

The development of a novel steerable bougie to assist in airway management

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RESEARCH

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ABSTRACT

Background

This paper describes the development of a new airway device that will improve the speed and safety of endotracheal intubation in anaesthesia and critical care. Case of need, design specification and fabrication of the steerable bougie mechanism is discussed.

Aims

Identify the need for a novel steerable bougie whilst considering technology readiness levels associated with medical device design. Analyse and produce suitable mechanisms utilising smart materials to increase device functionality aiding successful patient intubation procedures.

Methods

This work describes the total design activity that contributes to the successful development of medical devices, from case of need, to smart material actuation mechanisms. Research focuses on identifying a suitable control mechanism to allow a steerable tip to be integrated into a bougie with a control device attached to the laryngoscope.

Results

Data collected from a user group survey supported the development of a novel bougie, with better shape retention, variable rigidity within the tip, and an integrated steerable function. Analysis of several mechanisms, artificial muscles, and smart materials identified a cost-effective steerable mechanism that can be incorporated into a bougie.

Conclusion

Users have defined a need for an improved bougie. Controlling smart materials and mechanisms, within the predefined dimensions, identified strengths and weaknesses associated with steerable functions. The performance of the selected mechanism for incorporation requires a high level of control to accurately steer a device within the human airway.

Key Words

Airway management, Bougie, Emergency airway access, Intubation, Laryngoscopy, Steerable bougie

What this study adds:

1. What is known about this subject?

Airway management and intubation procedures continue to challenge anaesthetists. The current equipment available is not always adequate, suggesting device innovation is needed.

2. What new information is offered in this study?

Necessary improvements in airway devices are discussed, identifying suitable smart materials, actuators, mechanisms, and manufacturing processes required for a device with an integral steerable function.

3. What are the implications for research, policy, or practice?

Knowledge presented around actuator mechanisms, materials with respect to safety, control and response speeds are widely applicable; successful testing will lead to safer endotracheal intubation.

Background

The current state of knowledge and practice is that complications with airway management procedures have been documented for many years, with serious consequences, including mortality.¹

It is estimated that the total number of endotracheal intubations performed nationally per year in the UK is over one million. Difficult endotracheal intubation is an important part of overall difficulty with airway management. There is no one standard definition for a difficult airway, due to the numerous airway assessment and management techniques that exist and the complexities involved. Apfelbaum² defines the difficult airway as “the clinical situation in which a conventionally trained anaesthesiologist experiences difficulty with facemask ventilation of the upper airway, difficulty with tracheal intubation or both”. The incidence of difficult intubation is between 3–18 per cent³. Complications associated with difficulty include hypoxemia, awareness, trauma to the airway, aspiration of gastric contents, cardiac arrest and death.

A recent national survey of major complications of airway management in the UK suggests that improvements can be made in practice, design and choice of equipment.⁴

Optimally designed equipment is just one facet of difficult airway management, but recent devices have been demonstrated to improve airway management success rates.^{5,6}

Currently, there is a wide range of equipment on the market. Some devices are sophisticated and expensive such as videolaryngoscopes and fibreoptic scopes. Videolaryngoscopes, e.g., GlideScope®, Airtraq™ and C-MAC™, use a remote camera at the tip of the device to obtain an improved view of the larynx. Although this view is usually easy to obtain, manoeuvring the breathing tube to the correct position can prove challenging due to the acute angle at the base of the tongue “you see but you fail”.⁷

In addition to the physical limitations of these devices there are significant costs associated. The Glidescope® for example requires an initial setup cost of 8050.00 GBP which includes the monitor, mounted trolley and smart cable with the disposable blades costing between 8.00–27.00 GBP. Other single use devices such as the Airtraq™ are 35.00–45.00 GBP each, depending on their size.

In the most difficult cases, fibreoptic scopes are used. These steerable devices are expensive to buy and maintain, slow to set up and use in an emergency, and require a high degree of skill and experience to successfully operate.

The standard bougie by comparison is one of the most common intubation aids used in current practice. At Nottingham University Hospitals, approximately two thousand bougies a year are used; these are purchased at approximately 4.20 GBP per bougie compared to the Frova bougies which are approximately 11.00 GBP each. However, it is important to note that the original gum elastic bougies are still considered the gold standard device for use and cost 34.00 GBP each. The cheaper bougies available on the market perform poorly in comparison, and generate higher tip pressures.⁸

Bougies are long, flexible, relatively narrow, and have some intrinsic “memory”. They can be shaped and used when the view is limited and direct placement of the endotracheal tube itself would be difficult. Following successful placement of a bougie, an endotracheal tube can be “railroaded” over the tube itself to secure the airway. The bougie’s shape, however, cannot be adjusted while in the airway, so must be removed and reshaped if the orientation is not correct. The authors hypothesized that there was a gap in the currently available devices, between very simple bougies and the more sophisticated video and fibreoptic laryngoscopes.

We set out to determine whether firstly, there was a perceived need amongst clinicians for a mid-tier, steerable bougie, requiring minimal special training, as well as what features were required, and secondly, what options were available for construction of such a device.

Methods

An on-line survey was created by the authors, using the SurveyMonkey® website, to; establish a case of need, including, desired design improvements to current devices, and to inform the Product Design Specification (PDS). This was distributed to approximately 150 anaesthetists of all grades, at Nottingham University Hospital, UK. Our goal was to identify:

1. How commonly video laryngoscopy was used in their practice.
2. Type of video laryngoscopy device used.
3. Types of adjuncts used to aid intubation when using a video laryngoscope without a guided channel.

4. Experience of difficult or impossible intubation situations encountered despite having a good laryngoscope view and the prevalence of this situation.
5. Preferred new design features and increased functionality desired for a new device to assist successful intubation when using a video laryngoscope.

