

OPINION

Where next for the endoscope?

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Abstract | The concept of examining the body's interior and its organs dates back to ancient times. The roots of modern endoscopy lie in early nineteenth century Europe, and the intervening centuries have seen a steady evolution of devices and techniques. Nowadays, a wide variety of urinary tract disorders are successfully managed in a minimally invasive manner thanks to the endoscope and related technologies. Distal-sensor, 'digital', endoscopes have the potential to revolutionize the field, and change the way in which we use and think about endoscopy. Virtual endoscopy, capsule endoscopy, and a range of other techniques derived from physics and molecular biology all promise great improvements in visualization of the urinary tract and other urologic structures. Ultimately, the continued improvement of these minimally invasive technologies will enhance the quality of care that we can offer our patients.

Natalin, R. A. & Landman, J. *Nat. Rev. Urol.* 6, 622–628 (2009); doi:10.1038/nrurol.2009.199

Introduction

Endourologic treatment has advanced greatly in recent years, driven by technologic improvements in endoscopic visualization of urological structures and the development of ever-smaller endoscopes. The vast majority of urologic surgery and treatment, which once relied on invasive techniques and large open incisions, can currently be performed using minimally invasive techniques based on endoscopy. Throughout history, the field of urology has been a leader in surgical innovation and the application of minimally invasive techniques. Today, it continues to lead the cutting-edge application of endoscopy. In this Perspectives article, we review the evolution of contemporary endoscopy, highlight the most recent additions to the urologist's endoscopic armamentarium, and speculate about the bright future of urologic endoscopy.

History of endoscopic urology

The concept of examining the body's interior and its organs dates back to ancient times. The *Hippocratic Corpus* records perhaps the first successful rudimentary efforts at endoscopy, which used a rectal speculum. Although various historic references to devices and examination techniques

to study the human body can be found, most historians consider the first modern attempts at endoscopy to have been initiated by Philipp Bozzini (1773–1809; Figure 1a), who in 1806 introduced his 'Lichtleiter', or light conductor, in an effort to study hollow organs and human body cavities (Figure 1b). The Lichtleiter was constructed with angled mirrors positioned to project the image of internal structures to the human eye. The device incorporated a single candle as a light source to illuminate the body interior, and double aluminum tubes to be inserted into the body orifice that was being studied. The Lichtleiter is considered the first known endoscope in modern medicine.¹ Its urologic utility was limited, however, as it allowed inspection of only a small area of the bladder mucosa and the poor extracorporeal lighting compromised efficient organ evaluation.

A French urologist, Pierre Salomon Segalas (1792–1875), improved the Lichtleiter in 1826 by adding an extra candle as a light source and making a new cannulated catheter that drained the bladder and facilitated its inspection. This device was constructed from a gum elastic material in order to improve the safety and comfort of the procedure. Despite some improvement, this 'speculum urethra-cystique'² similarly failed to enable effective inspection of the bladder.

The term 'endoscope' is credited to the French urologist Antonin Jean Désormeaux (1815–1894), and was introduced in 1853 to describe a device based on Bozzini's Lichtleiter. Désormeaux replaced the candle with a bright flame achieved by burning a solution of 96% alcohol with turpentine, which produced a beam of light that could be focused, enhancing the endoscopic examination. Désormeaux also reconfigured the mirror angles used in the system so that the light could be concentrated more precisely, which enabled better visualization of the region reached by the reflected light beam.¹ Désormeaux performed the first successful endoscopic surgery when he reported the endoscopic excision of a urethral papilloma and urethral strictures—procedures made possible by the superior visualization of his system.³ Despite this improvement, Désormeaux's endoscope still lacked sufficient illumination and was only able to inspect a field millimeter by millimeter.

Recognizing the limitations of existing endoscopes, Maximilian Nitze (1848–1906) made two brilliant modifications to create what many historians consider to be the first successful contemporary endoscope (Figure 2). In 1876, Nitze augmented his device with prisms and lenses, which permitted transurethral visualization of the bladder with a wide field of view. Additionally, he introduced the first intracorporeal light source at the tip of the instrument, using a water-cooled electric platinum filament lamp.⁴ Nitze's cystoscope was initially cumbersome to use owing to the complicated and elaborate water-cooling system. Additionally, insertion of the endoscope was difficult, and the device produced an inverted image. Despite these drawbacks, however, the device proved to be very functional as it enabled visualization of the bladder interior. Nitze not only revolutionized endoscopy, but his cystoscope clearly paved the way for minimally invasive surgery.⁵ In 1910, Christian Jacobaeus used the Nitze cystoscope to perform the first endoscope-guided laparoscopy.⁴

The invention, in 1878, of the vacuum lamp—a carbon filament confined in a vacuum glass—led to production of the mignon lamp, a small vacuum lamp that fitted perfectly at the end of a cystoscope. In

Competing interests

The authors declare no competing interests.

