

New options for airway management: intubating fiberoptic stylets[†]

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Fiberoptic and video technologies are widely used for airway management. Fiberoptics have been used in most airway intubation devices, including rigid laryngoscopes and in the tracheal tube wall itself.^{10,22} Optical stylets, which incorporate flexible fiberoptic imaging elements in an intubation stylet, have now also become available.

More than 10 new optical stylet devices have been introduced since 1995, which shows that combining viewing capability with the familiar handling of a stylet is an appealing concept (Table 1). But are these useful tools? Are their clinical performances similar or is one best? We survey the evolution of optical stylets, describe their properties, summarize their clinical performance and describe an ideal system.

History

Almost 35 years ago, Murphy reported successful nasal intubation using a flexible choledochoscope placed through a tracheal tube.¹⁹ Flexible fiberoptic technology was then used to assist with intubation. The Flexible Fiberoptic Laryngoscope was a short flexible bronchoscope with a pistol-grip handle, angulation control lever and eyepiece (Fig. 1). The use of this device was reported in 1972³² and additional reports soon followed.^{3,9,23,33,40} Over the years other similar devices were developed—the Port-O-Scope (Mercury Medical, Clearwater, FL, USA) and the Rapiscope (Cook Critical Care, Bloomington, IN, USA)—but unlike the flexible bronchoscope, they never found widespread use.^{8,28}

Katz and Berci^{4,13} coined the term ‘optical stylet’ in 1979 to describe a straight rigid endoscope used as a tracheal tube stylet during intubation (Fig. 2). Although used extensively for teaching purposes, its rigid straight design limited its use in difficult airway management. Bonfils modified this by

adding a fixed curve to the distal end (Fig. 3). The Bonfils Retromolar Intubation Fiberscope (Karl-Storz, Culver City, CA, USA) was used for difficult intubations from a retromolar approach.⁷

The earliest intubation aid with fiberoptic technology in a semi-malleable and formable stylet was the Fiberoptic Stylet Laryngoscope, introduced in the mid-1970s (Fig. 4).²⁰ This configuration remains popular.

Commercial failures

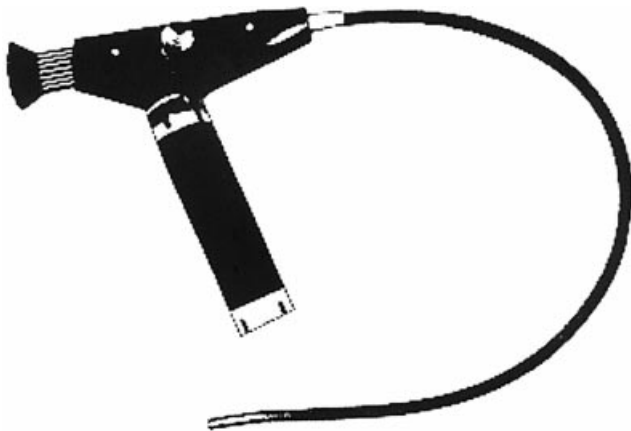
Despite their popularity, the first optical stylets developed are no longer commercially available. More recent devices with a Schroeder stylet design^{18,36} (Aeroview, Imagyn, Newport Beach, CA, USA; Video-optical Schroeder Stylet, Volpi AG, Schlieren, Switzerland; Flexguide, Scientific Sales International Inc., Kalamazoo, MI, USA) have also met with commercial failure. The Schroeder stylet does not hold a specific shape but can be flexed anteriorly by depressing a lever on the proximal end of the device (Fig. 5). The position of the lever means that these devices must be held at their proximal end like a dagger.

The Aeroview is the only Schroeder-stylet-based system that has been studied clinically (Fig. 6). In a small study using the Aeroview, only seven of 13 patients with uncomplicated airways were intubated successfully, despite jaw thrust, sniffing position and tongue retraction.¹⁸ Ease of use was 2.8 (SD 0.8) on a scale of 1–5 (poor–superior). The investigators concluded that experience was needed to use the device successfully and this may have contributed to its commercial failure.

[†]*Declaration of interest.* Dr Gravenstein has commercial interests in a company associated with intubating devices. The University of Florida owns patents in intubating devices.

Table 1 History of optical stylets. *Alternative designs without stylet functionality but with similar viewing capabilities

Manufacturer	Device	Year introduced/commercially available (✓)
American Optical	Fiberoptic Laryngoscope	1974
American Optical (for Karl Storz KG)	Optical stylet	1979
American Optical	Fiberoptic Stylet Laryngoscope	1983
Karl Storz KG (Germany)	Bonfils Retromolar Intubation Fiberscope	1983 (✓)
Anesthesia Medical Specialties (AMS)	Fiberlightview Shuttle	1994 (✓)
Clarus Medical LLC (Ventus brand name)	Shikani Seeing Stylet	1996 (✓)
Nanoptics, Inc.	Nanoscope	1997
Scientific Sales International	Flexguide	1997
Volpi AG (Switzerland)	Video-Optical modified Schroeder Stylet	1997
Pulmonx, Inc.	Visualized Endotracheal Tube (VETT)*	1997 (✓)
Imagyn Medical Technologies Inc. Volpi AG (Switzerland)	Aeroview Video-Optical Intubation Stylet (VOIS)	1998
Jedmed Instrument Co. (US distributor for Machida Corp. Japan)	Machida Portable Stylet Fiberscope (PSS-6)	1999
Nihon Koden (Japan)	StyletScope	1999 (✓ Japan only)
Acutronic Medical Systems AG (Baar, Switzerland – similar to device by Volpi AG)	Video-Optical Intubation Stylet (VOIS)	2000 (✓ Europe only)
Parker Medical	TrachView Videoscope*	2000 (✓)

