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INVITED REVIEW

Ureteroscopy from the recent past to the near future

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Abstract

Stone surgery is one of oldest surgical practices undertaken by man. Hippocrates refused to let his followers "cut for the stone" and it was only in February 1980, when the first human trial of shock wave therapy on a renal stone was performed with success that a new era in minimally invasive treatment (surgery) for stones was opened up and this condemnation was finally resolved in the Hippocratic Oath. Endoscopy, using natural orifices, supported by anaesthesia, incremented by technology and with access to all points along the urinary tract, began by competing with ESWL, but is now the treatment of choice in most cases. As far as we know humans have always had stones. First, lithiasis was endemic bladder stones in children, now it is renal in general. Added to this a number of well-known risk factors, a rapid increase in obesity in the population, as well as bariatric surgery for its treatment, are causing an increase in the prevalence and recurrence of lithiasis everywhere. A short history of the advances made with the introduction and development of the ureteroscope, along with auxiliary devices, will show why this is the preferred technique at the moment for treating lithiasis in general and for treating stones in pregnant women, children and the obese in particular. Being a minimally invasive surgery, with a low morbidity and a very high efficiency and stonefree rate, has become established as a clear future technique for both adults and children. This development is not only due to technological advancements, but also to the routine use of the Holmium: YAG LASER for intracorporeal lithotripsy, capable of destroying any stone regardless of its composition or location, surpassing the ability of any other lithotripter. It is also due to the development of devices that allow access to the ureter and all parts of the kidney, as well as auxiliary aids to assist in the handling of stones during treatment. New LASERs, robotic control of the fdURS and digital imaging, as well as disposable devices, have had and, indeed, continue to have a unique impact on future development in this field. However, success will continue to depend on the careful choice of fURS, energy source and ancillary instruments obtained by the urologist during both real life and virtual training in human simulators.

Keywords Ureteroscopy · Advances · Devices · Calculi treatment · Stones · Disposable ureteroscopes

Introduction

Since the beginning of the 20th century, the pattern of lifetime prevalence of urolithiasis in developed countries has changed a great deal and, more recently, in less developed countries as well. In Europe, cases of endemic bladder stones disappeared after the 1930s, and they continue to decline dramatically in countries where malnutrition is being treated with sufficient protein supplementation. In contrast, stones in the Upper Urinary Tract (UpUT), primarily those of calcium oxalate, are increasing worldwide. UpUT stones are a major social, clinical and economic burden for healthcare systems [1]. The increase in lifetime prevalence, more than 15% in some countries, is having a devastating impact on the running costs of these health services, forcing them to reallocate technical and human resources. Turney BW et al., shows that the number of ureteroscopies(URS) performed for stone disease in the UK, has increased by as much as 127% over the 10-year period between 2000 and 2010 [2].

The rise in urolithiasis can be attributed to a number of well-known risk factors, including poor dietary habits and fluid intake, sedentarism, age and gender. Increased levels of obesity, diabetes and the metabolic syndrome known as "diabesity" may also contribute to recurring cases of urinary stones [3, 4], as well as increased incidence.

The age of first stone episodes has decreased, with an increase of 19% in the number of children being diagnosed

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[2, 5]. Obesity is, in many cases, responsible for the increase in calculi; however, metabolic changes caused by bariatric surgery, undertaken as a weight loss treatment, can also now be to blame. With this in mind, the time has come to further educate the public in an attempt to prevent stone formation.

