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REVIEW ARTICLE

## New airways for resuscitation? ☆, ☆☆

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### KEYWORDS

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**Summary** Over the last 15 years supraglottic airway devices (SADs), most notably the classic laryngeal mask airway (LMA) have revolutionised airway management in anaesthesia. In contrast for resuscitation, both in and outside hospital, facemask ventilation and tracheal intubation remain the mainstays of airway management. However there is evidence that both these techniques have complications and are often poorly performed by inexperienced personnel. Tracheal intubation also has the potential to cause serious harm or death through unrecognised oesophageal intubation.

SADs may have a role in airway management for resuscitation as first responder devices, rescue devices or for use during patient extraction. In particular they may be beneficial as the level of skill required to use the device safely may be less than for the tracheal tube. Concerns have been expressed over the ability to ventilate the lungs successfully and also the risk of aspiration with SADs. The only SADs recommended by ILCOR in its current guidance are the classic LMA and combitube. Several SADs have recently been introduced with claims that ventilation and airway protection is improved. This pragmatic review examines recent developments in SAD technology and the relevance of this to the potential for using SADs during resuscitation. In addition to examining research directly related to resuscitation both on bench models and in patients the review also examines evidence from anaesthetic practice.

SADS discussed include the classic, intubating and Proseal LMAs, the combitube, the laryngeal tube, laryngeal tube sonda mark I and II and single use laryngeal masks.  
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☆☆ This article is based on a lecture given by Dr. Cook at Life Support 2005. It represents a personal interpretation of the literature on the subject and focuses primarily on the potential use of laryngeal masks during resuscitation. Other important supraglottic airways are discussed.

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## Introduction

Resuscitation is a broad term: for many it brings to mind in-hospital cardiac arrest, but it also includes out-of-hospital episodes including situations encompassing trauma and patient entrapment. Traditionally, the facemask and tracheal tube have been the accepted standards for emergency airway management during resuscitation.<sup>1</sup> In anaesthesia, airway management has been revolutionised over the last 20 years by the widespread use of the classic laryngeal mask airway (cLMA). In the last few years, an enormous number of alternatives to the cLMA have also been advocated for use in anaesthesia. These devices are generally known as supraglottic airway devices (SADs). This article examines, broadly, whether SADs have any role or advantages over the traditional methods of airway management during resuscitation. The only SADs mentioned in the 2000 International Liaison Committee on Resuscitation (ILCOR) Guidelines are the cLMA and Combitube.<sup>2,3</sup>

Airway management during resuscitation may be divided into three categories:

- 1 First rescuer (the first airway device used during resuscitation: ideally a reliable device easily inserted by relatively untrained personnel).
- 2 Airway rescue (a back-up device used when other techniques fail).
- 3 Specialised (a device used only in specific situations and likely to require specialist skills, e.g. trauma, entrapment).

Individuals whose experience and skill is likely to vary considerably may perform airway manage-

ment during resuscitation. Recommendations for airway resuscitation equipment should take this into account.

We must first consider what features are important in a device used for airway management during resuscitation. In all cases we need a device that restores and secures the airway rapidly and reliably, allowing oxygenation and ventilation. Further desirable features are permitting positive pressure ventilation, protecting the airway against regurgitation and 'failing-safe'. Outside the hospital environment, ease of use in circumstances where access to patients may be limited and safety during transfer are important additional considerations. The 'fail safe' concept is worth emphasising. A basic precept of medicine is to 'do no harm'. Devices that cause little or no harm if inexpertly or wrongly used, or simply when they fail, should be favoured over those that can cause harm in these circumstances.

A few general points are relevant. Airway obstruction is common during all critical illness and in particular at cardiac arrest and during trauma.<sup>4</sup> Airway obstruction is the fastest way to produce hypoxia and if unresolved will result in irreversible hypoxic brain injury or death within 2–3 min.<sup>5</sup> Put simply minutes (even seconds) are a matter of life and death during efforts to establish the airway in resuscitation.

There is evidence that the airway may not be managed well during resuscitation. In-hospital early airway management can be performed poorly and several years ago in our hospital we found that ventilation of the lungs was ineffective in 50% of cases until an anaesthetist arrived at a car-

diac arrest.<sup>6</sup> In a retrospective study of trauma deaths in the UK there was evidence of airway obstruction in 85% of deaths considered to have been survivable.<sup>7</sup> All other resuscitation efforts are futile if airway patency and oxygenation cannot be achieved and maintained. It is also important to note that unrecognised oesophageal intubation and ventilation will result in death, perhaps of someone who would have otherwise survived. Aspiration, although an important consideration, is not universally fatal and therefore avoidance of aspiration is a lesser priority than establishing a clear airway.

### Tried and tested devices

There is considerable data relating to several devices: the tracheal tube, bag-valve-mask, the classic LMA and the Combitube. These are discussed first.

### The tracheal tube (TT) and tracheal intubation

The TT provides a clear, protected airway (Figure 1). For many, it is considered as the 'gold standard' airway. This is reflected by the fact that TTs are carried by all ambulance crews and intubating skills taught to all paramedics in the UK.<sup>8</sup> However, tracheal intubation is a difficult skill to acquire and retain, requiring regular practice. As it is infrequently used by most paramedics there

is concern that it is prone to failure. There is also no doubt that during resuscitation and particularly out-of-hospital, conditions for tracheal intubation may be the most difficult of all encountered. One series from the USA reported a 50% failure rate amongst trained emergency medical technicians in the field (including 3% unrecognised oesophageal intubations).<sup>9</sup> An even higher rate of 65% failure has been reported amongst trained paramedics in the UK.<sup>10</sup>

Failure to intubate the trachea, while troublesome and time-consuming, is not the greatest concern over use of the TT. Unrecognised failure and oesophageal intubation are both potentially fatal and worryingly frequent. One study found a quarter (27/108) of TTs inserted by paramedics were misplaced, with the TT tip lying in the oesophagus in two-thirds of misplacements and in the pharynx in one-third.<sup>11</sup> Inexpert tracheal intubation with unrecognised oesophageal intubation may not only fail to save a life but actually cause death. So the two biggest problems with the TT are failure and the fact it does not 'fail safe'. It is therefore remarkable that a UK survey in 2004 reported that three quarters of ambulance services carried no equipment to confirm intubation except a stethoscope.<sup>8</sup>

It is outside the scope of this article to discuss, but the problems posed with intubation multiply in the case of resuscitation after trauma, when the need for cervical spine protection severely impedes conventional laryngoscopy.



