Clinical Paper

The impact of airway management on quality of cardiopulmonary resuscitation: An observational study in patients during cardiac arrest

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A B S T R A C T

Background: Minimising interruptions in chest compressions is associated with improved survival from cardiac arrest. Current in-hospital guidelines recommend continuous chest compressions after the airway is secured on the premise that this will reduce no flow time. The aim of this study was to determine the effect of advanced airway use on the no flow ratio and other measures of CPR quality.

Methods: Consecutive adult patients who sustained an in-hospital cardiac arrest were enrolled in this prospective observational study. The quality of CPR was measured using the Q-CPR device (Phillips, UK) before and after an advanced airway device (endotracheal tube [ET] or laryngeal mask airway [LMA]) was inserted. Patients receiving only bag-mask ventilation were used as the control cohort. The primary outcome was no flow ratio (NFR). Secondary outcomes were chest compression rate, depth, compressions too shallow, compressions with leaning, ventilation rate, inflation time, change in impedance and time required to successfully insert airway device.

Results: One hundred patients were enrolled in the study (2008–2011). Endotracheal tube and LMA placement took similar durations (median 15.8 s [IQR 6.8–19.4] vs LMA median 8.0 s [IQR 5.5–15.9], p = 0.1). The use of an advanced airway was associated with improved no flow ratios (endotracheal tube placement (n = 50) improved NFR from baseline median 0.24 (IQR 0.17–0.40) to 0.15 to (IQR 0.09–0.28), p = 0.012; LMA (n = 25) from median 0.28 (IQR 0.23–0.40) to 0.13 (IQR 0.11–0.19), p = 0.0001). There was no change in NFR in patients managed solely with bag valve mask (BVM) (n = 25) (median 0.29 (IQR 0.18–0.59) vs median 0.26 (IQR 0.12–0.37), p = 0.888). There was no significant difference in time taken to successfully insert the airway device between the two groups.

Conclusion: The use of an advanced airway (ETT or LMA) during in-hospital cardiac arrest was associated with improved no flow ratio. Further studies are required to determine the effect of airway devices on overall patient outcomes.

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1. Introduction

Good quality CPR is paramount to patient survival.1,2 Observational studies have shown that the quality of CPR is poor in real life.3,4 Interruptions in chest compressions decrease coronary perfusion pressure5 and are associated with decreased defibrillation success and poor outcome.4,6–9

Although endotracheal intubation allows continuous chest compressions,10 prolonged interruptions associated with intubation may negate this benefit. Wang et al. observed a median time to intubation of 46.5 s (IQR 23.5, 73) and substantial pauses in compressions 109.5 s (IQR 54–198). Overall intubation contributed to 22.8% of all CPR interruptions in their study.11,12 The same study demonstrated how serious complications could result from endotracheal intubation by inexperienced healthcare professionals with intubation errors found in 22.7% episodes. Of these, 3% had misplaced or dislodged endotracheal tubes, 3% had multiple attempts and 15% had failed intubations.

In the pre-hospital setting, questions remain whether advanced airway management improves patient survival with at times
contrasting results reported by studies in both adult and paediatric cardiac arrests.13–16 A nationwide registry study in Japan of 649,359 patients found no survival benefit from any advanced airway management compared with bag valve mask ventilation.17 The implementation of minimally interrupted cardio-cerebral resuscitation protocols in this setting has led to improved survival.18 The multi-centre Resuscitation Outcome Consortium (ROC) in the US observed higher survival in patients who did not receive advanced airway management. However in those patients who received advanced airway management, a survival benefit was associated with endotracheal intubation in survival to hospital discharge compared to supraglottic airway device (adjusted OR 1.40; 95% CI: 1.04, 1.89).19 To date, there is a lack of research to elucidate how airway management may impact on quality of cardiopulmonary resuscitation.

Current resuscitation guidelines recommend intubation to be undertaken only by those trained in advanced airway management. Supraglottic airway devices have been advocated as an alternative to endotracheal tube and are now part of new resuscitation guidelines.20 Their ease of insertion without interrupting CPR makes supraglottic devices such as laryngeal mask airway (LMA) an attractive option.21 To date, most research on airway management in cardiac arrest has focused on quality of CPR in manikins. This study aims to assess the effect of airway device on quality of CPR in adult cardiac arrests.

