EVOLUTION OF ENDOTRACHEAL AND ENDOBRONCHIAL INTUBATION

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Endotracheal intubation was probably first performed by the eminent Belgian anatomist, Andreas Vesalius in 1543 (Vesalius, 1543). After performing a preliminary tracheotomy on a pig, he inserted a tube of reed or cane into the trachea, opened the thorax and then applied artificial ventilation by blowing down the tube. This proved to be a most advanced and skilful manoeuvre, for it was not until centuries later that its value as a means of maintaining pulmonary ventilation after thoracotomy was fully appreciated.

The next two hundred years saw little further development in tracheal intubation, but by the end of that time, the need for more effective resuscitative measures was becoming increasingly obvious. Mouth-to-mouth breathing had been performed as a resuscitative technique since biblical times, and in the early part of the sixteenth century, Paracelsus, a physician and lecturer of Basle, reported the recovery of a case of asphyxia with a bellows connected to a tube placed in the mouth of the patient (Guthrie, 1945). It would appear that endotracheal intubation, as a means of resuscitation, was first performed in 1754, when Benjamin Pugh, a Chelmsford surgeon, designed an “air pipe” (fig. 1) made from a coiled wire covered with soft leather (Spencer, 1925). The “air pipe” was introduced orally into the trachea of an asphyxiated neonate by a tactile technique; the operator then blew down the tube intermittently. It proved to be an effective method, although introduction of the pipe was difficult and usually traumatic. Little further interest was shown in neonatal intubation during the next half-century, but in 1807 Chaussier, physician to the Maternité de Paris, produced a curved metal cannula (fig. 2) which could be introduced into the trachea blindly, and again the operator insufflated the lungs of the neonate by blowing down the cannula intermittently (Northrup, 1894). Similar cannulae were produced by Depaul (1845) in 1845 (fig. 3) and in 1858 by Ribemont (fig. 4), both obstet-
ricians at the Maternité de Paris. Ribemont's cannula had a conical tip to ensure an airtight seal with the larynx, while the cannulae of Chaussier and Depaul had sponge collars.

In the meantime Charles Kite, a surgeon of Gravesend, had encountered several cases of apparent drowning in the Thames, and in 1788 he reported having successfully resuscitated some of them by insufflation with the aid of a curved metal cannula (fig. 5) which he introduced into the trachea blindly.

During the first half of the nineteenth century, surgical procedures on the upper respiratory tract were performed more commonly and this led to a noticeable rise in the incidence of postoperative pneumonia. Attention was thus directed to the problem of preventing the aspiration of blood and debris during such operations. Freidrich Trendelenburg, while an assistant surgeon at Langenbeck's clinic in Berlin, showed interest in this problem and as a result he produced a tampon cannula which was merely a curved metal tracheotomy tube with a tampon collar (Trendelenburg, 1871). From this he developed the first inflatable cuff (fig. 6) which was a delicate double-walled indiarubber tube surrounding the tracheotomy tube. It was introduced in 1869 and although successful in that it prevented aspiration of foreign matter, it entailed tracheotomy, the need for which was obviated by later developments in laryngoscopy and orotracheal intubation.
The work of William Macewen (1880), a Glasgow surgeon, occupies a prominent place in the history of endotracheal anaesthesia because he was the first to administer an anaesthetic through an orotracheal tube. Like Trendelenburg, he was primarily concerned with preventing aspiration, but, like others, he disapproved of Trendelenburg's tracheotomy. In 1880 he designed a metal endotracheal tube with a sponge collar which was introduced by touch, the sponge occupying the laryngopharynx. Maydl (1893) of Prague also advocated the use of a pharyngeal sponge to prevent aspiration, but Eisenmenger (1893) of Vienna was probably the first to use an inflatable cuff attached to an orotracheal tube (fig. 7).

The next problem which influenced the development of endotracheal anaesthesia was that of preventing pulmonary collapse after thoracotomy. O'Dwyer (1887), a New York otolaryngologist, had acquired fame through his introduction of metal laryngeal tubes (O'Dwyer, 1887; see also Kelly, 1928) in cases of diphtheritic croup. In 1888 he went on to design a curved metal cannula with a conical end (fig. 8) to ensure an airtight seal with the larynx (Northrup, 1894). This cannula, together with the foot bellows invented by Fell of Buffalo, was used to apply a raised intratracheal pressure, thus preventing pulmonary collapse during thoracic surgery.

