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ORIGINAL RESEARCH

Laryngoscope Investigative Otolaryngology

A 3D printed smartphone adaptor for nasolaryngoscopy

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Abstract

Objective: The objective of this project is to create a three-dimensional (3D) printed smartphone adaptor for flexible nasolaryngoscopy (FNL) to provide an affordable alternative to commercial options and a better fit than generic telescope phone adaptors.

Method: We designed an adaptor using computer aided software to connect an iPhone XS to an Olympus Rhino-Laryngo Fibre Scope. We experimented with various 3D printing materials and iterative designs to create a case that allowed for quality recording of a nasolaryngoscope exam using the iPhone's built in ×2 telescopic zoom lens.

Results: Our 3D printed adaptor provides a cost-effective alternative to commercially available FNL smartphone adaptors and is capable of capturing high-quality images and videos of the nasopharynx and larynx. These images are useful for senior clinician review, decrease the need for repeat examination, can be utilized for education, avail telehealth review, and provides a way to digitally record examinations to electronic medical records for future comparison without the need for an endoscopy tower.

Conclusion: Smartphone adaptors for FNL have been established to be of clinical value. Despite being simple devices, they continue to be expensive. This potentially limits access to junior clinicians, who stand to gain most from the ability to review images of examinations with senior colleagues. Our 3D printed smartphone case provides a cost-effective alternative, with a better fit than generic adaptors, at a print cost of $29 AUD. This is $131 AUD less than the next cheapest commercial alternative. The files are freely available for use and modification.

Level of Evidence: 4

KEYWORDS

3D printing, education, flexible laryngoscopy, inpatient consultation, resident education, telemedicine

1 | INTRODUCTION

Flexible nasolaryngoscopy (FNL) is a key component of otolaryngologic examination and allows for the diagnosis of a wide range of nasal and laryngeal pathology. As portable devices, they can be used to aid diagnosis of otolaryngologic pathology under topical local anesthetic; however, historically the ability to view and record examinations digitally has been limited by price and mobility limitations of endoscopy towers.[1] A primary drawback of FNL is that many examinations are conducted by junior trainees, and in the case of diagnostic uncertainty, or for educational purposes, repeat examination may be performed by senior clinicians. When nasolaryngeal examination is required on hospital wards or in the emergency department, FNL is often used rather than endoscopic towers due to immobility, price, and lack of availability in clinics and emergency departments.

There are a multitude of smartphone adaptors available from various third party manufacturers allowing for examinations to be recorded and viewed on a larger screen in real time. This offers diagnostic benefit, educational value, and reduces the need to re-scope patients when findings are unclear to the primary operator.[2] These adaptors are either designed for a specific brand of nasendoscopes, or can be generic telescope or binocular adaptors.[1,3] Generic telescope adaptors have in our experience been associated with positional issues, both in fitting to the nasendoscope and lining up with the appropriate smartphone camera. Specific adaptors are more expensive than the generic alternatives, potentially limiting purchase to consultants rather than junior doctors, who are the key demographic that benefit from this mobile technology.

Our aim for this project was to make a cost-effective three-dimensional (3D) printed smartphone adaptor for nasendoscopic examination. We describe a method of designing, printing, and utilizing a 3D printed phone case adaptor allowing for easy attachment between an iPhone XS (Apple, Cupertino, California) and an Olympus Flexible Nasendoscope (Olympus, Shinjuku, Japan). This is a cheap and accessible method for doctors and allied health practitioners to record quality videos of flexible nasendoscopy examinations when compared to commercially available options and provides better fit than generic alternatives.

2 | MATERIALS AND METHOD

We designed the case utilizing Autodesk Fusion 360 (Digital River, Shannon, Ireland), a computer aided design (CAD) software program. The case was made to fit an iPhone XS and an Olympus ENF-GP Rhino-Laryngo Fiberscope. We utilized an iPhone XS template from teaching website Adafruit as our base model.[4] This model was modified in CAD to add a semicircular mount over the camera protrusion, with a 2 cm open rail allowing for the 31.5 mm diameter nasendoscope eyepiece to be slid into place in line with the ×2 telescopic zoom lens of the iPhone. Two main designs were created, a half phone case and a full case. The final model was the full phone case design as seen in Figure 1A,B. The scope holder was undersized to provide grip for the scope to keep placement.