2. Methods

2.1. Approvals

The study was approved by Birmingham and Black Country and Coventry Research and Ethics Committees. Given the observational nature of the study, the committees declared that individual patient consent was not required. The study was approved by Research & Development Department of Heart of England NHS Foundation Trust.

2.2. Setting

The study was conducted at Birmingham Heartlands hospital, a large teaching hospital with approximately 800 in-patient beds in Birmingham, United Kingdom. The Emergency Department sees approximately 100,000 new patients each year. The hospital manages approximately 350 in-hospital and 240 out-of-hospital arrests each year.

Consecutive cardiac arrests which took place from November 2008 to May 2011 were included in the study. Episodes were eligible for this study if airway device was inserted by a member of the hospital cardiac arrest team. All cardiac arrest team members have received training in the insertion of laryngeal mask airway (LMA) and are authorised to use them during cardiac arrest. It is the hospital policy that cardiac arrest team member must use a LMA unless they have been specifically trained and assessed as competent in endotracheal intubation.

2.3. Airway management and devices

Available airway adjuncts and devices in Heart of England NHS Foundation Trust were all disposable and included bag valve mask (Marshall Products, UK), endotracheal tubes (Portex®, Smith Medical, UK) and laryngeal mask airways (Marshall Products, UK).

2.4. Study design

This was a prospective observational study. Cardiac arrests were defined as loss of pulse that required chest compressions. Consecutive adult patients requiring cardiopulmonary resuscitation from in and out-of-hospital cardiac arrests were eligible for inclusion. Cardiac arrest episode was excluded if the cause was trauma, if patient was under 18 years old. Only data from the first arrest was collected if a patient suffered multiple arrests in order to avoid confounding factors. Episodes were also excluded if there was no quality of CPR data recorded or if the type of airway device used was not recorded.

2.5. Data collection

Background data about patients who suffered cardiac arrests included age, gender, location of arrests, presenting rhythm was collected from patient notes. Clinical data about the time of insertion of airway, any disruption to chest compressions, and the type of airway device used was collected by direct observation at cardiac arrests.

Quality of CPR data was collected from Heartstart MRx with QCPR (Philips Medical System) Management and Feedback Tool and analysed using QCPR Review software (Version 2.1.0, Laerdal Medical). The system consists of a small reusable compression sensor and a set of standard multifunction defibrillation electrode pads attached to a defibrillator. The Q-CPR compression sensor measures compression force and acceleration from which compression depth, proportion of compressions with depth ≤38 mm, proportion of compressions with leaning, compression rate and no flow ratio (proportion of resuscitation attempt when compressions are not being performed) are recorded.22,23 Thus a lower no flow ratio is associated with less interruptions in CPR and represents better quality CPR than a high no flow ratio. The multifunction pads measure chest impedance from which ventilation rate, average inflation time and average impedance change during inflation are calculated.24

Time of airway insertion was determined for each individual episode from the use of a stop watch during direct observations by a member of the research team, documentation from medical records and verified on the QCPR Review software. Time to insertion of airway was calculated manually from episodes and measured as the time from the beginning of episode until first recorded ventilation after successful insertion of airway. Time taken to insert the airway was recorded from direct observations by member of the research team and measured the time taken from starting to insert the airway until airway was secured and confirmed as effective.

2.6. Statistical analysis

The primary outcome was no flow ratio, the proportion of time from the first therapeutic event to the end of the episode when no chest compressions were provided as defined by international consensus.22 Based on data from a previous in-hospital CPR study,25 (no flow ratio standard deviation 0.13) we calculated that we would require 20 patients in each arm to detect a 0.1 difference in no flow ratio with 90% power. To allow for potential problems with data capture, we set out to recruit at least 25 patients into each arm of the study.

