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Video-Assisted Thoracic Surgery Major Pulmonary Resections

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1. Introduction

Video-Assisted Thoracic major pulmonary resections (VMPR) such as lobectomy, pneumonectomy and segmentectomy are rarely performed procedures, but steadily growing in popularity. Less than 4% of all lobectomies performed in the United Kingdom (UK)[1] and less than 5% in the United States [1] and Europe [2] are performed this way. The surgeon's knack, personal preference, and convictions about what constitutes a proper cancer surgery played a role in this reluctance to take up VATS lobectomy [3-7]. The first published series of VATS lobectomy was that of Roviaro et al 1992 from Milan [8]. The technique was already practiced by the American thoracic surgeons and popularised by Kirby, Landreneau and McKenna [9-10], but apparently Roviaro beat them at publishing. Kirby et al (US) published their initial experience with 35 patients undergoing VATS lobectomy in 1993. They have been performing the procedure 2 years prior to publication. 1993 witnessed the publication of several initial experiences with the technique. William Walker presented 11 cases from Edinburgh [11], and Coosemans, Lerut et al from Belgium published their series of four lobectomies [12]. However; it was McKenna who popularised the technique worldwide since his first publication in 1994 followed by publication of the largest series thus far of 1100 cases in 2006 (standing at 2600 cases in 2011 - by personal communication) [1, 10].

The operation is suited for early lung cancer and benign disease, but worry about the oncological feasibility of resection was one of the major criticisms against it. There is enough experience and data around the world to answer the questions of safety and long survival rates. With the advent of High Definition monitors, safer stapling devices and surgical instruments specifically designed for minimal access chest surgery, the procedure is expected to be adopted by new generations of thoracic surgeons. More and more the procedure is getting less invasive, and the literature already includes single port VATS lobectomy [13]. Progress of miniaturising the procedure is attributable to a head surge of similar technology by our peer gastrointestinal surgeons.

[1] Page R, Keogh B. First National Thoracic database report 2008. Published by the Society for Cardiothoracic Surgery in Great Britain and Ireland. 2008.P52, http://www.scts.org/documents/PDF/ThoracicSurgeryReport2008.pdf (21 June 2011).

In addition to conventional video-assisted thoracoscopic surgery (VATS), robotic technology with the da Vinci System® has emerged over the past 10 years [14]. Robotic major pulmonary resections proved to be feasible and safe. It requires training of the entire operating room team. The upshot of robotic surgery is the intuitive hand motion that translates the surgeon's movements into scaled, filtered and seamless movements to the robot arms, the 3 dimensional high definition vision with up to X10 magnification and the endowrist instrumentation designed to simulate the dexterity of the human hand inside the chest. The drawbacks are the exorbitant initial cost, the fact that the surgeon works away from the patient, and the loss of tactile feedback from the instruments. Its advantage over VATS is unproven; a longer follow-up period and randomized controlled trials are necessary to evaluate a potential benefit over conventional VATS approach.

VATS lobectomy programme is usually met by scepticism and resistance from the establishment, mainly due to financial and time constraints to meet cancer waiting times. There are problems of training and clinical governance issues but these are not insurmountable. Proper training and acquisition of the necessary skills is a prerequisite to starting such a programme. Safety of the technique is well established, and adherence to proper indications is essential. The technique is not recommended for central lesions, which should be removed by open thoracotomy.

2. Definitions

VATS major Pulmonary Resections (VMPR) relate to lobectomy, pneumonectomy, bilobectomy, segmentectomy and combinations thereof. This excludes procedures such as VATS wedge resection and lung biopsy. Controversy surrounds the definition of what constitutes minimal access surgery, but now there is wide acceptance of the following definition:

- Surgeon operating via monitor, and not looking directly through the wound.
- Strictly no rib spreading.
- Anatomical individual structure dissection, as opposed to simultaneous stapling of structures.
- Less than 5 ports, the aggregate length of which is <10cm (with the advent of 3mm ports this criterion is not mandatory).

3. Best practice evidence

There are three established randomised controlled trials (RCT) comparing VATS lobectomy to open thoracotomy. In 1995 Kirby et al randomized 61 patients with clinical stage I NSCLC to undergo lobectomy by VATS (31patients) or muscle-sparing thoracotomy (30 patients) [15]. The VATS were performed without rib spreading. They concluded that VATS did not increase risks, but did not state superiority of VATS over mini-thoracotomy in terms of length of stay, drain dwell time and postoperative pain. The study is criticised for not comparing VATS to full posterolateral thoracotomy.

The second RCT is the only one examining survival differences between VATS and open lobectomy published by a Japanese group, Sugi et al in 2000 [16]. They randomised 100 patients with clinical stage Ia lung cancer to VATS (48 patients) or open (52 patients) lobectomy and mediastinal lymph node dissection. They concluded no significant differences in the recurrence or survival rates. The overall 5 years survival rates after surgery were 85% and 90% in the open and VATS groups, respectively.

The third RCT comes from Edinburgh, and was published in 2001 by Craig, Walker et al [17]. It addressed the body immune responses to trauma, randomising 25 patients to open (16 patients) or VATS lobectomy (19 patients). Acute phase indicators were analyzed in patients undergoing surgery for suspected lung cancer. They concluded that VATS lobectomy was associated with less traumatic insult to the patient, and consequently reduced peri-operative changes in acute phase responses. This finding may have implications for peri-operative tumour immuno-surveillance in lung cancer patients.

There has been a number of published case-series, and the most impressive and the largest worldwide is that of McKenna et al [1]. Safety of the technique was proven beyond doubt to be at least equal to open thoracotomy, but benefits in less postoperative pain, shorter hospital stay and quicker recovery were now well established. Walker et al (2003) published long term survival results of VATS versus open thoracotomy [18]. The available evidence suggests that VATS lobectomy for clinical Stage I and II NSCLC is a technically safe procedure which is associated with long-term survival and recurrence outcomes that are at least equivalent to those provided by open thoracotomy.

4. Indications

VMPR is suitable for benign and malignant disease both with intension to cure or prolong the disease free interval. The following is a list of some of the current indications, but it keeps growing:

a. Benign:
   1. Hamartomas
   2. Solitary fibrous tumours
   3. Teratomas
   4. Fibromas / lipomas / leiomyomas
   5. Sclerosing haemangiomas
   6. MALToma (Mucosa associated Lymphoid tumours)
   7. Lung sequestration
   8. A-V malformations leading to haemoptysis
b. Malignant:
   1. Non Small Cell Lung Cancer stage cT1-2 N0-1 M0
   2. Small Cell Lung Cancer (contained disease)
   3. Carcinoid tumours
   4. Solitary or multiple secondaries within one lobe (usual rules apply: control of primary site, enough residual pulmonary reserve, absence of extra-thoracic metastases, and fitness for general anaesthetic).

The distribution of histological findings in our series of 156 patients considered for VATS resection is shown in Table 1.

All presumed lung cancer cases should be discussed in a multidisciplinary meeting. VMPR is designed for early lung cancer, and should be considered as first choice for T1-2, N0-1, M0 lesion on PET/CT. Tumours larger than 5-6 cm across, and central tumours are better removed by open thoracotomy. Resection of Non Small Cell Lung Cancer in the absence of mediastinal nodes is performed with a curative intent, an axiom supported by the international literature. The controversy arises in operable early cancer in the presence of a histologically proven single station mediastinal node (cT1-3, N2). The current best practice evidence supported by the S9900 trial follow up published in 2010 continues to show that the best treatment for N2 resectable lung cancer would be induction chemotherapy followed by surgery (evidence level 1b) [19]. Multizonal lung cancer is thought to be a systemic disease beyond cure by surgery alone, and is best treated by chemo-radiotherapy. Albain et al (2009) have shown that lobectomy will add little to Chemo-radiotherapy for patients with stage IIIa (N2) non-small-cell lung cancer, at the expense of higher mortality [20].

