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Borescopes as a Training Tool for Neuroendoscopy

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Abstract

Background Neuroendoscopy is increasingly utilized as a minimally invasive method. Due to its challenging learning process, there is a pressing need for cost-efficient training methods for residents and fellows in these surgeries. One such modality is using borescopes as substitutes for endoscopes, which could prove beneficial in resource-limited settings. However, existing literature on the use of borescopes in surgical practice for training remains scarce.

Methods A thorough literature review was conducted to assess the applicability of borescopes. The search encompassed original articles, review articles, and randomized control trials on PubMed and Cochrane library. Studies were analyzed to evaluate the operability and limitations of borescopes in medical settings, considering factors such as light source, water resistance, sterility, camera quality, rigidity, ease of operation, and cost. This review also draws on practical experience using borescopes in endoscopic training, supplemented by feedback from neuroendoscopic fellows and consultants who have participated in our biannual workshops since March 2022.

Results The literature search yielded 522 articles, which, after applying the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, resulted in 61 studies meeting the inclusion criteria. Universal serial bus (USB) powered borescopes have been employed as substitutes for endoscopes in training models using practice models and cadavers, facilitating the study of neuroanatomy and aiding in airway visualization during laryngoscopy. Despite lower resolution and fidelity compared to traditional endoscopy towers, their versatility and enhanced functionality through attachments make them an affordable alternative for endoscopes, contributing to improved surgical proficiency.

Conclusion Borescopes have demonstrated potential as substitutes for endoscopes in training models, with positive feedback from trial participants suggesting broader applications in practice settings and possibly even clinics. This could ultimately enhance accessibility to endoscopic surgery, particularly in underserved regions.

Keywords
- borescope
- endoscope
- neuroendoscopy
- skill training
- surgical practice

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Introduction

Endoscopes were introduced to neurosurgery in 1910 to manage hydrocephalus and visualize the third ventricle.[1] The first endoscopic third ventriculostomy was performed by Mixter using a urethroscope.[2] Besides the treatment of hydrocephalus, neuroendoscopy is now used in various procedures of neurooncology,[3] management of intracranial cysts,[4] minimally invasive spine surgery,[5] epilepsy,[6] etc.

Residents and fellows in neurosurgery require a specific skill set to acquire proficiency in neuroendoscopic surgical skills. These skills are difficult to impart directly on patients due to the risk involved, operative duration,[7] and the reduced number of caseloads now seen by surgeons in training compared to the past.[8] Due to these, training is best conducted on cadavers or via high-fidelity virtual reality simulators, especially for the development of dexterity and technical coordination skills. The use of physical models with scopes has been shown to be superior to virtual reality models[9]; however, there is a limit to both in availability.

For successful outcomes in surgeries, surgeons require hours of practice.[10] Cadavers are not very readily available, and most simulators are often too expensive for young neurosurgeons or even smaller hospital labs to afford and maintain. The endoscopic models require an endoscope for visualization, which increases the cost of the model. An alternative for an endoscope is a borescope, which can provide good visualization, with nearly similar capabilities. Borescopes have the potential to revolutionize surgical practices by serving as exceptionally cost-effective substitutes for high-end endoscopes. If effectively utilized, this technology could prove invaluable for resource-limited settings. Currently, there remains a paucity of literature on the application of borescopes in medical practice. In this article, we aimed to review the literature about the utility of borescope.

Materials and Methods

Literature Search

Our systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Two electronic searches were performed on the PubMed (http://www.pubmed.gov) and Cochrane Library (https://www.cochranelibrary.com/search) databases using the terms described in ►**Table 1**. Articles from the first search ("PubMed/Cochrane 1" in ►**Table 1**) were reviewed, and missing search terms were added for the second search ("PubMed/Cochrane 2" in ►**Table 1**). Studies published till June 2024 were included. The two searches were compiled, and duplicates were removed in Zotero Desktop V6.0.36. Ethical review board approval was not necessary for this review.

Study Selection

The inclusion criteria for the studies were (1) application of universal serial bus (USB) borescopes, (2) models made for endoscopic skill practice, (3) usage of USB-powered endoscopes or borescopes for clinical use or surgical practice, and (4) an article or abstract available in English.

Exclusion criteria: Articles that mentioned the use of models for irrelevant uses were not included in the study.