1883, David Newman was the first to adapt the incandescent electric bulb for use with the cystoscope. This modification greatly simplified the cystoscope and reduced the cost of its manufacture, which brought it into widespread use.

Urologic endoscopic treatment was vastly enhanced by the development of the resectoscope in 1926 by Maximilian Stern (1877–1946). In 1931, incorporation of a moving cutting loop into the resectoscope made this instrument suitable for use in transurethral resection procedures. These procedures soon became standard for most cases of benign prostatic hyperplasia and superficial bladder tumors.⁶

Another significant advance in endoscopy was the introduction of the zoom lens and rod-lens system, commonly referred to as the Hopkins telescope after the physicist Harold Hopkins. The use of glass fibers (fiberoptics), first for illumination and later for flexible optics, further advanced endoscopy. The introduction of coherent glass fiber bundles, and their ability to carry true video images, allowed for the creation of the first flexible endoscopes.⁷ French researchers pioneered the use of video cameras in endoscopy in 1956, which improved ergonomics, enhanced safety and increased success rates.⁸ In 1963 the first use of a flexible-fiber ureterorenoscope was reported.⁹

Nowadays, a wide variety of urinary tract disorders are successfully treated in a minimally invasive manner owing to the endoscope and related technologies (Table 1). Fiberoptic technology is widespread, but remains a ‘fragile’ modality with distinct imaging limitations that are intrinsically insurmountable.

Digital endoscopes

In 1970 Boyle and Smith created the charge-coupled device (CCD)—a chip that could store data in the form of electric charges within a grid for retrieval at a later time.¹⁰ Although it soon became obsolete as a memory device, this ability of a CCD to transfer electric charges made it well suited to recording images as a grid of pixels.¹¹ The CCD chip’s linearity of response, high sensitivity and instant image production were all advantageous over conventional film-based image capture. The complementary metal oxide semiconductor (CMOS) device—a low-cost alternative to expensive CCD chips—was patented in 1967. The CMOS chip offered reductions in cost and device

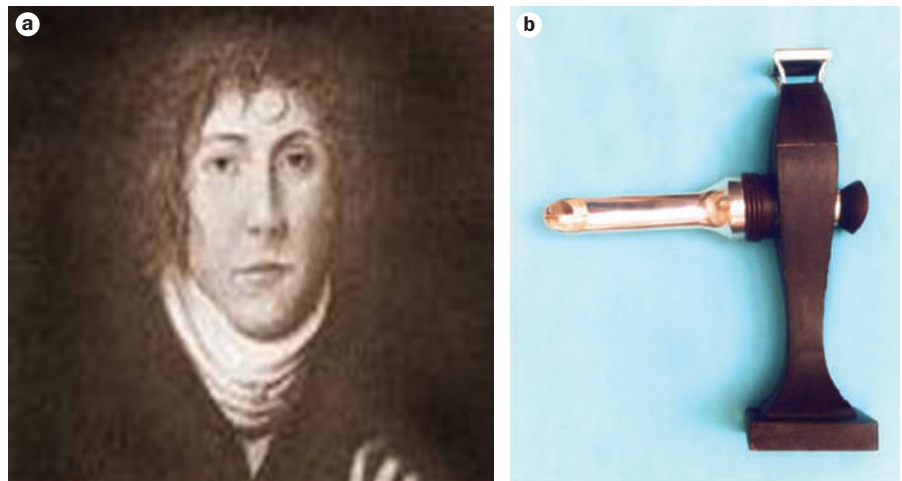


Figure 1 | Bozzini and his Lichtleiter. **a** | Philipp Bozzini (1773–1809). **b** | The Lichtleiter or light conductor.

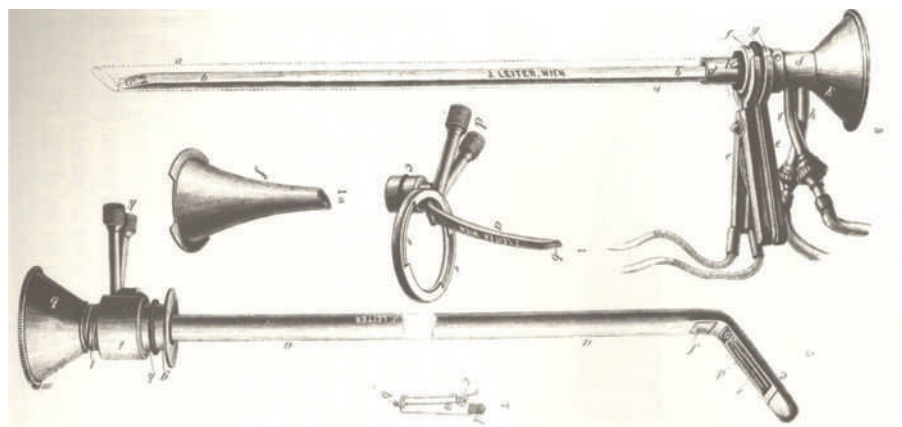


Figure 2 | Nitze's cystoscope.