Past and present of stone management

In the past, urinary stones have been managed using open surgery. From the 1980s onwards extracorporeal shock wave lithotripsy (SWL) emerged as a minimally invasive option for the treatment of stones, with acceptable stone free rates (SFR) [6, 7]. More recently, the advent of minimally invasive surgery, in particular URS, means that the number of SWL procedures being undertaken is falling. Recent data from around the world clearly suggests dramatic rises in the use of URS [8], far exceeding the small rises being seen in uses of SWL [2, 9, 10]. This change in the approach to UpUT stones is not only due to advances in design, improvement and innovation of ureteroscopes (the change from rigid to semi-rigid instruments) but also the introduction of flexible URS (fURS) and the development of new essential devices for safe, fast and effective procedures to remove stones from the urinary tract. Notable amongst these developments are new intracorporeal lithotripters. There are several options for stone fragmentation, including electrohydraulic (EHL), ultrasonic, pneumatic and LASER lithotripsy. Holmium:YAG LASER lithotripsy uses smaller devices than the other treatment methods and has also been shown to be more effective, with fewer complications, especially in the ureter. Ureteral access sheath (UAShs), stone retrieval devices, new guidewires, new JJ stents and numerous other devices, as well as thermosensitive gel that helps prevent the migration of fragments from the ureter to the kidney during fragmentation, are all other notable examples of auxiliary tools that have helped revolutionise URS. Technological advances in the fields of fibre-optic design, mechanics and miniaturisation and in digital imaging are responsible for astounding progress in the field of imaging, both radiological and URS.

Recently, another important advancement has been robotic manipulation in procedures using the existing fURS. Last, the development of Single-Use URS has brought both advantages and disadvantages, with a key stumbling block being the price. However, with cost reduction these are likely to become popular for large-scale production.

The first successful endoscopic stone manipulation was reported in 1889 by Gustav Kolisher [11], with the first documented URS taking place in 1912, when Hugh Young introduced a paediatric cystoscope into a child's dilated ureter [12]. Due to technical limitations, endoscopy remained a fairly stagnant field for a long period of time, until development and advancement was facilitated by progress in fibre-optics. Major improvements were made to the endoscopic light source during the development of the cystoscope. A system of mirrors and lenses was introduced, along with candlelight, to transmit light through a hollow tube. This development has been further improved by fibre-optic technology, utilising the principle of internal reflection and allowing the "bending" of light within flexible glass [6]. This knowledge ultimately led to the development of the rigid ureteroscope in 1977 by Goodman [9], with improvements made by Perez-Castro [13]. Perez-Castro worked in collaboration with Karl Storz to significantly further develop these improvements, introducing them into clinical practice. Separate working and optical channels were incorporated, proving to be a decisive step towards the modern URS [13].

Early ureteroscopes were rigid, as they used a system of rod-lenses and had a large diameter (10–16 French); replacing this rod-lense system with fibre-optics made them thinner. These were known as "semi-rigid", because they did not deform the image when subjected to small bends inside the patient's body. However, the quality of the image suffered and became inferior, although it was introduced into practice in the 1980s with great success. After improvements, it allowed for easier treatment of stones in the ureter, with good results [14, 15] and few complications. The short period of hospitalisation and rapid return to a normal life made this the preferred method of treatment.

The first flexible endoscope was used in 1965 by Marshall [14]. Designed by Curtis and Hirshowitz [16], it had to wait some time for technology to evolve. The fURS had advantages that required further development, as it allowed access to the renal cavities. Fibre-optic fURS were developed primarily as a response to concerns that the rigid URS (rURS) could cause damage to the urothelium when accessing the upper ureter. Flexible tip URS was introduced in 1983 [6].

It is important to note that deflection capacity means the flexion of the tip from straight to angled position. Primary deflection is the initial degree of deflection achieved from a neutral straight position of the scope tip and secondary deflection is a further degree of deflection in relation to an already curved or 'flexed' URS tip. Those URS that are capable of secondary deflection are particularly advantageous when it comes to exploring the lower pole calyces and in managing calculi located there [17]. The wide range of deflection capabilities and the 'S' shape allow the urologist to access any area of the collecting system [18]. The secondary deflection is also an advantage regarding treatment and endoscopy. Any curvatures are areas of stress for the URS and can limit its lifespan; secondary deflection helps to mitigate this stress but continues to limit LASER fibre diameter as well as the use of basket or forceps.