**Fig 1** The Flexible Fiberoptic Laryngoscope.

Optical stylet: design characteristics

The characteristics of all commercially available fibreoptic stylet devices are summarized in Table 2.

Special cases

Two devices, the Visualized Endotracheal Tube (VETT, Pulmonx, Inc., Palo Alto, CA, USA) and TrachView (Parker Medical, Englewood, CO, USA), are not optical stylets because the optics are not incorporated into a shape-retaining stylet (Figs 7 and 8). However, the VETT, with

optical fibres embedded in its wall, forms an image from the tip of the tube and can be manipulated using a standard stylet. The TrachView intubation system is a flexible fibreoptic viewing element designed to be placed either alongside a stylet within a tracheal tube or inside a tracheal tube when an external intubation guide is used to hold the shape of a tracheal tube (Fig. 9). The TrachView system resembles the method described by Lupien and colleagues¹⁷ using a flexible fibreoptic endoscope alongside a conventional intubation stylet in the tracheal lumen.

Stylet diameter

The stylet diameter determines the minimum size of tracheal tube that can be used. Paediatric versions exist of the Fiberlightview Shuttle (Anesthesia Medical Specialties, Santa Fe Springs, CA, USA), the Shikani Seeing Stylet (Clarus Medical, Minneapolis, MN, USA) and the Video-Optical Intubation Stylet³⁸ (VOIS; Volpi AG, Schlieren, Switzerland).

Type of fibres/image resolution (pixel count)

Most optical stylets use glass fibres to transmit the image to an eyepiece or camera. However, the Nanoscope (Nanoptics, Gainesville, FL, USA)^{11,12} (Fig. 10) and the StyletScope (Nihon Koden Corp., Tokyo, Japan)^{15,16} (Fig. 11), have image guides made of plastic. Plastic fibreoptic fibres are quite resistant to breakage compared with glass, but often have a lower pixel count, which

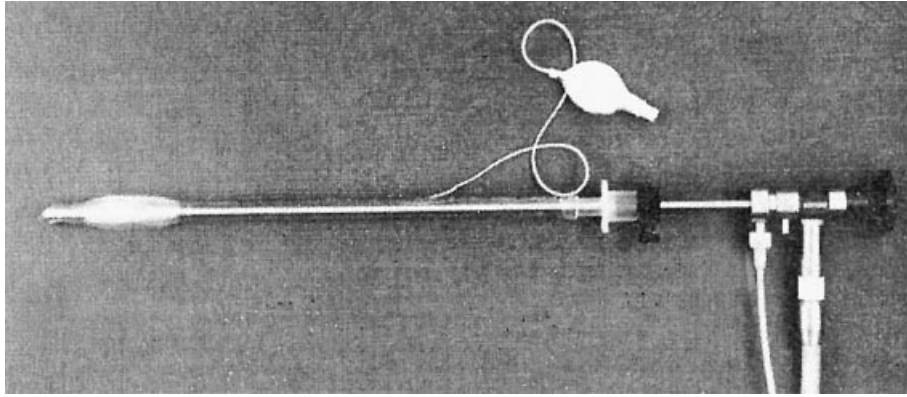


Fig 2 The straight rigid endoscope used as a tracheal tube stylet during intubation used by Katz and Berci in 1979, which they described as an 'optical stylet'.

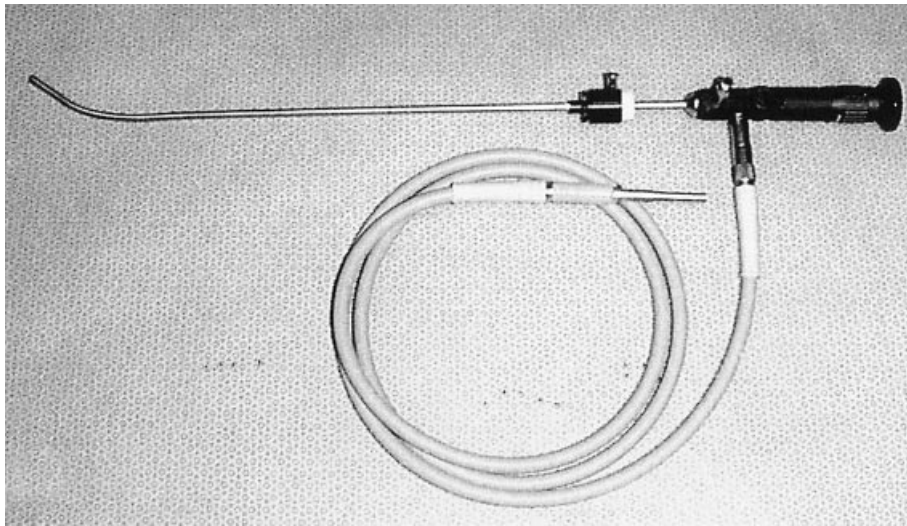


Fig 3 Modification of the Katz and Berci's 'optical stylet' (Fig. 2) by addition of a fixed curve to its distal end.