size, and was more suitable than CCDs for mass production.¹²

A move from fiberoptic endoscopy to distal sensor or ‘digital’ image-based endoscopy based on CCD and CMOS chips is a natural result of the current and projected advantages of these technologies (Box 1). Contemporary distal sensor endoscopes are able to meet the diminutive size requirements of all but the very smallest endoscopes. Certainly, as distal sensor technology improves, endoscopes that employ this technology will match the size of contemporary fiberoptic endoscopes and will ultimately be smaller. Distal sensor endoscopes are already superior to flexible fiberoptic endoscopes in terms of weight.

The key characteristic of any endoscope is its optical fidelity, which includes both the ability to provide adequate light at the target site, and the ability to provide a

high-quality representation of the target. The 30-year evolution of fiberoptic flexible endoscopes resulted in reasonable quality images. However, the finite diameter of image-carrying glass fibers made the pixelated ‘screen door’ effect an insurmountable problem for fiberoptic endoscopes. The first commercial distal sensor endoscope was the ACMI DCN-2010 digital flexible cystoscope (ACMI, Southborough, MA, USA), which was introduced in 2005. This cystoscope incorporated a digital camera and dual light-emitting diode (LED)-driven light carriers into the distal tip of the cystoscope, which reduced the need for cabling and the weight of the device. These measures increased the ergonomic compatibility of the device and facilitated its use.

Quayle and co-workers compared this first distal sensor cystoscope with three contemporary fiberoptic cystoscopes *in vitro*.

Table 1 | Urologic diseases commonly managed by endoscopic technique

Organ	Benign	Malignant
Kidney	Stone Stricture or obstruction Hematuria	Selected superficial urothelial tumors
Ureter	Stone Stricture	Selected superficial urothelial tumors
Bladder	Stone Selected diverticula	Superficial urothelial tumors
Prostate	Hyperplasia	Obstruction due to prostate cancer
Urethra	Stone Stricture	Superficial neoplasms

Box 1 | CCD and CMOS chips in endoscopy

Digital image capturing is possible through sensor array technologies such as those based on CCD and CMOS chips. Digital sensors are composed of millions of photodiodes, which convert photons into electric current that is later transformed into voltage, amplified and converted to a digital form.

CCD chips have a photoactive region (an epitaxial layer of silicon), and a transmission region. An image is projected through a lens onto the photoactive region, and each capacitor accumulates an electric charge proportional to the light intensity at that location. A control circuit then causes each photoactive region to transfer its contents to its neighbor. This circuit operates as a shift register, transferring the electric charge sequentially, row by row, column by column, to a common output structure that converts the charge to a voltage.³⁹

The color accuracy of the CCD camera allows enhanced visualization of reproduced images.⁴⁰ Other advantages of the CCD camera are the improved resolution and quality of the images achieved when three chips are present (one each for red, blue, and green light).⁴¹ Most small endoscopes use a single chip in which these color distinctions are created by filters.

CMOS chips, likewise, are capable of electronic registration of images projected onto their surface through the lens of a camera, and also provide image capture to a grid of pixels formed by photoelectric elements. The resultant electric charges are 'read' by a sensor, and a process of analog to digital signal conversion is required to produce images that can be stored. In a CMOS sensor, each pixel acts as its own independent amplifier of the image signal, which limits noise as the charge-to-voltage conversion takes place within each pixel. On both types of chips, the information is transferred to a controller box for image presentation or storage.

Compared with CCD chips, CMOS technology offers improved integration (more functions on the chip), lower energy consumption and less heat production. Additionally, CMOS technology requires fewer electronic components, which allows such chips to be smaller and more compact. However, to date, the advantages of CMOS chips often come at the expense of image quality and device cost.⁴² CMOS cameras still generally require companion chips to optimize image quality, which increases cost and power consumption.

Technological developments have enabled the production of a CMOS sensor with high energy efficiency, high spatial resolution, high speed, low power consumption and low cost.⁴³ In the future, CMOS camera endoscopes might reduce device costs and facilitate the spread of distal sensor endoscopy.