LASER fibres can often damage the fibre-optic based URS, resulting in reduced image quality, a 'grainy' picture and potential water infiltration of the optical lens. Nowadays, there are protective sheaths and devices available for the LASER fibres, to help minimise the risk of damaging the channel, whet during insertion or by helping to avoid accidentally firing the LASER whilst the fibre is inside the working channel. This will be refined by the development of robotic control.

Other URS advances include the minimisation of the distal tip [< 6 Fr ch] and the introduction of a tapered 'evolution' tip to facilitate ureteral cannulation, as seen in the Olympus URF-P5 flexible ureteroscope (Olympus, USA), as well as a LASER-resistant chip in the dURS, composed of a proprietary Laserite™ [18].

Digital imaging

While many ergonomic improvements have been seen in conventional fibre-optic fURS, including lighter scopes and improved manoeuvrability [19], it is the introduction of digital imaging that has truly changed the technical capacity and results of the fURS, along with its costs. Image quality is an invaluable technical improvement, not only for the treatment of stones, but also for the diagnosis and treatment of urothelial tumours, strictures, opening of diverticula, biopsies and many other key areas.

Introduced in 2006, the first digital ureteroscope was the Invisio® DUR®-D (Olympus). Since then, several other models have appeared on the market with a more or less identical design, each varying in minor details affecting their competitiveness either in price, technical advantages or ergonomic benefits, all of which manufacturers claim translate directly into clinical advantages.

Digital ureteroscopes (dURS), also known as the "chip on the tip", avoid the use of fibre-optics altogether for the transmission of images. The light comes instead from a distal LED source or is transmitted via the scope from a proximal source, which allows images to be transmitted from a digital sensor on the tip to a proximal point via a single wire, with any processing occurring at the proximal sensor. These dURS offer high-definition imaging, autofocus capabilities and digital magnification. This means that, in comparison with the fibre-optic URS, the image appears on a standard monitor up to 2.5 times larger and without the 'honeycomb' effect [19]. They are also fitted with a LASER detection system, which is capable of deactivating the LASER to prevent misfiring within the scope during the procedure.

Although digital technology is more expensive than fibre-optics, it has been reported that it is also more durable [20]. Eliminating the need for fibre-optics would also allow for larger working channels [21]. However, dURS are often larger than their fibre-optic counterparts [22].

Once initial limitations have been overcome, they develop rapidly into models with high deflection capacity, an irrigation channel and one or two working channels. Although originally designed with just a single deflection, many now offer a secondary deflection, which allows easy access to all calyces. The diameter has also continued to decrease, despite the multiple channels, which allows these endoscopes to enter the ureter without the need for pre- or per-operative dilation. The fURS is tapered proximally in its diameter, which allows for gradual dilation as the device is inserted. This ability to treat the patient without the need for dilation or the use of UASh makes for a much simpler procedure, lowering the risk of complications in the ureter and increasing post-operative comfort for the patient. The fURS and, more recently, the digital fURS (dfURS) have paved the way for retrograde intrarenal surgery (RIRS) for the treatment of lithiasis, tumours and other rarer clinical conditions. They have made it considerably easier to study the papilla and Randall's plaques, as well as small stone samples for analysis. Studying the papilla offers a new field of research for understanding stones, how they form and how they can be treated.

Guidewires and ureteral access sheaths

To realise the full potential of the URS, innumerable devices for expanding its functions are continually developed. Guide wires were designed not only to facilitate the introduction of the URS into the urinary tract, but also to make it possible to easily guide the insertion of ureteral access sheath (UASh) when desired. With the UASh in place, it is easier to enter and exit from the ureter, with a clear image and reduced risk of injury. When in place, UASh helps to remove calculi with or without them being destroyed prior to removal, and also reduces irrigation pressure in the upper urinary system.