Quality of CPR data was analysed for the whole episode for before and after airway insertion to investigate the impact of airway device. Data were assessed for normality using Shapiro–Wilk test. For before and after effects, normally distributed data was compared by paired t-tests, non-parametric data were analysed by paired Mann–Whitney U-test. To compare airway groups, data was analysed using ANOVA with Bonferroni correction. Between subject factor was type of airway used and within subject factor was episode. A p value of <0.05 was considered significant for all tests.

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3. Results

During the study period, the majority of out of hospital cardiac arrests had airway device inserted prior to arriving in the hospital, leaving 33 (28.7%) episodes that fulfilled study criteria. During the same time period, 67 (82.7%) of in hospital cardiac arrests fulfilled study criteria and were included in the study (Fig. 1). A total of 100 episodes were included providing 1108 min of CPR data and 79,283 chest compressions for analyses.

Endotracheal tube (ETT) was inserted in 50 episodes, laryngeal mask airway (LMA) was used in 25 episodes and bag valve mask ventilation was used (BVM) in the 25 episodes. There were no significant differences in age, gender, presenting rhythm between patients in all three airway groups (Table 1). There were also no significant differences in ROSC and survival to discharge rates.

3.1. Quality of chest compressions before and after insertion of airway device

All episodes in the study achieved continuous compressions and asynchronous ventilations after insertion of either ETT or LMA. Compressions to ventilations ratio of 30:2 were maintained throughout episodes in BVM groups.

To differentiate temporal difference in CPR quality over time, we included a ‘before and after insertion’ effects for BVM group. The median time of insertion of both ETT and LMA (140 s) was used as the cut point for before and after insertion in BVM group.

Comparing before and after insertion of an airway device, both ETT and LMA led to significant reduction in NFR (ETT p = 0.012, LMA p = 0.0001) (Table 2). There was no significant changes in NFR BVM group (p = 0.888). The insertion of airway did not affect other quality of chest compression parameters.

3.2. Ventilation before and after insertion of device

There were 14 episodes (3 in ETT group, 2 in LMA group, 9 in BVM group) where no change in impedance tracing attributed to ventilations could be found. It was unclear whether this was due to misplacement of airway device leading to inability to achieve effective ventilation or overall poor quality of impedance recording. These episodes were therefore excluded in further analyses.

Average inflation time was calculated as average time between start and top of ventilation and was measured in seconds. In BVM group, the average inflation time increased in time from 0.81 s to 0.92 s suggesting that time needed to inflate the chest increased with the duration of arrest but this was not found to be statistically

Table 1
Characteristics of three airways groups. Data given as number (%) except for mean age ± SD.

<table>
<thead>
<tr>
<th></th>
<th>ETT (n = 50)</th>
<th>LMA (n = 25)</th>
<th>BVM (n = 25)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>OHCA</td>
<td>18 (36%)</td>
<td>4 (16%)</td>
<td>11 (44%)</td>
<td>0.751</td>
</tr>
<tr>
<td>Mean age ± SD</td>
<td>71.7 ± 13.3</td>
<td>72.4 ± 11.2</td>
<td>73.1 ± 15.3</td>
<td>0.802</td>
</tr>
<tr>
<td>Male</td>
<td>31 (62%)</td>
<td>16 (64%)</td>
<td>19 (76%)</td>
<td>0.488</td>
</tr>
<tr>
<td>Shockable rhythm</td>
<td>8 (16%)</td>
<td>3 (12%)</td>
<td>2 (8%)</td>
<td>0.121</td>
</tr>
<tr>
<td>ROSC</td>
<td>24 (48%)</td>
<td>6 (25%)</td>
<td>8 (32%)</td>
<td>0.079</td>
</tr>
<tr>
<td>Survival to discharge</td>
<td>6 (12%)</td>
<td>1 (4%)</td>
<td>2 (8%)</td>
<td>0.514</td>
</tr>
</tbody>
</table>
significant \( (p = 0.076) \) (Table 3). There were also non-significant increases in average inflation time after airway insertion in both LMA \( (p = 0.888) \) and ETT group \( (p = 0.787) \). These trends may reflect deteriorating pulmonary compliance which is seen when the duration of the resuscitation attempt increases.\(^{26,27}\)

Average change in impedance between start and top of ventilation and was measured in ohms. There was no statistically significant difference found between before and after insertion in all 3 airway group (Table 3).