Although Macewen had introduced orotracheal anaesthesia in 1880, it was Franz Kuhn, of Kassel in Germany, who popularized it (Fischer, 1933). The value of endotracheal intubation in preventing aspiration was now fully appreciated. At the turn of the century, however, Franz Kuhn became aware of the importance of intubation as a means of removing secretions from the tracheobronchial tree, as well as providing a good airway for smooth anaesthesia and it appears that he was the first to appreciate this. He designed a malleable endotracheal tube made from a wire spiral with a rubber insertion (fig. 9), and intubation was performed by touch with the aid of a curved metal introducer. Although Kuhn had considered the possibility of metal tubes causing trauma to the trachea and larynx, he felt that the material made little difference, but it was realized elsewhere that the resilience of the rubber tube minimized the trauma of intubation and from this time rubber became the material of choice.

So far, endotracheal anaesthesia had been inhalational, that is, inspiration and expiration took place through a wide-bore tube, but in 1907 Barthelemy and Dufour of Nancy introduced the method of insufflation. Here a continuous flow of gases delivered by a narrow endotracheal tube ventilated the lower respiratory passages and expired gases returned to the exterior via the space between the tube and trachea. Meltzer and Auer (1909), New York physiologists, further developed the technique, and after extensive studies, they claimed that insufflation
anaesthesia was the solution to the problem of preventing pulmonary collapse in surgical pneumothorax. They also stated that it was an efficient method of artificial ventilation and that the return flow of gases prevented aspiration. Thus insufflation anaesthesia rapidly became popular in America and Europe, but it is interesting to note that Kuhn never advocated its use, and strongly disagreed with Meltzer on its merits.

It was soon realized, however, by Magill and Rowbotham (Rowbotham, 1926) in this country, and by Waters and Flagg (Flagg, 1927) in America, that the claims made for insufflation anaesthesia could not all be substantiated. Firstly, it was no guarantee against aspiration, and secondly, carbon dioxide elimination was unsatisfactory. Thirdly, alarming intrapulmonary pressures could arise, if the return gas flow became obstructed. These findings caused a reversion to inhalational methods in both Europe and America.

Until 1910, the greatest hindrance to the widespread adoption of endotracheal anaesthesia had been difficulty in intubation and although Kirstein, a Berlin physician, had advocated direct laryngoscopic intubation with the Kirstein Autoscope, the idea did not receive immediate approval.
(Kirstein, 1895). This was largely because the Autoscope was a somewhat primitive instrument and the technique of laryngoscopy required practice as well as a good deal of muscular relaxation. However, by 1920 the technique was more widely accepted and its popularity was further increased by the improved laryngoscope introduced by Chevalier Jackson in 1920. This resulted in a wider acceptance of endotracheal methods in the next decade. Another factor which contributed to this trend was the large number of casualties from the 1914-1918 war requiring plastic surgery to the head and neck. It was at this time that Magill and Rowbotham who were working with the British army plastic unit, played a prominent part in the development of endotracheal methods. Rowbotham designed a wide-bore tube with an inflatable pharyngeal cuff and double inflating bellows, and Magill designed a similar orotracheal tube but with a tracheal cuff. He also designed a nasotracheal tube which was thin-walled because this afforded a larger lumen and because the nasotracheal curve, being more gradual than the orotracheal one, made the tube less likely to kink (Rowbotham and Magill, 1921).

So far, the inflatable cuff had been less popular than the pharyngeal sponge, largely because it was cumbersome and had presented manufacturing difficulties, but after the latter had been overcome it became widely used. In 1928, Guedel and Waters (1931) reintroduced the detachable inflatable cuff previously designed by Trendelenburg (1871), Eisenmenger (1893), and Dorrance (1910).