Abbreviations: CCD, charge-coupled device; CMOS, complementary metal oxide semiconductor.

In simulated adverse conditions, the distal sensor endoscopes provided superior optics.¹³ Borin and colleagues compared a distal sensor, digital, flexible cystoscope with two standard fiberoptic endoscopes by studying contrast, resolution, and color discrimination. In 12 of 13 optical tests, the distal sensor cystoscope was superior to the fiberoptic cystoscopes. The authors

noted that imaging with the distal sensor endoscope was improved by the ability to identify lesions as small as 1 mm at a greater distance than was possible with the fiberoptic endoscope.¹⁴ They speculated that this optical advantage could potentially result in improved clinical evaluation, for example by increasing the sensitivity of surveillance cystoscopy.

Okhunov and colleagues conducted a prospective clinical comparison of distal-sensor and fiberoptic cystoscopes in over 1,000 patients who underwent office cystoscopy. The investigators evaluated the optics, clinical performance, and durability of these devices. All surgeons found the distal sensor endoscopes to be lighter and easier to handle, and the majority preferred these cystoscopes to the fiberoptic devices. Both subjective optical and functional metrics were significantly better with the distal sensor cystoscopes than with the fiberoptic ones. Distal sensor video imaging provided rapid and high-quality image capture. The images were easily stored and transferred by standard computer memory technologies. Both the fiberoptic and distal sensor cystoscopes were very durable with proper care.¹⁵

Evolution of distal sensor imaging has facilitated the construction of ever-smaller distal sensors, and the technology has been extended to other urologic endoscopes, such as ureteroscopes and nephroscopes. The quality of image captured by the contemporary digital ureteroscope is comparable to the image from a rigid Hopkins lens. However, distal sensor ureteroscopes offer superior illumination and resolution. Another advantage of digital imaging is the ability to digitally magnify an image up to 1.35 times its original size.¹⁶

Andonian and co-workers have evaluated the application of distal sensor imaging in a nephroscope. This device has a 15 Fr (5 mm) working channel, which enables the insertion of instruments such as forceps, lithotripsy probes and suction devices. The image produced has true color and retains good resolution.¹⁷

The superior optics of distal sensor ureteroscopes and nephroscopes is hypothesized to result in superior surgical performance. However, this theory has not yet been evaluated, and at present no evidence supports the superiority of distal sensor ureteroscopes in the clinical setting.

Beyond imaging

From the perspective of imaging alone, the change from fiberoptic endoscopy to distal sensor endoscopy represents an important but limited advance in the history of endoscopy. However, distal sensor technologies offer additional capabilities that are just beginning to be explored. The intrinsic abilities of CCD and CMOS chips to stratify