<table>
<tr><td rowspan="4">Malignant
142</td><td>Lung cancer – NSCLC
Subtypes:
Adenocarcinoma 86 (55.1%)
Squamous Carcinoma 24 (15.4%)
Adeno-squamous carcinoma 4 (2.6%)
Broncheoloalveolar 4 (2.6%)
Large cell 3 (1.9%)
Other 6 (3.8%)</td><td>127
(81.3%)</td></tr>
<tr><td>Lung cancer – Small Cell</td><td>3
(1.9%)</td></tr>
<tr><td>Carcinoid tumour
Typical 3
Atypical 3</td><td>6
(3.8%)</td></tr>
<tr><td>Lung cancer – metastatic
Breast 1
Kidney 1
Colon 3
Endometrium 1</td><td>6
(3.8%)</td></tr>
<tr><td>Benign
14</td><td>Inflammatory mass 4
TB granuloma 2
Hamartoma 3
Aspergilloma 1
Benign cyst 1
Other 3</td><td>14
(8.9%)</td></tr>
</table>

Table 1. Histological types of surgically removed 156 specimens suitable for VATS resection.

5. Contraindications

1. Central tumours. Interpretation of the CT scan must establish clearance to apply stapling devices before embarking on VATS pneumonectomy.
2. Large tumours possibly >5-6 cm, as these will require large incision and rib spreading for retrieval. The surgical specimen should not be divided in pieces to improve retrieval, as histological details or limits of invasions can be lost.
3. CT evidence of clear invasion of central vascular structures by tumour or lymph nodes. Very high experience in VMPR is required to deal with vascular invasion.

VATS pneumonectomy was proven to be feasible and safe [21]. Tumours crossing the fissure from one lobe to the other could either be dealt with by lobectomy and wedge of the neighbouring lobe, or pneumonectomy according to the side. The presence of a thick major fissure is also no longer a contraindication, as the technique of fissure-last dissection is widely practiced [22, 23]. Obese patients with BMI>30 could pose a challenge as the chest wall thickness might be greater that the port length. By the same token, these are the very same patients who would benefit maximally from VATS procedure, as their postoperative rehabilitation is much better compared to open thoracotomy.

As experience with this procedure increases more challenges are taken up by thoracic surgeons. VMPR used to be contraindicated for redo procedure after previous thoracotomy, or cardiac procedure that has breached the pleura. This is not the case anymore, and more surgeons are venturing into the realm of redo surgery by VATS. New indications are being explored for VMPR as the surgeons become more experienced and daring. Currently surgeons are attempting chest wall resections, extrapleural pneumonectomy for mesothelioma and sleeve resections by VATS [24-26].

6. Preoperative investigations

Preoperative investigations should target the following areas:

a. The patient's general fitness for undergoing a 3 hours operation under general anaesthesia.
b. Residual pulmonary reserve after lung resection.
c. Feasibility of VATS resection and extent of resection.
d. Risk assessment and estimation of life quality after surgery.

The following is not an exhaustive list of investigations and should be individually tailored to the patient:

- Pulmonary function tests (lung capacity FEV1, FVC, and gas transfer TLCO)
- Calculated predicted postoperative FEV1 ($PPOFEV_1$) expressed as % predicted
- Calculated predicted postoperative T_{LCO} ($PPOT_{LCO}$) expressed as % predicted
- Fresh CT chest and abdomen, within 4-6 weeks of operation.
- Fusion PET/CT full body within 4 weeks of operation.
- CT/MRI brain to exclude the 10% brain metastases at time of presentation (particularly adenocarcinoma).
- Flexible bronchoscopy possibly performed by the chest physician for histological diagnosis.
- In selected cases CT-guided needle aspiration biopsy should be considered. If this was turned down by the radiologists then a VATS wedge resection and frozen section should be planned. Patients with previously treated extra-thoracic adenocarcinoma pose a special challenge, as frozen section might not be able to determine the original mother organ of adenocarcinoma cells obtained at operation. Currently there is no reasonably quick method of staining for TTF1 marker which is almost pathognomonic of primary lung adenocarcinoma.
- N2 disease suggested by PET/CT should be confirmed histologically by mediastinoscopy, EBUS, EUS, TEMLA (Trans-cervical Extended Mediastinal Lymph Adenectomy) or VATS nodal dissection. Confirmed single station N2 disease should receive neoadjuvant chemotherapy before consideration of VMPR.

- Other studies might be necessary to decide on fitness of patient, such as exercise tolerance test, 6 minute walk test, Shuttle test, quantitative V/Q scan and echocardiography.

7. Technical aspects

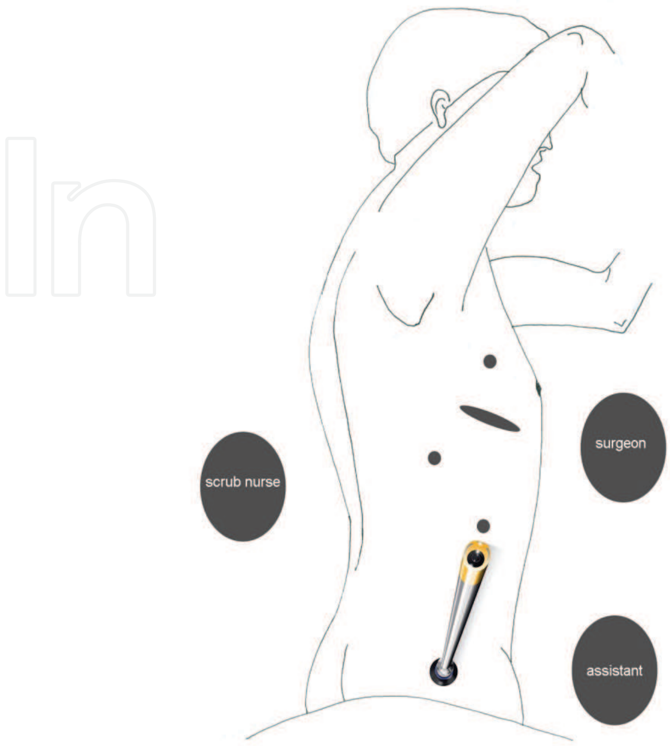
7.1 General considerations

The patient should be consented for VMPR by the highest authority, usually the consultant surgeon who will personally perform the procedure. The side of operation must be visibly marked on the patient before going to theatre. The CT scans should be available in theatre for reference, and the side and site of lobe to be removed should be confirmed by the operating team before starting. Prior cross matching of blood is not necessary, but this depends on how quickly blood could be cross matched in case of vascular injury. Under general anaesthesia the operation is usually started by rigid and/or flexible bronchoscopy in the anaesthetic room to ascertain operability and exclude obvious contraindications. The anaesthetist then slips in a double lumen endotracheal tube or bronchial blockers and a single lumen tube, to establish single lung ventilation. The patient is then positioned on the operating table, on the lateral side, operative side up, as for a standard thoracotomy. Breaking the operative table at the torso, or elevating a bridge under the chest opens the intercostal spaces. Early isolation of the lung by the anaesthetist at this stage pays dividend when complete collapse of the lung is welcomed by the operating surgeon. A central venous access and arterial invasive monitoring are not mandatory and are not routinely practiced at the author's institution. After draping the patient, the port sites are chosen and operation started. Co2 insufflation is completely unnecessary as it does not add space and can be life threatening. High intrathoracic pressures can lead to mediastinal shift and cardiac arrest. Space could be at a premium in badly emphysematous lungs due to trapped air, despite good lung isolation by the anaesthetist. Sometimes deliberate digging of holes in the target lobe using diathermy, might improve lung collapse and allow more room for operating. VMPR is usually performed via three port sites, but more minimisation of the technique is making it possible to work through a single port (uniportal approach) [13]. The principle of triangulation of ports is important to observe in our institution, and fencing (scissoring) of instruments is to be avoided. The use of a 0° scope gives a good image but is slightly limited, and might necessitate the camera to be moved from one port to the other. Certainly the vision could be improved by using a 30° scope, but the camera operator should be aware of standardising the orientation of the scope over the camera. If this orientation is not adhered to anatomical disillusion can easily occur, and identification of structures can be erroneous. Anatomical disorientation usually does not occur with the 0° scope, and bendable 0° scopes will probably go a long way. The surgeon, assistant, anaesthetist and scrub nurse should carefully rehearse beforehand their roles in the event of a major uncontrollable vascular injury requiring immediate thoracotomy.