The next evolutionary phase of intubation was largely governed by the anaesthetic management of patients undergoing thoracic surgery. By 1920 the problem of paradoxical respiration in surgical pneumothorax had been solved by the use of controlled ventilation. Excessive bronchial secretions were a potential hazard, but this was mitigated by the use of posture with suction and by the employment of more rigorous pre-operative physiotherapy. Problems remaining were the prevention of transbronchial spillover and difficulties of ventilation in such cases as valvular pneumothorax, bronchial fistula and tension cyst. The solution depended on isolating the respiratory passages of one lung from those of the other and this entailed either bronchial intubation or blockage. Early experimental work of this nature had been undertaken towards the end of the nineteenth century, when extensive studies were carried out on the respiratory physiology of dogs by Head (1889), Wolffberg (1892), and Werigo (1892). This manoeuvre involved endotracheal and endobronchial intubation, so Head cleverly designed a curved metal endobronchial tube with inflatable cuff attached to an endotracheal tube (fig. 10). He was thus able to study differential pulmonary physiology and this is the first evidence of a double lumen tube being used. One of the first endobronchial tubes for anaesthetic use (fig. 11) was designed by Gale and Waters (1932). The tube was made of rubber and could be moulded in hot water to form a lateral curve. It was then blindly introduced into one or other bronchus. The carinal cuff, while providing an airtight seal for the intubated bronchus, also occluded the other main bronchus. A similarly styled tube, made from woven silk, was intro-
duced by Rovenstine (1936) (fig. 12), but both these tubes were found to be unreliable because of their instability. Having realized this, Magill (1936) designed right and left endobronchial tubes with cuffs (fig. 13). Since the right main bronchus is shorter than the left, the right tube had a terminal wire spiral to permit aeration of the right upper lobe. Originally these tubes consisted of a rubber-covered wire spiral but later they were made from rubber, except for the terminal wire spiral of the right bronchial tube.

Furthermore, Magill designed an inflatable bronchial suction blocker (Magill, 1936) (fig. 16) for cases in which endobronchial intubation was not feasible. A similar one introduced by Vernon Thompson (Rusby and Thompson, 1943) (fig. 15) has a gauze cover for the balloon thus giving the blocker a more secure hold against the bronchial wall. The stem of Magill’s, however, is slim enough for it to be placed within the lumen of the endotracheal tube, so that the cuff of the tube can make an airtight seal with the trachea. In the meantime, Crafoord had also considered this problem of preventing transbronchial spill-over and in 1938 introduced the technique of endobronchial tamponage (Nowsorthy, 1941). This consisted of packing off one or other main bronchus with ribbon gauze inserted through a bronchoscope (fig. 14) and then admitting gases to the other lung through an endotracheal tube.

A later development in this field is the Stüertzbecher (1953) tube (fig. 17). This is essentially an endotracheal tube with an incorporated suction stem and blocker, the length of which may be 7 cm or 9 cm. The 7-cm blocker is used for the occlusion of one or other main bronchus and the longer one for occlusion of a lobar bronchus. Introduction is performed with the aid of a laryngoscope, while the blocker is directed into one or other bronchus by means of a wire stylet.
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For left bronchus

For right bronchus

**FIG. 13**
Magill's endobronchial tubes (1939).

**FIG. 14**
Crafoord's tampon (1938).

**FIG. 15**
Vernon-Thompson's endobronchial blocker (1943).

**FIG. 16**
Magill's endobronchial blocker (1936).
The Macintosh-Leatherdale tubes (Macintosh and Leatherdale, 1955) are of similar design (fig. 18) except that they are made of moulded rubber conforming to the shape of the trachea and bronchus and thus afford stability. They are passed with the aid of a laryngoscope only, so that bronchial intubation is blind and because of this they are of value to the less experienced anaesthetist. One tube combines a left endobronchial suction blocker with an endotracheal tube and is used for operations on the left lung, while the other is a left endobronchial tube with incorporated suction stem for operations on the right lung.

In 1954, Vellacott (1954) described a right endobronchial tube (fig. 19) for use in patients requiring right upper lobectomy when the affected lobe contains fluid, or for patients having bronchopleural fistula with empyema following right upper lobectomy. The tube has an endobronchial cuff, designed to occlude the right upper lobe bronchial orifice, together with an endotracheal cuff. An orifice in the left lateral wall between the cuffs permits aeration of the left lung. The tube is a single-lumen latex one, reinforced with a spiral wire and stiffened with a malleable stylet built into the wall. It is introduced over a bronchoscope.

The difficulty in intubation of the right main bronchus without occluding the orifice of the right upper lobe bronchus has been overcome in several ways. Examples are the endobronchial tube of Gale and Waters, and Magill's right endobronchial tube. A further example is the Green-Gordon tube introduced in 1955 (Gordon and Green, 1955). This is a single-lumen right endobronchial tube with tracheal and bronchial cuffs, the latter having a slit which becomes apposed to the orifice of the right upper lobe bronchus, and communicates with the lumen of
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the tube. It is of moulded rubber, and at the tracheobronchial angle there is a hook which grasps the carina and prevents the tube being advanced too far. The tube permits aeration of the whole of the right lung, so that surgery of the left lung can be undertaken.