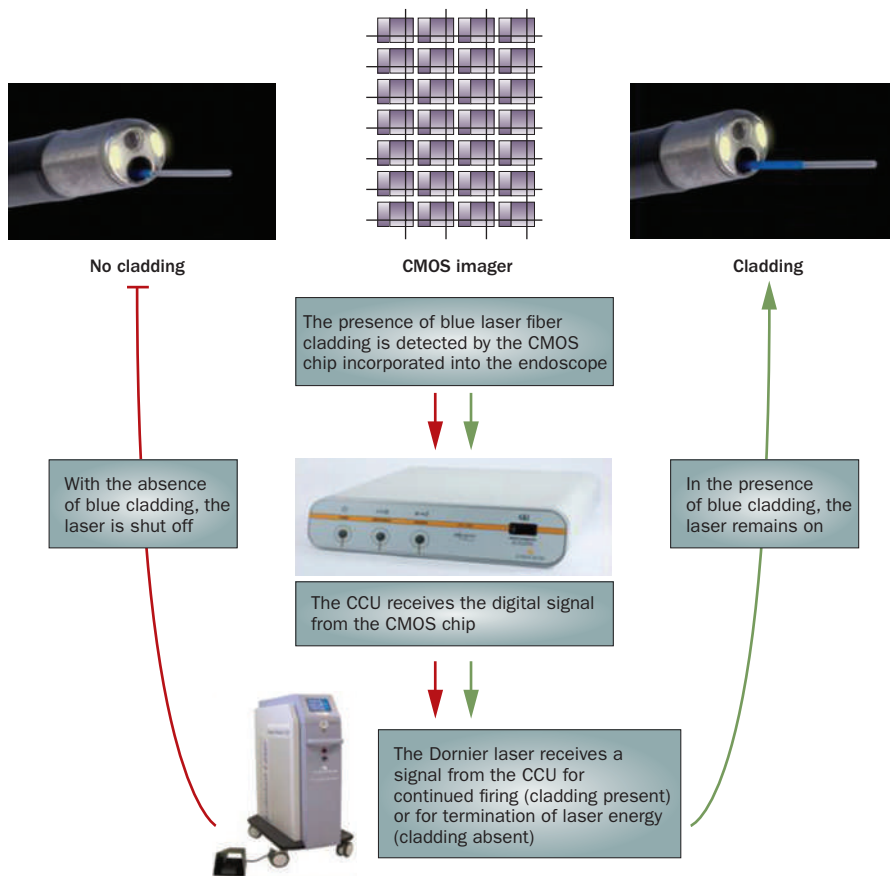


Figure 3 | Endoscope protection system (EPS). Constantly tracking the presence of the laser fiber via the CMOS chip avoids blind functioning of the laser, reduces endoscope damage and probably decreases procedure costs. Abbreviations: CCU, camera control unit; CMOS, complementary metal oxide semiconductor.

and process information have engendered a revolutionary change in the nature of the endoscope.

The first step beyond endoscope imaging was made in 2008 by Gyrus-ACMI (Southborough, MA, USA), who offered a software update known as the endoscope protection system (EPS; Figure 3) for use with their Invisio (DUR-D) digital flexible ureteroscope. The EPS exploited the ability of the CMOS sensor incorporated into the DUR-D ureteroscope to detect colors in different portions of the optical field in order to detect the blue cladding of a Dornier DURHL-20 laser fiber. When the EPS is active, the CMOS chip continuously detects the presence of the laser fiber as a blue color in a specific portion of the optical field. When the laser fiber is retracted (or obscured), information is transmitted from the CMOS chip to the computer control unit. This control unit is connected to the laser and is able to initiate shutdown of

the system within milliseconds, which prevents the laser from functioning 'blind' and reduces endoscope damage and probably procedure costs.

This system was highly effective *in vitro*,¹⁸ and was similarly efficacious in a pilot clinical trial.¹⁹ False-positive shutdown of the laser did occur when the part of the field of view occupied by the laser fiber was obscured by stone fragments, but the system remained highly valuable. As a complement to standard good laser policy, the EPS system is likely to prevent a substantial proportion of ureteroscope malfunctions caused by laser damage. As such, the EPS system might help to diminish the cost of ureteroscopy and diminish the risks associated with training.¹⁹

Another technology made possible by information stratification, this time by the CCD chip, is narrow-band imaging (NBI), which was introduced by Olympus to work in association with their cystoscopes and

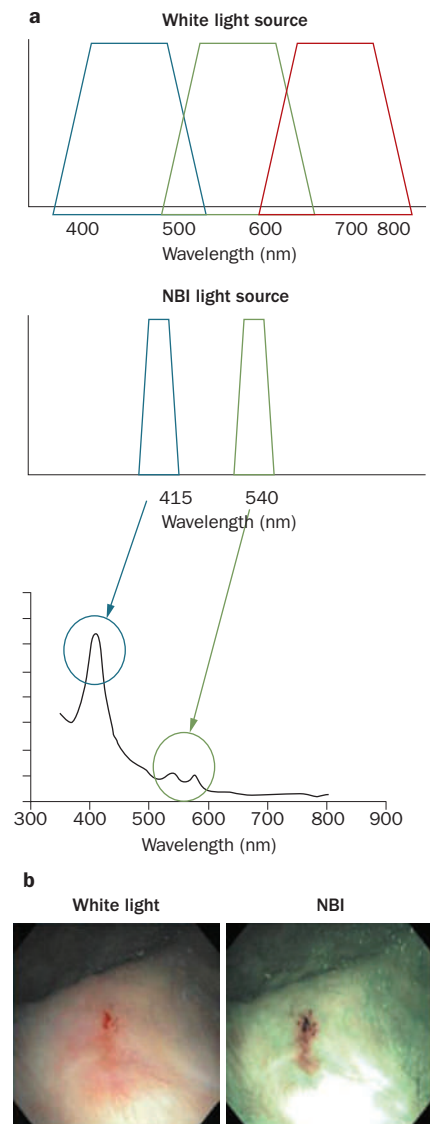


Figure 4 | NBI system. **a** | Rather than utilize the entire white light spectrum, NBI employs optical interference filters to detect specific wavelengths of light. **b** | This approach improves the definition of the epithelial surface and emphasizes the mucosal microvessels, which appear as dark brownish structures. Abbreviation: NBI, narrow-band imaging.