reduces image resolution. The image brightness also decreases more rapidly in plastic fibres as the image guide length increases, because plastic fibres absorb more light than do glass fibres. More recently, plastic optical fibres with 7000 or more pixels and high clarity have begun to rival their glass counterparts. A comparative clinical trial of a 3000-pixel Nanoscope graded the view as 8 on a 1–10 scale, compared with 10 by direct laryngoscopy and flexible fiberoptic endoscopy.¹² The poorer image quality did not affect the success rate for intubation in this comparative study. The image quality of the StyletScope with 3500-pixel resolution appeared to be inferior compared with glass fibrescopes, which typically use 10 000 or more pixels.¹⁶ However, the 3500-pixel resolution of the StyletScope was clear enough for successful intubation. The minimum number of pixels needed for a clinically useful image is not known. Both pixel count and display size affect image quality. Low-pixel-count devices tend to use eyepieces or smaller display screens (15 cm diagonal or less) because

they pack pixels more tightly and give the illusion of a sharper image.

Angle of view and focal length

Objects are focused by a distal objective lens in the tip of the optical stylet. The lens has an angle of view, which is the cone-shaped visual field. Greater angles provide a more panoramic view. Fiberoptic stylets have angles of view ranging from 50° to 100°. Wide-angled views can help to find the glottic opening when the stylet tip is not in the midline or encounters an anterior or deviated glottis. The distal lenses in all the fiberoptic stylets have a focal length of 5–50 mm, which is adequate for intubation purposes.

Channels

Stylet channels allow oxygen insufflation, drug administration, and suctioning. Few optical stylets have channels

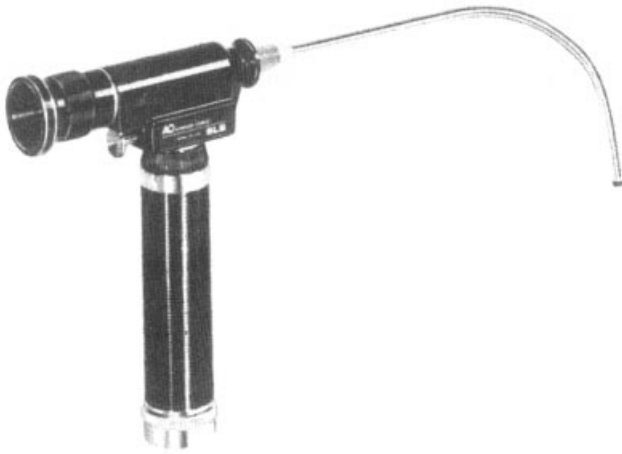


Fig 4 The Fiberoptic Stylet Laryngoscope.

(Aeroview, Bonfils fiberscope, Fiberlightview Shuttle (Fig. 12), Optical Stylet) because they increase stylet diameter and limit the size of the tracheal tube that can be mounted. In reusable systems, these channels can transmit infection if they are not properly cleaned.²⁴ The Shikani Seeing Stylet (Fig. 13) lacks an oxygen insufflation channel but allows for insufflation through the tracheal tube itself. The VETT has a large unobstructed channel for selective suction under indirect vision because the optical fibres are in the tracheal tube wall.

Proximal viewing element

Most fibreoptic stylets have a proximal focusing lens in a standard 32-mm outside-diameter eyepiece. A camera can be attached to the eyepiece, in the same way as with flexible fibreoptic endoscopes, for viewing on a monitor. However, adding hardware to the proximal end of the tracheal tube can increase the stylet weight, which makes the optical stylet difficult to manoeuvre with one hand. With a camera attached to an eyepiece, the monitor display size should be considered. Larger displays (38 cm diagonal) can be used for devices with 10 000 or more pixels. If a larger display is used with devices with fewer pixels, the image shows the cladding around the individual optical fibres, producing a honeycomb-patterned image that can be difficult to interpret.

In contrast, the Nanoscope, TrachView Videoscope (Parker Medical, Englewood, CO, USA), VOIS (Fig. 14) and VETT do not use a traditional monocular eyepiece with a proximal lens. Instead, they use a long image guide that connects to a charge-coupled device, which transmits the image directly to a monitor. This avoids adding weight to the stylet–tracheal tube assembly, but needs special connectors, a custom light source and a monitor.

