One-lung anaesthesia

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Chapter 7

One-lung anaesthesia[1]

We now focus on the practical details of positioning double-lumen tubes and the subsequent management of one-lung anaesthesia. The core skills are (a) knowledge of the relevant anatomy, (b) some facility with the fibrescope, and (c) a clear idea of what defines the 'optimum' position of the tube or blocker. For anaesthetic details regarding the standard range of thoracic operations/procedures see the excellent overviews by Sanders (2006) and by Pearce & Gould (2005). Always use a CVP line for thoracotomies.

Preoperatively it is important to look at both the chest X-ray and CT-scan for potential problems not only with the operative side, but also with the dependent side and the trachea. Listen to the chest to identify, among other things, any silent areas; after intubation such areas might otherwise mistakenly suggest tube malposition. In particular, note whether the upper lobes sound clear or not.

7.1 Right double-lumen tube

Owing to the hazard of obstructing the right upper-lobe bronchus, relatively few right-sided tubes are used—probably only when a left-sided tube or bronchus blocker cannot be used (e.g., a sleeve resection of the left main bronchus).

7.2 Left double-lumen tube

For most left-lung surgery and all other thoracic surgery it is possible to use a left-sided tube or a bronchus blocker. However, when planning to use a left-sided tube or blocker for left lung surgery, it is a good idea to discuss this with the surgeons, just in case they are expecting a right-sided tube to be used. For example, they might anticipate having to do a sleeve resection for which you may not be able to use a left-sided tube.

Since a left sided tube is used for both left *and* right thoracic surgery the strategy *while on one-lung* varies slightly depending on whether the endobronchial part of the tube is in the top lung (operative side) or the bottom lung (dependent side). The position of the patient (supine or lateral) also influences the strategy.

Top-side (left endobronchial tube)
In this case the primary danger is that the bronchial cuff may migrate back into the trachea and obstruct ventilation to the bottom lung. Consequently the strategy *when on one-lung* is to try and

[1] `http://www.nickalls.org/dick/papers/thoracic/hand-onelung.pdf`

keep the bronchial cuff well below the carina, and not to worry unduly if the tip of the tube gets fairly close to the left subcarina.

If when on one-lung, ventilation suddenly becomes obstructed, then this is almost always because the bronchial cuff is obstructing the bottom lung, and so the solution is (a) deflate the bronchial cuff temporarily, (b) push the tube further down the left main bronchus, (c) re-inflate the cuff, and finally (d) check the cuff position with a fibrescope. While you are on one-lung it is of no matter if the tip of the tube now obstructs the left upper lobe—the tube can be pulled back as necessary when returning to two-lungs, or when the surgeon needs to staple a lobar bronchus.

Note that once the patient is in the *lateral position*, then the bulk of the cardiac output is going to the bottom lung, and so inadvertently obstructing the upper-lobe prior to going on to one-lung is not too problematic—the top lung will be collapsed anyway once the surgeons open the chest. However, this is *not* the case while the patient is supine (e.g., in the anaesthetic room) and significant desaturation may occur if the tube is pushed too far down at this stage.

Bottom-side (left endobronchial tube)
In this case the primary danger is that the tube may migrate further down and obstruct ventilation to the left upper lobe. Consequently the strategy *when on one-lung* is to try and keep the bronchial cuff close to the carina. Sometimes the endobronchial part of the tube is slightly too long for the patient, such that the tip is dangerously close to the left subcarina even when the cuff is at the carina, in which case a smaller tube is necessary.

7.3 Placing double-lumen tubes

Is there an optimum method for placing a given double-lumen tube? If by 'optimum' we mean the most efficient sequence in the sense that information arising from each manoeuvre builds logically on previous manoeuvres, then the answer would seem to be 'yes'. Prior to intubation it is important to exclude a supernumerary or displaced 'tracheal' bronchus (see Section 4.4) during bronchoscopy[2]. Once intubated, it makes sense to start bronchoscopy with the tracheal side (view the carina via the tracheal lumen), and then progress to the endobronchial side, since information gathered by looking at the tracheal side influences how one interprets findings on the endobronchial side. An optimum sequence for positioning a double-lumen tube would seem to be something along the following lines.

- Listen to the chest preoperatively.
- Bronchoscopy (to detect a tracheal bronchus, visualise the position of the RUL orifice and configuration of its bronchopulmonary segments, suction secretions).
- Insert double-lumen tube.
- Stethoscope check (to detect upper-lobe obstruction by the tube),
- Bronchoscope check:
  - tracheal side first (to see if the tube is down the correct side, and if there is any bronchial cuff above the carina).
  - bronchial side second (fine-tune position of the end of the tube).
  - tracheal side again (check and fine-tune position of bronchial cuff).

Note that numerous studies have shown that double-lumen tubes are rarely optimumly positioned without bronchoscopic fine tuning.

It is useful to consider the process of placing a double-lumen tube in several stages as follows: (a) preparation, (b) intubation, (c) stethoscope check, (d) bronchoscopy check. We now consider these in order.