Insertion of ETT led to a significant increase in ventilation rate from \( 6.9 \pm 4.9 \text{ min}^{-1} \) to \( 10.6 \pm 4.3 \text{ min}^{-1} \) \( (p = 0.0001) \). Similar increase in ventilation rate was not seen in LMA and BVM group (Table 3).

### 3.3. Airway device and time to insertion

There was no significant difference in median time to insert ETT and LMA (Table 4). There was no difference found in median time taken to successfully insert the airway between the two groups (ETT \( 15.8 \text{ s IQR 6.8, 19.4 vs LMA 8.0 s IQR 5.5, 15.9, p = 0.109} \) (Table 4).

Of note, there were three episodes where LMA was used to provide airway management but was then deemed unsatisfactory by the operator. On all three occasions, LMAs were changed into ETts by anaesthetists. In ETT group, all patients were successfully intubated on first attempt and there were no recorded failed intubations in our sample. No regurgitation after airway insertion was reported in the study.

### 4. Discussion

This is the first clinical study to demonstrate that the use of ETT or LMA significantly improved the quality of cardiopulmonary resuscitation by reducing overall no flow ratio. This occurred primarily due to switching from a compression to ventilation ratio of 30:2 to continuous chest compression and asynchronous ventilation. Airway devices were inserted with minimal interruptions in CPR (ETT 15 s, LMA 8 s) and the quality of CPR (compression rate, depth, leaning) was maintained after device insertion.

There are limited published data on the impact of airway device on quality of CPR in the clinical setting. In a simulation study, Abo and colleagues compared insertion of oesophageal combitube (ETC) vs endotracheal intubation (ETT) by paramedics.\(^{28}\) Time to successful airway insertion was measured and combitube was found to be significantly faster than ETC (ETC 75.5 s IQR 66, 99.5 vs ETT 110.5 s IQR 87.5, 125.5, \( p = 0.002 \)). Once inserted, ETC was associated with reduced no flow time (ETC 66.5 s IQR 60–74, ETT 73.5 IQR 68.5, 95, \( p = 0.005 \)). An observational study by Wiese et al. compared the use of the disposable airway device - laryngeal tube suction (LTS-D) with bag mask ventilation (BMV) during simulated resuscitation on a manikin. Their results suggested that NFT could be reduced significantly with the use of LTS-D compared to BMV (105.2 s vs 149.7 s respectively, \( p < 0.01 \)) in a simulated setting.\(^{12}\) These findings are consistent with an observational study by Kramer-Johansen et al. in humans which measured the quality of CPR before and after intubation. Mean no flow ratio decreased from mean 61% (SD 20) before intubation to 41% (SD 18) after intubation.\(^{29}\) Number of compressions delivered per minute was also significantly higher (47 min\(^{-1} \) (SD 25) before, 71 min\(^{-1} \) (SD 23) after). Ventilation rate also increased after intubation (5.6 min\(^{-1} \) (SD 3.7) before, 14 min\(^{-1} \) (SD 5.0) after) reflecting the transition from ventilation between cycles of compressions and continuous chest compression but also higher risk of hyperventilation.

There are a number of uncertainties about the role of advanced airways in cardiac arrest. Firstly there is uncertainty about whether ventilation is required at all in the early stages of cardiac arrest. A

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**Table 2** Quality of CPR before and after insertion of airway device. Data given as mean ± SD, except for proportions which are given as median (IQR).