An integral camera could provide a better image than a traditional eyepiece, with automatic focus, automatic zoom and image enhancement filter. However, these features may not always produce a better image. Excessive light may

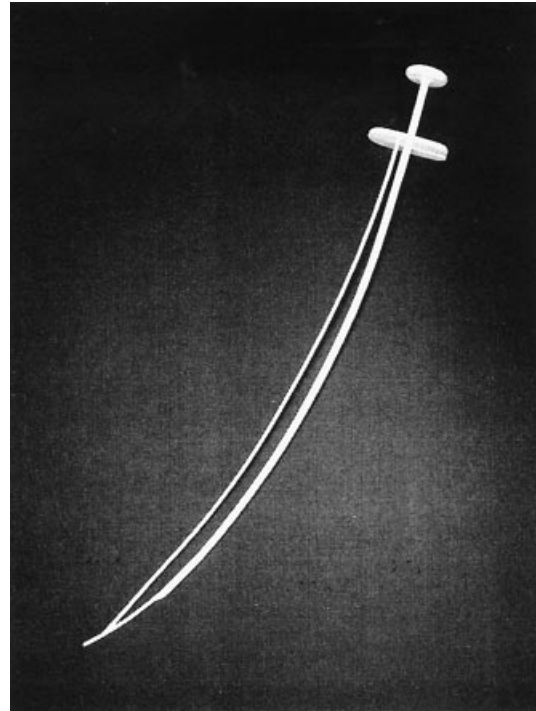


Fig 5 The Schroeder stylet.

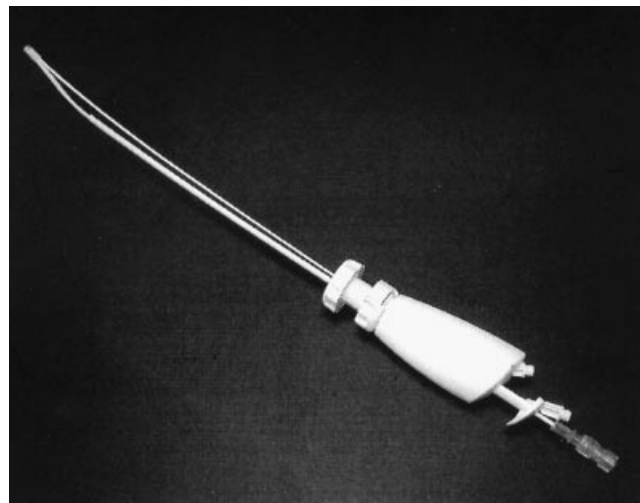


Fig 6 The Aeroview.

saturate a charge-coupled device, turning the displayed image into a blank screen. The video system of the Aeroview did not reliably adapt to increased light intensities and we experienced numerous ‘whiteouts’ during intubation.

Light source

Many fibreoptic stylets have a battery-powered light source. This is convenient because the user is no longer tethered to

Table 2 Technical specifications of commercial devices (alphabetical order). *Length of the device part on which the tracheal tube is mounted.

Device	Stylet diameter × length	Fibre type	Pixel count	Angle of view	Viewing element	Light source	Flexibility and radius of curvature
Bonfils Fiberscope	5 mm × 40 cm	Glass	12 000	90°	Eyepiece	Storz fiberoptic connector	Rigid with 45° anterior tip curvature
Fiberlightview Shuttle	3.5 mm × 33.5 cm (0 channels)	Glass	10 000	70°	Eyepiece	Battery handle	Stylet malleable to 90° (deflectable tip optional)
Machida Portable Stylet Fiberscope	5.4 mm × 39.5 cm	Glass	NA	80°	Eyepiece	Battery-powered light source	Malleable to 90°
Shikani Seeing Stylet	5mm × 27 cm	Glass	30 000	70°	Eyepiece	Fiberoptic connector, laryngoscope handle or battery handle	Malleable to 90°
StyletScope	7.0 mm ET	Plastic	3500	50°	Eyepiece	Light source handle and battery box	Deflectable tip with 75° anterior flexion
Trachview Videoscope	5.5 mm ET	Glass	10 000	100°	CCD	Custom	Used with stylet or external ET guide
Video-Optical Intubation Stylet (Acutronic)	3.8 mm × 40 cm	Glass	10 000	50°	CCD	Custom	Malleable to 90°
Visualized EndoTracheal Tube	10.4 mm (OD) 7.0 or 8.0 mm (ID)	Glass	6000	70°	CCD	Custom	Flexible—use with any stylet

ET=endotracheal tube; CCD=charge-coupled device; OD=outer diameter; ID=internal diameter; NA=not available

the fiberoptic light source. However, a lithium battery can increase cost if batteries have to be replaced frequently.

Flexibility and radius of curvature

If a stylet cannot be bent forwards, it may not be useful if neck extension or mouth opening is limited, or if the larynx is anterior. The Bonfils Retromolar Fiberscope is a rigid scope but has a 45° curvature built into its distal end. The newest StyletScope is rigid proximally but the tip has a 90° anterior flexibility.¹⁴ The remaining fiberoptic stylets have varying degrees of malleability with an anterior curvature of at least 90°.