Figure 1 Intubation may be difficult in the resuscitation scenario.

For those skilled and practiced in tracheal intubation this remains an excellent option: however, for the inexperienced, the unpracticed and for when it fails we must consider alternatives.

### Bag-valve-mask (BVM) ventilation

Ventilation with a self-inflating bag and non-return valve attached to a mask (popularly known as bag-valve-mask or BVM) can, and undoubtedly does, save lives. It is a rapidly deployed technique. It allows high concentration oxygen to be delivered, and is hygienic unlike mouth-to-mouth or mouth-to-mask ventilation. However, BVM ventilation again requires skill and practice.<sup>12</sup> Over-enthusiastic BVM ventilation with high tidal volumes and high airway pressures leads to an increase in the proportion of ventilating gas entering the oesophagus rather than the lungs.<sup>13</sup> As the lower oesophageal pressure falls rapidly after cardiac arrest<sup>13</sup> gastric inflation is likely. This has several adverse effects: regurgitation and therefore pulmonary aspiration increase and intra-abdominal pressure rises, splinting the diaphragm and reducing lung compliance. This in turn may lead to higher airway pressures during ventilation starting a spiral of worsening lung compliance and increased fractional leak of inspired gas into the stomach. Good BVM technique therefore demands gentle smooth and relatively slow ventilation via a patent airway. Success is considerably improved by airway clearing manoeuvres (head tilt, chin lift, jaw thrust: though the former two are not appropriate in trauma patients with suspected cervical spine injury) and by use of airway adjuncts such as the Guedel (oro-pharyngeal) airway and/or nasopharyngeal airway. For patients in respiratory or cardiac arrest when using BVM ventilation with oxygen supplementation ( $\geq 40\%$  oxygen), a tidal volume of 6–7 ml/kg (approximately 400–500 ml) given over 1–2 s is recommended. Chest rise will be just visible. If atmospheric air is used a larger tidal volume of 10 ml/kg (700–1000 ml) given over 2 s is recommended: the chest will be clearly seen to rise. Similar volumes are recommended during mouth-to-mouth ventilation with expired air.<sup>13</sup> For those undertaking BVM ventilation practice should include routine techniques, knowledge of guidelines and use of two or even three person techniques for patients with 'difficult airways' (Figure 2a and b).

Disadvantages of BVM ventilation include gastric inflation which is more problematic than when using the cLMA,<sup>14</sup> air leak which is around 40% even in experienced hands<sup>13,15</sup> and failure to protect the airway from aspiration of gastric contents.<sup>16</sup>

### Classic LMA (cLMA)

The cLMA was introduced in 1988 and was the first of the modern SADs. It has revolutionised anaesthesia since its introduction. It consists of a 'mask' and a 'tube' section (Figure 3). The mask sits over the larynx, with an inflatable cuff surrounding the larynx forming a seal that allows ventilation. A tube runs from the mask section to the outside of the mouth allowing connection to a self-inflating bag or ventilator/anaesthetic circuit. It is inserted with the patient's head and neck in the 'sniffing position' by pushing the device along the roof of the mouth and the posterior wall of the pharynx (the same route a bolus of food would follow), until it stops. Correctly positioned the cLMA tip lies at, and partially blocks, the top of the oesophagus. It can be reused up to 40 times, and is available in sizes suitable for all patients. Experience with its use is extensive, with 2500 publications and an estimated 200 million insertions worldwide. Although slower to deploy than BVM ventilation<sup>17</sup> evidence from anaesthetic practice is that it establishes an airway in more than 99% of cases and will resolve airway obstruction when BVM ventilation is impossible in more than 95% of cases.<sup>18</sup>

When compared to the TT, the cLMA has been found to have advantages in both trained and untrained hands. With untrained naval medics, the cLMA was faster to use (25 s versus 35 s), and twice as successful, with '100% first time success' versus 'progressive improvement in intubating technique'.<sup>19</sup> Similarly, in paramedic trainees, the cLMA was quicker (cLMA 39 s, TT 89 s), and more successful (cLMA 94%, TT 69% first attempt success, cLMA 100%, TT 87% after three attempts).<sup>20</sup> Trained American paramedics and respiratory therapists demonstrated similarly favourable performance (cLMA 39 s, TT 206 s, cLMA 100% first attempt success, TT 53% 'still failing to intubate after three attempts').<sup>21</sup> These studies highlight two important points: the cLMA is more frequently successful and it saves precious seconds, in the last study an average 'lifesaving' 167 s.

Several studies have examined the use of the cLMA for in-hospital cardiac arrest. In a landmark paper, a series of 164 patients was reported with 71% first time insertion success, rising to 97% with two attempts, 86% satisfactory ventilation, and a median time to establish the airway of 2 min.<sup>22</sup> Regurgitation and aspiration are often quoted as problems with the cLMA: of the 14% of patients that regurgitated in this study, 12% did so before CPR was commenced and only 2% during insertion. Of these, only one aspirated (overall incidence 0.6%). The authors concluded that 'the cLMA offers advan-



(a)



(b)

**Figure 2** (a and b) BVM ventilation with one and two hands should be practiced.

tages over other airway techniques (BVM, mouth-to-mouth) for CPR on the wards'. A randomised controlled trial of BVM versus cLMA followed and studied 797 patients receiving in-hospital CPR. Though 22.6% regurgitated, in half of these this occurred before starting CPR. Of the 713 patients who had not regurgitated prior to CPR, the rate of regurgitation was 12.4% amongst those receiving BVM ventilation (with or without subsequent intubation) and 3.5% in those managed with a cLMA (also with or without subsequent intubation). The authors concluded that 'when a cLMA is used as a first airway

device regurgitation is relatively uncommon'.<sup>16</sup> The cLMA is endorsed as a suitable airway for use during resuscitation in the ILCOR Guidelines 2000.<sup>2,3</sup>

The cLMA is recommended for airway rescue (re-establishing the airway when ventilation and/or intubation fails) in all major national airway guidelines for anaesthetists. Martin et al. reported a series of airway failures during air ambulance transfer.<sup>23</sup> In 16 of 17 (94%) cases, the airway was successfully rescued with a cLMA and oxygenation and ventilation were optimal. There were no complications in this series.