7.2 Different surgical approaches

There are two approaches to VMPR, based on where the surgeon stands in relation to the patient. Each approach has its advantages and disadvantages:

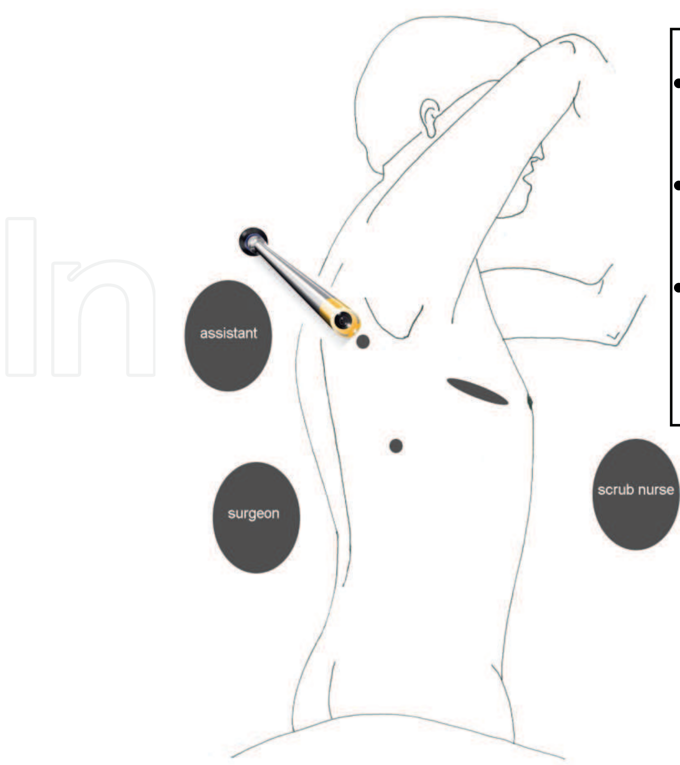
1. The anterior approach: championed by R. McKenna, Cedars Sinai Medical Centre, Los Angeles, California.



<u>The anterior approach:</u>

- **Surgeon stands at the front of the patient, with his assistant (camera operator) to his left on the same side.**
- **4 ports are fashioned, the utility port 5-6 cm is fashioned low at the 5^{th} or 6^{th} space.**
- **30° scope.**
- **Direct approach over the hilum.**
- **Less operative time.**

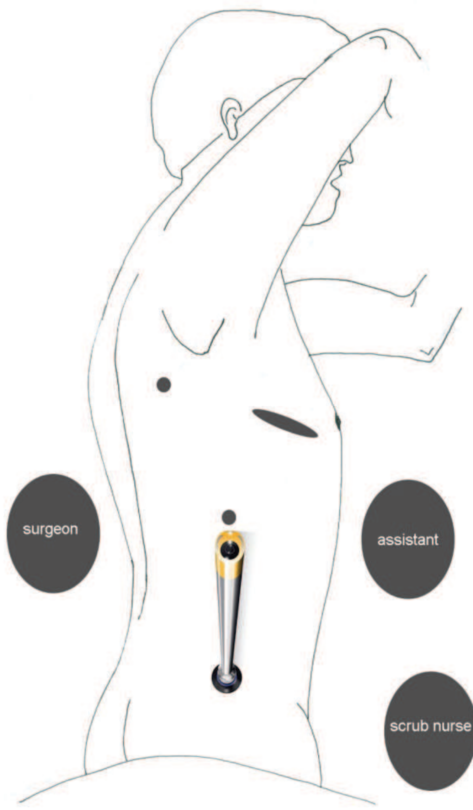
2. The posterior approach (fissure oriented approach), preached by W Walker, Edinburgh Royal Infirmary - UK.



<u>The posterior approach:</u>

- Surgeon stands at the back of the patient, assistant to the left, same side (camera operator).
- 3 ports and the utility port is 4-5 cm at the widest space anteriorly (5^{th}, 6^{th}, or 7^{th}).
- 0° scope introduced from the back top port in line with the axis of the major fissure. Camera is moved from one port to the other.

3. The Southampton approach, practiced by the author, Southampton General Hospital – UK.



The Southampton approach:

- Surgeon stands at the back of the patient, opposite assistant (camera operator – helper - retractor).
- 2 ports + the utility port; 3-4 cm at the widest space anteriorly (4th, 5th).
- 30° scope introduced from the inferior port in line with the axis of the hilum, and stays there.

Whereas the anterior approach is the widely used internationally, the posterior approach is the one commonly taught in the UK. The Southampton approach is an adaptation of the posterior approach. The anterior approach is the quickest, gives a better view of the anterior hilum and apex, but poor view to the back of the hilum. The view is foreshortened when stapling the fissures and as a result the tip end of the stapling device is not visible, requiring a leap of faith to staple the fissures. Also the view is not optimal for nodal dissection, especially the subcarinal space. Anatomy is viewed from an unfamiliar angle, and the surgeon's brain requires retraining to appreciate structures from different perspective. In case of conversion to thoracotomy, the surgeon has to swap sides, or extend the utility port into an anterior thoracotomy and stay anterior to the patient.

The posterior approach is oriented around the axis of the oblique (major) fissure, and gives also a good view, except for the superior vein. To get a right angle approach of the stapling device to the superior vein, the camera has to swap ports. Dissection usually starts at the centre of the fissure, and the advantage of this approach is lost when the fissure is thick, or does not peel easily.

The Southampton approach keeps the 30° camera at the inferior port, in line with the hilar axis, thus giving good views anterior as well as posterior to the hilum. The anatomical view is exactly as open thoracotomy, at all times. Good access to harvest all groups of nodes when performing Systematic Nodal Dissection (SND), however; a utility port below the 5th space makes access to stations 2-4 at the apex difficult. As lung retraction is essential, it take longer than other approaches.

7.3 Port site fashioning

The ports must be carefully chosen and designed, as this could influence the ease of surgical accessibility. The technique of microthoracotomy is commonly used [Figure 1], whereby the use of a long forceps blades are used to retract the incision, and the muscles over the superior border of the rib are diathermised down to the pleural space. Care must be taken not to diathermise in midspace, as this might lead to nerve injury, and short and long term neuropathic pain would ensue [Figure 2].

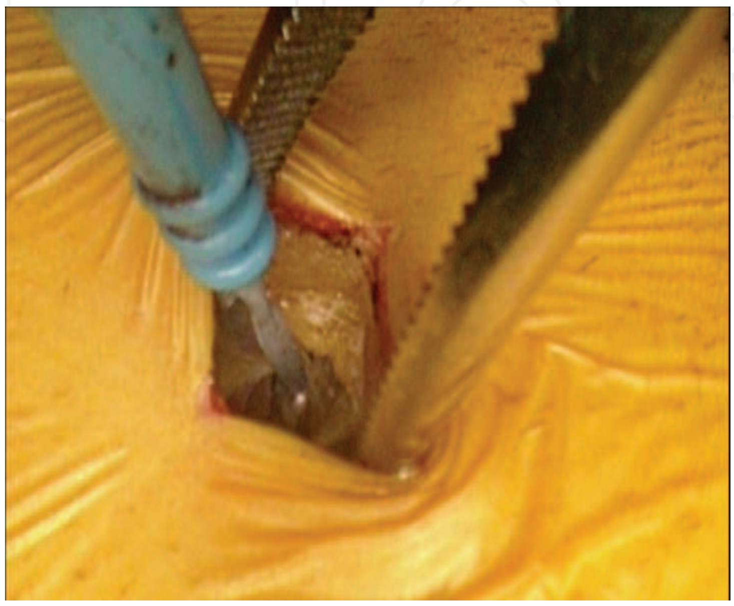


Fig. 1. Microthoracotomy by diathermy 10mm wide.