[2]Typically this is performed by the surgeons; it is important to (a) check for a tracheal bronchus, (b) check the position of the right upper lobe bronchus, and (c) suction any secretions, particularly in the 'bottom' lung.

7.3.1 Preparation

Consider a 'secretion drying' premed (e.g., hyoscine)

Hyoscine hydrobromide[3] (0·2–0·4 mg IM 1 hour preop).

This greatly helps visualisation of the bronchial anatomy, and facilitates double-lumen tube placement. I routinely use a hyoscine premed when I intend to place either a right-sided double-lumen tube or a bronchial blocker, as in these cases it helps to have particularly good viewing conditions since correct placement is sometimes not straight-forward.

Getting the timing/dose of hyoscine right is quite important, since the action of hyoscine rarely lasts longer than about 90 mins in my experience.[4] The doses I use are: average female (0·2–0·3 mg IM); average male (0·3–0·4 mg IM).

Check the tubes, cuffs and suction catheters

- Double-lumen tubes.

  Make sure you are familiar with the particular variety of double-lumen tube to be used, and that all the appropriate sizes are available. Make sure the correct connectors are available and that they all fit together. Check that the pilot balloons connect to the correct cuffs (see Nystrom 2003) and that the cuffs are intact; tracheal cuff (approx. 8 mls); bronchial cuff (approx. 3-4 mls).

- Check the tube accommodates the 'intubating' fibrescope.

  If you are likely to need the 'small' double-lumen tube (35 Fr), then check that the fibrescope will pass through the tube. The Mallinckrodt *BronchoCath* sizes 41–37 Fr will always accept the 4·5 mm diam intubating fibrescope. However, sometimes the 35 Fr ('small') tube will not accept the 4·5 mm fibrescope, so it is as well to check this before (i.e., find a 35 Fr which *will* accept the fibresope). As regards lubrication, consider using Xylocaine spray as this seems to be much better than KY-jelly.

- Check the suction catheters are long enough (165 cms)

  The suction catheters should be about 5 cm longer than the double-lumen tube.

Consider starting with a single-lumen tube

In potentially difficult patients, and those likely to be in the anaesthetic room for a long time (e.g., oesophagectomy and other major cases), consider starting with a single-lumen tube, and placing the double-lumen tube as the final anaesthetic-room procedure once all the lines are in. This has the advantage of allowing you to place the CVP, arterial line, NG-tube, bladder catheter etc. without worrying whether the double-lumen tube may have moved in the meantime, possibly resulting in the upper-lobe becoming obstructed (see Section 7.3.3). I therefore routinely adopt this approach in all cases needing a CVP line.

Anticipate the insertion distance of the double-lumen tube

The TEPID database of tubes is useful for predicting both tube size and length for a given patient (see Section 6.4.3). In general the required size for an average male and female is 41 Fr and 39 Fr respectively. The distances are roughly as follows: 41 Fr (30–31 cm), 39 Fr (29 cm), 37 Fr (27–28 cm), 35 Fr (25–26 cm). A rough rule for the number of centimetres is the French gauge minus 10.

[3] Hyoscine hydrobromide (ampoules of 0·4 mg in 1 ml) Hyoscine is an anti-muscarinic agent; slightly sedating; and sometimes results in a slowish heart rate. Important to use the full name on the prescription form to avoid possible confusion with Buscopan (hyoscine butylbromide; 20 mg in 2 mls.)

[4] It may therefore be better to use a longer acting agent like glycopyrollate instead, but I have not used it in this setting.

7.3.2 Intubation

Apply gel lubrication to the tracheal cuff as it reduces leakage past the cuff (Sanjay *et al.* 2006). Use the stylette to give a suitable bend on the endobronchial part of the tube, and insert with the curve facing upwards. Once the bronchial cuff is through the cords rotate the tube back into its anatomical position, and push *gently* into position. Since the trachea has only a thin layer of muscle posteriorly, it is easily perforated. If there is any resistance then consider trying a smaller tube.

Both cuffs are extremely delicate and are easily torn. Consequently take great care not to let the cuffs touch the teeth; consider using a protective gauze/drape if necessary. Always check that the cuffs are still intact following intubation—it will be difficult to change the tube once the patient is on the table.

Once the tube is in place, then inflate the tracheal cuff so you can ventilate both lungs satisfactorily. Then inflate the bronchial cuff with a small amount of air (say, 2–3 mls) just so that you will be able to see the cuff when viewing with the fibrescope. Its not important to have the bronchial cuff fully inflated at this stage.

Railroading the tube

Sometimes intubation can be extremely difficult, and the only way is to 'railroad' the tube over a bougie. Check that the bougie is long enough—at least 60 cm long (i.e., $35 + 25$ cm). Railroading a double-lumen tube usually requires a fair bit of force, and so some care is necessary in order not to damage the trachea or lung. The aim is to keep the end of the bougie above the carina at all times.