**Figure 3** The classic LMA: comes in a variety of sizes.

Despite this evidence, use of the cLMA in resuscitation remains infrequent. A postal survey in 2004 reported that only 39% of ambulance services carry cLMAs.<sup>8</sup> A study of UK hospitals in 2002 found that only one-quarter had cLMAs available during cardiac arrests.<sup>24</sup> Those not making them available cited 'concerns about airway protection, difficulties in training, cost and the concept that when anaesthetists were available on cardiac arrest teams these devices were unnecessary'. It is worth noting that the cLMA does fail safe. It is almost impossible to actively harm a patient with a cLMA, in the manner that tracheal intubation can through unrecognised oesophageal intubation.

So what are the disadvantages of the cLMA? Concerns include ability to ventilate the lungs effectively, aspiration risk, reuse of devices and cost. Each of these is considered briefly.

1. *Ability to ventilate the lungs:* The cLMA can achieve a clear airway in over 99% of cases, however, it forms only a low-pressure seal with the airway. The average seal is 18–20 cmH<sub>2</sub>O.<sup>25</sup> For many patients this will be adequate to allow lung ventilation. However, if airway pressures higher than this are required there will be some gas leak.<sup>14</sup> At low pressures, almost all gas leak is out of the mouth and is of little consequence. However, as airway pressures rise the proportion of gas leaking increases and the proportion of leaked gases entering the oesophagus increases, thereby increasing the risk of both

ineffective ventilation and of gastric inflation.<sup>26</sup> As with BVM ventilation, when using a cLMA it is advisable that ventilation should be low volume and low pressure. When increasing peak airway pressure from 15 to 30 cmH<sub>2</sub>O the proportion of ventilating gas lost as 'leak' increases from 13 to 27% and the proportion of that leak entering the oesophagus increases from 2 to 35%.<sup>26</sup>

2. *Aspiration risk:* The cLMA is routinely regarded as providing no protection against aspiration or regurgitation, although evidence suggests that the correctly placed cLMA does offer some protection.<sup>27</sup> It has even been proposed that the cLMA may actually promote regurgitation and aspiration by relaxing the lower oesophageal sphincter<sup>28</sup> and may channel regurgitated gastric contents toward the larynx.<sup>29,30</sup> There is little, if any, evidence to support this. The incidence of aspiration using a laryngeal mask in elective surgery is between 1 in 4–11,000 cases<sup>31,32</sup> with only one death known to have occurred as a result.<sup>33</sup> Use of a TT or BVM are also not risk-free. BVM ventilation is known to cause more gastric inflation than use of cLMA and offers no protection against aspiration.<sup>34</sup> In a series of over 200,000 surgical cases examining aspiration it was noted that one in three aspirations occurred during laryngoscopy.<sup>35</sup>
3. *Cross-infection:* The risks of cross-infection from reusable equipment have been a cause of recent publicity and concern. Miller et al. found that protein deposits remained on most

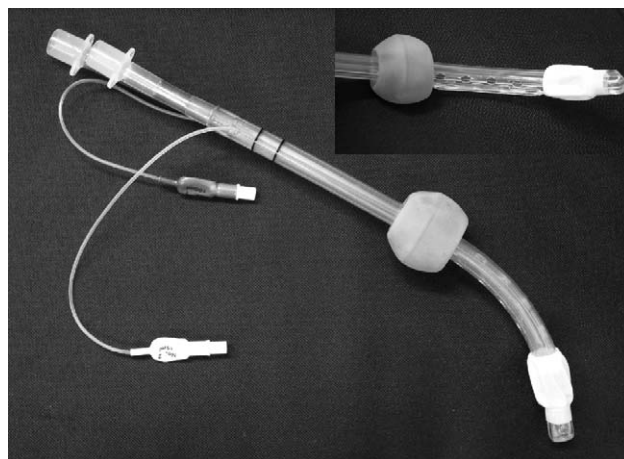
'cleaned' devices, including 20 sterilised cLMAs and 66 cleaned laryngoscopes.<sup>36</sup> The emergence of variant Creutzfeldt-Jacob disease (vCJD) has heightened these concerns although the prevalence of prion disease remains unconfirmed and vast down-scaling of estimates have occurred in the last 4 years, from over 100,000 in 2001 to 40 (95% CI 9–540) in the next 70 years by 2003.<sup>37</sup> There are no reports of cross-infection from reuse of reusable airway devices. Improved cleaning techniques can remove more than 90% of the protein load.<sup>38</sup> Cross-infection is certainly a theoretical problem, whether it is a practical issue remains unclear. Despite this the trend is towards increasing use of disposable devices even in the face of the economic and environmental issues raised.

4. **Cost:** The cLMA, with 40 uses, costs approximately £90 (€140). With cleaning costs this is approximately a total of £5 (€8) per use. Single-use LMAs are a similar cost and are discussed below.

Balancing the arguments for and against the cLMA, the authors believe that it remains under-taught, under-available and under-used for resuscitation. It has a role as an airway for use by the 'first rescuer' and also as a 'rescue' device when other airway techniques fail and may even be used when access to the patient is limited. Increased use of cLMAs would first require routine teaching of the skills needed for their use. It is possible, though controversial, to argue that this might be a more appropriate use of training than teaching tracheal intubation.