The use of the double-lumen tube has recently become more popular in this country, because it affords differential pulmonary ventilation with all its concomitant benefits. As has been pointed out, the idea was probably conceived in 1889 when Head designed such a tube to study respiratory physiology in dogs. In 1934 Frenckner produced a metal double-lumen bronchoscope (fig. 21) for bronchospirometric studies and this was followed by a rubber bronchospirometric catheter designed by Zavod in 1940. An improved double-lumen catheter (fig. 22) was designed by Bjork and Carlens in 1949 (Bjork and Carlens, 1950), again for bronchospirometric studies but it has since proved of considerable value in anaesthesia for thoracic surgery. This is because it renders the air passages of one...
lung independent of those of the other, in that
differential pulmonary ventilation is afforded and
spillover of secretion is prevented. Thus it com-
bines all the advantages of endobronchial tubes
and blockers with stability, as well as the benefits
conferred by differential pulmonary ventilation.
The latter include more operating room within
the thorax, suture of the open amputated bron-
chus, easier dissection of pulmonary segments,
and the maximum use of available pulmonary
tissue for gaseous exchange. Stability is afforded
by the carinal hook, but also by the fact that the
tube is moulded to the shape of the trachea and
left main bronchus and occupies their whole
diameter, whereas with an ordinary endobronchial
tube, the tracheal part fits loosely within the
trachea because its size is governed by the
diameter of the bronchus and this makes for
instability. Since the left main bronchus is longer
than the right, the left tube is made endobron-
chial, while the right one terminates just above
the carina. Thus the Carlens catheter is unsuit-
able in cases of left pneumonectomy, where it
is necessary to amputate the bronchus close to
the carina, because the tube must first be with-
drawn from the left main bronchus and this
often leads to ventilation difficulties. To obviate
this complication, the writer has designed a
double-lumen right endobronchial tube (fig. 23)
which is essentially the combination of two pre-
vious developments, namely, the slit endobron-
chial cuff and the double-lumen tube (White,
1960). Here the carinal hook is even more im-
portant because it ensures the correct relation-
ship between the slit of the cuff and the orifice
of the right upper lobe bronchus.

Occlusion by kinking is not an uncommon
complication of intubation, and various tubes have
been designed to overcome this difficulty. As
mentioned previously Kuhn invented a metal
endotracheal tube (fig. 9) in 1900 to prevent
kinking, and the thin metal wall also afforded a
large lumen. Trauma to the larynx and trachea
caus ed metal tubes to fall into disuse, until Flagg
introduced a new one in 1929. This was fol-
lowed by the Corylls McKesson tube (Corylls,
1932, 1933) and the Woodbridge tube (1934).
These were of similar design except that they
had various lengths of flexible wire spiral to
negotiate the pharyngeal curve. In 1954, Ballan-
tine and Jackson designed a flexometallic tube
which is simply a latex-covered wire spiral in
which the tracheal end is cut at right angles to
avoid occlusion of the orifice by the side wall of
the trachea or bronchus. The Oxford tube intro-
duced by Alsop in 1955 has a reinforced pharyn-
geal portion and is moulded to a right angle.
The reinforcement reduces the possibility of
kinking and the shape of the tube helps it to
maintain a constant position.

From this brief and general survey, it would
seem that the development of endotracheal and
endobronchial tubes has followed a somewhat
erratic course, and been largely dependent on
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surgical requirements. Vesalius (1542) had shown advanced ideas, for not only had he appreciated the hazards of thoracotomy but had overcome them by employing controlled ventilation with an endotracheal tube. Further development was stimulated in the mid-eighteenth century when attention was drawn to the inefficient resuscitative measures prevailing at the time, and about forty years later to the high incidence of post-operative aspiration pneumonia. Another century passed before the problem of surgical pneumothorax came into prominence, and then, towards the end of the nineteenth century, the value of endotracheal tubes for smooth abdominal surgery and the removal of secretions slowly became recognized. Insufflation anaesthesia then became popular as an alternative solution to the problem of pulmonary collapse in surgical pneumothorax, but at the beginning of this century there was a reversion to inhalational methods. Since that time, further advances have been aimed to meet the requirements of anaesthesia for thoracic surgery as well as to minimize some of the hazards of endotracheal intubation.

Finally, many tubes have not been mentioned because the purpose of this article is, firstly, to emphasize those which have punctuated development and, secondly, to stress the influencing factors.

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