Since the carina is approximately 24–25 cms from the teeth (adult male), then in order to keep the end of the bougie above the carina (to avoid damage from inadvertently pushing it in too far) it is useful to make a clear mark on the bougie at about 24 cms, and maintain this at or above the teeth when railroading the tube. Since all tubes are now transparent, this mark will be easily visible through the tube wall.

If encountering problems, consider placing a single-lumen tube and checking the anatomy with a fibrescope

If there are significant problems positioning the double-lumen tube then it is sometimes a good idea simply to replace it with a single-lumen tube and check the anatomy carefully with the fibrescope, rather than run the risk of making things worse (e.g., obstructing an upper lobe and collapsing it).

Sometimes just checking you can identify the anatomy, or even measuring the distance to the carina or left subcarina, will greatly help during the next attempt at placing the double-lumen tube. Consider railroading the double-lumen tube over the fibrescope. Consider using a single-lumen tube and a bronchus blocker. The TEPID database can be a useful guide for tube size and length, especially in short patients (see Section 6.4.3).

The commonest initial problems are (a) the tube keeps going down the wrong side, (b) the endobronchial part of the tube is too big and fails to go down the main bronchus, (c) the tube is in too far, (d) sometimes the endobronchial part of a left-sided tube is slightly too long for the patient, and a smaller tube is needed.

7.3.3 Stethoscope check

- Once the double-lumen tube is in place first check that there is good air entry (i.e., with no added sounds) to both upper lobes by listening with a stethoscope just inferior to (and touching) the clavicles. Air-entry here should sound *exactly* the same as for the lower lobes (see Chapter 4 for surface markings). If there are any added sounds in the upper-lobe zone (or if it is quiet) then gently withdraw the tube about 1 cm at a time while listening until the air entry improves.

  For example, if after placing a left double-lumen tube we hear added sounds over the right upper lobe, then we can assume (providing it was clear before) that the tube has gone down the wrong side. Conversely, if the left upper lobe is now quiet, then we know the tube is down the correct side, and all we need to do is pull it back until we have good air entry in the left upper lobe.

  It is important to auscultate the upper lobes *immediately and carefully* after intubation because an undetected obstructed upper-lobe will very quickly collapse (within about 5 minutes); the speed being hastened partly by the high inspired oxygen typically used at this stage, and partly by the increased pressures generated by the ventilator.[5] Once the lobe has collapsed, auscultation over the lobe may well seem quite normal, since the remaining lung expands to fill this space.

  If the collapsed lung is on the operation side ('top' side) then this will be revealed at thoracotomy.[6] However, if this occurs on what will be the dependent side ('bottom' side) and goes un-noticed, then this could be disastrous—most probably resulting in severe hypoxia when on one lung.

- Next, check air-entry to the lower lobes by listening on the mid-axillary line below the level of the nipples (see Figures 4.2 and 4.3 for surface markings).

- Now check lung isolation. Clamp each side in turn and check (a) that there is no air-entry on the clamped side (add air to the bronchial cuff as necessary), and (b) that there is good air-entry on the opposite side. It should be easy to squeeze the bag when on one lung—any significant resistance at this stage is usually a sign that the tube is not correctly positioned. If in doubt, let the bronchial cuff down and then check further with the fibrescope—the bronchial cuff can be inflated later after confirming that the tube is correctly positioned.

- Mark the tube at the teeth (with a felt-tip pen) and then tie the tube in place using a rolling-hitch, as described recently by Frank Aldridge (Aldridge 2006), making sure the mark is visible above the knot and from the 'top' side (so you can see it once the patient is in the lateral position). This mark will be useful during the operation (to indicate if the tube has moved), and also at the end of the operation when the patient is supine again (the tube can be pulled back to its original anaesthetic-room position—see Section 7.6).

  Make sure that the two pilot balloons are *inside* the tie—if they remain outside there is the danger that they may be damaged if the tube position has to be adjusted and the knot moved along the tube.

- Finally, suck out audible secretions at this stage (i.e., before using the fibrescope).

[5] Note that the pressures generated by the ventilator tend to keep a *partially* obstructed lobe open. Once a lobe is *totally* obstructed it will experience a net compression from the lung surrounding it. This, plus a high $F_{I_{O_2}}$, results in rapid collapse of the lobe.

[6] This may be associated with some desaturation, especially while supine—see Section 7.2.1

7.3.4 Bronchoscopy — left-sided tube

The strategy underlying placement of a left-sided tube has two aims as follows.

1. To position the bronchial cuff at or below the carina.
2. To position the tip of the tube proximal to the left subcarina.

Bronchoscope check—tracheal side

We proceed by asking three questions.

1. Is the tube down the correct side?

   If not, then reposition the tube. If simple measures to reposition the tube fail (withdrawing the tube, turning the head to the right, advancing the tube again), then consider railroading the tube into the left main bronchus under direct vision over the fibrescope (place the fibrescope down the endobronchial (left) side; withdraw the tube so the end is just above the carina—usually at about 23–24 cms at the teeth in an average man; advance the fibrescope down the left main bronchus close to the left subcarina, and railroad the tube down to a suitable position).
2. Is there any bronchial cuff above the carina?