ureteroscopes. NBI employs optical interference filters that restrict the wavelengths of light used for imaging to a narrow portion of the spectrum used in conventional white light endoscopy. Use of NBI improves the definition of the epithelial surface and emphasizes the mucosal microvessels, which appear as dark brownish structures (Figures 4 and 5). NBI might improve the identification of neoplastic tissue, which

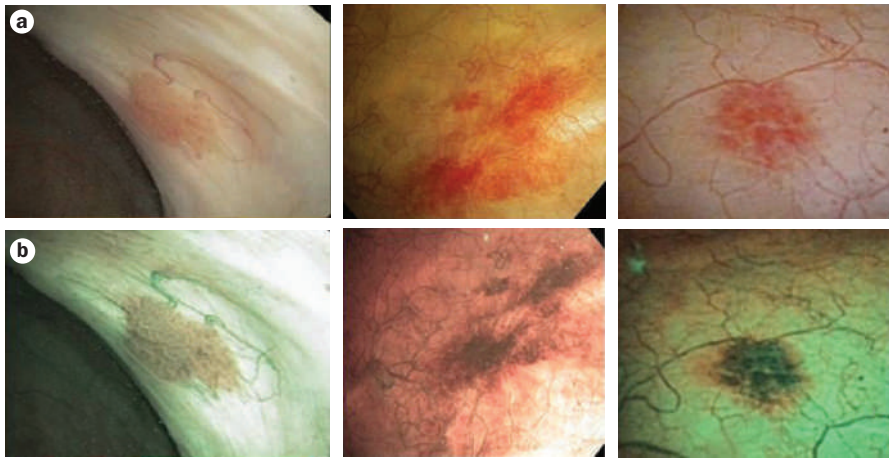


Figure 5 | Improved visualization of bladder lesions with NBI. **a** | Lesions seen with white light cystoscopy. **b** | The same lesions seen with NBI. Abbreviation: NBI, narrow-band imaging.

has high microvessel density and usually appears darker than the normal mucosa. The system is operated by simply pressing a switch on the endoscope to activate the optical filters and change from conventional imaging to NBI.²⁰ NBI has demonstrated superior sensitivity for identifying recurrent flat and papillary superficial bladder tumors in a surveillance setting, when compared with standard white light cystoscopy.²¹ NBI technology might also improve diagnosis and early identification of recurrence for high-grade tumors and carcinoma *in situ*, but this capability has yet to be definitively established.

Similar improvement in the sensitivity of detection of upper urinary tract transitional cell carcinoma (TCC) might be achieved through NBI-enhanced ureteroscopy. Rabbani and colleagues²² studied patients with bladder cancer who were undergoing long-term surveillance for upper urinary tract TCC, and found a relatively constant incidence of such disease over time, even 10 years after the initial cancer diagnosis. NBI achieves a higher detection rate of bladder cancer recurrence during surveillance than does white light cystoscopy.²³ Thus, the advanced imaging techniques offered by distal sensor endoscopes might enhance early diagnosis and long-term survival in these patients, although further clinical assessment is required in this setting.

Virtual endoscopy

Virtual endoscopy utilizes three-dimensional computer-enhanced reconstruction of CT and MRI anatomical information to generate images that recreate the endoscopic

perspective with great detail (Figure 6). This type of computer-driven reconstruction has been applied to the majority of luminal structures in the human body, including the urinary tract.²⁴ It potentially represents an inexpensive and noninvasive technique to evaluate the urinary tract.

Owing to the high recurrence rate of bladder cancer, close cystoscopic surveillance after transurethral resection is currently the standard of care to establish early diagnosis of recurrence and to improve cancer control.²⁵ Standard cystoscopy, however, even with contemporary diminutive flexible instrumentation, results in some discomfort for the patient and can cause morbidity such as infection, bladder perforation, scarring, and stricture of the urethra.

At present, virtual endoscopy does not offer sufficient sensitivity to replace conventional cystoscopic evaluation in this setting. However, virtual cystoscopy is a feasible technique for the detection of bladder lesions smaller than 5 mm. Virtual imaging of the urinary bladder, in multiple planes and with a 360° view, currently allows difficult areas of the bladder to be accessed. At present, the major application of virtual cystoscopy is in patients for whom conventional cystoscopy is not applicable or is contraindicated.²⁶ Kivrak and colleagues found that, in selected patients, virtual cystoscopy can be successfully used for noninvasive detection of bladder lesions with a sensitivity of 90% and specificity of 94%.²⁶ Lopes and co-workers reported similar results, with a sensitivity of 95.1% and specificity of 91.2%.²⁷ These authors justifiably point out, however, that virtual cystoscopy will not be able to detect

flat lesions such as carcinoma *in situ*, and does not afford the surgeon the opportunity to biopsy suspicious lesions.