Understanding common practice and utilisation of equipment allows additional information to be considered based on the costs associated with anaesthetic procedures. A costings target can then be generated for a new device based on this data.

It is necessary to formulate a PDS to identify the design and manufacture needs of a product. Pugh⁹ emphasises that a PDS is a dynamic document which requires updating as more information is presented within a project. This is encapsulated by Pugh as “the establishment and evolution of the product design specification (PDS), and its acting like a mantle enveloping the whole core activity”.⁹

Predefining a design methodology mapped to the specification promotes an optimum total design activity, ensuring successful design and manufacture activities. Due to the experimental nature of medical device design research, the authors recognise that to ensure the successful design and manufacture of a medical device, a complete understanding of the device’s specifications and limitations have to be determined through concept development, observational research conducted through existing device training and real life procedure observations.

A PDS acts as an evaluative tool that allows the necessary review points to be identified. However, as the research phase progresses and technical problems are encountered, new information is continually added.

It is also important to consider technology readiness levels (TRL’s) during the planning and design of any new medical device. TRL’s are a systematic metric/measurement system which allows the assessment of the maturity of technologies or concepts compared to the maturity between different types of technologies.¹⁰ The research presented in this paper highlights the testing and selection of technologies considered for implementation into a new emergency airway device. Through initial concept development based on the PDS requirements set and mechanism testing, progression through TRL phases 1–3 as described by Mankins is expected to be demonstrated.¹⁰

Mankins¹¹ also discusses the effective use of technology readiness assessments (TRA’s) as an assessment of the riskiness of any new development. As such, it is important to consider the performance objectives, technology readiness levels and research and development degree of difficulty. Combining TRL’s, TRA’s, PDS’s and design methodologies together, this ensures that detailed design and manufacture phases are constantly monitored and reviewed to allow the optimum emergency airway device to be constructed.

In order to identify suitable materials and mechanisms to be integrated into any new device an initial material selection assessment was required based on the criteria presented within the initial design brief. The initial design brief stipulated that the steerable bougie should be a new steerable device capable of completing an intubation in thirty seconds, therefore increasing the speed of current intubation procedures. The new device should perform in a similar manner to the gold standard gum elastic bougie, but with increased steerable functionality within the 5mm diameter limitation of an adult bougie. The response time of the steerable function should be fast and positive with reaction and relaxation times of one second to ensure the device can be utilised on patients who are either unconscious or unable to breathe on their own.

Based on these initial criteria a review of suitable materials for device integration required the identification of existing steerable mechanisms, this was conducted analysing their construction and material properties. The identification of suitable materials used in existing mechanisms ensured a material property analysis could be conducted using a material selection database (CES Granta Design®). Within this material selection process the performance objectives highlighted within design brief were critical to material selection considerations which included a cost versus performance analysis.

Additional performance analysis charts were analysed based on design requirements utilising material screening, however it was also important to consider the bougie geometric limitations and design constraints which affected the potential outcomes. The material selection process identified the need to further analyse shape memory alloys, shape memory polymers and artificial muscles as possible solutions.

Shape Memory Alloys & Shape Memory Polymers

Breedon and Vloeberghs¹² described a small number of alloys which can undergo shape memory transformation.

Shape memory alloys (SMAs) can be heated to remember a previously set shape before being deformed to simulate a pre-set movement. One of the most common shape memory alloys, Nickel Titanium (Nitinol), has been used in a variety of aerospace and medical applications, but the control of the material can be difficult.

When a shape memory alloy is in its martensitic phase, it can be deformed and reshaped, however when heated through the transitional temperatures the alloy will return to an austenite phase. During this transitional phase, the forces produced activate the pre-set movement, dependent on the pre-set characteristics. Nitinol can be found in a number of different forms, the most common being Nitinol wire, bar, and tubing, Flexinol® wire and NiTi Springs, these can be used differently to meet an application's need.

An alternative to shape memory alloys is shape memory polymers (SMPs); there are a greater number of SMPs available compared to SMAs. SMPs varying properties allow them to be used in several different applications. SMPs are stimuli responsive materials which change shape based on an external stimuli.¹³ The most common stimulus used is a thermally induced reaction. SMPs can be stimulated using a variety of other stimuli; chemicals, pH, light or magnetic field, but the construction of the material defines the movements created and manipulated.¹⁴ Perhaps the most common types of shape memory polymers used are Electroactive Polymers (EAPs), and these are readily available in electronic and ionic forms. Kim and Tadokoro¹³ suggest that shape memory polymers now “enable new designs to be developed that are cost effective with small size and weights”.

Any mechanism or material used to develop emergency airway access devices will have to operate within an extremely small working area. In order to manipulate an SMP in a similar way to the movements observed in existing emergency airway devices, alterations will need to be made in relation to the devices physical shape to allow for positioning of intubation tubes.

Manipulating the shape of a polymer will require an alteration of the polymer elastic properties. However, it is important to note that the stimuli, or source used to create a steerable tip movement, will need external activation from the body and must not cause any alterations to the physical status of the patient while inside the trachea. Considering this, the use of heat activated controllable materials may be unsuitable for device control. Temperatures of internal tissues cannot be altered,

therefore an electrical stimulus should be considered for this application.

Low Cost Artificial Muscles & Applications

Even though there are various artificial muscles available for use in a variety of applications, suitable applications within the medical field, especially within emergency airway devices, are extremely limited. There are several performance and efficiency issues associated with high powered artificial muscles. High cost, large stroke rate and high stress artificial muscles have been associated with a number of performance issues which have limited their application within this field, especially when used in portable devices.¹⁵

Some of the main issues linked to the use of artificial muscles in portable devices are due to the current state of battery technology and their documented limitations. These range from small battery size to power output ratios, battery disposal and recycling issues (some of which are detailed in the regulations set out by the Medicines & Healthcare Products Regulatory Agency (MHRA)). However, Haines et al.¹⁵, proves that it is now possible to create low cost artificial muscles using fishing line and sewing threads, which replicate the high cost powerful artificial muscles.