Data Collection

Two authors (A.B. and J.B.) screened the abstracts independently for relevance. This review is also based on our experience with the use of a borescope in endoscopic training. It incorporates feedback from neuroendoscopic fellows and consultants who have attended workshops held semiannually since March 2022.

Results

The literature search revealed 522 articles, which gave 61 eligible studies after filtering. The detailed literature search result is shown in ►**Fig. 1**.

Study Selection and Types

Two authors (A.B. and J.B.) screened a total of 522 articles after applying the search criteria mentioned in ►**Table 1**, out of which 51 were relevant to the scope of this article and were sought for retrieval. Forty-four articles were eligible and retrieved, and further search through citations and a web search yielded 17 articles, leading to a total of 61 articles that were mentioned through the narrative of this article. The studies included were 46 original articles,[9,11–32] 3 review articles,[33,34] 1 book chapter,[35] three web pages,[36–38] 6

Table 1 Study selection criteria

PubMed 1	(endoscopic[Title/Abstract] OR endoscope[Title/Abstract] OR boroscope[Title/Abstract] OR borescope [Title/Abstract] OR neuroendoscopy[Title/Abstract] OR neuroendoscopic[Title/Abstract]) AND (training [Title/Abstract] OR simulation[Title/Abstract] OR skills[Title/Abstract] OR model[Title/Abstract]) AND (cheap[Title/Abstract] OR inexpensive[Title/Abstract] OR cost-effective[Title/Abstract]) AND (surgery OR skill OR simulation OR training) AND (English[language])
Cochrane 1	(endoscopic OR endoscope OR boroscope OR borescope OR neuroendoscopy OR neuroendoscopic) AND (training OR simulation OR skills OR model) AND (cheap OR inexpensive OR cost-effective) AND (surgery OR skill OR simulation OR training)
PubMed 2	(Universal serial bus OR USB) AND (Endoscope OR endoscopic OR borescope OR boroscopic)
Cochrane 2	(Universal serial bus OR USB) AND (Endoscope OR endoscopic OR borescope OR boroscopic)