Multidetector CT urography is an accurate, noninvasive imaging approach for diagnosing TCC in patients with gross hematuria; this technique has higher sensitivity than conventional excretory urography.²⁸ The initial clinical experience with virtual CT nephroscopy (a modality based on CT urography) was reported by Takebayashi and colleagues, who assessed 32 patients with suspected renal pelvic tumor. CT nephroscopy revealed 22 of 24 tumors (92%) while axial CT detected only 20 (83%) lesions. Virtual nephroscopy was also superior to axial CT in detecting pedunculated and infiltrating lesions.²⁹

Impressed by the fine detail of the ureteric anatomy seen in this study, these same authors subsequently presented a similar study of 16 patients with suspected ureteral tumors. Virtual ureteroscopy successfully detected the presence of ureteral tumor, with a sensitivity and specificity of 81% and 100%, respectively. Additionally, virtual ureteroscopy facilitated the evaluation of extrinsic compression by lymphadenopathy and could be used to differentiate strictures from urothelial tumors.³⁰

Contemporary data on virtual urologic endoscopy have shown that virtual ureteroscopy is safe, noninvasive and enables effective endoluminal navigation of the entire ureter. Battista *et al.*³¹ concluded that virtual ureteroscopy provides superior anatomic information to that obtained by axial CT.

Despite the many potential advantages of virtual endoscopy using CT urography, limitations remain. Perhaps the most critical are the inability to identify alterations in mucosal texture and color and to administer treatment. Important pathology such as carcinoma *in situ* is unlikely to be identified with contemporary virtual endoscopy. While urinary cytology can be used to identify the majority of carcinoma *in situ*, the poor sensitivity of CT urography for identifying bladder pathology continues to support the use of cystoscopy in the majority of patients.

Magnetic resonance urography is a noninvasive diagnostic imaging technique which, unlike CT urography, does not require the application of ionizing radiation or iodinated contrast. T₂-weighted magnetic resonance urography is the first relevant means of visualizing the urinary tract with MRI; the static fluid within the

urinary tract is visualized as though it was a structure of the body for the purposes of image reconstruction. Magnetic resonance urography using gadolinium-based contrast material and T_1 -weighted images yields a bright appearance of urine. In conditions of low urine output, imaging is suboptimal. As such, intravenous diuretic administration is recommended when possible to enhance the quality of excretory magnetic resonance urography images under these conditions.³²

As with CT urography, magnetic resonance urography has significant limitations, including a relative insensitivity for detection of renal calculi, a lengthy image-acquisition period, significant movement artifacts and lower spatial resolution when compared with CT.

Capsule endoscopy

A new and promising technology in the urologic field is wireless capsule endoscopy (WCE), in which a camera and a wireless radio transmitter are contained in a small capsule that is inserted into the urinary tract. A capsule endoscope comprises the capsule device, an external receiving antenna with attached data recorder, and a computer workstation with the appropriate software for interpretation of images. The capsule has two main parts: optics, namely a lens with short focal length, a narrow aperture to increase the depth of field and illumination by LEDs; and an assembly of magnets to assist with device manipulation.

Capsule endoscopy is currently indicated after upper and lower gastrointestinal endoscopy has failed to identify the origin of obscure bleeding. Various other indications have been proposed for WCE, such as the investigation of unexplained anemia, evaluation of the small-bowel mucosa in patients with Crohn disease, as well as diagnosis and surveillance of patients with hereditary polyposis syndrome, protein-losing enteropathy, or irritable bowel syndrome. Within esophageal disease, WCE can evaluate the presence of reflux disease and portal hypertension.³³

Limitations of WCE include that it is not recommended for patients with swallowing disorders owing to the risk of aspiration, the possibility of false-negative results and the inability of contemporary devices to obtain a biopsy specimen or to perform endoscopic treatment. Currently, the best applications for WCE are as a complement to conventional endoscopy, to avoid unnecessary examinations.³⁴

WCE has only been used experimentally in urologic disorders. It has been successfully used to evaluate the urinary tract in a porcine model, where it produced continuous images and identified specific landmarks. In this setting, the device could be manipulated by means of an external magnet.³⁵

In the future, WCE might be significantly enhanced by the development of capsules that can be actively steered, which would dramatically increase the sensitivity of this imaging modality. Similarly, capsules could be modified to enable tissue biopsy and treatment, and even to deliver medication such as bacillus Calmette–Guérin or chemotherapy after bladder tumor resection. We can speculate that a self-propelled ‘untethered intracorporeal endoscope’ could be developed, which could be introduced into the lower urinary tract and guided ‘upstream’ by a chemical signal derived from administration of an organ-specific targeting substance.