These low cost artificial muscles are capable of providing fast, scalable, non-hysteretic, long life tensile and torsional muscles which are capable of lifting loads over 100 times heavier than a human muscle if compared at the same length and weight.¹⁵ These low cost artificial muscles can be manipulated in a similar manner to SMAs through electrical current or heat stimuli.

Suitable actuators and smart materials require testing to establish the timings and technical parameters required for integration into the steerable bougie. In particular, the device should be capable of moving the 50–60mm steerable tip within the pre-defined curvature control of 120 degrees (same plane) in a one second time frame. It's important to ensure that the forces involved in moving a steerable tip do not exceed potential tracheal damaging forces.

Testing was conducted on Nitinol/Flexinol® Wire, NiTi springs in combination with a pull wire and artificial muscles constructed from fishing line and sewing threads. Five hundred millimetre lengths were used due to material and manufacturing restrictions. These actuators and smart materials were controlled by an electrical or thermal stimulus, dependant on the underlying mechanism.

Measurement of the actuator's movements in comparison to the reaction and relaxation times was observed by visual markers and time recordings. The aim being, to establish whether the mechanisms were capable of completing the several tip movements required within the predetermined time frame.

A comparison of the costings associated with these materials and the activation capabilities' considering potential design limitations was performed to ensure consistency with the PDS.

The manufacture of the fishing line and sewing thread muscles required the coiling of a longer length of thread suspended from a clamped motor. The line/thread was held tight at one end by a small weight. This encouraged the coiling process as described by Haines et al.¹⁵ In order to produce fishing line and sewing thread muscles of 500mm length, up to two metres of line/thread was required.

To produce 700mm muscles, lengths exceeding 2.5m would be required. However manufacturing restrictions prevented this from occurring. In order to produce the desired pulling action, thermal contraction of the fishing line and sewing thread muscles is necessary. A heat gun was used to heat the muscle to generate the contraction/pulling forces. The heat applied had to be no greater than 240°C otherwise the reversible thermal contraction will be abolished.¹⁵

Results

The on-line survey was completed by 52 anaesthetists as shown in Figure 1. Representing a >30 per cent response rate. The majority (83 per cent) were senior trainees with over four years specialty experience or consultants. Figure 2 suggests that ninety two per cent used video laryngoscopy within their practice, and the majority of respondents were familiar with devices both with and without a guided channel. Respondents reported a range of adjuncts used with the video-laryngoscopes to aid endotracheal intubation, as shown in Figure 3. Despite this, 75 per cent of anaesthetists still reported being familiar with the situation whereby despite having a good view they were unable to intubate, with a third of respondents indicating this was a common finding; this is in keeping with the findings by Nielsen.¹⁶

Figure 4 presents participants results when asked what new properties would be desirable for a new bougie. There was a common theme related to improved tip flexibility and control. The results supported the argument for an improved bougie, particularly in connection with the use of

video laryngoscopes, and in particular that there is professional interest in a steerable function.

Combining the information collated from the survey results, the mechanism and material review, and the original project design brief, a detailed Product Design Specification (PDS) has been produced. The key issues associated with current equipment used for difficult intubation were identified and used to inform the PDS, particularly relating to identification of suitable materials, mechanisms and smart actuation systems relevant to the design and manufacture of a steerable bougie. A shortened version of the PDS detailing the key criteria is presented below:

Performance

1. The steerable bougie must add additional steerable functionality to the standard bougies.
2. Increase the ease of endotracheal intubation (reducing hypoxemic events).
3. Be capable of functioning as a standard bougie, with easy activation of its steerable function, in-situ in the airway if required.
4. Connection of the controller to the steerable bougie requires an accurate and quick fix connection to enable single-handed operation, therefore removing the need to pre-load endotracheal tubes.
5. The steerable bougie requires accurate tip curvature control of 120 degrees in one plane.
6. The steerable mechanism must provide a positive movement with reaction and relaxation times of one second without exceeding tracheal damaging forces.
7. The procedure should take no longer than 30 seconds, therefore providing sufficient time for multiple intubation attempts (if required) and reducing the possible need for surgical airway access procedures (i.e., cricothyroidotomy).
8. The device must function in conjunction with standard laryngoscopy equipment currently utilised in practice, a compatible control grip will be attached to the laryngoscope.

Size

1. The bougie length should be a total of 700mm long including a 50–60mm steerable tip.
2. The bougie shaft diameter should be no greater than 5mm and retain or improve bougie memory retention.
3. The detachable power connector located at the base of the bougie shaft should be no greater than

6.5mm in diameter and be of a suitable weight that will not hinder or impede the intubation procedure.

Product Cost

1. The targeted price range for the steerable bougie is 25–30 GBP.

Environment

1. The steerable bougie is to be used in direct contact with patient airways.
2. The steerable bougie is to be used by anaesthetists, intensive care and emergency room physicians during endotracheal intubation.
3. Selected materials must be safe to use during device operation whilst inside the human body, without causing a reaction to human tissue.
4. The human body normal temperature (37 degrees) must not affect device performance and material manipulation.

Maintenance

1. The device must have minimal or zero maintenance other than battery maintenance and sterilisation procedures.
2. The steerable bougie component is to be designed and used for a single operation and disposed after detachment from the reusable control grip. The disposal of components must comply with Health & Safety legislation, European Union Directives and Waste Electrical and Electronic Equipment (WEEE) legislation.
3. A battery indicator must be incorporated to ensure the notification of device inactivity.
4. The steerable bougie component must be capable of constant operation for a period of ten minutes with a maximum of forty moves per operation with a mean average of 25 moves \pm 20 per cent.