<table>
<thead>
<tr>
<th>Quality parameter</th>
<th>Before</th>
<th>After</th>
<th>( p ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No flow ratio</td>
<td>0.24(0.17, 0.40)</td>
<td>0.15(0.09, 0.26)</td>
<td>0.012</td>
</tr>
<tr>
<td>Continuous compression (mm)</td>
<td>11.6 (7.6, 16.3)</td>
<td>11.5 (7.6, 16.3)</td>
<td>0.01</td>
</tr>
<tr>
<td>Compression rate (s/min)</td>
<td>110 (89, 128)</td>
<td>110 (89, 128)</td>
<td>0.01</td>
</tr>
<tr>
<td>Prop comp depth &gt; 30 mm</td>
<td>0.08(0.02,0.37)</td>
<td>0.02(0.00,0.18)</td>
<td>0.12</td>
</tr>
<tr>
<td>Prop comp with leaning</td>
<td>0.00(0.00,1.00)</td>
<td>0.00(0.00,1.00)</td>
<td>1.00</td>
</tr>
</tbody>
</table>

\( * \) Significant at \( p < 0.05 \).
series of recent studies from the Arizona and other groups support the value of prioritising cardio-cerebral resuscitation over ventilation in the early stages of out-of-hospital cardiac arrest.\textsuperscript{30–32} The present study examined patients in the later stage of out-of-hospital cardiac arrest or in-hospital arrest (higher percentage of patients with secondary cardiac arrest) where some form of ventilation is required. Our study was not powered to examine patient focused outcomes. Thus our finding of no statistical difference in ROSC rates (ETT 48%, LMA 25%, BVM 32%, p = 0.078) or survival to discharge rates (ETT 12%, LMA 4%, BVM 8%, p = 0.519) needs to be interpreted with caution. In other studies advanced airway management (ETT/Combitube,\textsuperscript{13} ETT/\textsuperscript{14,16}) was associated with worse outcomes.

The timing of airway intervention and any impact on interruptions in chest compression are likely to be important. There is evidence supporting avoidance of interruptions in CPR particularly during the early phases of resuscitation.\textsuperscript{6,7,33,34} Interruptions in CPR are linked to reductions in coronary perfusion pressure\textsuperscript{35} and development of ventricular fibrillation.\textsuperscript{36} Clinical studies have produced conflicting results with Shy identifying early intubation (within 12 min) as linked to improved survival in out-of-hospital cardiac arrest (RR late intubation 0.42, 95% CI 0.26, 0.69).\textsuperscript{37} By contrast, the American Heart Association’s National Registry of Cardiopulmonary Resuscitation failed to find any association between early advanced airway intervention (<5 min) vs late (>5 min) for ROSC or survival to discharge rates.\textsuperscript{38}

Given these uncertainties it is essential that if an advanced airway is planned, interruptions in CPR are kept to a minimum. In this study, the median recorded time taken to insert ETT was longer and took 15.8 s (IQR 6.8, 19.4). In comparison, median time taken to insert LMA was shorter (8.0 s IQR 5.5, 15.9) and within the recommended time. Although the difference was not found to be statistically significant, LMA was quicker to insert. Similar findings were reported in a manikin study by Gatward and colleagues who compared time taken to intubate with time needed to insert other supraglottic devices during chest compressions.\textsuperscript{39} Endotracheal intubation was found to be the slowest amongst the volunteers (19.0 s IQR 15.9, 24.0), followed by LMA (14.6 s IQR 12.8, 20.0) and iGel (7.8 s IQR 7.2, 9.0). The shorter time taken to insert airway in this study could be explained by hospital policy and resuscitation guidelines that intubation was only undertaken by those competent at intubation.\textsuperscript{40}  

One major advantage of using LMA is the ease of insertion even by non-experts but research has shown that airway management training on the ALS course on its own could not provide enough practical airway management and ventilation skills for non-anaesthetic trainees to become competent in managing an airway. A study by Deakin reported 37.5% of ALS trained non-anaesthetic trainees failing to insert LMA in anaesthetised patients, 11% resulting in airway complications compared to none in anaesthetic trainees.\textsuperscript{40} Interestingly, this study reported three episodes where effective ventilation was not achieved with LMA and this was later changed to ETT. In contrast to some published studies,\textsuperscript{11,41,42} the results did not reveal a high complication rate from endotracheal intubation and no failed intubation was reported.