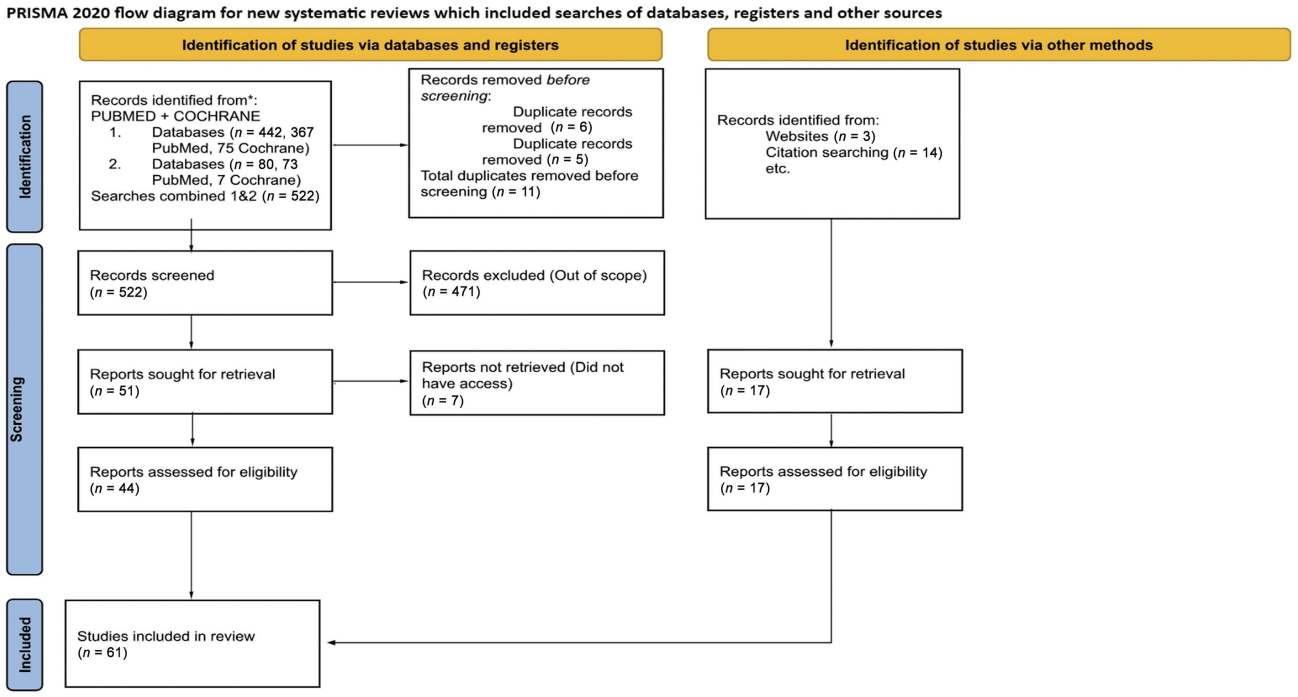

Fig. 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.

randomized control trials,[39–41] and 2 comments[10] made on a journal article.

Borescope as an Alternative to Endoscope

A modern borescope is an instrument designed with an image sensor or lens at one end and another consisting of an eyepiece or a link to a display via a USB port. The traditional borescopes (like endoscopes) used to have complex optic cables running through them with a torch handle attached below to serve as a source of illumination; however, newer versions have replaced the optic cables with simple inexpensive electronic cables connected to an image sensor.[36] The image seen on the camera end is transmitted to the screen via optical or electronic signaling. They were originally used to inspect the bores of large guns, thus the name "bore-scope" or less commonly "boroscope."[35] These terms have been used interchangeably in our article.

The borescopes mentioned are paired with a laptop or mobile phone display via a USB type B/C or USB 2.0 port[38] and have light emitting diodes (LED) inside them that do not need an additional source of electricity and do not produce additional heat despite being a little lower powered compared to the Xenon light produced by Hopkins endoscopes. Depending on the manufacturer, the borescope can be of a variable length and may have magnification too. Triple-camera borescopes with two side view cameras allow the user to experience a 234-degree view.[37] They are extremely lightweight and portable compared to endoscopy towers. The borescopes are generally much cheaper than conventional endoscopes, costing around INR 1,100.

Images were collected by a mobile phone, and the borescope shown in ►**Fig. 2** is the MatLogix 5.5 mm/7 mm 2 Meters Waterproof Mini Endoscope USB Wire Snake Tube Inspection Borescope Camera Compatible with Android Smartphone PC (5.5 mm) and a laptop along with a Kerrison punch on a model developed by Bajaj et al.[21]

The use of USB-powered endoscopes is not new to modern medicine. A USB-powered endoscope was used to perform 25 successful endoscopic facelifts by plastic surgeons in 2004.[16] However, most experiments have only used endoscopes, and the data on the use of borescopes are extremely limited.

Neuroendoscopy Training

- **Borescopes for learning hand–eye coordination:** In our prior study for learning hand–eye coordination, the borescopes were shown to be useful.[42] The wired borescope was made into a rigid endoscope by attaching a K-wire or an 18-cm wooden stick to stimulate it with a nasal endoscope. Different neuroendoscopic exercises like transferring an object between pins and passing copper rings over the pins can be used to learn hand–eye coordination, reducing tremors, avoiding blind spots, etc.[21]
- **Borescope for modified pure endoscopic approach:** Borescopes connected to a computer screen have also been used in cadavers for accessing various neurosurgical approaches like subfrontal approach, anterior