   If there is cuff above the carina, then push the tube down a bit further so the cuff is just below the carina. If you can't see the cuff at all, then the tube may well be too far down (we check this later when looking down the endobronchial side). However, in view of the earlier stethoscope-check we should be confident at this stage that the tube is not so far down that it is compromising the left upper-lobe.
3. Is the tracheal lumen of the tube very close to the carina?

   If it is too close (less than one finger width) then the tube may well be too far down (see Section 5.3 on how to measure this distance).

Armed with all this information, we now bronchoscope the endobronchial side.

Bronchoscope check—endobronchial side

There are two stages.

1. Observe the carina and right main bronchus (dark circular shadow) through the plastic wall of the tube (i.e., looking medially). Notice the position of the bronchial cuff (blue) in relation to the carina—i.e., check to see that the top of the bronchial cuff is at or below the carina.
2. Position the end of the double-lumen tube optimumly in relation to the left subcarina, by noting the position of the upper and lower-lobe bronchi in relation to the end of the tube (see Figures 7.1 and 5.1). The closest the tube should be to the subcarina is when the orifices of the two second-order bronchi either side of the left subcarina, together just fit into the diameter of the end of the tube, as shown in the schematic diagram in Figure 7.2. The tube can of course be further out than this, providing that the bronchial cuff remains at or below the carina.

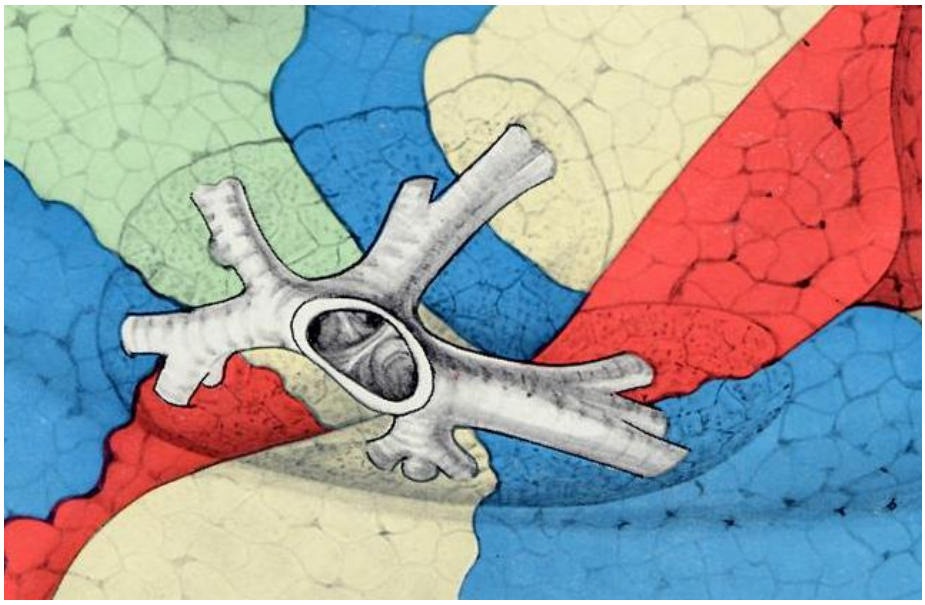

Figure 7.1:
Left lung: medial supine view of the hilum — enlarged from Figure 4.7 and rotated into the supine position. Notice how in the supine position the bronchus to the (yellow) apical segment of the lower lobe descends vertically down from the first part of the left lower-lobe bronchus–compare with Figure 7.2 where the orifice is denoted by the letter A (From Brock (1942-1944), with permission).

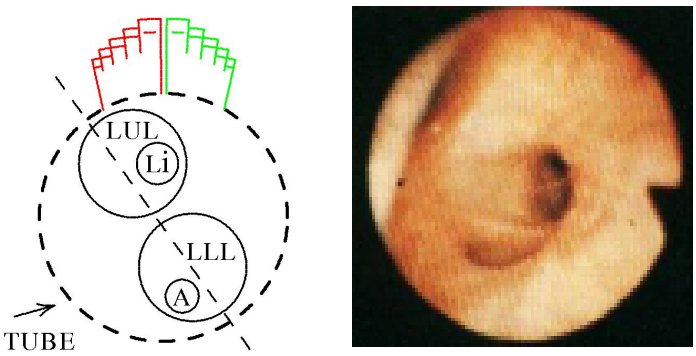

Figure 7.2:
Left: This is a schematic showing the position of the orifice of the lingula bronchus (Li) and the origin of the bronchus to the apical[a] segment (A) of the left lower lobe in relation to the second-order bronchi and the end of the double-lumen tube (dashed circle), as viewed down the fibrescope from the head end in a supine patient.

This schematic depicts the closest safe approach of the end of the tube to the left subcarina. We can define this as being when the two diameters of the orifices of the second-order bronchi bordering the left subcarina just fit into the diameter of the end of the tube. Compare this with the bronchoscopic image on the right which shows the view seen when the tube is slightly too far down.