An iterative design process was utilized. We first designed a model utilizing CAD, then ordered and printing the model adaptor, tested it with the scope and phone, and finally incorporated feedback into subsequent designs. Success criteria for the adaptor were quality of image capture, adaptor fit, and operability by junior medical staff.

Image capture was assessed to ensure the adaptor allowed for proper visualization of the nasendoscope images. Success was determined if focused images and recordings of the usually visualized anatomical structures were obtained, with minimal clipping of the image frame.

Fit to scope and scope operability are subjective measures, our aim was to create an adaptor that tightly fits both the iPhone XS and the scope. The adaptor was designed for the scope to slide into place, where it is gripped tightly enough to stop rotation and lateral movement throughout the examination. After the examination, the scope needed to be removed from the adaptor without requiring excessive force.

Operability was determined if the scope could be used with two hands, not requiring a hand to be holding the iPhone or adaptor, by junior and senior medical staff. This required tight fit as described above.

Iterative small corrections were made on the CAD design for sizing and alignment purposes, and we experimented with half and full

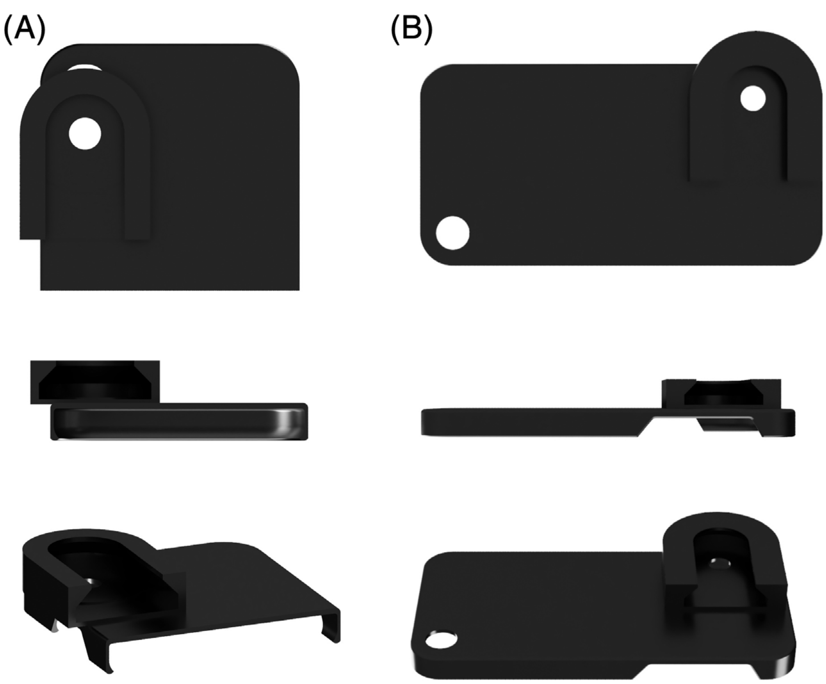

FIGURE 1 A, Initial prototype CAD drawing of the adaptor. B, Final CAD drawing of the adaptor. CAD, computer aided design