Ergonomics

1. The device should be suitable for single hand operation and the grip must be capable of being easily detached from the steerable bougie mid-operation.
2. The device should be optimised for use by both male and female adults, considering the 5th and 95th percentile hand dimension statistics available for design analysis.
3. The device should be easy to pass between operators during device operation and intubation procedures.

4. The controls should be intuitive and easy to operate with a single thumb also considering hand dimensions.

Safety

1. The steerable bougie must reduce the need of surgical airway access and improve the safety of standard bougie related procedures using existing emergency airway access devices.
2. The device must conform to the necessary medical safety guidelines and regulations; consideration must be made to Medical Device Directive 93/42/EEC.
3. The materials used for construction must minimise the chance of damage to airway soft tissues.
4. The forces generated by activation of the device must not be capable of damaging airway tissue.

Legislation

1. For successful operative integration, the device must adhere to the applicable medical regulations and pass clinical trials, providing proof of increased usability and safety in comparison to existing devices available on the market.
2. All materials and systems incorporated require the necessary medical approval and must conform to the appropriate medical legislation, i.e., Medical Device Directive 93/42/EEC, CE Mark Legislation and MHRA Medicines and Medical Device Regulations.

Considering the projects design brief and PDS, testing completed has identified a suitable mechanism for integration into the steerable bougie. This was conducted by testing the contraction and relaxation timings of artificial muscles through observational recordings utilising physical markers. These recordings were monitored based on the timings associated with the movements presented within the pre-set measured markers once the artificial muscle is activated. The movement of physical markers was monitored against a pre-measured rig, this allowed data to be collected based on the results of pulling actions. Initial pre-testing of artificial muscles suggested that reducing the total length by 2.8–3 per cent, would provide enough contraction to steer a bougie tip, therefore these measurements defined the location of the measurement markers. All of the materials and mechanism tests were conducted on 500mm muscle lengths.

Table 1 presents the data collected for the fishing line and sewing thread artificial muscles, along with data collected

from a Flexinol® wire setup and a constructed NiTi spring and pull wire mechanism. The PDS states a maximum mechanism reaction time of one second.

The results presented in Table 1 identify Flexinol® muscle wire as the most efficient and suitable mechanism for use (based on reaction times). Even though Flexinol® is the most expensive solution, this comfortably sits within the approved costings project plan. To ensure the reaction times of the Flexinol® wire are suitable for standard bougie lengths of 700mm, testing has been completed comparing the reaction times of 500mm and 700mm lengths.

Table 2 presents test data collected comparing the reactions times of 500mm and 700mm lengths of 150µm Flexinol® wire. Immediately it is noticeable that the reaction times are longer for the 700mm length compared to the 500mm length in order to generate the 2.8–3 per cent reduction in length. However a mean reaction time of 0.763 seconds was found and this still fits comfortably within the set requirements highlighted in the PDS.

Discussion

This work investigated the case of need for a new difficult airway device that could increase the safety and efficacy of endotracheal intubation without significantly changing the required training or costs. Our survey results clearly confirmed the presence of a concern amongst anaesthetists and intensivists in clinical practice around use of video laryngoscopes with conventional bougies. The data also suggested interest in steerable functionality. Although our user survey involved a relatively small sample of around 150 clinicians with a response rate of ~30 per cent, this was a highly representative group. The survey produced clear trends consistent with existing published concerns (particularly in relation to angled blade video laryngoscopes), and we believe the results supported the case for a steerable bougie.¹⁷

The data presented in Table 1 identifies a superior smart material (Flexinol® Wire 150µm), which should be incorporated into the steerable bougie. The NiTi spring and pull wire mechanism is not suitable as this presents a mean reaction time of 6.76 seconds to replicate the 2.8–3 per cent reduction in length.

The fishing line muscles manufactured from clear monofilament 4lb fishing line, did not meet the PDS requirements due to a mean reaction time of 3.06 seconds. The clear monofilament 6lb fishing line and the nylon monofilament sewing thread presented quicker reactions

times, (mean reactions times of 1.966 and 1.933 seconds), but this too is outside the PDS requirements. The 150µm Flexinol® wire presented a mean reaction time of 0.463 seconds, and was superior to all of the other mechanisms trialled and was the only material to fit comfortably within the requirements.

However, with the requirements set for a 700mm bougie, the analysis of the reaction times of a 700mm length of 150µm Flexinol® wire was required to ensure that suitable reaction times can be generated in order to create the necessary 2.8–3 per cent reduction in length. The Flexinol® wire is the most expensive actuator to purchase per metre, however if the device is mass-produced, this will significantly reduce the cost of purchase. Based on its current price and considering the total price point for the steerable bougie as highlighted in the main PDS, Flexinol® wire does not exceed the initial costing plans and can be affordably integrated into the device.

Following testing, the Flexinol® wire control mechanism appeared the best choice for inclusion; however, there are multiple different grades of Flexinol® available with different control parameters. Further investigation is necessary to ensure the optimum grade is identified. One of the concerns with the use of Flexinol® is its vulnerability to failure if the parameters are not carefully controlled. The integration of a pulse width modulation system to help control these parameters is desirable, therefore reducing hysteresis. Similar expectations were highlighted and achieved by Breedon and Vloeberghs when integrating Nitinol wire into facial nerve paralysis systems.¹²

The use of Nitinol has been extensively documented since its initial integration into medical devices and it is actively used in a wide variety of different applications, most commonly with vascular stents. The use of SMAs in medical devices is likely to increase as new devices are designed and manufactured, however, SMAs do have some significant drawbacks described by Morgan and Broadley.¹⁸ These specifically relate to increased brittleness displayed after a period of use, and the required power consumption. The steerable component of our proposed system is single use, therefore, repeatability and over use of the mechanism will not be an issue.

