comparing the performances of 3D HD and 2D HD video systems whilst being used to perform complete thoracoscopic lobectomies (CTL) found no adverse effects such as nausea, vertigo or ocular fatigue. However, supporting staff did experience self-limiting headaches which lasted approximately 15-minute period, which was resolved by providing a second 2D HD display [16].

Other developments within the field of three dimensional thoracoscopy include the use of autostereoscopic glasses-free 3D displays such as those used in gaming devices (Nintendo DS) [14]. They overcome the barriers associated with traditional passive polarising systems in that they can be used by multiple individuals at a variety of different positions and distances from the screen without any degradation to the image quality [14].

Several studies have shown additional benefits of 3D VATS when compared to the traditional 2D VATS with respect to operative time, learning curve, accuracy, and error rate [16,18-22]. Additionally, there is a general subjective preference for 3D VATS regardless of any objective benefit, thought to be due to the reduction in cognitive workload that comes from improving image quality and restoring depth perception [23]. 3D VATS has seen a recent peak in interest that has shown promise from the initial trials investigating its effectiveness and has become a valuable, cost effective alternative to both robots assisted thoracic surgery (RTS) and 2D HD VATS [17,24]. Furthermore, a recent trial comparing 2D HD VATS to RTS for lung cancer surgery, showed no differences in the postoperative complication rates between the two approaches but a much higher cost per case for the RTS technique [24].

Image Guided Video Assisted Thoracic Surgery (iVATS)

Traditional techniques used to excise tumors and nodules within the lung rely on pre-operative CT/PET imaging as well as tactile feedback, followed by surgical resection of the lesion with a clear margin of normal lung tissue. This can be difficult especially with minimally invasive techniques such as VATS and as a result may lead to the removal of a larger proportion of the lung tissue than would have otherwise been required.

One method to overcome these issues to accurately identify small pulmonary nodules has been through the development and use of various imaging modalities. Examples of intraoperative techniques include ultrasonography,whereas pre-operative methods consist of hookwire insertion, micro coil insertion, use of dyes/liquid agents (lipidol/methylene blue /iodine) as well as bronchoscopy techniques to mark nodules with either dyes or fiducials [25]. These methods are primarily aimed at improving the success rate of identifying and excising small pulmonary nodules via a VATS approach. Each method has its own strengths and weaknesses which gives the surgeon an opportunity to choose the method which best suits the patients' needs [25].

Another approach has been through the development of hybrid theatres equipped with CT imaging allowing accurate, real-time localization of the tumor, permitting a more efficient and precise resection of the lesions [26]. The use of this approach has the added benefits of allowing the surgical team to conduct post-operative CT scans which can confirm the complete resection of the lesion [27]. Early clinical trials on image-guided video assisted thoracoscopic surgery have demonstrated the success of this approach at removing small lung nodules with complication rates comparable to the traditional VATS procedures [27]. However, despite the many advantages of this approach it requires a large multidisciplinary team involving technicians, interventional radiologists and dedicated nurses [27].

The emergence of iVATS has been due to the new application of existing technologies and has potentially created a paradigm shift in the surgical workflow within the field of thoracic surgery [26,27].

Intraoperative lymph node mapping

VATS Sublobar resections are associated with an increased rate of disease recurrence [27]. Consequently, Intraoperative localization of lymph nodes has become a subject of clinical significance, as it is a factor that can influence disease recurrence and long-term mortality [27]. The sentinel lymph node is the first draining lymph node from which neoplastic cells are likely to spread from a primary tumor. Identification and sampling of the sentinel lymph node for histological analysis allows assessment of the spread of disease in the remaining lymph nodes. This influences management and helps determine the extent of resection required: whether a sublobar resection (wedge resection or segmentectomy) will be sufficient or a more extensive lobectomy is required [27]. Both near infrared technology (NIR), as well as indocyanine green (ICG) which migrates from the primary tumor site to the sentinel lymph node, have been used in combination to provide real time assessment of lymph node status and guide surgical management [28]. One study conducted looked at the outcomes in 83 patients with stage IA non-small cell lung cancer (NSCLC) who underwent VATS segmentectomy with and without lymph node mapping using ICG [29]. In the study, 20 patients underwent ICG mapping and sentinel node biopsy (SNB) and 63 did not. The results showed that the accuracy of the SNB was 80%. They also found that in the SNB group there was no disease recurrence, however in the group without the SNB there was a local recurrence rate of 6.3%, but the difference between the two groups was not statistically different. They concluded that their study demonstrated that intraoperative mapping with ICG could potentially be useful in guiding VATS segmentectomies and that larger studies would be required to draw further conclusions [29]. Other smaller studies have also found similar results [30,31]. Another study developed and tested the use of NIR fluorescent quantum dots as lymphotropic optical probes on porcine models [28,32]. They were able to demonstrate that quantum dots could be used as an alternative to ICG for rapid real-time sentinel lymph node mapping in lung parenchyma [28,32].

Conclusion

Since the first VATS lobectomy in Italy in 1991, there have been massive improvements in technology and imaging systems leading to safer surgery and the ability to perform therapeutic operations on patients previously thought to be inoperable [33]. VATS has become a well-established technique that avoids many of the complications involved with open procedures both in terms of cost and safety. Innovations in technology such as the one discussed in this article have helped VATS develop into the gold standard treatment of many lung pathologies.

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