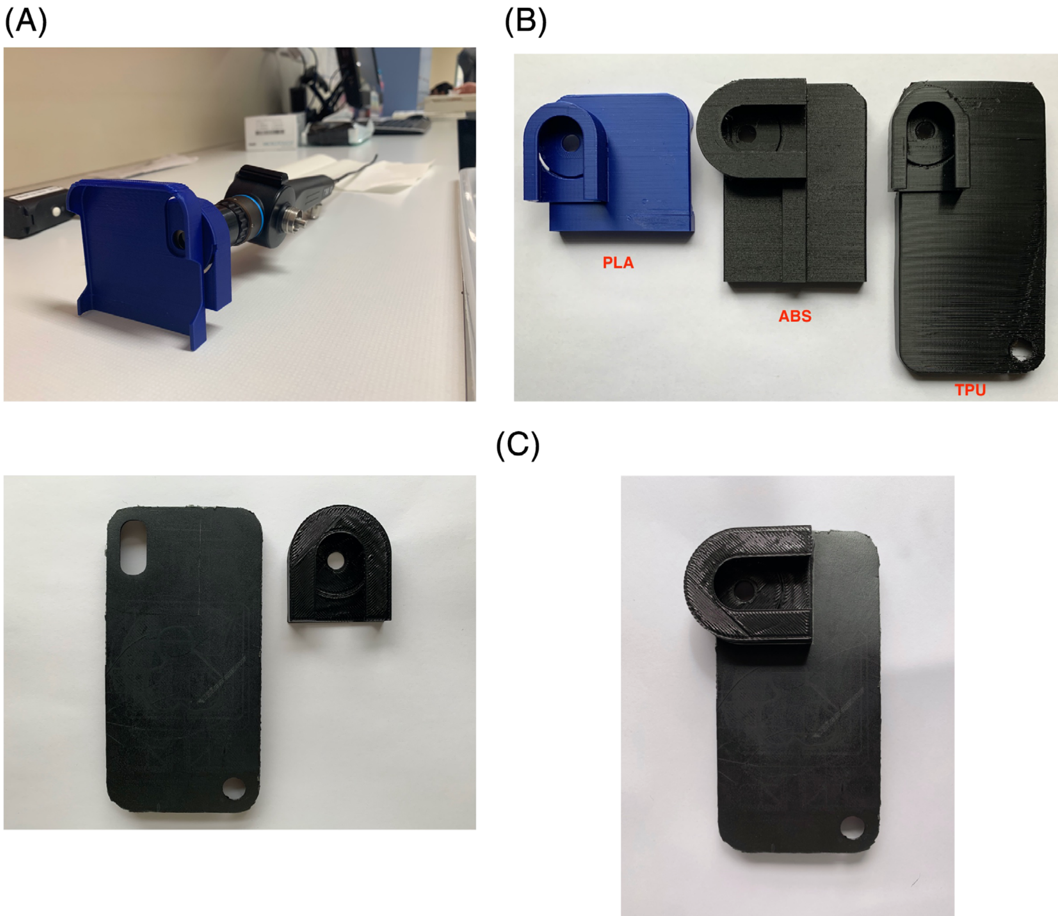

FIGURE 2 A, Prototype print in PLA. B, Test models in variety of materials and scope adaptor orientations. C, Final print in TPU, flexible plastic. Printed in two sections and glued together. PLA, poly(lactic acid); TPU, thermoplastic polyurethane

TABLE 1 3D printed FNL adaptor print material cost and comparison table

Material	Cost (AUD)	Advantages	Limitations
PLA	$8.24 (half case)	• Cheap • Widely available • Quick to print • Half or full case suitable • Printed in one piece	• Inflexible • Brittle
ABS	$10.89	N/A	• Inflexible • Brittle
TPU	$28.75	• Best grip to scope/phone • Resistant to breakage	• Printed in two pieces requiring assembly • Not suitable to half-case

Abbreviations: ABS, acrylonitrile butadiene styrene; FNL, flexible nasolaryngoscopy; PLA, poly(lactic acid); TPU, thermoplastic polyurethane.

FIGURE 3 Nasendoscope adaptor in use

case models, both were suitable for use as seen in Figure 1B. Multiple test models were created in different materials including poly(lactic acid) (PLA), a cheap and readily available plastic filament, thermoplastic polyurethane (TPU), a flexible plastic, and acrylonitrile butadiene styrene (ABS) seen in Figure 2B. Our final 3D print, Figure 2C was created with TPU, a flexible plastic. Initial prototypes were printed in one piece as seen in Figure 2B; however, due to printing technicalities, a higher-quality print was made if printed in two pieces. The final model was printed as two pieces, a phone holder and scope holder as seen in Figure 2C which were glued together with Tarzan's Grip Super Glue (Selleys Australia).