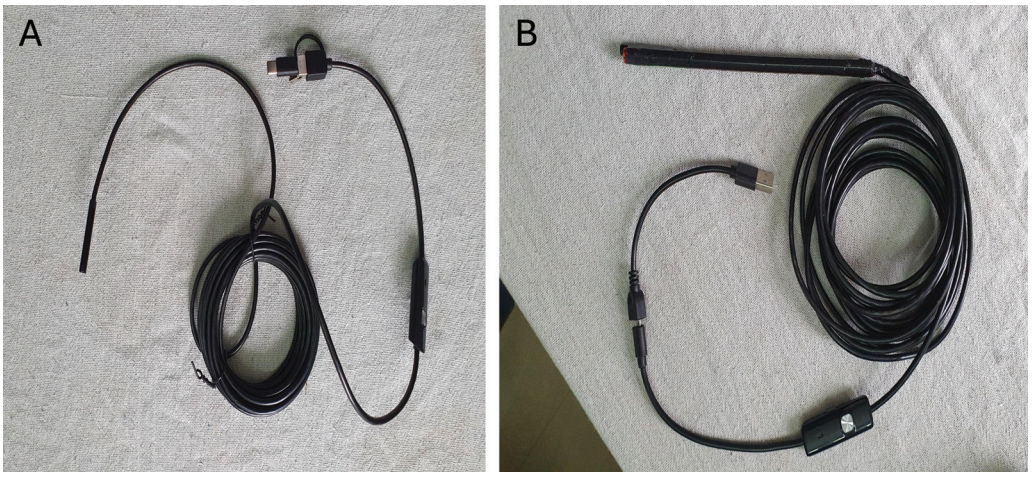

Fig. 2 (A) A borescope. (B) A borescope with an 18-cm-long pencil taped toward the camera end.

interhemispheric approach, subtemporal approach, supracerebellar infratentorial approach, and low retrosigmoid approach to visualize critical neuroanatomy.[19]

- **Endoscopic third ventriculostomy (ETV):** Borescopes have been used as a mimetic **endoscope** for usage in ETV. In a study by Garling et al, the ETV model along with the borescope was found to be helpful for resident training by 87% of participants and for orientation with endoscopes by 93% of participants.[43]
- **Our lab experience:** We regularly use borescopes in our skill lab for training purposes. During various neuroendoscopic training programs, the borescope has been used by 200 neurosurgeons at our center since March 2022. On a Likert scale of 1 to 5, most of the responses were excellent (either 4 or 5, $n = 195$) for its utility as an alternative to the endoscopes for skill-enhancing practices.

Ear, Nose, and Throat Surgery

Connecting endoscopes to mobiles has been used widely by ear, nose, and throat (ENT) surgeons with no significant difference in video quality or viewer's diagnostic ability between endoscopes connected to the mobile via a USB cable and endoscopy towers.[44] Similar works can be attempted using a borescope.

Laparoscopy

Training laparoscopic skills can be significantly enhanced through simulation models.[45] Recently, training models using a USB borescope equipped with interchangeable side mirrors and a built-in LED light, inserted into a stainless tube to simulate laparoscopic surgery, have been developed.[22] These models achieve varied camera angles through a semirigid design secured by binder clips.

Efforts to perform low-cost laparoscopic surgery using USB borescopes have been initiated on rats, with 66% successfully completing procedures without complications. However, further research is essential to ensure safe implementation in clinical practice.[26]

Gynecological Surgery

Gynecology residents reported a feeling of higher surgical competence after being trained in their laparoscopy skills via a box training model and an animal one using laparoscopes.[46] Similar practice models can be created for residency programs using borescopes as a cheaper substitute in resource-deprived areas. To our knowledge, no simulation models for gynecological surgery using borescopes have been created thus far, but this presents an opportunity for future development.

Colonoscopy

Endoscopes have been used for training models to increase proficiency for colonoscopy via practice models.[34] Simulation models when operated with endoscopes have already been shown to be beneficial for surgeons.[24] These models can be repeated with borescopes to test for validity and fidelity while cutting costs further.

Anesthesia

Borescopes have been integrated with direct laryngoscopes (DLs) to facilitate visualization during endotracheal intubation.[13] It is especially useful in situations where capnography may produce unreliable results such as during cardiac arrest, cardiopulmonary resuscitation, or when patients have ingested carbonated beverages or antacids.[47] In such instances, when uncertainty arises, visualizing the airway with a borescope is preferred due to the high cost and limited availability of fiberoptic bronchoscopy, especially in rural and developing areas.

Elshazly et al[41] attached a borescope to a DL to make a cheaper alternative to the video laryngoscope (VL) to intubate patients and learn to intubate airways that are otherwise difficult with a DL. They found a higher satisfaction with the DL attached to the borescope. The intubation times were comparable; however, the VL had a better view and also showed less fogging compared to the borescope. This demonstrates that borescopes can provide an ease of teaching without depending on a VL and still maintain high fidelity at minimal cost. Another study

showed USB borescope–attached laryngoscopes to have similar intubation times to VL, with both having better times than DLs.[17]

Laptop as an Endoscopic Screen

Dias et al described the use of endoscopes paired with a laptop, resulting in an exceptionally lightweight system weighing approximately 5 lb.[18] This is also an alternative to endoscopy towers. Similarly, cadaveric models have been used to study neuroanatomy using endoscopes.[14]