Clinical performance review

True difficult airways—case reports

The first detailed case report was of the Fiberoptic Stylet Laryngoscope for intubation in a patient with a difficult airway caused by an anterior mediastinal mass and superior vena cava syndrome.²⁹ Having a hand free to position the head and palpate and manipulate the larynx was noted to be an advantage. An optical stylet can be used in stand-by mode for rescue when conventional direct laryngoscopy fails, as shown with the VOIS.³⁴⁻³⁹ Two patients with unexpected Cormack grade III views were successfully

intubated using the VOIS to display the vocal cords on a video screen. The head, neck and larynx did not need manipulation, nor was help needed from an assistant. Gravenstein and colleagues reported a similar experience with a Nanoscope prototype.¹² Two abstracts describe the intubation of 35 emergency patients with a VETT.^{21,22} Eleven of the airways were ‘difficult’ because of anatomy, blood or secretions but all were intubated successfully. The VETT aided success in eight of these intubations.

True difficult airways—clinical trials

The Bonfils Retromolar Intubation Fiberscope was used in a clinical trial of 103 patients with unexpected difficult airways.²⁵ Initial airway evaluation was made under general anaesthesia. Most of the patients in this trial (80%) were undergoing ENT or oro-maxillo-facial surgery and 17% had Cormack grade III and IV airways. All the patients were intubated successfully by the mouth (not retromolar) using the Bonfils Retromolar Intubation Fiberscope. The optical stylet was the sole intubation device in 80% of patients. However, a Macintosh blade was still used in conjunction with the Bonfils Fiberscope in the remaining 20% of patients. No patient with limited mouth opening or severely limited neck extension was intubated during this study. Presumably the fixed anterior curvature of the device would make it difficult to negotiate the oro-tracheal angle in these

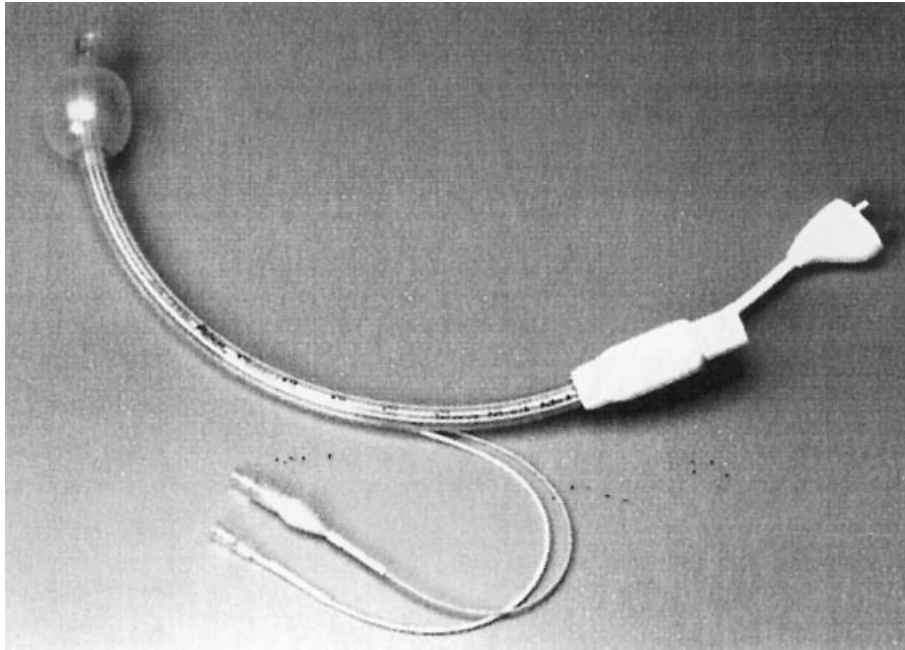


Fig 7 The Visualized Endotracheal Tube.



Fig 8 The TrachView.

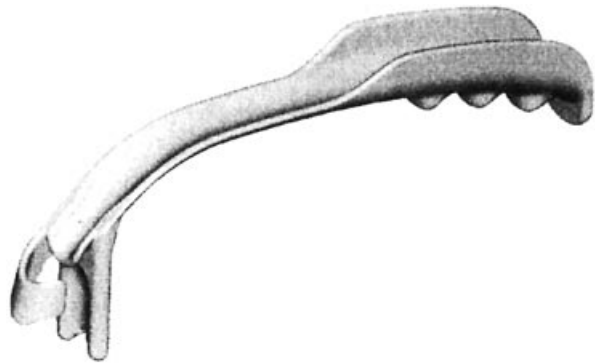


Fig 9 The Trach view external endotracheal tube guide.

patients, and the authors themselves remarked that the device was probably not suitable for such patients.