As with all new medical devices, uptake and effective use is a key issue when hoping to penetrate the medical device market. For the steerable bougie to be successful, a clear increase in procedure speed is required. It is also hoped that a reduction in required training compared to alternatives

and increased skill retention can be demonstrated. Device uptake relies not only on evidence of efficacy but also effective marketing and distribution. Uptake in the UK and the NHS can potentially be encouraged by creating an evidence file for the NICE (National Institute for Health and Clinical Excellence) device appraisal route.

Further testing is required for bougie construction utilising a variety of medical grade materials, in combination with the identified mechanism. Ensuring the mechanism's integrity during manufacturing process will be critical, especially due to the delicate nature of the Flexinol®. Initial proof of concept models have now been completed, and the subsequent sequential manufacturing plans have been produced. Trials will be required to ensure that manufacturing processes can be completed economically and in line with current medical regulations and legislation.

Airway perforation and tissue damage is always a risk with bougies. Previous studies have recorded forces as low as 0.8N causing injury, and this is a significant design challenge.¹⁹ It is hoped that by increasing the functionality and improving the shape retention, the forces exhibited will reduce and therefore improve the safety profile.

The results provide a firm foundation for the next TRL stages. Currently suitable bench trials are being designed with clinical and ergonomics partners to assess the device's performance in comparison to existing devices. These trials will have several key endpoints including task acquisition and skill retention, tissue injury, ease of use and physician satisfaction.

Conclusion and Further Development

The initial research has identified a case of need as well as the short-comings of existing devices. Design and manufacturing criteria have been generated and will be implemented during the next phases.

Work is currently being conducted with the Medical Engineering Unit at Queens Medical Centre, Nottingham, in order to develop the steerable bougie. Following construction of new prototypes, initial testing on manikins and suitable test rigs will be required; the force data collected can be compared to existing literature related to forces exerted on bougie tips similar to the studies completed by Hodzovic, Wilkes and Latta.²⁰⁻²¹

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CONFLICTS OF INTEREST

The authors declare that they have no competing interests.

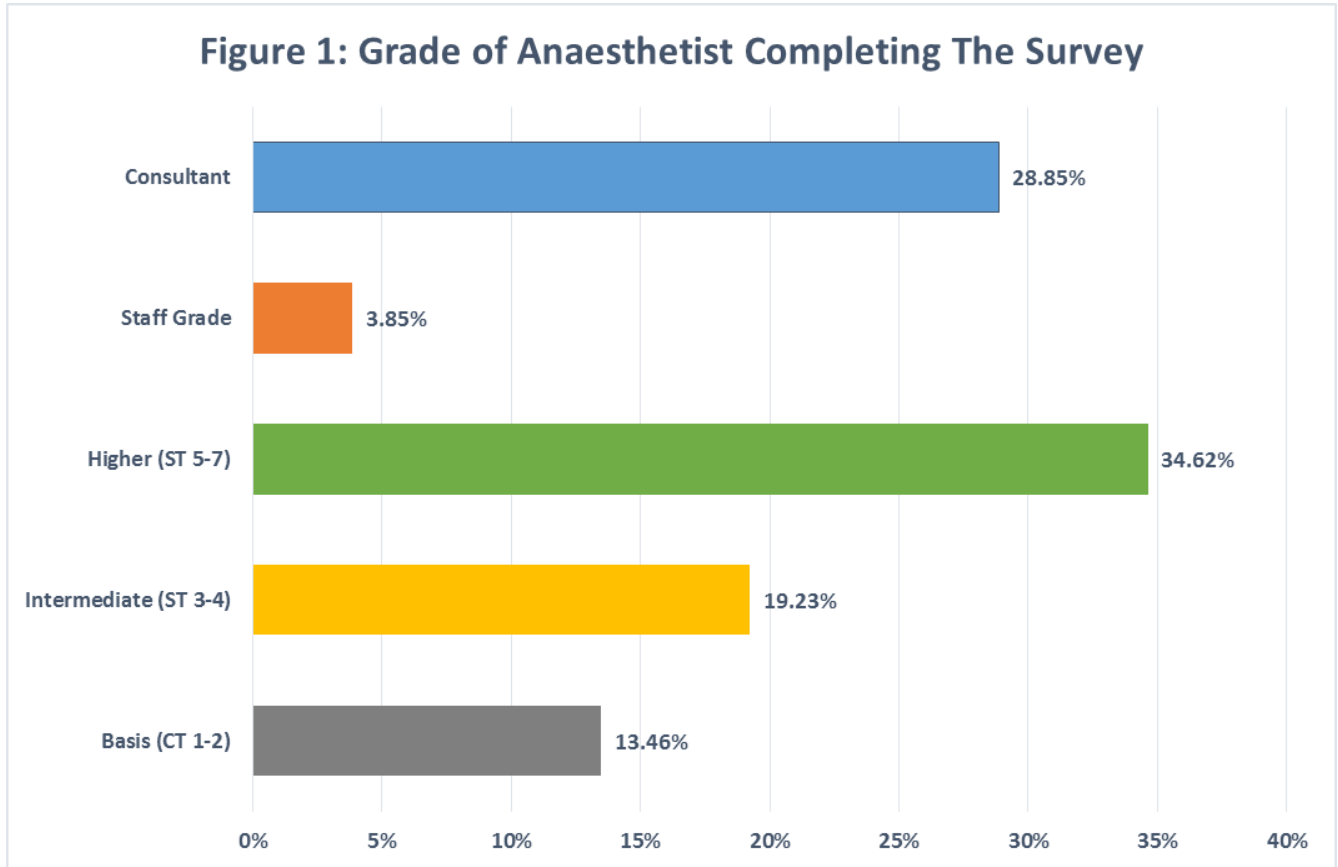
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Mr F.L.Siena is a funded PhD student at Nottingham Trent University by a Vice Chancellors PhD Bursary. The development of a novel steerable bougie is now also supported by a successful Nottingham University Hospitals Charity and NUH Department of Research and Development Pump Priming grant which is solely being used for product development and manufacturing.