## The Combitube

The Combitube is a dual lumen airway developed in the 1980s. It resembles the oesophageal obturator airway. It is made of a double lumen tube with dual cuffs. There are two sizes but these are only suitable for adults (greater than 1.5m height). The distal portion of the tube looks like a cuffed tracheal tube: more proximally there is a larger proximal cuff and a second tube terminating between the cuffs (Figure 4). The combitube can be inserted into the trachea and is then simply used as a tracheal tube with the breathing circuit attached to the 'tracheoesophageal tube'. When the distal tube is inserted into the oesophagus, the distal cuff is inflated to obturate the oesophagus and the proximal cuff lies at the level of the base of the tongue. This high volume cuff is inflated to stabilise the tube position and occlude the oropharynx. Ventilation is then achieved through the 'pharyn-



**Figure 4** (a and b) The Combitube. Inset shows the airway orifices between the proximal and distal cuffs.

geal tube' via ventilation holes sited between the two cuffs. The Combitube has depth of insertion markings to aid positioning. In the second position, delayed expiration through the ventilation holes may lead to development of PEEP and may improve oxygenation. In the emergency situation, the Combitube is placed blind. The head and neck may be in the neutral or flexed position but the sniffing position is actively avoided. During insertion the anterior mandible and tongue are lifted anteriorly by gripping these between the operator's fingers while the combitube is advanced along the tongue: note the contrasting insertion technique to the cLMA.

The attraction of the Combitube design is that whether the distal tube is placed in the trachea or in the oesophagus, ventilation of the lungs is possible. When placed in the oesophagus the distal cuff and tube may offer protection from aspiration of regurgitated matter. A criticism of the design is its potential complexity and confusion in its use, particularly to those unfamiliar with it. The naming of the ventilation tubes does little to help this. The rescuer has to diagnose the positioning of the distal tube and if this is not correct then effective ventilation will not be achieved. As with the TT there is the potential to 'fail dangerously'.

Clinical reports, particularly from paramedics and emergency medical technicians in North America, have shown the Combitube can be very successful when used as a rescue device after failed tracheal intubation. During blind placement the distal tube is placed in the oesophagus in about 98% of cases. Therefore, it should be expected, until shown otherwise, that the distal tube is in the oesophagus. Use of the Combitube both in- and out-of-hospital has recently been reviewed.<sup>39,40</sup>

Practice with the Combitube (the manufacturer recommends five elective uses before use in the emergency setting) is difficult to acquire, as its use during routine anaesthesia is rare and controversial. It is a single-use device and costs approximately £30, which makes it relatively expensive to use for 'practice'. It also causes airway trauma considerably more often than other SADs. Oesophageal rupture has been reported. The Combitube remains significantly less popular in the UK than in North America for either primary management of the airway or management of failed emergency tracheal intubation. The Combitube is carried by only 3% of ambulance services<sup>8</sup> and available in only 3% of UK hospitals during cardiac arrest.<sup>24</sup> In a study of 15 patients whose necks were immobilised in a hard cervical collar Combitube insertion failed on 10 occasions (67%) and was associated with minor airway trauma in 7 cases (47%).<sup>41</sup>

The Combitube has a role in out-of-hospital airway rescue in those trained in its use. It is part of the ASA difficult airway management algorithm and the 2000 ILCOR recommendations for airway control during cardiopulmonary resuscitation. The authors of this article have little practical experience of the Combitube but do not recommend its use to those who are not familiar with it.

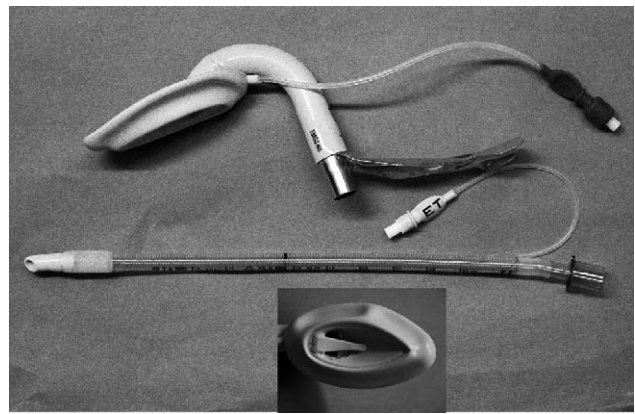
## Alternatives SADs?

There are many alternatives to the above devices. Few of the devices described below have been evaluated or reported for use in airway resuscitation. They are included because of potential benefits in performance or caveats about their use. Benefits include improved success with ventilation, improved airway protection and specialised roles for trauma, patient extraction and facilitation of intubation.

### Intubating LMA (ILMA)

The intubating LMA (ILMA) is a modification of the cLMA designed to enable blind tracheal intubation.<sup>42</sup> The mask section is similar to that of the cLMA. However, the airway tube is a rigid, shorter, wider tube and there is a 'handle' that allows insertion without placing the fingers in the mouth. It is available in three sizes, suitable for patients larger than 30 kg (Figure 5).

There are several reasons to consider the ILMA.<sup>43</sup> First the ILMA is reported to be inserted faster and with a greater degree of success than the cLMA by inexperienced operators (first time insertion suc-



**Figure 5** The intubating laryngeal mask airway. Inset shows the 'epiglottic elevator'.

cess ILMA 92%, cLMA 76%; successful ventilation ILMA 89%, cLMA 71%; tracheal intubation via ILMA 67%).<sup>44</sup> In this study, participants found the ILMA easier to use (ILMA easier 61%, cLMA easier 11%) and most would chose the ILMA in preference to a cLMA in an emergency (76%, cLMA 24%).<sup>44</sup> By comparison experienced operators are able to successfully insert the ILMA in over 98% of cases.<sup>45</sup> Second, it provides an airway seal slightly better than the cLMA (ILMA 34 cmH<sub>2</sub>O, cLMA 27 cmH<sub>2</sub>O) enabling ventilation in a higher proportion of patients (leak-free ventilation ILMA 77%, cLMA 56%).<sup>46</sup> Finally, after insertion and use as an airway it allows tracheal intubation with a high degree of success (67% success with 'blind' first attempt, >95% after three attempts).<sup>44</sup> The ILMA offers similar protection against aspiration as the cLMA.

Its disadvantages are a slightly increased risk of airway trauma, compared to the cLMA, and its cost. The cost of the ILMA (approx £300) has precluded its realistic consideration for routine or even rescue airway management in resuscitation, except in specialised areas. This year the manufacturers have launched a single-use plastic and poly vinyl chloride ILMA. This is unevaluated, but if routine performance matches that of the reusable ILMA this will be a device worthy of further study.