The Machida Fiberscope (Fig. 15) was used with patients with Cormack grade III and IV (16 of 34 patients) on conventional direct laryngoscopy.²⁷ The optical stylet was inserted beyond the tongue along the blade of the laryngoscope. Visualization and intubation was successful in all patients, but it was not clear if the Machida Fiberscope could be used as a sole intubation device. This is the only study that reports the duration of intubation. The 28–30 s duration of intubation was not significantly greater than in patients with Cormack grade I, II or IIIa airways (where ‘a’ denotes that the epiglottis does not touch the posterior pharynx). Duration of intubation was longer in some

patients with Cormack grade IIIb and IVa airways (‘b’ indicates that the epiglottis is in contact with the posterior pharynx), taking up to 64 s. The jaw-thrust manoeuvre might move the epiglottis away from the posterior pharyngeal wall and is better than conventional direct laryngoscopy.²

The Shikani Seeing Stylet was evaluated in both adults and children.³⁰ A small number (4%) of patients were intubated awake. In anaesthetized patients, intubation was with the patient in the sniffing position with manual jaw elevation. The Cormack grade was not measured by direct laryngoscopy, but according to the first view obtained through the optical stylet; 6% of the patients had Cormack grade III or IV airways. Cricoid pressure was needed in 17.5% of patients to see the glottis, and a Macintosh laryngoscope was needed in 8% of patients to retract the tongue. The Macintosh blade combined with the Shikani



Fig 10 The Nanoscope.

Seeing Stylet was better than either the blade or the stylet alone. The success rate was 88% after one intubation attempt, 97% after two and 100% after three attempts.

In all of these clinical trials, the sniffing position was used when possible and conventional laryngoscopy was often used as well. Success rates might be different if these devices were the sole intubation device in patients with limited neck extension, limited mouth opening or recognized difficult airway.

Simulated difficult airways – clinical trials

The Nanoscope study was the only clinical trial in which a prospective randomized comparison was made between optical stylet intubation, conventional direct laryngoscopy and flexible fibreoptic endoscopy.¹² The Nanoscope was used as a sole device, without conventional direct laryngoscopy. Patients with known or suspected difficult airways (Mallampati class IV²⁶) were excluded from the study, but a difficult airway was partially simulated by intubating patients while keeping the head position neutral. Novice users obtained a success rate of 96%, with one failure due to bleeding. This compared well with flexible fibreoptic endoscope intubations. Intubation time was longer than direct laryngoscopy but shorter than with flexible fibreoptic bronchoscopy.

In the StyletScope clinical trial, head positions were also deliberately kept neutral to simulate a difficult airway.¹⁶ The device was used in conjunction with a Macintosh blade, which was used to help elevate the tongue. The successful intubation rate was 94% after one attempt and 100% after two attempts. The pre-operative Mallampati classification was not related to the time for intubation (29 (SD 14) s). Similar results were obtained in a study when patients were intubated in the sniffing position with no attempt to simulate a difficult airway.¹⁵

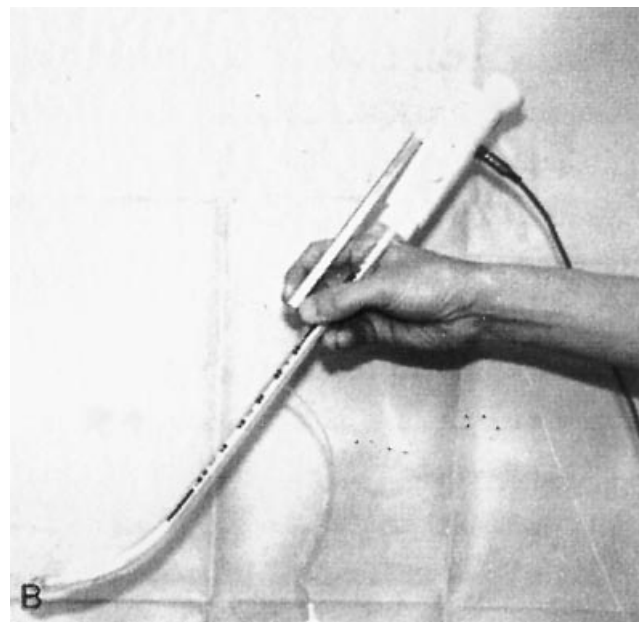


Fig 11 The StyletScope.

Weiss and colleagues³⁷ used a manikin with a simulated difficult airway by limiting head extension to give a Cormack grade III view. Forty anaesthesia personnel compared, in randomized order, the Bullard laryngoscope and VOIS. Mean intubation times were similar – about 19 s – but the VOIS was associated with fewer failed intubations (8/400 vs 41/400). The VOIS was also compared with a conventional malleable stylet in this way.⁶ While the VOIS needed 20.4 (7.7) s for intubation, 10 s longer than with a conventional stylet, it avoided oesophageal and endobronchial intubations (both 39.2% of times with the conventional stylet). Another manikin-based difficult-airway study of the VOIS had no failures, and a mean intubation time of 17.4 (6.8) s.⁵