Mobile Phone as an Endoscopic Screen

Endoscopes can be connected to mobile phones and are used as tools used by veterinary surgeons as well.[15] Smartphone adaptors have been developed to attach endoscopes to a mobile phone. Some of these adaptors also feature built-in magnification and can be used in otorhinolaryngoscopy, otoscopy, rhinoscopy, anesthesia, urology, and gynecology.[15] The use of adaptors to connect endoscopes to mobiles and their impact was recorded to increase learning in 81 to 88% of cases.[32]

YazanoScope is a wireless camera attached to an old discarded endoscope. It was reported to be good for providing haptic feedback.[23] This experiment can be conducted by using a borescope or attaching a borescope to a discarded endoscope since the concept behind the two devices is similar.

Other methods to gain skill in endoscopic practice for young neurosurgeons can be something as simple as playing videogames; however, these growth spurts are short-lived and only help to a certain extent.[11]

Attachments and Modifications

Aldiscope: A study by Smith et al conducted to establish a budget-friendly anatomical research facility situated in rural Australia attached a borescope with an infant feeding tube to maintain irrigation to clean the camera lens during a skill training session on cadavers.[48] It was greatly valued, especially by eager medical students who wished to see neuroendoscopic skills in practice. They named this makeshift endoscope "Aldiscope" because the borescope was bought from a nearby Aldi store. This scope offers medical students an affordable way to gain hands-on experience with neuroendoscopic procedures. However, its main limitation is the lower image quality when compared to traditional neuroendoscopes.

In 2022, Ofstead et al suggested visual inspection of endoscopes to maintain sterility and reduce the incidence of contamination in the operation theater (OT) due to debris remaining in the endoscopes.[49] They did this via magnification and visual inspection via borescopes and found that 100% of the endoscopes used in the study had some kind of visible damage or residue.

Besides their independent use, borescopes can also be coupled with endoscopes to function as image-capture devices that can be used in teaching models.[29] A similar setup can also be achieved by attaching a wireless camera to a discarded endoscope to achieve a relatively cheap setup for practicing procedures and yielding a higher satisfaction rate than virtual simulators.[23]

Borescopes have recently been found to be useful in inspecting endoscopic lumens and surgical instruments used in endoscopy. Borescopes are almost 2,000 to 3,000 times cheaper than endoscopes and can be connected to any laptop or mobile device with a USB type B/C or 2.0 ports.[38] Cheaper alternatives to endoscopic training also involve simply using cameras and LED sources and coupling them to create a simulation model; however, this process can be avoided by getting a borescope. They are often readily available and are not as fragile as endoscopes. Even if they do get damaged, they can easily be replaced. They also have an inbuilt lighting system with LEDs that do not require an external light source and work by a single source connection, unlike endoscopes that require a heavy setup that is often difficult to dedicate to skill labs due to its expensive nature.

Rigid Borescope

Borescopes can be attached with a rigid rod/pencil to simulate practice with a rigid endoscope (►**Fig. 2B**). They are not limited in length, unlike endoscopes that come in fixed lengths, thus reducing the additional cost of purchasing different-length endoscopes. The variable intensity knob can be used to control the intensity of light and a 1,080-HD image can be produced on any screen be it for recording or transmitting during a video conference (►**Fig. 3**).

The borescopes have been used extensively during various fellowship programs conducted by Yadav et al. Various models have been developed to provide training for hand–eye coordination, suturing, incising under an endoscope, fine dissection, keyhole concept, drilling, and simulation of laminectomy and ligamentum flavum resection with indigenous training models. We have found favorable results as recorded by the residents and fellowship trainees.[21] All these training models are now being practiced using borescopes (►**Fig. 4**).