In the future, urologic imaging by virtual endoscopy or advanced WCE would certainly result in diminished discomfort for patients and decreased cost; these advances allow endoscopy to be performed effectively in the least invasive manner possible.

Future directions

The future of endoscopy is difficult to predict. However, we are likely to see improvements in this field that currently seem almost unimaginable. The creative application of novel technologies from other disciplines has always enabled endoscopy (and indeed all aspects of minimally invasive surgery) to move forward. Imaging devices will certainly continue to decrease in size, such that ‘microendoscopy’ will be feasible in the near future. Endoscopy of any luminal structure, including the vas deferens, will certainly follow.

Nanotechnology, including small robots built from novel materials, has already been demonstrated to be feasible. Self-assembling robots constructed from nucleotides have already been created. As has already been envisaged in science fiction, a time when small ‘robots’ will patrol biologic structures to constantly survey and help protect normal anatomy and physiology is not difficult to imagine.

The incorporation of advanced physics and molecular biology techniques will almost certainly complement endoscopy, and are likely to eventually eliminate the need for endoscopy altogether. The first

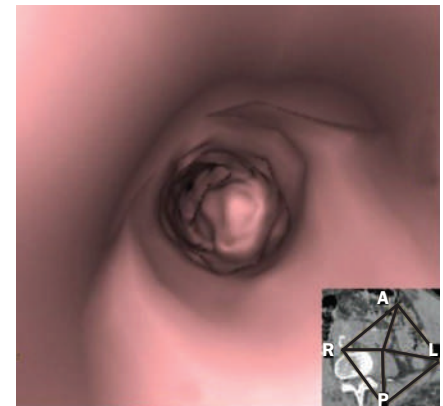


Figure 6 | Virtual ureteroscopy image of urethelial tumor, created from a CT scan.

efforts to assimilate molecular biologic techniques into endoscopy have been made. Raman endoscopy consists of a powerful light-scattering technique used to identify the internal structure of molecules and crystals. Light of a known frequency and polarization interacts with and is scattered by a sample. The scattered light is then analyzed for its frequency and polarization, which can provide information on the characteristics of the sample.³⁶

Raman spectroscopy might greatly improve real-time histologic tissue diagnosis by measuring the molecular components of tissue in a qualitative and quantitative way. Light scattered by each tissue type has a characteristic spectrum, which can be used to generate a pseudocolor map; thus, by analyzing the tissue’s spectrum we will be able to tell if its composition is of a normal or a pathologic nature.³⁷ The time needed to obtain such spectra is around 10–20s, which allows fast decision making that might enable real-time decisions as to whether to perform conservative or radical surgery, to define limits of resection or to differentiate benign from neoplastic tissue.

Another application of physics within endoscopy is optical coherence tomography (OCT). This imaging modality is capable of producing high-resolution, cross-sectional, subsurface tomographic imaging of the microstructure in biologic systems by measuring backscattered or backreflected infrared light. Its underlying physical principle is similar to that of B-mode ultrasonography, but instead of sound OCT applies light.

OCT devices use a low-power infrared light with a wavelength of 750–1,300 nm and images are generated from measuring the echo time delay and the intensity of

back-scattered light. The depth of penetration of OCT imaging is approximately 1–3 mm, depending upon tissue structure, depth of focus, and pressure applied to the tissue surface. All the tissue layers of the bladder (urothelium, lamina propria, and muscularis propria) can be individually visualized by use of this technology according to their different light-reflecting properties.³⁸

Patients with other pathologies might benefit from the use of OCT to improve treatment and surgical decision making. For example, in the future, OCT may help to evaluate neurovascular bundle involvement in patients with prostate cancer and thus inform resection decisions. Similarly, OCT might be applied to kidney, ureter and collection system tumors to help optimize resection.

Conclusions

Urologic endoscopy has evolved tremendously since its inception, with massive improvements in our ability to image the urinary tract. Similarly, our ability to diagnose and treat pathologies of the urinary tract continues to improve. We have already seen the applications of technology lead to improvements in imaging, device characteristics and the caliber of available instrumentation. These advances have enabled urologists to perform a range of minimally invasive treatments, which have reduced morbidity and improved recovery of patients.

Ongoing research and technological improvements will keep endoscopes in a constant state of evolution, in which novel technologies constantly extend the abilities of endoscopic techniques. The endoscope is becoming a trusted 'partner' to the surgeon in that it can help to optimize the control of other equipment in the operating theater and evaluate tissue better than the human eye alone. Certainly, in the future, our current concepts of endoscopy will change dramatically, and our patients will benefit from the continued expansion of these minimally invasive technologies.

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