Right: View of the entrance of the left lower-lobe bronchus (same orientation as in the schematic on the left). If you see this view bordered by the end of the tube, then the tube is slightly too far down. The shadow at the 11 o'clock position is the orifice of the left upper-lobe bronchus (partially hidden by the end of the tube which is almost touching the left subcarina).

Since the endobronchial end of the left double-lumen tube is unfortunately bevelled slightly medially,[b] a tube in this position tends to look down into the left lower lobe, as illustrated here. The orifice at the 6 o'clock position is the entrance of the bronchus to the apical[a] segment of the left lower lobe; the remaining orifices are basal bronchi[c] of the left lower lobe—compare with Figures 7.1, 4.7 and 5.2 (from the website of P Slinger[d] with permission).

[a] Sometimes (wrongly) described as the *superior* segment.
[b] The tube should really be bevelled slightly laterally (i.e., to be facing the subcarina).
[c] Two of the three basal bronchi are visible at the 3 o'clock position
[d] http:/www.thoracicanesthesia.com/

7.3.5 Bronchoscopy — right-sided tube

The strategy underlying placement of a right-sided tube has two aims as follows.[7]

1. To align the side hole with the right upper-lobe bronchus.
2. To ensure there is an adequate gap between the endobronchial part of tube and the wall of the upper part of the right main bronchus[8] (i.e., distal to the right upper-lobe bronchus). This is a useful precaution, since if the side hole later becomes mis-aligned (often the case once the patient has been turned into the lateral position) then the gases can still get in and out of the right upper-lobe by passing between the tube and the bronchial wall.

The commonest initial problem associated with placing a right double-lumen tube is to inadvertently position it too far down; the top of the medial part of the bronchial cuff needs to be extremely close to the carina—at least initially anyway.

Bronchoscopy—tracheal side

Since it is generally necessary to have the bronchial cuff very close to the carina in order to align the side hole with the right-upper lobe bronchus, start by positioning the tube so that the medial side of the top of the bronchial cuff lies at or *just* below the carina (i.e., as close to the carina as possible). Note that the Mallinckrodt right-sided tube has a large amount of blue plastic cuff-material stuck to the tube *above* the bronchial cuff on the medial side, so look carefully to distinguish between the blue 'real' cuff and the reflected blue plastic on the tube proximal to the cuff.

Having positioned the cuff close to the carina, then mark the tube on the top side at the teeth (with a felt-tip pen) making sure the mark is just visible above the knot.

Bronchoscopy—endobronchial side

There are two stages.

1. Pass the fibrescope to the end of the tube and withdraw slowly looking towards the right-hand side of the tube until the side hole comes into view. Advance the fibrescope through the side hole and try and locate the right upper-lobe bronchus. If the bronchus or edge of the orifice is visible, then move the tube slightly (rotating it if necessary) in order to get maximum alignment. If the bronchus is not visible, then move the tube in and out slightly, repeating after a small rotation if necessary, until the right upper-lobe bronchus is found.
2. Now proceed to determine whether there is an adequate gap (distal to the side hole) between the endobronchial part of the tube and the bronchial wall. Advance the fibrescope through the side hole and try to look distally at the space between the tube and the bronchial wall. If there is a gap then it is usually fairly easy to see. Even if it seems quite small, this is usually acceptable since the gap will increase slightly when on 'one-lung' ventilation as the mean airway pressure will be increased then. If there is no gap at all, then consider using a smaller tube, or perhaps a bronchus blocker, unless you are confident you can maintain good alignment in the lateral position. For a given patient, I therefore use a smaller right-sided tube (one size smaller) than I would for a left-sided tube.

7.3.6 Final tidal volume and pressure check

Just before turning the patient into the lateral position it is useful to check while the patient is still supine that the ventilator pressures and tidal volume generated by the theatre ventilator are appropriate. Strange pressures at this stage may suggest that all is not well with the tube position.

[7] Note that the algorithm for placing a right-sided double-lumen tube is significantly different from that for placing a left-sided tube.

[8] This used to be called the bronchus intermedius—see Section 4.5 for correct nomenclature.

As a general rule, a normal tidal volume (TV) and respiratory rate (RR) will generate a pressure on two lungs of about 20 cm H_2O (average male using a 41 Fr double-lumen tube). Clamping the 'top' side should then result in the peak pressure rising to no more than 30–35 cm H_2O, with a plateau of about 25 cm H_2O. If the pressures are much different from these, then now is a good time to adjust the TV, flow and RR accordingly—the fine tuning can be done later. Aim to use the same TV and RR for one-lung as for two-lungs.

7.4 Turning the patient laterally

The initial bronchoscopy after turning the patient into the lateral position commonly shows some degree of tube malposition—sometimes major malposition—the bronchial cuff typically now appearing to be positioned slightly above the carina, even though it had been perfectly positioned when supine. The tube position, however, is generally unchanged relative to the teeth, since the tube is usually well tied in. The cause is therefore, *not* tube movement, but movement of the carina.