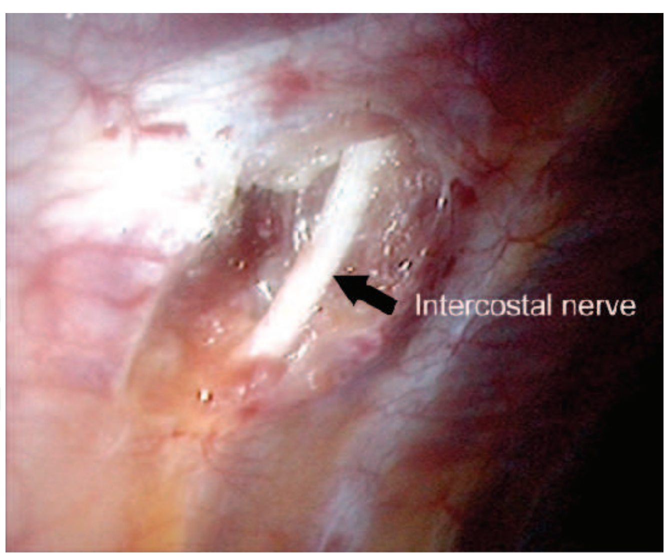


Fig. 2. Midspace diathermy resulting in nerve damage.

We usually start the procedure by fashioning the anterior utility port over the (widest) 4^{th}-5^{th} space, centred over the mid-axillary line. There is advantage in fashioning the utility port first, as this enables finger palpation of the primary tumour site, and early usage of conventional thoracic instruments. The port would be used at the end to retrieve the specimen out of the chest, so it is sensible to open the full 3-4 cm right at the beginning.

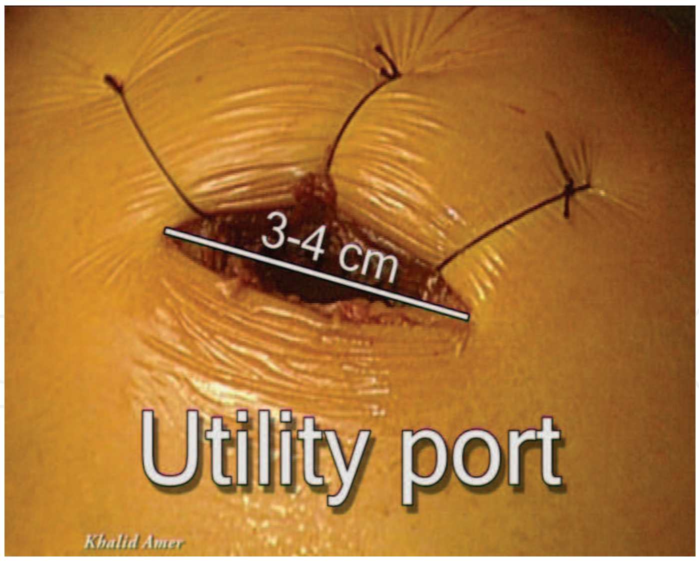


Fig. 3. Utility port kept open by stay sutures.

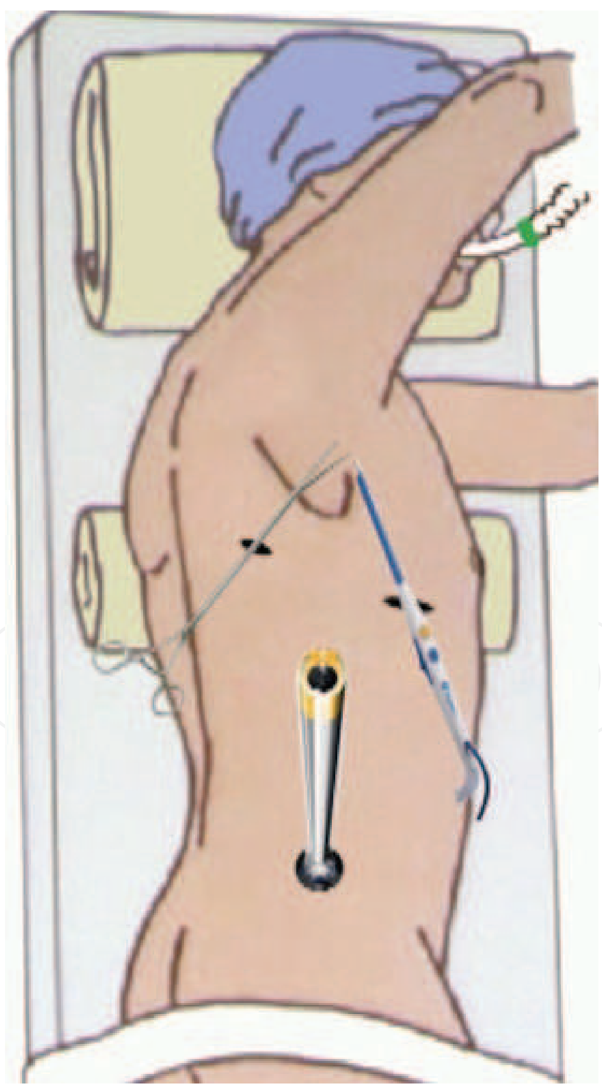
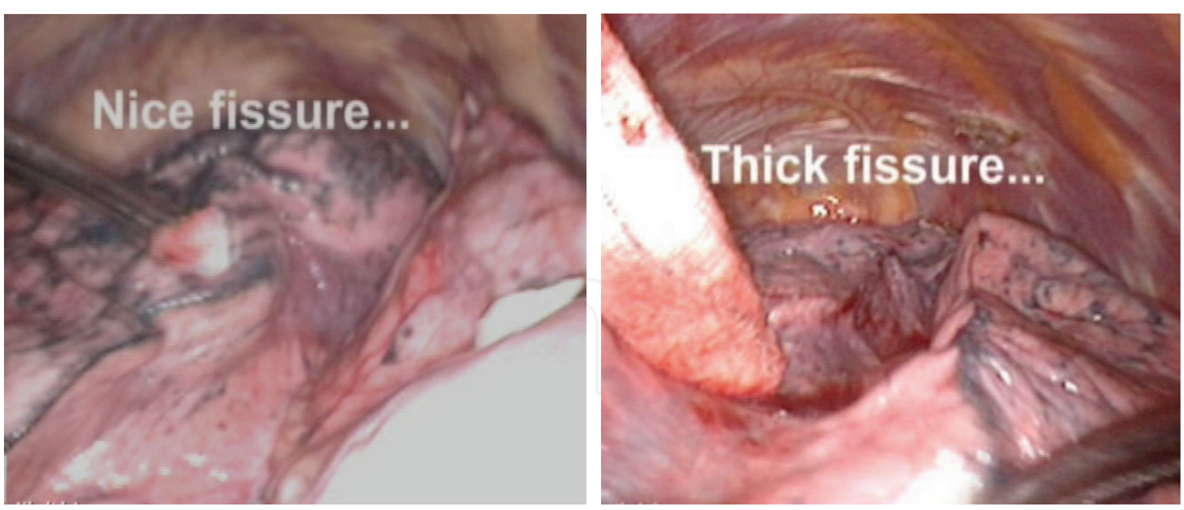


Fig. 4. Fashioning ports for VMPR: the inferior port is dedicated to the camera.

Beyond the skin incision the fibres of latissimus muscles are split in the direction of its fibres, rather than cut. The rib is exposed using the diathermy spatula and the upper border of the rib is cleared of muscle attachment, until the pleura is entered. The port is then kept open at all times by stay silk sutures taken deep to the muscles and over the skin [Figure 3]. This ensures a dry and self retracted port, suitable for accommodating more than one instrument at any given time. Similar silk sutures could be used to keep the other operative ports open, so that instruments could be passed directly without the need for a plastic or metal port. However; the use of such port is recommended for the camera, as this insures the lens will be dry for a longer period. Port site bleeding can be a problem, and may require too frequent cleaning of the camera lens, therefore it is best to construct the camera port site carefully, bloodlessly and first time. The 30° scope is then inserted, and a quick scout for pleural deposits is performed. Having excluded secondary deposits, attention is then paid to creating the inferior port. This is fashioned in line with the hilar axis, over the highest most point in the dome of the diaphragm. The camera scope is then transferred to the inferior port, where it remains for the rest of the operation. The posterior port is fashioned over the auscultatory triangle, one or two finger's breadth from the medial border of the scapula [figure 4].