A similar workshop was conducted using a DEPSTECH Wireless Endoscope, WiFi Borescope Inspection 2.0 Megapixels HD Snake Camera to make a cost-effective minimally invasive spine surgery simulator by another group of neurosurgeons.[50]

Endoscopes can similarly be replaced by borescopes and used in endoscopic sinus surgery skill simulators used by ENT and neurosurgeons to further reduce the cost of making low-fidelity indigenous models or models with higher fidelity using animal heads (sheep,[24] etc.). Simulation models, when operated on with endoscopes, have already been shown to be beneficial for surgeons and may show similar results when equipped with borescopes.[24,39]

Discussion

Practicing endoscopic skills is vital before embarking on actual surgeries. Borescopes can be utilized as an inexpensive alternative to the costly endoscopes for

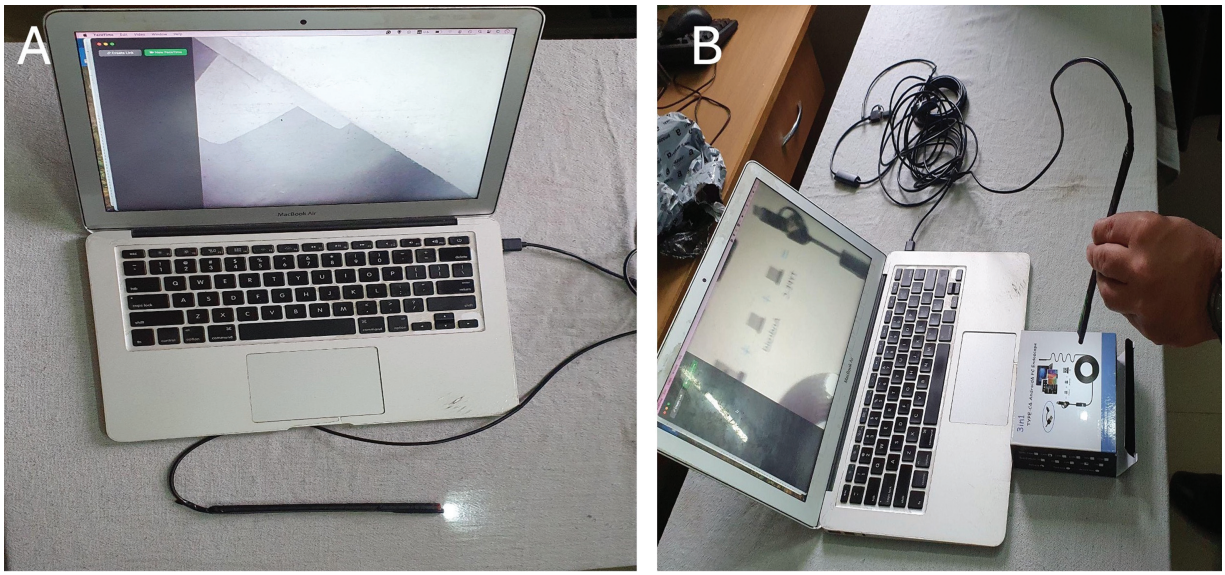

Fig. 3 (**A**) A rigid borescope connected to a laptop. (**B**) The borescope can be held in one hand after making it rigid.

practicing in the lab and on animals. ►**Table 2** highlights the key differences between a borescope and an endoscope.

Although cadavers may be considered a gold standard for simulation and practice, virtual models made with certain materials such as synthetic thermo-retractile and thermo-sensible rubber called Neoderma[28] or certain special resins,[30] silicon, plastic, ovine models,[24] and rat models can replicate the tissue conditions and improve training.[26] Initially, indigenous models[31] can be used. With further progression and experience, one can practice on models with narrower and deeper corridors.[21,33] Ideally, a simulator should be able to train a resident in their decision-making skills, dexterity, and comfortability with the instruments and not just hand–eye coordination. These simulators are extremely helpful initially, especially to young neurosurgeons; however, the benefits provided by them plateau after a certain time[11] and even benefits gained by initial practice through experience gained playing videogames are short-lived[11] and further skill development takes place through clinical practice.