Prints were ordered online through Treatstock (Newark, New Jersey) and were priced based on size. The vendor who printed our adaptors used a consumer grade 3D printer, the Original Prusa i3MK3 (Prusa Research, Czech Republic).

Images were captured with an iPhone XS using the ×2 telescope zoom lens. Video mode on the camera was used and required setting the camera to 4 K 60 fps recording to force the camera to use the ×2 zoom lens, as the camera defaults to the ×1 lens outside of this mode in low light conditions. This allowed for the highest possible quality images to be taken in an attempt to overcome scaling issues from the small scope eyepiece, however resulted in video recordings with large file sizes. Videos were edited by the native iOS photos application to be shorter videos, or photos which could be shared via the hospitals secure messaging service MedX (MedX/JuicyMed, Cheltenham, Australia). Videos were taken and could be stored on the personal

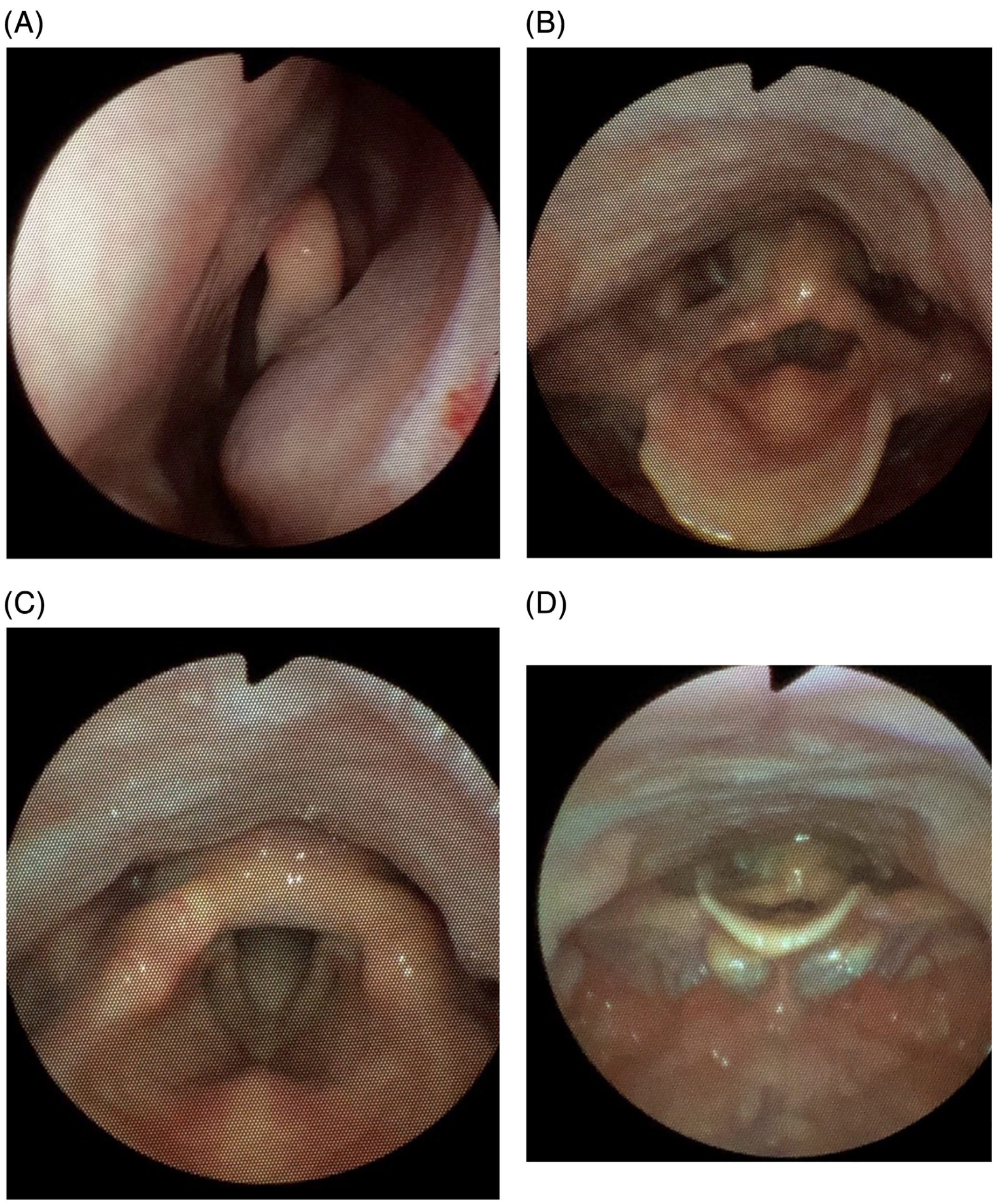

FIGURE 4 A, Inferior and middle turbinates. B, Adducted vocal cords. C, Abducted vocal cords. D, Base of tongue and vallecular

device; however, as our institution does not have a method for securely sharing videos, this was limited to on-device review.

For the purpose of demonstration in this study, nonidentifiable images were captured utilizing the adaptor from a volunteer member of the ENT department, who provided a waiver for image publication.

3 | RESULTS

The iterative design process resulted in multiple suitable adaptor designs in a number of 3D printed materials. We ultimately found an adaptor printed in two sections in TPU to provide the best image quality, easiest operability, and best fit to scope and phone, despite slightly increased assembly requirements.

The initial prototype was printed utilizing PLA, a cheap and readily available plastic filament. We ordered our prints through Treatstock, an online 3D printing service to print the model. The prototype print cost $8.24 AUD. A photo of the initial prototype is found in Figure 2A. A cost table for prints is provided in Table 1.

Two different adaptor designs were created in CAD, a half phone case and a full case (Figure 2B). We thought a half case would be preferred if successful due to smaller size for storage. We found the half case adaptor printed in PLA to be functional and suitable for use, however felt less secure than the full case. A half case design is unable to be printed in TPU, as in this configuration the flexible material is cannot provide sufficient grip to the phone.