7.4 The fissures

We define a nice fissure as a fissure that goes all the way from the surface of the lung down to the pulmonary artery. The perivascular sleeve of the artery is clearly visible throughout the length of the fissure; there are no crossing veins and no lymph nodes stuck to the artery. A nice fissure peels easily when two kissing peanuts are dissecting in opposite directions (Bill Walker manoeuvre) [27]. A thick fissure on the other hand goes a short distance from the lung surface, the artery is not seen and the fissure does not peel easily. It would be futile to persevere with dissecting such a fissure, as good time would be wasted, and major bleeding might result in conversion [Figure 5a & 5b]. In such cases the fissure-last technique is adopted [22, 23].



(a) (b)

Fig. 5. (a) Nice major fissure, and (b) Thick or incomplete fissure.

7.5 VATS lobectomy

Right upper lobectomy:

After fashioning the triangulated three ports, the pleural cavity is scrutinised for secondary deposits that might contraindicate proceeding with the operation. The index finger is then introduced via the utility port, to palpate the lesion, helped by a peanut on a Robert to push the lung towards the palpating finger. Sometimes the tumour puckers the surface of the lung and confirmation of the lesion *and* target lobe is obvious. If the target lobe could not be identified at operation, we strongly recommend conversion to open thoracotomy (even if the CT clearly locates the lesion and the lobe!) [Figure 6].

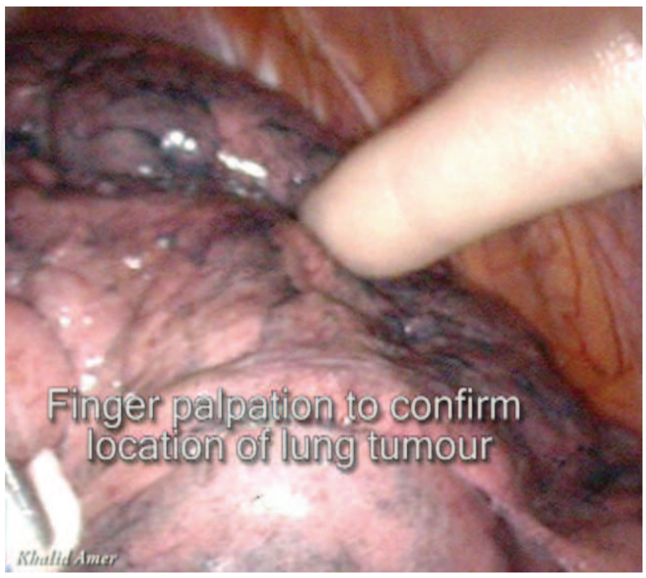


Fig. 6. Early visual and tactile identification of the lesion within the target lobe.

The operation is started at a simple and constant step, and the level of complexity is increased as the operation proceeds. The inferior pulmonary ligament is released, the inferior vein confirmed to arise separately from the main pulmonary vein (sometimes it joins the superior vein in a single trunk as a delayed origin). The anterior hilar pleura is opened lateral to the phrenic nerve and the veins from middle and upper lobe are confirmed. The upper lobe vein is then skeletonised and secured using a stapling device [Figure 7]. It is to be remembered that taking the middle lobe vein by mistake will lead to infarction of the middle lobe later, so ample time must be spent to ascertain the venous anatomy.

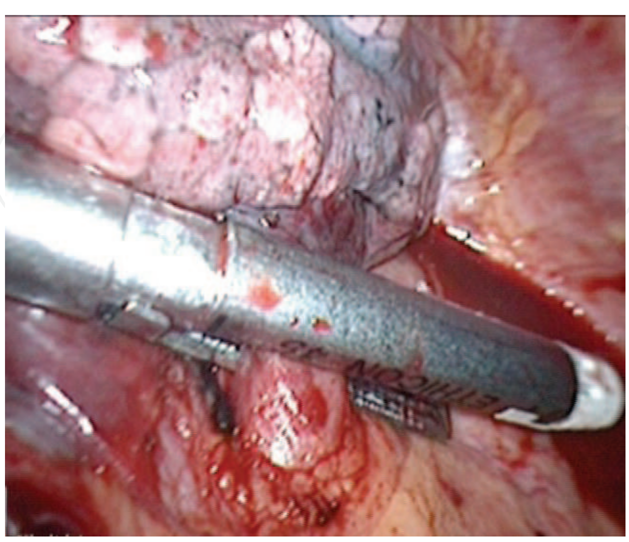


Fig. 7. Stapling the upper lobe vein (part of the superior pulmonary vein) using a 3 row stapling device.

This manoeuvre exposes the pulmonary artery branches. An anterior pulmonary artery branch might lend itself readily to stapling at this stage, but it is usually difficult to secure the Truncus arteriosus (which usually divides into 2 branches). At this stage attention is drawn to the bronchus. The lung is retracted anteriorly and the pleura over the back of the hilum is opened from inferior ligament to Azygos vein. The right main bronchus is exposed, and its division into upper lobe and bronchus intermedius is displayed. Blind dissection around the back of bronchus has to take into account that the truncus artery lies closely behind the bronchus in a blind spot. Opening of curved devices behind the bronchus has to be very gentle, until the tip of the instrument is seen emerging from the other side of the bronchus. The bronchus is then encircled with a vascular sloop and a (green) stapling device is placed perpendicular to the longitudinal axis of the upper lobe bronchus, flush with bifurcation. No matter how clear the anatomy is, the stapling device should not be fired before test inflating the lung, to ensure that the remaining lobes are not obstructed or stapled by mistake. Only then the bronchus is transacted. This manoeuvre exposes the posterior segmental artery and the truncus. Both of which should be skeletonised and secured. Different methods have been used to secure large vessels, ranging from simple endoscopic tying, stapling, clipping or using energy devices, such as ultrasonic or bipolar devices. The choice depends on the diameter of the vessel and what the operator feels comfortable with. If the anterior arterial branch was not encountered earlier on, it might be visible after securing the posterior segmental artery from a posterior view. The lobe by now should be attached to the rest of the lung by the fissures, which are stapled off. If the horizontal fissure is not well developed, incomplete or absent (25% of cases), it might be helpful at the beginning of the operation to staple the lung at an imaginary line between the upper and middle lobes, where the fissure is thought to have existed. This is done at the medial anterior border of the lung, to mark the spot for joining later from a posterior approach, when all structures had been secured. The free lobe is then retrieved in a sturdy Polythene bag. Systematic nodal dissection is performed if it was deferred to this stage.

Right middle lobectomy:

Same as above, but the sequence would be; inferior ligament followed by middle lobe vein, middle lobe bronchus before identifying and tackling the middle lobe artery. All three structures are approached anterior to the hilum. Beware of the delayed origin of the middle lobe bronchus arising from the lower lobe bronchus, as this might be included in a stapling device aimed at freeing the medial part of the oblique (major) fissure.