The ILMA has particular potential for management of trauma patients and for trapped patients. It may be inserted from in front of, at the side, or behind the patient and requires no additional instruments to establish an airway. Where necessary it allows seamless progress to attempts at tracheal intubation, again without additional tools and without the need to see the vocal cords. Unlike many SADs the ILMA is designed to be used with the patient's head and neck in the neutral position, so may be ideal when cervical spine protection is in place. Upper cervical spine movement during its use

with in line stabilisation is minimal (of the order of 2° flexion and 1 mm posterior displacement), which is unlikely to be clinically important.<sup>47</sup>

There are, however, two warnings: first, intubation via the ILMA requires practice (>20 uses are recommended to achieve skill) and when blind intubation is practiced it is vital to ensure oesophageal intubation is excluded. Second, both the presence of a hard collar<sup>48</sup> and application of cricoid pressure<sup>49</sup> prevent correct placement of the ILMA.

Despite these reservations the ILMA has an important role in out-of-hospital airway management (for which it has been reported)<sup>50</sup> and in-hospital tracheal intubation of trauma cases. At present these remain specialised uses. Whether the single-use ILMA has a role in establishing an airway during resuscitation requires further research. Again the authors believe the ILMA is a device that is currently under-used in resuscitation.

### ProSeal™ LMA (PLMA)

The PLMA is the most recent addition to the laryngeal mask series. Introduced in 2002, it is a laryngeal mask designed for controlled ventilation and increased airway protection. It has a larger 'deeper' mask section than the cLMA, with a posterior cuff: both factors that improve the seal with the airway. In addition, there is a drain tube that runs from the tip of the mask to the proximal end (Figure 6a). The drain tube reduces the likelihood of leaked gases entering the oesophagus and acts as a vent if regurgitation occurs. When correctly placed the PLMA functionally separates the respiratory and gastrointestinal tracts (Figure 6b and c).<sup>51</sup> In this respect, the PLMA can, unlike other airway tubes, be considered to act as an 'artificial larynx'. The drain tube also allows diagnosis of misplacement of the PLMA tip.<sup>51</sup>

The airway seal is approximately 50% higher with the PLMA than the cLMA (PLMA 27–31 cmH<sub>2</sub>O, cLMA 16–22 cmH<sub>2</sub>O). This is well established with nine comparative studies of 1470 patients.<sup>51</sup> This improved seal permits a greater proportion of patients to be effectively ventilated, particularly when higher airway pressures are needed. At pressures above 30 cmH<sub>2</sub>O, leak-free ventilation would be expected in 48% of patients with the PLMA but only 4% with the cLMA, and at pressures exceeding 40 cmH<sub>2</sub>O, 21% with the PLMA and none with the cLMA.<sup>52</sup> An oro-gastric tube is reliably easy to pass through the PLMA drain tube when it is correctly positioned.<sup>51</sup> This improves its safety over the cLMA in preventing aspiration.

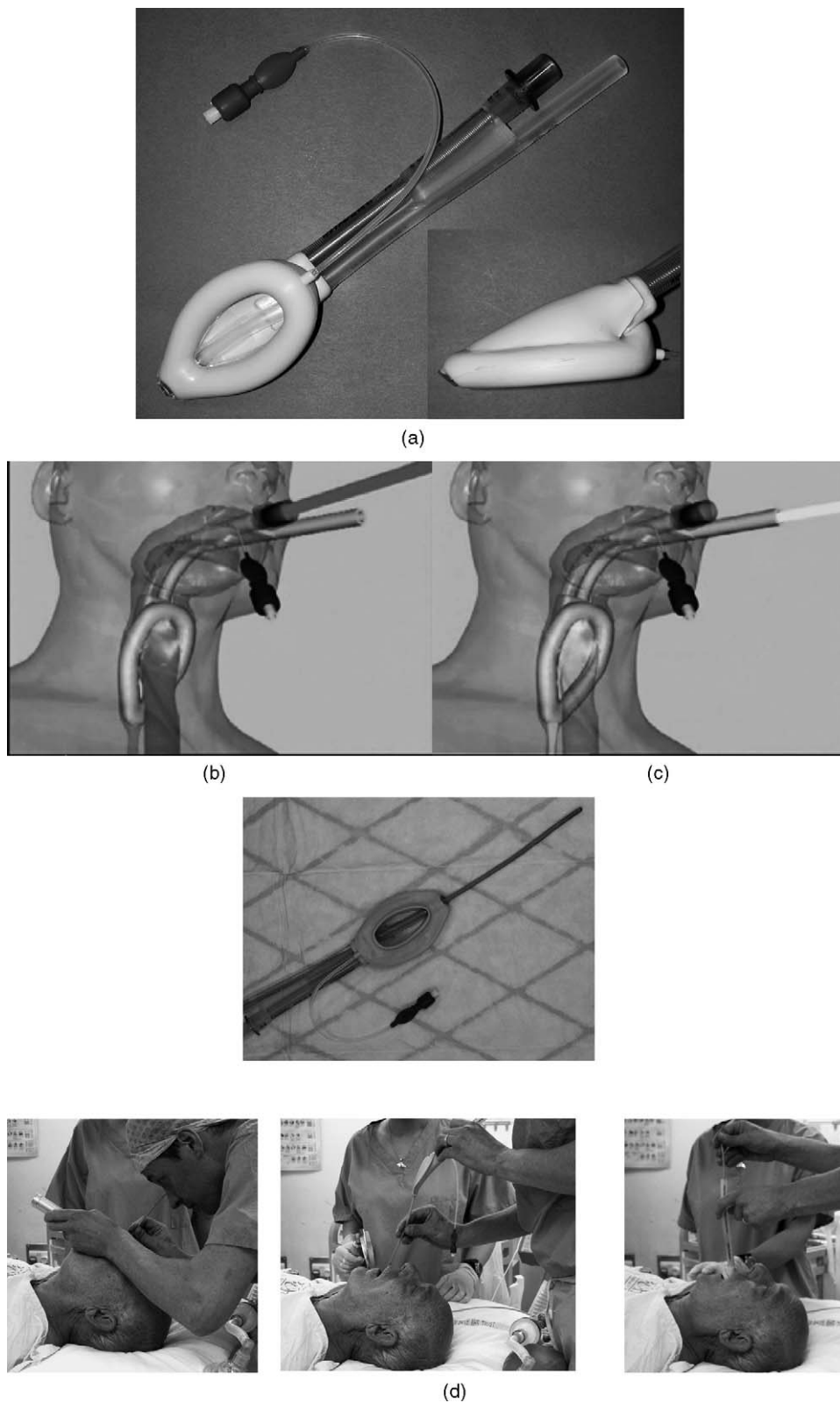
There is good evidence to support increased safety with the PLMA. Several studies looking at