Three different materials were explored for suitability in the phone case, PLA, TPU, and ABS. Comparison is provided in Table 1. PLA was primarily used for prototyping as it is fast to print and is approximately half the price of the cheapest alternatives. The PLA adaptor fitted well to scope and phone and was amenable to printing in both half and full case designs. Adaptors printed in PLA were usable and we would recommend it for initial prints; however, it has minimal flexibility, and was not chosen for the final design as it felt susceptible to breakage.

Our second prototype material was printed using ABS; however, this resulted in a brittle scope that was less suitable for use and required an additional brace section to allow for printing (Figure 2B). This material is not recommended for this design.

The best prints were achieved utilizing TPU, which is a flexible polymer. This resulted in an adaptor resembling a commercially available silicon phone case. As TPU is flexible, printing is more technically difficult, and works best using a large flat surface as the base of the model. We attempted to print TPU in one piece as seen in Figure 2B; however, the print was rough and low quality. This was fixed utilizing a two-piece print, subsequently assembled by super-gluing the segments together (Figure 2C). This was a simple process and took no longer than a minute.

All prototypes were sufficiently operable by junior doctors and allowed for two-handed control of the scope. Improvements were made predominately to fit and alignment. In the first prototype, the rail for scope insertion was too undersized and thus a great deal of force was required to insert and remove the scope from the adaptor. These prototypes were successful in capturing images of the larynx; however, misalignment resulted in clipping of the edges of the image, resulting in capture of partial images from the eyepiece. Subsequent designs corrected for this, upsizing the rail, and altering the position of the center of the scope holder to allow for greater inclusion of the eyepiece in the cameras field of view. Our final print still presented a small amount of right sided clipping, again due to minutely incorrect alignment; however, this did not impact upon visualization of anatomic structures. Figure 3 demonstrates the final printed adaptor in use with a scope.

To establish the adaptors utility, trial images were taken from a volunteer in the ENT department. Figure 4A-D shows images of the nasal cavity and larynx, captured utilizing the final adaptor. Success criteria were visualization of expected anatomy and the return of in-focus, and interpretable images. The final adaptor proved adequate in obtaining these views. The adaptor was operable by all members of the ENT team, from juniors to consultants, and provided sufficient grip to phone and scope, thus meeting all of our design requirements.