Right lower lobe:

This could be the trickiest to remove especially if dissection is retrograde, and the fissures were thick. Nevertheless; dissection is started by releasing the inferior ligament and confirming a normal venous drainage of all lobes. The inferior vein is taken next. This exposes the lower lobe bronchus, which must be carefully dissected proximally to satisfy one's self with the take-off of the middle lobe bronchus. Again the stapling device across the bronchus should not be fired unless the middle lobe is seen to inflate fully and easily. It should be resisted to staple the lower lobe bronchus obliquely as a matter of convenience. Enough time must be paid to make sure that the lower lobe bronchus is stapled perpendicular to the longitudinal axis of the bronchus. Oblique stapling could lead to stenosis of the origin of the middle lobe bronchus [figure 8]. It should be remembered that the wall of the bronchus at the stapling line is stiff, and gradually widens from the site of the staples to the full diameter of the bronchus, in a funnel shape profile that practically narrows the lumen by further 2-3 mm. This is usually overlooked, and leads to unexpected stenosis in the postoperative period. An hour-glass anatomy of the origin of the middle lobe leads to twisting of the bronchus as the remaining lobes inflate, and that might lead to complete dynamic obstruction in the postoperative period. The postoperative chest x-ray would reveal a collapsed middle lobe, which fails to re-inflate with aggressive physiotherapy. The middle lobe artery take-off has to be identified before taking the common basal trunk. There could be one trunk dividing into common basal and apical lower arteries, or the apical branch might require separate stapling. Also be wary of a posterior segmental artery to the upper lobe arising from the apical lower branch (delayed branching).

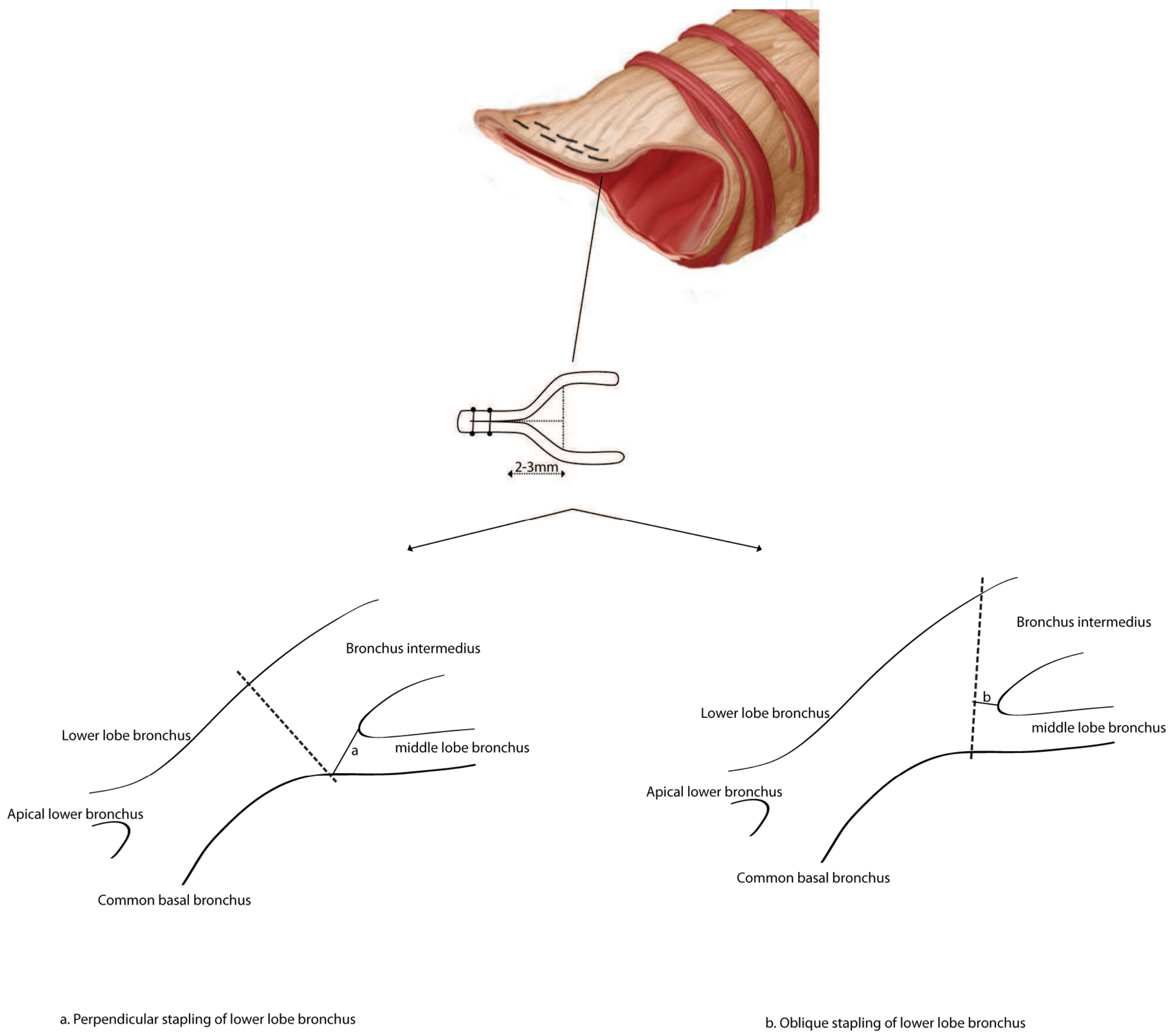


Fig. 8. (a) Perpendicular transverse stapling of lower lobe bronchus resulting in a normal patent orifice of the middle lobe bronchus. (b) Narrowed orifice of middle lobe bronchus as a result of oblique stapling.

Left upper lobectomy:

The sequence of dissection is more or less similar to the right side. Dissection is started with the inferior ligament, and venous anatomy identified. The superior vein is taken either as a single trunk or for ease of dissection taking the lingular vein first might simplify the dissection. It is recommended to keep the vascular stumps as short as practicable, to avoid clot formation and embolisation. The bronchus is exposed next. It must be further cleared to identify the secondary carina, and subsequently the upper lobe bronchus. Make sure you include the lingular bronchus in the sloop. Again before firing the stapling gun, the lung is inflated to ensure patency of the lower lobe bronchus. Doing this as a matter of routine ensures that no mistake is made, and the left main bronchus is not mistaken for the upper lobe bronchus (it can happen!) [23]. At this stage the lingular arteries (1 or 2) would have lend themselves amenable to stapling. Next the Truncus artery is taken, and the fissure is tackled as before.

Left lower lobectomy:

This is the easiest lobe to remove, and perhaps a good one to start training with. After releasing the inferior ligament the inferior vein is stapled. This exposes the bronchus, which is dissected proximally until the bifurcation is identified and a stapling device is placed across. The lung is inflated and the bronchus transected. Further retrograde dissection identifies the branches of the pulmonary artery, and the arrangement verified. Again there could be one trunk, or two separate branches; common basal and apical lower arteries. These are taken and the fissure completed by stapling, peeling, diathermy or ultrasonic device.

From the previous description, fissure-last technique is the default technique to start with, but in our experience a nice fissure should be taken advantage of. The sequence of dissection could be modified to start with the fissure and deal with the arterial branches first. Previously it was claimed that early venous stapling leads to engorgement of the lung and that might impede dissection. In our experience, it does not make any difference what so ever. In fact it serves the oncological principle of preventing the dissemination of malignant cells resulting from handling the tumour or the target lobe.

VATS segmentectomy:

The same principles apply for removing a segment of a lobe. It is to be remembered that pulmonary arteries are end arteries, i.e. ligation of an artery by mistake leads to infarction of part of the lung. There is quite a lot of shared venous flow, and ligation of veins (apart from the central final tributaries, such as the middle lobe vein) does not lead to infarction. The most important structures to secure are the segmental bronchus and the artery. The vein could be ignored or stapled as part of stapling the fissure. If the fissures are permitting then dissection is started at the centre of the fissure. The arterial pattern is identified and the segmental artery is secured. This usually exposes the bronchus, where it is identified and cross clamped, using a Robert forceps. A fine butterfly needle is connected to a giving-set plastic tube and air is injected into the segmental bronchus, using a bladder syringe, distal to the clamp. This will inflate the anatomical confines of the segment, demarcating the intersegmental plane [28]. Alternatively, the anaesthetist could inflate the upper lung while the segmental bronchus is clamped, and the segment will stay deflated. The first method is preferred by the author, as it keeps the lung deflated and allows space to operate. However; pressurised air from an Oxygen cylinder should not be used, as the danger from massive air embolisation is high [23]. The lung parenchyma is then stapled off the rest of the lung, guided by the intersegmental demarcation.