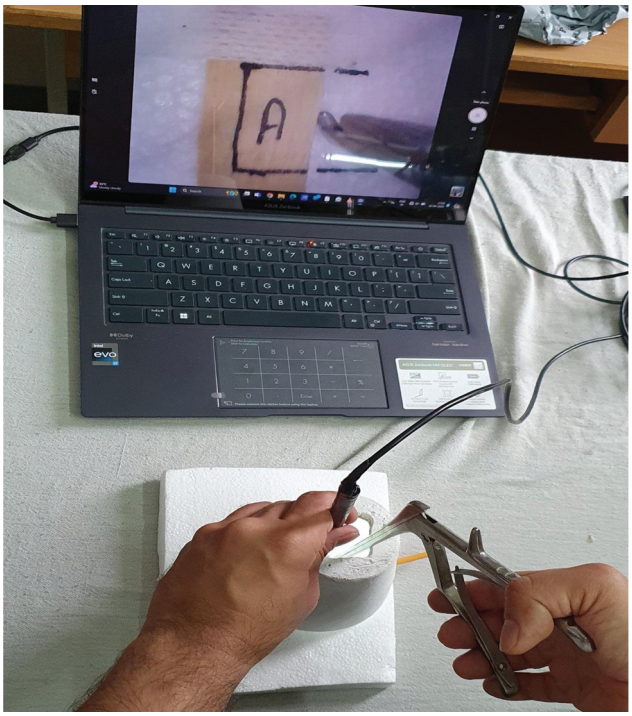

Fig. 4 Demonstration of endoscopic skills using a borescope and a Kerrison punch on a model.

Advantages

Inexpensive and ideal for practice models, borescopes are great for frequent use and can be easily replaced if damaged. Due to their low cost, they are suitable for use in underprivileged countries, rural areas, or by students looking to gain insights into the field of neuroendoscopy. Borescopes are incredibly versatile, capable of being attached to various objects such as a DL, K-wire, semirigid objects, irrigation tubes, or even a broken endoscope, resulting in multiple utilities with each attachment or modification.

Equipped with LED lights instead of xenon, they do not produce heat and require only a single light source. They can be used to record and transmit videos and come with USB and type B/C ports ensuring compatibility with almost every phone or laptop. These cheap alternatives to endoscopes feature variable lengths and magnification and offer side view cameras with up to a 234-degree view. Lightweight and portable, borescopes can weigh as little as 5 lb, including the laptop used for operation.

Drawbacks

A question on the sterility of the borescope (when attachments are made with tape) can be raised, and until a sterile way of creating attachments to a borescope cannot be made, it will be difficult to use them in the OT. A lower resolution as compared to endoscopes is often found in cheaper borescopes along with a weak light source. The

Table 2 Key differences between borescopes and endoscopes

Aspect	Borescope	Endoscope
Main purpose	Used for industrial inspections (e.g., machinery, pipes)	Used for medical procedures to view internal body structures
Camera/lens type	Comes with a basic camera or lens at one end	Equipped with a high-resolution camera, often featuring advanced imaging technology
Connection method	Typically connects to a display via USB (type B/C or 2.0)	Connects to specialized medical displays and equipment
Lighting	Features built-in LEDs, produces little heat, and no external power needed	Utilizes high-powered xenon or LED light sources for intense illumination
Viewing angle	Certain models provide up to a 234-degree view with side cameras	Generally offers a 100- to 120-degree viewing angle, depending on the model
Portability	Compact and easy to carry	Tends to be bulkier, often integrated into larger medical systems
Magnification	Varies by brand, typically adjustable	High magnification, optimized for detailed medical imaging
Flexibility	Usually semi-rigid, with flexible options available	Commonly rigid, although flexible versions exist as well
Price	Lower cost overall	Higher price due to specialized medical technology and materials
Sterilization	Not made for use in sterile settings	Must be sterilizable for medical applications
Display interface	Basic interface, usually compatible with laptops or mobile devices	Advanced medical monitors with real-time data integration

Abbreviations: LED, light emitting diode; USB, universal serial bus.

camera of a borescope can also get dirty during procedures and would require an irrigation system to keep visibility clear. A borescope is also an individual equipment that does not come with attachment sites. Hence, any modification made to it, such as attaching an infant feeding tube (for irrigation) or a pencil (to make it rigid), can prove arduous. To make a borescope capable of bending, it would require modifications by adding a continuum body and a case, both of which can be 3D printed.[12]

Conclusion

Borescopes are electronic devices that functionally work similarly to endoscopes; however, they have yet to make their way into clinical practice. These devices can substitute expensive endoscopes for practicing in the lab at a fraction of their cost and work well with simulation models for teaching or learning endoscopic surgical skills in different specialties such as neurosurgery, ENT, general surgery, gynecology, orthopaedics, and anesthesia. Borescopes can make the neuroendoscopic field more accessible to newcomers and observers constrained by geography or resources.

Conflict of Interest
None declared.

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