ETHICS COMMITTEE APPROVAL

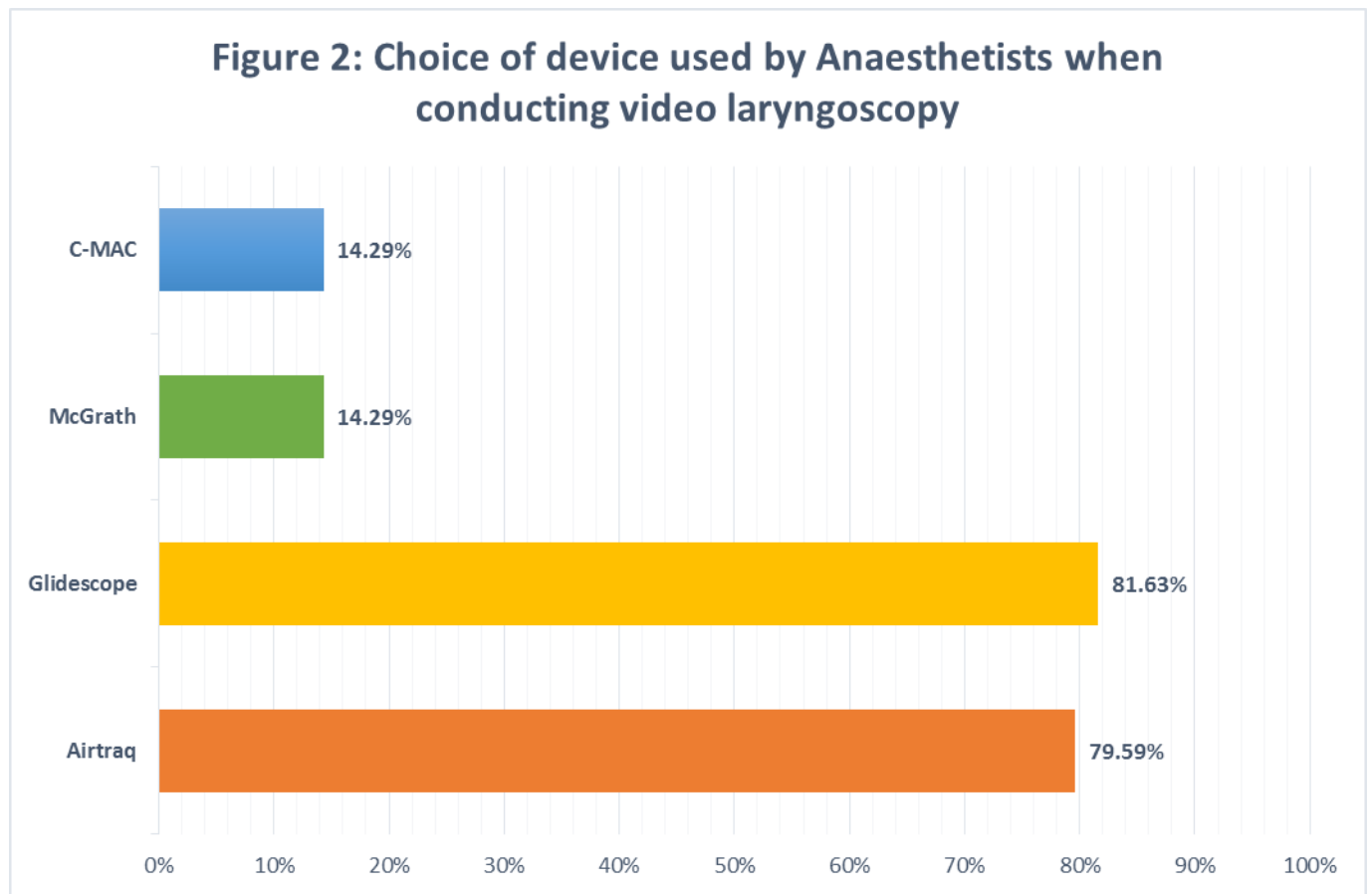
Not considered to be required at this stage.