4 | DISCUSSION

In this feasibility study, we describe the process of designing, building, and utilizing a 3D printed FNL smartphone adaptor. This adaptor allows for the capture of high-quality images and provides an alternative to more expensive third party adaptors. Smartphone adaptors have been established to provide clinical benefit and educational advantage, and we believe our scope is an affordable and accessible way for junior medical staff to record and view FNL findings. In our practice, this scope has already seen usage in clinic and emergency settings to allow for remote diagnosis and review of images by senior clinicians.

The clinical utility of smartphone adaptors for FNL was examined by Quimby et al in a systematic review, which identified high diagnostic accuracy, quality, and enhancement of resident education.[1] Smartphone-coupled FNL portable recording systems were compared to endoscopy towers by Lozada et al in a blinded study, and found good concordance between exams, having only to repeat 1 in 79 examinations (1.3%) due to image quality concerns.[2] While this study did not use our adaptor specifically, we believe from experience that our adaptor provides similar image quality to commercial alternatives. Further research would be of use in establishing this clinically.

Recording nasendoscopy findings presents several key benefits compared to using the scope with an eye piece. It allows for senior peer review, allowing for remote diagnosis and reduces repeat scoping. It also allows for key images to be saved to electronic medical records. This allows for continuity of care and for future comparison in patients undergoing clinical surveillance. A further benefit is use in teaching and analysis. Images can be enlarged on a screen, and anatomy and pathology can be identified and appreciated by clinicians and students alike. Finally, the use of recordings from FNL can be of use in visually demonstrating findings to a patient, for explanation and patient education.

Barriers that we encountered with our design were limited to technical issues in creating and printing. Iterative designs were created to correct minor sizing and alignment issues. A key technical difficulty was in the printing process, as 3D prints are ideally printed with the largest aspect at the base and iteratively printing layer by layer to build the model. Printing the largest aspect at the base allows for better stability and a higher quality print. This was not possible with our all-in-one design as the large scope adaptor meant that the case required printing from the top of the phone case up, rather than from the back. This was solved by printing the case in two segments and gluing them together; however, this has increased the work required to create the scope, and as such we recognize the scope can be utilized both as an entire piece printed in hard plastic (PLA), or as two pieces of flexible plastic (TPU) glued together.

As an already established technology, we believe this adaptor's main advantage over commercially available specific adaptors is cost. Costs of commercially available adaptors were compared in a systematic review.[1] The price range between reviewed adaptors was from 99GBP/$186 AUD for the RVA Smart Clamp—a universal adaptor, to the Sortz Smart Scope USD 790/$1157 AUD, which features a light source and built in magnification.[1] These are significantly more expensive than our 3D print which cost $29 AUD. Fit to device is subjective and with many different adaptors available, is highly dependent on choice of device. In our experience, the use of cheaper, generic adaptors to acquire video recording offered a poor fit and grip to the scope. This consequently makes examination and image acquisition difficult.

There are a few notable limitations of this adaptor. First, 3D printing requires access to a 3D printer. This was overcome in our study utilizing Treatstock, a service allowing easy access to 3D prints without the outlay associated with purchasing a 3D printer. Another limitation is that our adaptor is designed to fit specific models of phone and scope. This is a limitation shared by some commercial adaptors, requiring repurchase when changing phone or scope. As our design relies on 3D printing from a CAD design, modification to fit other phones and/or scopes is possible however would require significant redesign. We have had early success with a Google Pixel prototype (Google, California). We aim in future to create a two-piece version allowing for interconnection with different phones and scopes; however, designing and printing such a model is significantly more technical than the adaptor described in this study. A final limitation with the flexible TPU full phone case is the assembly requirements, however as described above these are modest and quick, and resulted in a significant improvement in print quality.

5 | CONCLUSION

We describe a method for creating, implementing, and utilizing a low-cost 3D printed nasendoscope adaptor allowing for high-quality recordings to be made at a fraction of the cost of commercially available specific adaptors with better fit than generic alternatives. The files are available at request and are free to be utilized and modified.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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