The reality, therefore, is that turning patients from supine to the lateral position is often associated with significant caudal movement of the carina. This is especially the case in obese patients, and those with a pronounced abdominal paunch. Conversely, there is rarely much movement of the carina in thin patients.

This caudal movement of the carina is most likely due the fact that the diaphragm descends further once the patient is in the lateral position since the abdominal contents will move caudally and outwards. Consequently the lungs also descend, resulting in the carina being pulled downwards towards the bronchial cuff, with the effect that the bronchial cuff may then come to lie in the trachea. If turning is also associated with some outward movement of the tube at the teeth, then catastrophic tube malposition can easily occur, with the end of the tube coming to lie in the trachea, or even in the *wrong* bronchus.

- Before turning first check that the patient is on two-lung ventilation. With a top-side tube consider temporarily deflating the bronchial cuff (leave the 5-ml syringe attached so you can easily inflate the cuff with the same volume afterwards).
- In patients in whom the tube has been difficult to position, consider checking the ventilation pressures and volumes just prior to turning; these can serve as a useful guide after the patient has been turned (see Section 7.3.6).
- Hold the tube at the mouth during turning, taking care to not to let the tube come out any distance at all. In an obese patient push the tube in slightly during turning to the lateral position (perhaps 1 cm) to compensate for the anticipated caudal movement of the diaphragm and hence of the carina also.
- Once the patient is in the lateral position, check that you have easy access to the two pilot-cuff balloons. Reinflate the bronchial cuff if you deflated it prior to turning (keeping the syringe attached serves as a useful reminder).
- Finally, check the tube position bronchoscopically and adjust accordingly. Try to do this before starting one-lung ventilation.

  If the cuff is now in the trachea, then check first whether or not the tip is still in the correct bronchus before pushing it further down. If already on one-lung ventilation, then consider returning to two-lung ventilation before repositioning the tube, since you can then deflate the bronchial cuff and see more clearly. You may be forced to deflate the bronchial cuff anyway if ventilation becomes obstructed while on one-lung. Deflate both cuffs before moving the tube in order to avoid damaging the trachea and bronchus.[9] After repositioning the tube you may well have to tie the tube in again.

[9] A useful technique is to first attach an empty 5 and 10 ml syringe to the bronchial and tracheal cuffs respectively. When you are ready to advance the tube under bronchoscopic control, ask someone to deflate the cuffs—but to keep the syringes firmly attached. Once the tube is in the new position, the cuffs can be quickly inflated.

7.5 One-lung anaesthesia

It is convenient to consider the following stages: (a) preparation, (b) going on to one-lung, (c) management of one-lung anaesthesia, (d) returning to two-lungs, (e) turning supine, (f) extubation.

7.5.1 Preparation

- Check the position of the tube with the fibrescope.
- Check the tidal volume (TV) and pressures.

  An average-sized man with a 41 Fr double-lumen tube and normal tidal volume and respiratory rate (say, 10/min) will have a peak inspiratory pressure with two-lung ventilation of approximately 20 cm H_2O. With one-lung ventilation the peak inspiratory pressure typically increases to about 30 cm H_2O.

  Two lungs: Check that the TV is reasonable and that the inspiratory pressure is $\leq$ 20 cm H_2O. Use a relatively slow rate (say, 10 /min).

  One-lung: Clamp the top lung (at the end of expiration) just for a few breaths to see what TV and pressures are generated. Check that the inspiratory pressure rises smoothly and uniformly. Aim for a peak one-lung pressure of $\leq$ 30 cm H_2O, with a plateau pressure of $\leq$ 27 cm H_2O (Slinger 2003). If the peak pressure remains high, then exclude causes of increased resistance (e.g., secretions, bronchospasm, tube too far in etc). If the plateau pressure remains high with a reasonable TV, then check the tube position. If the tube position is fine, then consider reducing the TV slightly, and adjusting the respiratory rate as necessary.
- Check the end-tidal P_{CO_2}.

  If this is high, then try to bring this down to normal values before the surgeons need one-lung ventilation.
- Have a Jackson-Rees paediatric T-piece circuit available on a separate oxygen flowmeter for use later with the top lung.

7.5.2 One-lung ventilation

- Before going on to one-lung ventilation (a) note the tidal volume, end-tidal P_{CO_2}, saturation and airway pressures (peak and plateau), and (b) increase the $F_{I_{O_2}}$ to at least 50%.

  If using nitrous oxide and a volatile remember to increase the volatile concentration when reducing the nitrous oxide concentration in order to maintain the same MAC—see Figures 9.1, 9.2, 9.3.
- Go on to one-lung ventilation by clamping the top lung (proximal to the suction orifice) at the end of expiration, and open the suction orifice to air (to allow the top lung to collapse).
- Check that the tidal volume and airway pressures are appropriate on one-lung.

  If there is an air-leak check that the bronchial cuff is adequately inflated. If the airway pressures are too high coupled with a small TV consider going back on to two lungs and reviewing the tube position.
- Check to see if the top lung is deflating (ask the surgeons if necessary).
- Check for auto-PEEP.