Figure 1: Grade of anaesthetist completing survey



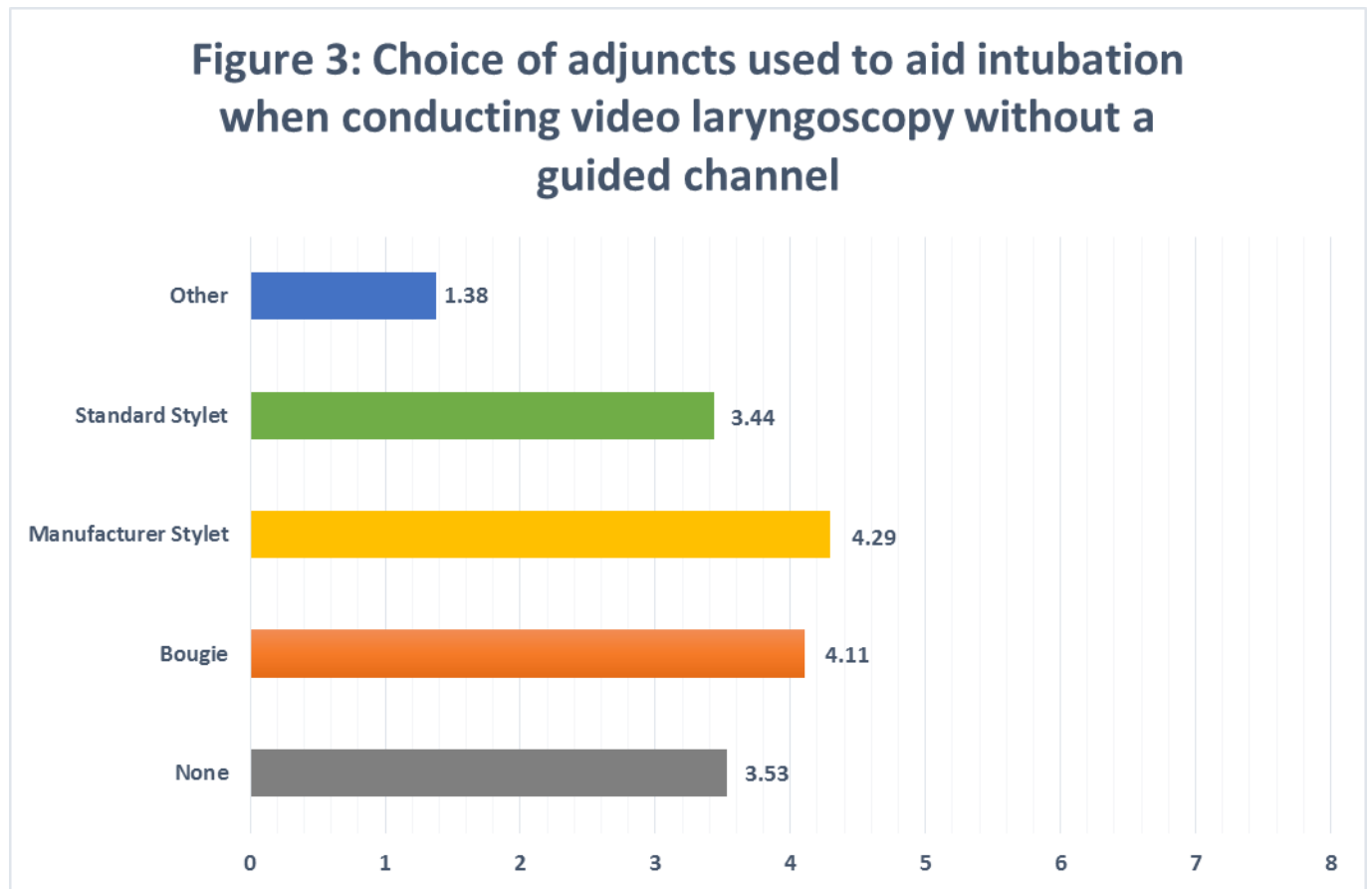
| Grade of Anaesthetist Completing The Survey | | |
|---|-----------|------------|
| Device Type | Responses | Percentage |
| Basis (CT 1-2) | 7 | 13.46% |
| Intermediate (ST 3-4) | 10 | 19.23% |
| Higher (ST 5-7) | 18 | 34.62% |
| Staff Grade | 2 | 3.85% |
| Consultant | 15 | 28.85% |
| Total No of Respondents | 52 | - |

Figure 2: Choice of device used by Anaesthetists when conducting video laryngoscopy



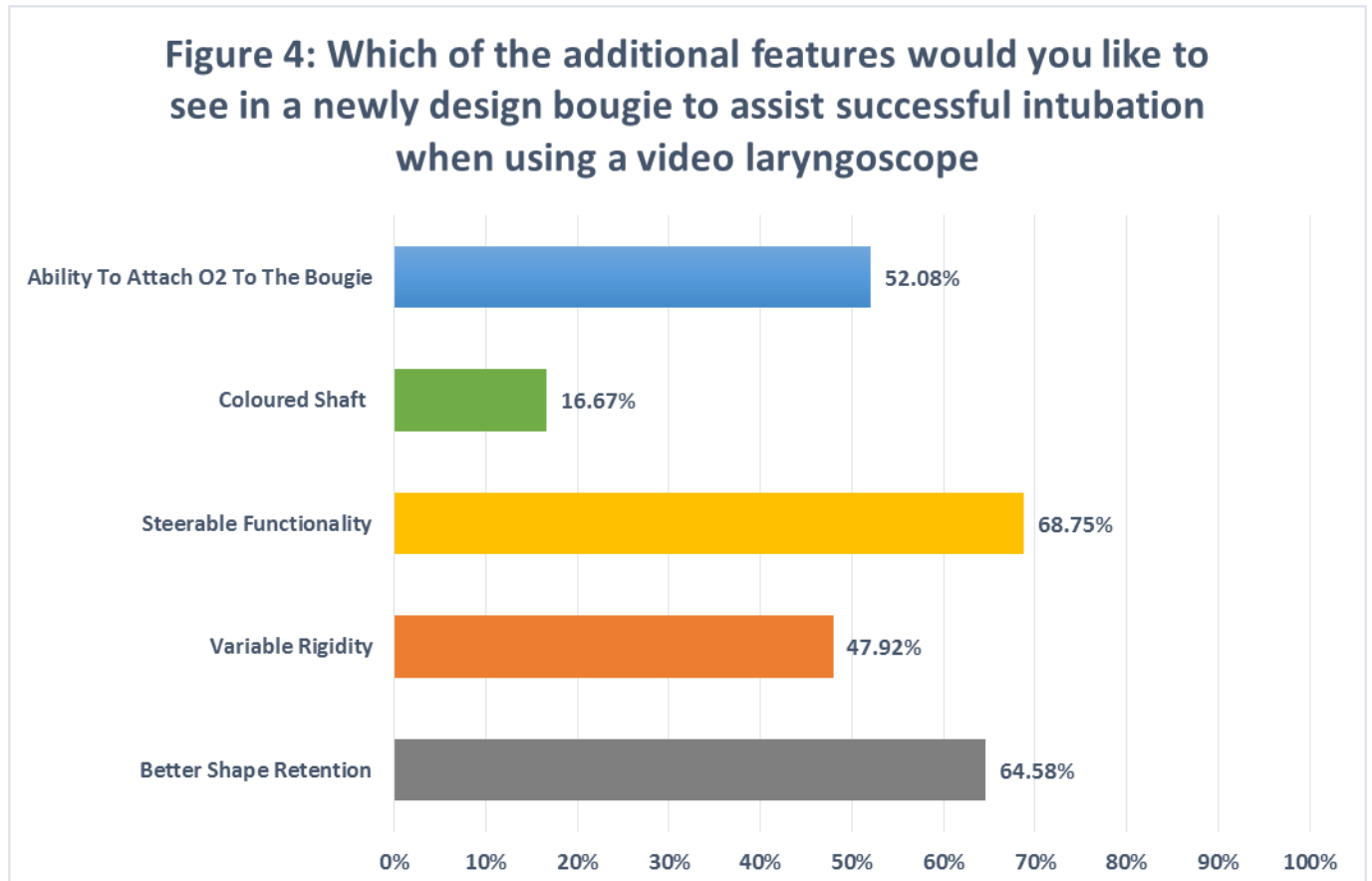
| Device Type | Responses | Percentage |
|-------------------------|-----------|------------|
| Airtraq | 39 | 79.59% |
| Glidescope | 40 | 81.63% |
| McGrath | 7 | 14.29% |
| C-MAC | 7 | 14.29% |
| Total No of Respondents | 49 | - |