its use during laparoscopic cholecystectomy have shown no significant gastric distention during controlled ventilation.<sup>53,54</sup> Bench-top research has demonstrated the PLMA vents fluid injected into the oesophagus at 15 ml/s.<sup>55</sup> These findings make gastric inflation (with all its potential problems) during controlled ventilation in the resuscitation setting considerably less likely with the PLMA than either BVM or the cLMA. In cadavers incremental filling of the oesophagus does not lead to tracheal soiling if the drain tube is left open.<sup>28</sup> In a further study of 102 patients, the PLMA protected the larynx from methylene blue in the upper oesophagus,<sup>56</sup> and there are 12 reported cases of gastric regurgitation in which the PLMA protected the airway from soiling.<sup>51</sup> Despite this evidence, to prove improved safety definitively compared to the cLMA would be very difficult. Assuming aspiration risk with the cLMA is 1 in 11,000 and that the PLMA reduces this by 50%, an adequately powered trial to confirm this would require 1,300,000 patients per group.

The less frequent gas leak, reduced gastric distention, effective venting of gas or fluid via the drain tube and access to the gastrointestinal tract all serve to provide increased airway protection compared to the cLMA or ILMA.

There is laboratory/manikin evidence of effective performance of the PLMA during simulated cardiopulmonary resuscitation. A comparison of different laryngeal mask airways in a resuscitation model was undertaken by Genzwurker in 2003. The cLMA, ILMA, PLMA, LMA Unique (a single-use laryngeal mask), facemask and TT were evaluated by attachment to a bag or ventilator on a manikin with chest thumper: ventilation was measured both during interrupted and uninterrupted chest compressions. In the interrupted group, all devices performed adequately, although the PLMA, ILMA and TT performed best. However, when CPR was continuous, only the PLMA, ILMA and TT were satisfactory, the others resulting in gastric inflation.<sup>57</sup> In a second manikin study, the performance of the PLMA, Combitube and Laryngeal Tube Sonda (LTS) (see below) were all equivalent.<sup>58</sup> These are important findings and should lead to further investigation in animal or human studies.

There are significant caveats. The first is that the PLMA is not widely available and therefore there is user 'unfamiliarity'. Second, the PLMA is somewhat more difficult to insert than the cLMA or ILMA. In 28 studies comparing a total of 2388 patients overall first time insertion success was 85% with the PLMA, compared to 93% with the cLMA.<sup>50</sup> However, after three attempts insertion success was equivalent at greater than 99%.<sup>50</sup> One small comparative study examined insertion success by nurses who had



**Figure 6** (a) ProSeal™ LMA. Inset shows the posterior cuff of the ProSeal LMA. (b and c) ProSeal LMA showing 'airway tube' (Fig. 6b) and 'gastrointestinal route' (Fig. 6c). (d) ProSeal™ LMA inserted through the drain tube and 'railroaded' over a gum-elastic bougie.

not used either cLMA or PLMA. After 1-h training the investigators found no difference between performance, with first time PLMA insertion success of 85% and overall success of 100% within 45 s.<sup>59</sup> Overall, the PLMA takes a few seconds longer to insert than the cLMA.<sup>51</sup> Most of this work has been based on PLMA insertion techniques that are identical to the cLMA (digital insertion) or the ILMA (using an introducer). More recently an insertion technique has been described with 100% first time success.<sup>60</sup> This technique involves placing a gum-elastic bougie into the oesophagus then railroading the PLMA into place over it, via the drain tube. Because of its apparent reliability it may well be that this is the insertion technique that should be taught to, and adopted by, unfamiliar users and during resuscitation (Figure 6d).

With regard to the possibility of using the PLMA as a rescue device when tracheal intubation fails there are 11 reported cases of 'airway rescue' with the PLMA, in several of which both tracheal intubation and the cLMA had failed before the PLMA succeeded.<sup>61</sup>

The above evidence suggests that the PLMA has many characteristics that make it well suited for use during resuscitation. However, at present there are no reports of its use during out-of-hospital or in-hospital resuscitation.

The PLMA is a reusable device. A single-use device is expected in 2006 but is at present unevaluated. The PLMA offers significant potential advantages over other SADs during resuscitation. A trial to examine its value in these circumstances is surely justified.

### Laryngeal tube (LT) and Laryngeal Tube Sonda (LTS)

The LT is a supraglottic airway consisting of a silicone tube with distal and proximal cuffs. Unlike the Combitube there is no tube beyond the distal cuff. The distal cuff is designed to seal off the oesophagus leaving the proximal cuff behind the base of the tongue. When both are inflated the pharynx (above) and the oesophagus (below) are sealed off and ventilation takes place via airway orifices that lie between the cuffs. The LTS is a development of the LT with a suction tube running posterior to the airway tube. In this respect, the LTS is to the LT what the PLMA is to the cLMA. Both are reusable devices (designed for 50 uses) though there is now a single-use LT available (LT-D) (Figure 7a).