  Listen to the bottom tube with a stethoscope (use the diaphragm) while watching the airway-pressure dial, and check that (a) the inspiratory and expiratory breath sounds are clear and uniform, and (b) no auto-PEEP is being generated (i.e., check there is an end-expiratory pause).

  If there is no end-expiratory pause then lengthen the expiratory phase by first reducing the respiratory rate (see the excellent paper by Szegedi *et al.* 2002), and adjust TV as necessary to minimise rise in end-tidal P_{CO_2}. Suck out any audible secretions.

- If everything is fine (and the lungs are visible[10]) then connect the Jackson-Rees T-piece (with 100% oxygen at about 1–2 L/min) to the top lung. It seems that even when the lung has collapsed down there is significant entrainment of gas by the lung (see articles by Pfitzner *et al.* 1999; 2001), and so the idea of the T-piece is to allow oxygen to be entrained by the lung instead of air. Have the oxygen enter the T-piece as close to the double-lumen tube as possible.

  Check that the T-piece bag has a hole in it (note that some disposable T-piece circuits use a valve and a *closed* reservoir bag).
- Check that the pulse, blood pressure and end-tidal P_{CO_2} are satisfactory.
- Start monitoring the saturation more closely as this will usually begin to fall over the next few minutes.

7.5.3 Management of one-lung anaesthesia

There are some general concepts worth bearing in mind.

- Keep the saturation $\geq 90\%$ by increasing the $F_{I_{O_2}}$ as necessary.

  In particular, avoid the combination of low saturation plus low cardiac output (i.e., low oxygen delivery to the coronaries). To this end, avoid giving very much down the epidural until the saturation and BP have stabilised at a reasonable level. If necessary periodically squeeze oxygen into the top lung manually[11] in order to maintain an adequate oxygenation (avoid applying PEEP to the bottom lung—unless the patient is obese—as this generally makes matters worse by shunting more blood to the top lung). Once you know you can control the saturation at a reasonable level, then gradually 'top-up' the epidural as necessary.
- Avoid excessive ventilator pressures.

  Slinger (2003) highlights the association of postoperative acute lung injury with plateau ventilatory pressures on one lung > 27 cm H_2O.
- Try to keep the end-tidal P_{CO_2} below 5·5 kPa.

  The end-tidal to arterial P_{CO_2} difference can be quite large on one-lung (Ip-Yam PC *et al.* 1994), so it is best to try and keep the end-tidal level reasonably low to avoid a respiratory acidosis. Do a blood-gas to check the Pa_{CO_2} if necessary.[12] As a general rule the end-tidal P_{CO_2} is a poor guide to the arterial P_{CO_2} if it does not plateau out, in which case a blood gas is more useful.
- Suction out the top lung periodically.
- Periodically check the tube position with the fibrescope.

  Avoid looking down the 'bottom' lung unnecessarily at this stage in order to keep the bottom lung well inflated, since there is always a leak when using the fibrescope. Once you are happy the tube is correctly positioned, then top lung bronchoscopy will serve as a guide to tube movement.

  With a **right-sided** double-lumen tube check (a) the alignment of the side hole with the right-upper lobe orifice, and (b) the position of the bronchial cuff in relation to the carina.

  When a **left-sided** tube is used in the *bottom* lung avoid having the end of the tube too close to the subcarina (danger of the tube obstructing the upper-lobe of the bottom lung). Conversely, when a left-sided tube is used in the *top* lung avoid having the bronchial cuff too close to the carina (danger of the bronchial cuff herniating above the carina and obstructing gas flow to the bottom lung).

[10] This precaution lessens the risk of barotrauma should the hole in the T-piece bag become obstructed—providing the surgeons can see the lung they will alert you if the lung starts expanding.

[11] E.g., using a paediatric T-piece circuit.

[12] Make a note of the arterial–end-tidal difference for use as a guide later.

- Control hypotension with fluids and/or vasoconstrictors as necessary.

  A thoracic epidural will usually make the hands vasodilate significantly, and this, when it occurs, is a helpful sign. Metariminol (10 mg in 20 mls saline; dose 1–2 mls) seems to be better and longer lasting than phenylephrine (1 mg in 20 mls saline; dose 1–2 mls). If having to give frequent boluses, then consider a noradrenaline infusion (2 mg in 50 mls saline; rate 2–8 mls/hr)—see also Section 8.1. Consider dopamine (200 mg in 50 mls; rate 2–8 mls/hr) for bowel surgery (e.g., oesophagectomy).

- Avoid excessive IV fluids, especially crystalloids.

  Slinger (2003) highlights the association of postoperative acute lung injury with excessive IV fluids in the first 24 hours. Limit crystalloids to about 1 L, and then use only Gelofusin or blood depending on the haematocrit. If the patient is clearly vasodilated (perhaps from the epidural) then consider using a noradrenaline infusion (Section 8.1). Aim to be more conservative with fluids for a pneumonectomy.