Figure 3: Choice of adjuncts used to aid intubation when conducting video laryngoscopy without a guided channel



| | 1st | 2nd | 3rd | 4th | 5th | Total | Score |
|-------------------------|--------|--------|--------|--------|--------|-------|-------|
| None | 46.67% | 6.67% | 6.67% | 33.33% | 6.67% | N/A | 3.53 |
| Number of Respondents | 7 | 1 | 1 | 5 | 1 | 15 | N/A |
| Bougie | 32.43% | 45.95% | 21.26% | 0.00% | 0.00% | N/A | 4.11 |
| Number of Respondents | 12 | 17 | 8 | 0 | 0 | 37 | N/A |
| Manufacturer Stylet | 51.61% | 32.26% | 12.90% | 0.00% | 3.23% | N/A | 4.29 |
| Number of Respondents | 16 | 10 | 4 | 0 | 1 | 31 | N/A |
| Standard Stylet | 28.00% | 16.00% | 28.00% | 28.00% | 0.00% | N/A | 3.44 |
| Number of Respondents | 7 | 4 | 7 | 7 | 0 | 25 | N/A |
| Other | 0.00% | 0.00% | 12.50% | 12.50% | 75.00% | N/A | 1.38 |
| Number of Respondents | 0 | 0 | 1 | 1 | 6 | 8 | N/A |
| Total No of Respondents | 42 | - | - | - | - | - | - |

Figure 4: Additional features Anaesthetists in a newly design bougie to assist intubation



| Which of the following features would you like to see on a newly designed bougie to assist in successful intubation when using a video laryngoscope? | | |
|--|-----------|------------|
| Device Type | Responses | Percentage |
| Better Shape Retention | 31 | 64.58% |
| Variable Rigidity (More Flexible Tips) | 23 | 47.92% |
| Steerable Functionality (To Allow Shape Change With Device In Situ) | 33 | 68.75% |
| Coloured Shaft (To Guide Insertion Depths) | 8 | 16.67% |
| Ability To Attach O2 To The Bougie | 25 | 52.08% |
| Total No of Respondents | 48 | - |

Table 1: Comparison of reaction times for smart materials and artificial muscle systems at 500mm length

| Smart Material/Artificial Muscle Type | Reaction Time 1 (Seconds) | Reaction Time 2 (Seconds) | Reaction Time 3 (Seconds) | Average/Mean Reaction Time (Seconds) | Price Per Metre |
|--|---------------------------|---------------------------|---------------------------|--------------------------------------|-----------------|
| Clear Monofilament Fishing Line 4lb | 3.2 | 2.8 | 3.4 | 3.133 | £0.044 |
| Clear Monofilament Fishing Line 6lb | 2.0 | 1.8 | 2.1 | 1.966 | £0.044 |
| Nylon Monofilament Sewing Thread Clear 0.24mm Diameter | 1.9 | 1.8 | 2.1 | 1.933 | £0.0012 |
| NiTi Spring Plus Attached Pull Wire | 6.8 | 6.4 | 7.1 | 6.766 | £1.23 |
| Flexinol® 150 Wire - 150µm | 0.45 | 0.48 | 0.46 | 0.463 | £1.61 |

Table 2: Comparison of reaction times of Flexinol® wire at different potential steerable bougie lengths

| Smart Material/Artificial Muscle Type | Reaction Time 1 (Seconds) | Reaction Time 2 (Seconds) | Reaction Time 3 (Seconds) | Average/Mean Reaction Time (Seconds) |
|---|---------------------------|---------------------------|---------------------------|--------------------------------------|
| Flexinol® 150 Wire - 150µm-500mm Length | 0.45 | 0.48 | 0.46 | 0.463 |
| Flexinol® 150 Wire - 150µm-700mm Length | 0.80 | 0.73 | 0.76 | 0.763 |