The LT, and to a lesser extent the LTS, have undergone extensive laboratory evaluation in the context of airway management during resuscitation. Indeed both were originally designed for

'emergency airway management' including out-of-hospital use.<sup>62,63</sup> Much of this work comes from Europe and is mostly based on evaluation in manikins.<sup>43,64,65</sup> Superior ventilation with the LT when compared to BVM ventilation has been demonstrated in at least two manikin trials.<sup>64,66</sup> Genzweurker found the LTS and LT perform similarly to each other and better than the facemask during CPR on a manikin, achieving slightly higher tidal volumes with less gastric inflation.<sup>67</sup> Another study by Hinkelbein reported similar tidal volumes to the TT in a bench model without chest compression.<sup>68</sup> User preference for the LT has also been demonstrated in a manikin trial by Asai, where 93% considered LT insertion easier than cLMA insertion.<sup>69</sup> Finteis described a comparison of cLMA, Combitube and LT and found that 63% of 86 German paramedics would use the LT when given a choice between the three devices (combitube 23%, cLMA 14%).<sup>70</sup> Comparisons with the PLMA and Combitube are referred to in other sections. A recent report on out-of-hospital use during CPR by minimally trained nurses found 87% of users expressed a positive opinion about the laryngeal tube.<sup>71</sup>

In addition to manikin work, there are case reports of successful use of both the LT<sup>71,72</sup> and LTS during out of hospital resuscitation.<sup>73</sup> A recent study reported 30 uses of the LT as the primary airway for out-of-hospital airway management during CPR by nurses who had received 4 h of training. The LT was placed successfully in 70% at the first attempt and enabled adequate ventilation in 80%. Twenty-six of 30 users (87%) of users expressed a positive opinion about the laryngeal tube.<sup>74</sup> The study was performed in 2002–2003, and it is therefore unclear which version of the LT was used in this study.

Experience from anaesthesia has however raised several concerns. The LT is easily inserted but early versions were associated with a high incidence of airway obstruction.<sup>75</sup> As a result, the LT was redesigned and recent versions have improved performance.<sup>76</sup> The LT performs similarly to the cLMA during ventilation in anaesthetised patients, but with a higher incidence of airway obstruction.<sup>77</sup> The PLMA enables ventilation more readily than the LT in anaesthetised patients.<sup>78</sup> There is little evidence to allow judgement as to whether the LT provides any protection against regurgitation or aspiration.

Described as a device for emergency use,<sup>79</sup> the LTS is the more logical device to use for resuscitation as, like the PLMA, it allows separation from (and access to) the gastrointestinal tract, thereby, at least in theory, increasing safety. There are several reports comparing LTS and PLMA performance

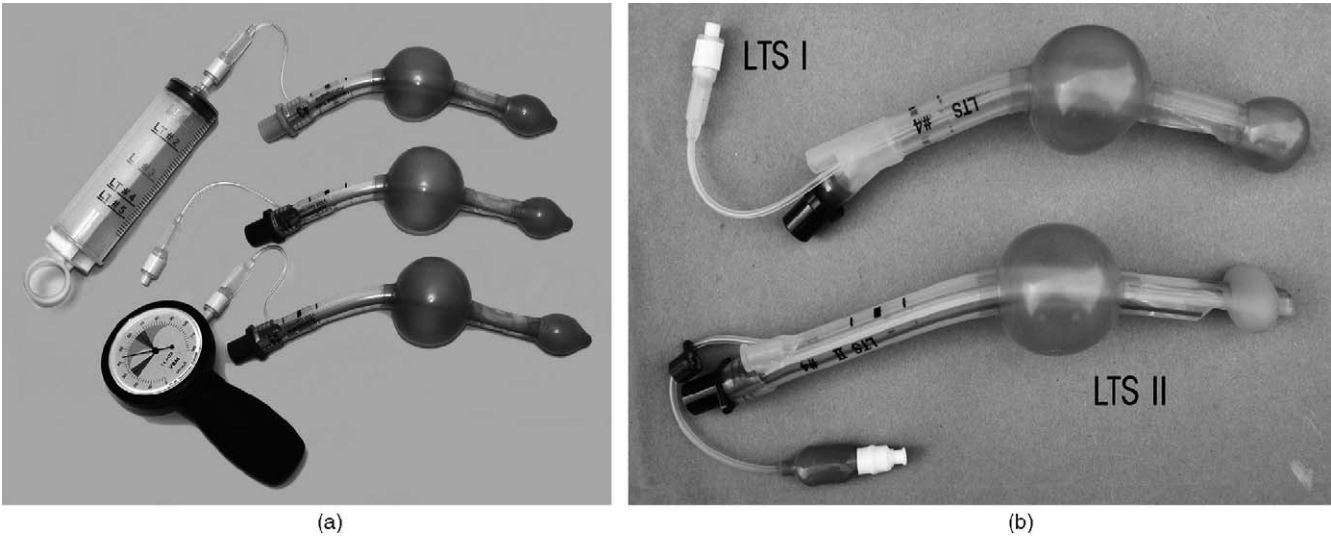


Figure 7 (a) Laryngeal tube. (b) Laryngeal Tube Sonda and Laryngeal Tube Sonda II.

with three reporting equivalence.<sup>80–82</sup> This is not our experience and in our evaluation we found the LTS both difficult to insert (30% failed first attempt insertion) and unreliable for ventilation (ventilation sub-optimal in 30%).<sup>83</sup>

There are two comparisons of the LTS with the combitube. In one study, the LTS was inserted more successfully (100% versus 87%) and faster (39 s versus 79 s). Ventilation was effective with both devices, gastric inflation did not occur and the combitube had a higher seal pressure (36 cmH<sub>2</sub>O versus 26 cmH<sub>2</sub>O). The authors suggested the LTS was 'less complex' to handle.<sup>84</sup> In a second study, the LTS was faster to insert, with less airway trauma.<sup>82</sup>

Regarding use in patients with difficult airways and for airway rescue Paventi used the LTS in 24 'predicted and unpredicted emergencies': 12 were patients with features suggestive of airway difficulty and 12 were unpredicted difficult emergencies. All patients were successfully managed with the LTS.<sup>85</sup>

In inexperienced hands the LTS is reported to perform well. Ten medical students and 10 paramedics without experience of use of either device required fewer attempts to perform 10 consecutive successful insertion/ventilations of a manikin with the LTS than the cLMA (students 19 versus 11 attempts, paramedics 19 versus 13).<sup>86</sup> In addition, in both groups two students failed to achieve 10 ventilations within 30 attempts with the cLMA. Both groups favoured the LTS.