VATS pneumonectomy:

Very rarely lung cancer allows the performance of a VATS pneumonectomy. The reason for that is by the very same nature of the central lesion that dictates pneumonectomy, makes it unsuitable for VATS technique. Clearance of the 3 major structures; bronchus, artery and vein is usually not possible, and this judgement could be made on scrutinising the CT scan. However; sometime a central tumour at the bifurcation of the secondary carina, crossing the fissure, and resectable only by pneumonectomy, might have sufficient clearance on the main bronchus, artery and vein (possibly intrapericardially). These cases are rare but resectable by VATS [21, 23]. The utility port has to be slightly bigger, but no rib spreading is required. Sturdy Polythene bag is indispensible. Generally speaking central tumours are best dealt with by open operation. The advent of the articulating 3 row stapling devices has given a great boost to the confidence of stapling major vessels such as the main pulmonary artery, which has a thinner wall than the main pulmonary vein.

Retrieval of surgical specimens:

The initial case-series of VATS lobectomy reported port-site seedling, and recommended retrieval within a Polythene bag. It has become our standard practice to exteriorise the resected lobe within a polythene bag for that matter. However, McKenna et al suggested the use of the bag does not completely eliminate this risk [1]. We encountered a single port-site seedling in a series of 200 cases (0.5%) [figure 9]. The patient had a previously resected colonic adenocarcinoma. The adenocarcinoma within the lobe was retrieved in a bag, but none of the nodes. Incidentally all nodes were free from metastases. Port-site metastasis could not be explained merely by mechanical seedling in our case, and humoral spread had to be presumed.

Fig. 9. Port-site seedling 3 months after VATS left upper lobectomy.

Closure:

After retrieval of the specimen and securing haemostasis we routinely test the bronchial stump under water and partial inflation up to 20-30 mm Hg. An extra pleural catheter is inserted under videoscopic guidance, for continuous infusion postoperative analgesia. The chest is closed over a single chest drain, 24-28F with an extra basal hole. We use the camera port for the drain site, and close the utility and posterior ports in layers, after observing the lung expanding satisfactorily. Care must be exercised to close the utility port in proper layers, as mass closure might lead to unsightly ledge or step if the skin is fixed to the deeper tissues. The final resulting scars of the ports are usually pleasing to the patient [Figure 10]

Fig. 10. The cosmetic scars of VATS lobectomy.

8. Surgical operative time

The average time of performing VATS lobectomy + SND is 03:00 hours. Table 2 shows the mean operative time in 133 completed procedures in our unit. There was no statistical difference between the lobes.

Lobe removed	Frequency	Mean operative time (min)	Standard Deviation
RUL	44	232	51.7
RML	9	186	34.3
RLL	23	227	63.5
LUL	35	218	65.5
LLL	18	203	52.7
Right Lower Bilobectomy	2	250	56.1
Pneumonectomy	1	220	
Apical RLL Segmentectomy	1	125	

Legend:
RUL=Right Upper Lobectomy, RML= Right Middle Lobectomy, RLL= Right Lower Lobectomy, LUL= Left Upper Lobectomy, LLL= Left Lower Lobectomy,

Table 2. Completed 133 VATS major pulmonary resections and mean operative times (excluding node dissection time. Not significant by ANOVA test p=0.15)

9. Complications

Table 3 shows the complications encountered in our unit, which are consistent with previously published complications [29]. 62 patients (40%) had no complications during their short hospital stay, whereas 94 patients (60%) had at least one operative or post operative event, including those picked at clinic follow up visits. Air leak remains the most critical factor in postoperative rehabilitation and prolonged LOS [30]. This might out-balance the expenditure, and tip the cost-effectiveness away from VATS lobectomy. A lung sealant could be used to reduce intercostal tube dwell time, and subsequently LOS. Adopting the fissure-last technique has resulted in significant reduction in air leak, as the fissures are nearly always stapled. However, the combination of ferocious air leak and a collapsed lung on the chest x-ray is an indication for re-exploration of the leak site. A Bronchopleural fistula is usually the culprit. Generally speaking there are high post operative incidences when starting a VATS lobectomy programme, but these include the trivia and the serious. The LOS in our series stayed at 4±4 days (range 1-25), and 45% of the patients were discharged on or before the third postoperative day [23].

Bronchial complications:

The technique of fissure-last lobectomy necessitates absolute mastery of the anatomical relations inside the chest, in different angles and perspectives. This can be very tricky at times especially on performing right lower lobectomy. Early in our experience we were tricked twice into removing the middle lobe as a result of anatomical disorientation. The first time the bronchus intermedius was mistaken for the lower lobe bronchus, and in the second instance stapling of the medial part of the oblique fissure failed to identify the delayed origin of the middle lobe bronchus within it. The middle lobe had to be removed in both cases without additional morbidity.
In another case the left main bronchus was mistaken for the left upper lobe bronchus, and thoracotomy was performed to re-implant the lower lobe bronchus into the left main

bronchus. Starting with systematic nodal dissection may have predisposed to this complication, as dissection around the subcarinal area skeletonised the left main bronchus, making it easier than the usual to encircle it from an anterior approach. This patient was discharged 5 days later and had no complications on follow up clinic visits. No matter how clear the bronchial anatomy is, the bronchus should never be stapled before inflating the lung and ensuring patency of other lobes.

Bronchopleural fistula (BPF) occurred in two patients, who were treated aggressively by returning to theatre and exploring the air leak via the same port-sites. In both patients a small hole was found proximal to the stapling line, possibly caused by the stapling device. Videoscopic stitching using Vicryl 2/0 controlled the leak and the rest of their hospital stay was uncomplicated. Similar complication was reported before [31]. Two further patients developed ferocious air leak and severe surgical emphysema on the first postoperative day. BPF was suspected and they were both re-explored on the same day via the same port-sites. Apical ruptured bullae were found in both cases and were treated by bullectomy and partial pleurectomy. We now staple incidental bullae prophylactically to safeguard against such a scenario.

Wound complications:

There was one port-site seedling with malignant adenocarcinoma, with evidence of pleural recurrence 3 months after VATS lobectomy [Figure 9]. This was treated by wide surgical excision and radiotherapy. The patient died 24 months later of disseminated disease. Similar dissemination to port-site was reported from the Memorial Sloan-Kettering Cancer Centre, New York [32]. Follow up in clinic detected 7 (4.5%) port-site infections. Only one port-site needed surgical debridement and healing by secondary intension.

Pain control and long term pain:

Compared to thoracotomy, VATS lobectomy was associated with shorter chest tube duration, shorter length of hospital stay, and improved pain control. Open thoracotomy patients required 42% more morphine and 25% more nerve blocks than VATS patients who were 33% more likely to sleep following surgery [1, 31, 33, 34]. At clinic follow up port-site discomfort, paraesthesia and dermatome numbness were common. Complete recovery within 6-8 weeks was the rule. Two (2.1%) out of 156 of our patients experienced prolonged port-site neuralgia. Both were referred to specialised pain clinic and received Gabapentin and Amitriptyline long term. Similar long term pain has been reported before [35]. In our opinion this could be related to inattention at port-site creation. The technique of diathermy microthoracotomy to create bloodless ports must stick to the superior border of the rib [27]. Mid space diathermy can lead to nerve injury [Figure 2]. We now fashion the utility port by avoiding muscle cutting. The latissimus dorsi is separated in the direction of its fibres.

Thromboprophylaxis and Pulmonary embolism:

All patients should receive low molecular weight heparin on the first postoperative day. There were no incidences of in hospital deep vein thrombosis or pulmonary embolism (PE) in our series. At least three patients had thrombotic complications two proving fatal (1.2%) two weeks and 36 days after discharge from hospital. The Edinburgh experience reported one death within 4 postoperative days, and two further deaths within 30 days, all due to pulmonary embolism [31]. This highlights the possibility of hypercoagulability in this cohort of patients. Despite the fast-tracked physiotherapy and early discharge from hospital they should be considered a higher risk for thrombosis compared to open operation. The protracted hospital stay in the latter allows adequate anticoagulation until mobility is resumed. It is not unusual for patients discharged early after VATS lobectomy to reduce their activity and 'take it easy', whilst not covered by thrombo-prophylaxis. Further studies are needed to look into the role of domiciliary low molecular weight heparin and low dose Aspirin.