7.5.4 Returning to two-lungs

- Always suction out the top lung *before* inflating it.
- Following a lobectomy or pneumonectomy the surgeons will usually wish to test the stump under water using inflation pressures of approximately 30–40 cms water, so remember to remove the tube clamp and close the suction orifice. If there is a lung leak then you may need to return to one-lung for a while before testing the stump again. Once the surgeons are happy with the stump then return to two-lung ventilation (with smaller tidal volumes perhaps while the chest drains are inserted). Sometimes going back on to two-lungs is associated with a fall in blood pressure, so be prepared to infuse fluids or give vasoconstrictors at this stage.
- Once the saturation is adequate, then the $F_{I_{O_2}}$ can be reduced as necessary. Remember to reduce the volatile concentration (if adding nitrous oxide) in order to avoid an unduly high total-MAC.
- Check all parts of the lung are adequately inflated before the surgeons close the chest completely.
- Adjust the epidural rate/dose as necessary so as to have given an adequate amount before the end of the operation (i.e., at least 15–20 mls 0·25% bupivicaine before the end).
- Make sure the chest drains are attached to the under-water seal as soon as the chest is air-tight.

  Check that the chest-drain bottles are attached correctly (i.e., chest drains are attached directly to the under-water seal tube) and that the under-water seal is working. Check also that the air-exit hole is not obstructed—remove the bung completely if in doubt. Inflate the lungs manually a few times to remove as much of the residual air as possible.

7.6 Turning the patient supine

Turning the patient from the lateral position (on the table) to supine onto the HDU bed is a particularly hazardous moment (see Pearce and Gould 2005) with respect to cardiac arrest (the heart can get trapped in a pericardial window—cardiac herniation), exsanguination (a vascular tie can slip or work loose) and tension pneumothorax (a chest drain can become occluded).

- Keep the saturation probe and the arterial line attached and running (monitoring) until after extubation to safeguard against overlooking significant haemodynamic or respiratory changes.
- Increase the $F_{I_{O_2}}$ to 100%.

- The effect of changing posture back to the supine position will cause the carina to move cranially (see Section 7.4), with the effect that the endobronchial part of the tube may inadvertently occlude the upper lobe bronchus. Following a pneumonectomy, hypoxia at this stage may indicate an obstructed upper lobe. Such problems can be avoided by (a) pulling the tube back out to the position it had in the anaesthetic room (i.e. look for the mark on the tube—see Section 7.3.3), and (b) sitting the patient up somewhat.
- Check the chest drains for any significant blood loss or air leak.
- If the patient is to be electively ventilated in ITU then change the tube to a single lumen tube before going to ITU. Suction out both lungs before changing the tube.

7.7 Extubation

- Position the patient sitting up at about 45 degrees.
- Suction out both lungs before extubation.
- If the operation is a pneumonectomy, then just prior to extubation remember to inflate the lung well and clamp the chest drain (two clamps) while the pressure is maintained (usually only one drain following a pneumonectomy).

7.8 Complications

7.8.1 Intraoperative

Most intraoperative complications are tube & airway related (damage to the trachea, obstruction from tracheal compression (thyroid surgery, big mediastinal tumours), lung collapse secondary to failure to position the tube correctly). Other significant problems are pneumothorax of the dependent lung (often difficult to diagnose), hypotension, major blood loss, bradycardia/cardiac arrest (carcinoid tumours).

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7.8.2 Postoperative

Pulmonary complications are the leading cause of morbidity in the postoperative thoracic patient; for example atelectasis, secretions, lower respiratory infection and ventilator insufficiency. Postoperative bronchoscopy therefore has a major role in managing these common and potentially

life-threatening complications. All too often bronchoscopy is unduly delayed; it should be seen as an adjunct to physiotherapy and other more routine elements of postoperative care, and not viewed as a treatment of last resort. See the excellent review and pointer to recent literature by Keith and Kernstein (2005). This is on the CD.

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Acute lung injury/pulmonary oedema

An excellent editorial by Slinger (2003) comments on the findings of Licker *et al.* (2003), and highlights four factors thought to be significant independent risk factors for 'acute lung injury' following one-lung anaesthesia, namely (a) excessive intravascular volume, (b) high intraoperative ventilatory pressures ($>$ 27 cm H_2O), (c) pneumonectomy, (d) preoperative alcohol abuse. Suggested guidelines for the management of one-lung anaesthesia are as follows.

1. Avoid over inflation of the dependent lung. Consider using smaller (more physiological) tidal volumes if possible (say, 5 mls/kg) plus oxygen insufflation, and with PEEP if necessary. Limit plateau inspiratory pressures to $<$25 cm H_2O.
2. Minimise pulmonary intravascular pressures. This is primarily by fluid restriction, but also by minimising hypercarbia and hypoxia.

To this end a plot of the Datex AS/3 monitor's plateau ventilatory pressure has been added to the computer generated anaesthetic sheet for theatre 6, so we can keep a record of this parameter in the notes.

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