One persistent problem with the LT and LTS is that the devices have been changed on several occasions. The LT has been modified at least three times since its introduction in 1999. Because of publication delay, it is often not possible to determine whether a clinical report relates to the currently available device or to a (now obsolete) older version. The currently available LT was introduced in 2002. The original LTS was withdrawn in late 2004 and a substantially modified device (the LTS II) introduced in its place in November 2004. Therefore, any publication describing the LTS (rather than the LTS II) (Figure 7b) describes evaluation of a device that is no longer available. While the manufacturers are to be applauded for their efforts to improve these devices, the repeated changes in design make careful evaluation of currently available devices problematic.

To summarise data on the LTS and LT: these devices are promising. Insertion is generally atraumatic and readily achieved even by the inexperienced. Controlled ventilation is usually possible, but obstruction is not uncommon. Little is known about protection against aspiration with either device. Most data on both devices comes from

manikin trials. Clinical trials of currently available devices are needed.

### Single-use laryngeal masks

The patent for the basic design of the cLMA expired in 2003. Since then several companies have released single-use competitors. At present there are six different single-use laryngeal masks marketed. All have design differences from the cLMA (particularly grills across the bowl of the cLMA which remains under patent until 2008), and there is insufficient published data on any of them to draw conclusions about their performance. As all are made of poly vinyl chloride/plastic, whereas the cLMA is made of silicone, performance is unlikely to be equivalent. Early reports suggest that there may be increased difficulty with insertion of some single-use laryngeal masks,<sup>87–89</sup> with the reusable device generally being preferred for routine use.<sup>89,90</sup> The single-use laryngeal masks may well have improved airway seal compared to the reusable version.<sup>88,89,91</sup> There are no studies of single-use laryngeal masks during resuscitation either in or out of hospital. Marketing of the single-use laryngeal masks is often based on infection risk of reusable devices but at present it is unclear whether this is more than a theoretical problem. For out-of-hospital use and in areas with limited access to sterile services a single-use device has potential logistical benefits. The advantage of single-use laryngeal masks over the cLMA is cost, particularly in circumstances where they are infrequently used. Most single-use laryngeal masks cost between £4 and £8. Considerable work is still required to establish which, if any, single-use laryngeal masks are acceptable and whether their performance is equivalent to the well established reusable version.

### Others

New SADs continue to be developed and introduced at such a rate that the subject remains very hard to keep up to date with. Other available SADs include the Airway Management Device (AMD), Pharyngeal Airway xpress (PAx), Streamlined Liner of the Pharynx Airway (SLIPA), Cobra Perilaryngeal Airway (CobraPLA) and Elisha Airway Device. At present there is insufficient evidence (or in some cases negative evidence) regarding these devices and the authors do not recommend them for use in resuscitation, while other useful alternatives that have been more thoroughly evaluated, are available.

## Gastric inflation, and use of Inspiratory Impedance Threshold Valves with SADs

Gastric inflation and its complications will occur with any extraglottic device (i.e. BVM, SAD) that allows gas to leak into the oesophagus during controlled ventilation and CPR. The recommended tidal volumes when using such a SAD should logically be as for BVM. However, it is notable that some SADs are likely to lead to oesophageal leak during ventilation (e.g. cLMA), some are known to be less likely to (e.g. PLMA, Combitube) but for many this data is not known. Whether these recommendations therefore apply for individual SADs is not clear.

Inspiratory Impedance Threshold Valves (ITVs) are devices attached to resuscitation breathing circuits that prevent passive indrawing of air during chest recoil/decompression following chest compression as part of CPR. In doing so the ITV enhances the period of negative intrathoracic pressure thereby augmenting venous return and so improving CPR-generated cardiac output.<sup>92</sup> ITVs are particularly effective when combined with active compression–decompression CPR (ACD CPR) but also provide some benefit during conventional CPR.<sup>93,94</sup> In order for the ITV to be effective a negative intrathoracic pressure must be maintained. To date ITVs have been used with tracheal tubes and facemasks, with the latter producing less fall in the intrathoracic pressure.<sup>94</sup> While the extent of the negative pressure is relatively small at approximately 10 cmH<sub>2</sub>O, a poorly sealing SAD would render an ITV ineffective. Of note sealing the airway during CPR is more demanding than during anaesthesia where most SADs have been evaluated. Those SADs that create a higher seal with the airway are likely to be more reliable to use with an ITV than those with low sealing properties. However, once again this hypothesis has not been tested.

## Conclusions

Airway obstruction is frequent in the critically ill and injured. Restoring a clear airway is an immediate priority and if this fails death is inevitable and rapid. For those skilled and practiced in its use the tracheal tube remains the best airway during resuscitation. However, alternative airway management may be required initially and in circumstances when tracheal intubation fails. There is a reasonable argument that intubation should not even be attempted by the inexperienced or unskilled. The supraglottic airways therefore have role in resuscitation both for first responders and for rescue when other techniques fail. International Liaison Com-

mittee on Resuscitation (ILCOR) currently lists only the classic laryngeal mask airway (cLMA) and combitube in its guidelines. An ideal supraglottic airway should be rapidly and reliably inserted with minimal training. It should allow controlled ventilation even in difficult patients and during chest compression. Ideally, it should provide protection against aspiration. It would be beneficial if it also facilitated subsequent tracheal intubation. A supraglottic airway that can be inserted when access is restricted may have benefits in out-of-hospital resuscitation. No single device fulfills all these requirements. However, the cLMA, intubating LMA (iLMA), ProSeal™ LMA (PLMA), combitube and laryngeal tube (LT) all fulfill some of them. The choice of supraglottic airway is therefore a compromise between these goals and different devices might be chosen in differing circumstances. New developments in supraglottic airways may offer benefits over the currently preferred devices. Considerable further research in this area is justified. This might include an examination of the appropriateness of training tracheal intubation to those who rarely use the technique.

## Additional Information

The British Medical Journal published a case report in November 2004, which described gastric rupture ascribed to the use of a SAD during out-of-hospital CPR.<sup>95</sup> The article was heavily criticised for lacking evidence for any causal relationship between the choice of airway and the complication. However, the considerable electronic correspondence<sup>96</sup> that followed is well worth reading for any reader interested in further details of this debate.

## Conflict of interest

Dr. Cook has been paid to lecture by Intavent Orthofix and the LMA Company, both distributors of laryngeal masks.

## Acknowledgement

Figure 6b and c are included with the permission of the LMA company.

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