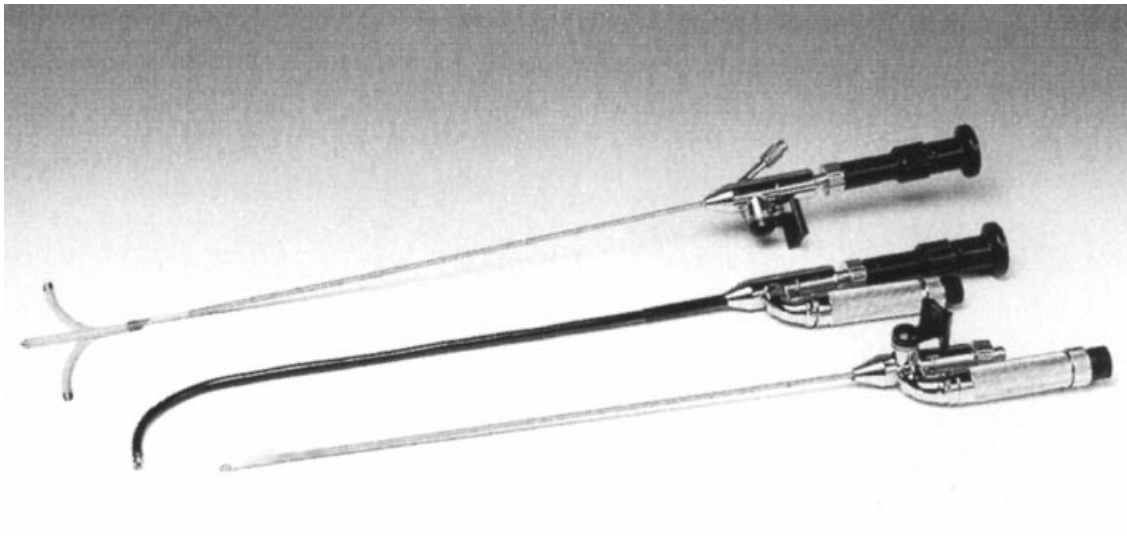


Fig 12 The Fiberlightview Shuttle.



Fig 13 The Shikani Seeing Stylet with stylet bending tool shown below.

Learning requirements

Extensive learning for optical stylets was not noted in studies,³¹ except for the Aeroview system. For the Shikani Stylet, a brief initial learning period was noted for a single operator.³⁰ An intubation success rate of 96% was achieved in another study of a device used by 16 novice operators,¹² but these intubations were done under the guidance of more experienced users. For the Stylet Scope trial, no preliminary training specific to the technique was made and no

significant difference was found between intubation times for the first five patients (33 (8) s) compared with the last five patients (29 (14) s) on a total of 32 intubations.¹⁶ The lack of significant further decrease in intubation time after 27 uses suggests that operation of the device was easy to learn.

With a simulated difficult airway in manikins, the number of failed attempts using a Bullard laryngoscope decreased from the first five intubation attempts (30/200 failures/attempts) to the last five (11/200).³⁷ For the VOIS in the same study, failed attempts were few and did not decrease from attempts 1–5 to attempts 6–10 (6/200 and 2/200, respectively). However, the mean intubation time improved by 6 s (27%).³⁷ The fewer failures and shorter intubation times suggest that the VOIS was easier to use. Simulating a Cormack grade III laryngeal view in 50 paediatric patients, a 92% successful intubation rate within 40 s was obtained with the VOIS.³⁵ Intubation time improved by the fifth patient (20.8 (10.9) s) compared with the first (24.5 (17.3) s) but this difference was not significant.

When four operators with over 3 years experience used the Shikani Seeing Stylet as a sole intubation device,¹ the intubation success rates were lower than in the original trial by Shikani, which suggests that training is needed.

Generally, learning with the optical stylets seems rapid, but most studies were by the original inventors or by people working under their guidance.

Complications

Failure to intubate

Failure to intubate had several causes, but was rarely because of device malfunction. The Bonfils Fiberscope trial had a 3.7% failure in the initial part of the study, caused by a