	Complications	**VATS completed N=133**
Major	protracted air leak >3 days (range 3-19 days)	13 (9.8%)
	ITU / HDU admission (total)	14 (10.5%)
	For mechanical ventilation	7 (5.3%)
	For inotropic support	4 (3%)
	For CPAP / BIPAP (HDU)	3(2.3%)
	Postoperative bleeding requiring re-exploration	1 (.8%)
	Bronchial complications	5 (3.8%)
	Out of hospital PE	2 (1.6%)
	Sputum retention requiring bronchoscopy under general anaesthesia	4 (3%)
Minor	Pulmonary complications / collapse / consolidation requiring antibiotics	14 (10.5%)
	Atrial fibrillation >24 hrs	7 (5.3%)
	Extra drain / reinsertion of drain	3 (2.3%)
	Pneumothorax, residual air capping after drain removal	19 (14.3%)
	Surgical emphysema	7 (5.3%)

Table 3. Complications for VATS completed major pulmonary resections

Conversion to thoracotomy:

There were 23(14.7%) true conversions to open thoracotomy in our series, for brisk bleeding 13(8.3%), thick fissure 3(1.9%), time constraint 2(1.3%), bad vision 2(1.3%), main bronchus transection 1(0.6%), massive air embolism during segmentectomy 1 (0.6%) and densely adherent nodes 1(0.6%). Our conversion rate of (14.7%) is in keeping with a recent meta-analysis reporting VATS to open lobectomy conversion rate ranging from 0% to 15.7% (median = 8.1%) [33]. Conversion should not be considered as a failure of VATS technique, and certainly should not be counted against the surgeon. It should be regarded as a patient safety necessity. Conversion does not prejudice immediate and long-term outcomes [36]. However; thoracotomy following a successful VMPR for postoperative bleeding is not always mandatory, as bleeding could be controlled videoscopically in most cases.

We cannot over emphasise the golden rule that VATS lobectomy should not be attempted by anyone who is not trained to deal proficiently with sudden brisk bleeding. Moderate bleeding early in our series led to conversion in 3 cases. However, with experience it was possible to salvage 3 major bleedings in excess of 500mls, and continue the VATS lobectomy to completion. Such confidence comes after a sizable experience with bleeding.

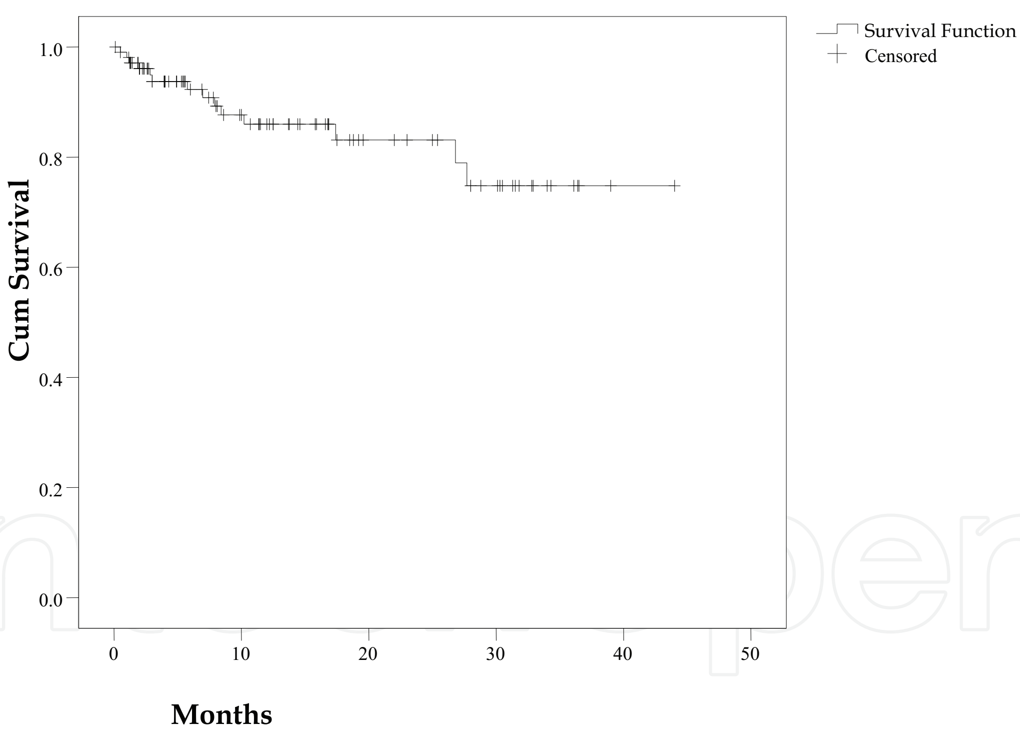
10. Disease progression and survival analysis

Table 4 shows the pattern of recurrence in 13(8.3%) patients with primary NSCLC treated by VATS resection. One patient with a negative PET scan was diagnosed with fresh bone metastases two weeks after the operation. She was well 2 year after chemo-radiotherapy and surgical knee replacement. The Kaplan-Meier survival at 1, 2 and 3 years of patients who had VATS resection of NSCLC (all stages) was 85±3.8%, 82.2±4.2% and 73.5±7.0%, respectively [Figure 11]. This compares well to McKenna et al in his large multi-institutional series [1].

Stage	Clinical staging (preoperative)	Pathological staging (postoperative)	Local Recurrence (progression)	Distant Metastases (progression)
Ia	54 (42.5%)	36 (28.8%)	0	3
Ib	48 (37.8%)	55 (43.3%)	4	3
IIa	7 (5.6%)	4 (3.2%)	0	0
IIb	5 (4%)	12 (9.6%)	3	2
IIIa	6 (4.8%)	13 (10.4%)	1	
IIIb ✞	4 (3.2%)	5 (4%)		1
IV	3 (2.4%)	2 (1.6%)		1

✞ One patient with a T4 lesion on CT scan proved to have two synchronous primaries, hence down staged to T2 N0.

Table 4. Clinical and pathological staging and pattern of recurrence in 127 primary NSCLC suitable for VATS resection.



Years	At risk	Events	% survival	SE
0	156	0	100	-
1	92	10	85.0	3.8
2	35	12	82.2	4.2
3	7	16	73.5	7.0

Fig. 11. Kaplan-Meier estimated survival in 156 patients undergoing major VATS resection (all stages).

11. Costing and service commissioning

Cost implications of a surgical procedure are difficult to evaluate [37]. It is difficult to assign a financial value to early return to work, reduced pain and better cosmetic results. Yet we found that VATS lobectomy on average cost £1300 more than an open procedure in terms of operative consumables. On the other hand reduced LOS enable high turnover of beds and improved throughput. The reduced LOS comes at the expense of theatre time, which means fewer cases will get through per operative list.

12. Conclusion

VATS major pulmonary resections are safe and long term results are not compromised. They should be considered first choice for T1-2, N0-1, M0 lung lesions. Aggressive approach to postoperative complications reduced length of hospital stay to a median of 4 days. Air leak remains the most important cause for prolonged hospital stay

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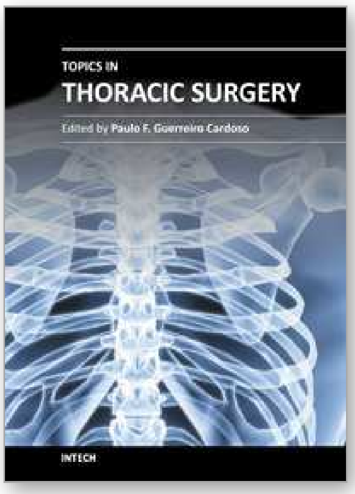

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