The use of LMAs can be problematic in the emergency setting. The pressure seal formed by LMA is relatively low which can prevent effective ventilation when there is high airway pressure or low pulmonary compliance as seen in cardiac arrest.\textsuperscript{43} A recent study by Segal and colleagues elicited impact of supraglottic devices (SAD) on cardiovascular haemodynamics in pigs.\textsuperscript{44} In the swine model, three different SADs designed for human use (King tube, LMA and Combitube) all caused significant reduction in carotid bloodflow. The authors suggested that the increase in supraglottic pressure led to potential compression of carotid arteries which was also demonstrated in carotid angiography post mortem. Due to the obvious limitation of the animal model, the authors urged more research into this important area. In clinical use, LMAs can also be easily dislodged, requiring care with their use and frequent repositioning. Compared to ETT, the use of LMAs cannot isolate the airway and aspiration risk is high due to reduced oesophageal sphincter pressure during cardiac arrest.\textsuperscript{45} Although a Japanese study on out of hospital cardiac arrests reported a higher arterial pH with patients ventilated through LMA than BVM (pH 7.117 vs 7.075, p = 0.02).\textsuperscript{45} The group did not report any difference in gaseous exchange (PO\textsubscript{2} or PCO\textsubscript{2} or survival benefit. A recent propensity matched observational study in out-of-hospital cardiac arrest which included 5278 patients treated with BVM, intubation or LMA. This study found lower survival to discharge amongst patients receiving LMA compared to BVM (OR 0.45 (0.25–0.82)).\textsuperscript{47}  

### 4.1. Limitations

This study has several limitations. The sample size was small and there were more episodes in ETT group than LMA and BVM groups. The study sample included both out-of-hospital and in-hospital cardiac arrests therefore it was not possible to evaluate any impact on ROSC or patient survival. The study only compared two commonly available types of airway devices: ETT and LMA and their effects on quality of CPR. Other supraglottic airway devices are also suitable to be used in cardiac arrests such as iGel\textsuperscript{39,48}, laryngeal tube,\textsuperscript{49} and combitube.\textsuperscript{50}

Data collection was via defibrillator pads and measurements of thoracic impedance. Once robust review of our collected data was undertaken, we could not eliminate the artefacts imposed on segments of data during ongoing chest compressions. This effect may have most impact on ventilation parameters. Another measure of ventilation was capnography which we were unable to collect due to limited availability of equipment. A study by Edelson examined the use of capnography and thoracic impedance found that both

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**Table 3**

<table>
<thead>
<tr>
<th>Ventilation rate*</th>
<th>Average inflation time [s]</th>
<th>Average change in impedance [Ω]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before insertion</td>
<td>After insertion</td>
</tr>
<tr>
<td>BVM (n = 16)</td>
<td>9.1 ± 4.6</td>
<td>6.9 ± 4.1</td>
</tr>
<tr>
<td>LMA (n = 23)</td>
<td>6.6 ± 4.0</td>
<td>7.9 ± 4.7</td>
</tr>
<tr>
<td>ETT (n = 47)</td>
<td>6.9 ± 4.9</td>
<td>10.6 ± 4.3</td>
</tr>
</tbody>
</table>

* Excluding episodes with no ventilation detected.
Significant at p = 0.05.

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**Table 4**

<table>
<thead>
<tr>
<th>Time to insertion and time taken to insert device of the two groups.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Endotracheal tube</strong></td>
</tr>
<tr>
<td>Time to insertion (s)</td>
</tr>
<tr>
<td>Time taken to insert airway (s)</td>
</tr>
<tr>
<td>Failed insertion (%)</td>
</tr>
</tbody>
</table>
tend to underestimate ventilation rate. As yet there is no reliable method of assessing delivered tidal volumes and efficiency of ventilation during cardiac arrest.

5. Conclusions

This is the first study to demonstrate that the use of ETT or LMA significantly improves overall no flow ratio during resuscitation episodes when compared with using BVM in the in hospital environment. There was also no significant difference in quality of chest compressions between three airway groups. Time taken to insert airway devices was within recommended limits. Further studies are needed to examine the effectiveness of different airways during cardiac arrests.

Conflict of interest statement

Dr Yeung received a Resuscitation Council UK PhD fellowship from 2008 to 2011 which covered her PhD fees. No other funding was received for this study. The authors declared no conflict of interest.

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