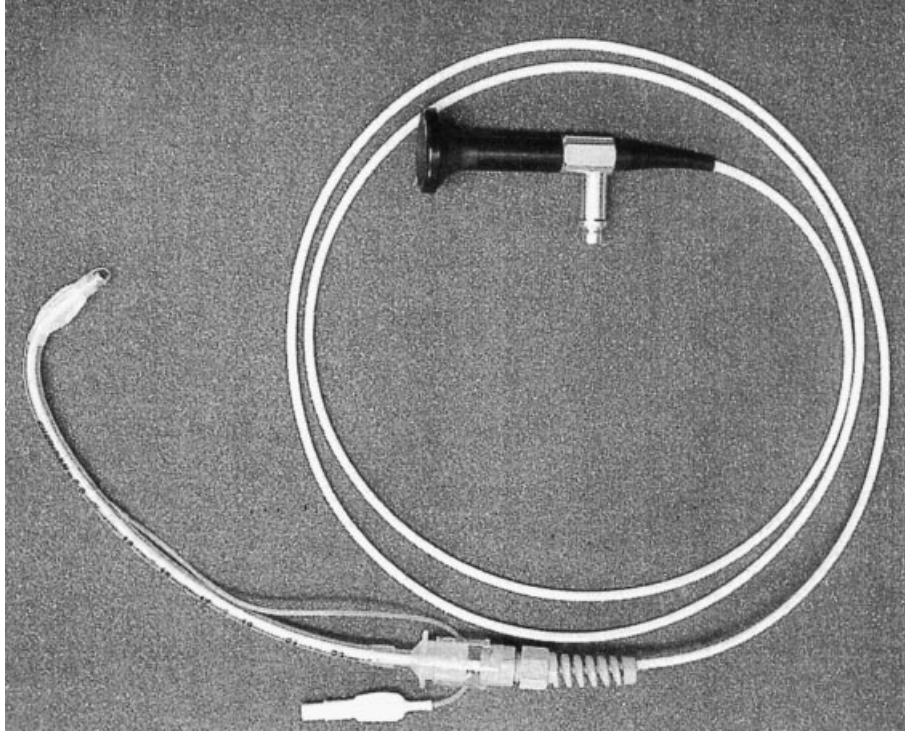


Fig 14 The Video-Optical Intubation Stylet (VOIS).

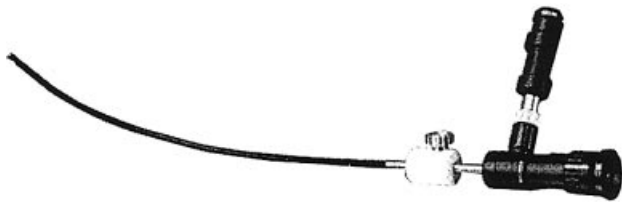


Fig 15 The Machida Fiberscope.

problem with the fixation of the tracheal tube onto the stylet. This problem was quickly solved. A study that tested for failure using a prototype plastic optical fibre system reported a partial distal lens separation after 40 bend-and-straighten cycles.¹¹ No other study found technical difficulties with the optical stylet devices.

Secretions can obscure the lens, which with the Shikani Seeing Stylet caused a 20% failure rate on first attempt.¹ Kitamura and colleagues^{15 16} reported two failures resulting from mucus on the lens, requiring additional attempts. The Nanoscope study had a failed intubation caused by blood on the recessed lens.¹² Secretions caused complications with the Shikani Seeing Stylet, and successful intubation required a change from the original stylet curvature to a hockey-stick shape in 10% of patients.¹ The curve of the stylet required adjustment in one patient in the Machida Fiberscope trial.²⁷ This shows that perhaps up to 100° of anterior flexion may be needed for successful intubation in some patients. Not all fiberoptic stylets provide this amount

of flexion. In the Nanoscope trial, one patient was described where no view was obtained.¹² Conventional direct laryngoscopy with a Miller 3 blade found a true difficult airway with Cormack grade IV view. The optical stylet was then passed under the retracted epiglottis to show the vocal cords and the patient was intubated successfully.

Sore throat and hoarseness

The StyletScope trial reported minor sore throat in 28% patients and minor hoarseness in 25% on the first post-operative day.¹⁶ The optical stylet in the Nanoscope trial caused less sore throat (median 1.0 on a scale of 0–10, with 10 being the worst) than direct laryngoscopy (median 3.0) but not statistically less than with fiberoptic bronchoscopy (median 2.0).¹² Avoiding direct laryngoscopy may limit pharyngeal trauma and reduce the severity of postoperative sore throat.

The ideal optical stylet

Optical characteristics

The ideal optical stylet provides an image of high clarity, which requires more than 10 000 pixels. The stylet must provide illumination. Orientation and steering are best with a lens of long focal length (50 mm) and large angle of view ($\geq 90^\circ$).

Physical characteristics

The ideal optical stylet system will be available in paediatric and adult sizes. Compared with a conventional stylet, the optical stylet will provide features such as imaging, illumination, an accessible channel, malleability and additional tip flexion without altering the weight, diameter, balance or handling. It produces an image that can be viewed from an eyepiece or displayed on a monitor. Reusable systems will be robust and tolerate multiple bend-and-straighten cycles. Temperatures in excess of 60°C, needed for re-sterilization, will not affect components.

Cost

Cost varies, and is not considered here because no cost-per-use analysis of an optical stylet has been reported. All systems except the VETT are reusable, but no information about the average number of uses before mechanical failure or maintenance and repair costs is available for any device.

Recommendation

A review of the reports of clinical experience with the intubating fibreoptic stylet scopes suggests they are useful devices whose operation is easy to learn. It seems likely they will find an expanding role in the management of the airway.

The features of different stylets reflect different preferences and practices among clinicians. We found that the most important features are image quality and familiar handling. Availability of an extra channel or tip flexion were less important. The device whose use and feel is most like a conventional stylet, gives a view from the tip of the tracheal tube, and can be bent to view around an obstruction will need least time and effort to learn. The VOIS is the only commercially available device that has good optics and can be used very much like a conventional stylet. The Stylet Scope is an alternative but has a lower resolution image. Unfortunately, because experience of re-use of these systems has not been described, we cannot offer an opinion on the value of these devices in comparison with other methods.

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