Guidewires

Despite ongoing controversy, the guidewire continues to be indispensible in preparing for URS. It assists in the introduction of the ureteral catheter into the ureter, providing a safe way in which to enter for study and navigation. If the decision to use a guidewire is appropriate and well-founded, then it offers perfect navigation that is also extremely safe. It can help the ureteral catheter progress with minimal risks of perforation or creation of false routes. In terms of medical guidelines, the guidewire must be part of the urological arsenal, with a number of varieties available to allow the correct choice to be made in difficult situations, such as impacted stones or strictures that need to be negotiated. This also happens when the ureter is dilated and when there are kinkings.

Fibrotic changes due to surgery or radiation, with multiple curvatures or scars, are all challenges that can occur, and making the correct choice can dictate whether the situation ends in success, failure or complications. Several factors can be decisive in ensuring a successful outcome, including rigidity at critical points, the design and firmness of the tip in terms of the resistance offered by the ureter, and the ease with which it slides between the stone and the ureteral wall. The same is true regarding the introduction of the URS into the ureteral meatus. The use of one or two guidewires is essential to ensure risk-free insertion and ascent, particularly when using rigid or semi-rigid instruments and when inserting the UASh.

There are many options available on the market, including straight tipped and curved j-tip, firmer and more malleable, longer and shorter, as well as those that can be altered when necessary and those with fixed cores. There are also guidewires that are stiffer throughout and others with durability and thickness that vary along the guidewire's length. Being malleable at either end, yet harder and straighter through the middle, prevents the guidewire from bending when force is needed. These hybrid guidewires may make it possible to carry out procedures in fibrotic and anatomically deformed areas. The current tendency is to choose a hybrid guidewire with a hydrophilic surface coating, as these offer the flexibility of a hydrophilic tip combined with the sustained rigidity of a stiff body [22]. This allows it to slide smoothly and offers firmness with any required bending, with the malleable tip allowing for atraumatic movement. For some urologists, the use of a safety guidewire when treating calculi is almost mandatory, and is supported by the guidelines put in place by urological associations [21]. It avoids losing the chosen path, allows the URS to enter and exit safely where necessary, and serves to stabilise the UASh once in place or to aid its ascent during placement. However, this can also be a source of complications [23, 24].

Ureteral access sheath

The use of ureteral access sheath continues to be a point of contention. Many see them as a risk, primarily for fear of complications occurring during placement. A UASh can cause wall injury, and kinking may occur in the prostatic urethra in male patients. If the procedure is long and the UASh remains in place for a considerable time, it can also result in ischemia. It also promotes an acute inflammatory response in all patients, due to prolonged pressure being placed on the ureteral wall. The UASh is also not indicated for treatment of distal ureteral stones. It can be argued that the placement of a parallel double guidewire for stabilisation could be a source of complication, by fixing the ureter too firmly in position and causing injury when it is advanced or retreated along this wire.

However, a clear majority feel that the advantages are overwhelming. The placement of UASh during URS allows lower irrigation pressures to be maintained, allowing the pulverised stones to be removed rapidly and reducing the risk of ureteral rupture. This also helps to protect the renal pelvis, reducing the risk of retroperitoneal extravasations and pyelolymphatic or pyelovenous backflow. Reducing the pressure can also minimise the chance of sepsis, a risk that cannot be ignored, and offers reduced operating time. The ease of moving and placing the URS helps to improve handling, reduce stress on the device and contribute to scope longevity [25]. This was already the case with regards to the fURS, and is even more so when it comes to the dfURS. Improved visibility seems to be a factor in reduced risk of complications. UASh can also help reduce intermittent bladder drainage. It also appears that, when ureteral dilation is required, the use of UASh is associated with fewer post-operative symptoms in comparison with balloon dilation. Ng et al. [26] found that the size of the UASh (10–16 Fr) has only a minimal impact on irrigation flow while the working channel is occupied, demonstrating that improved flow dynamics could be achieved using a concurrent ureteral access catheter (4 or 5 Fr) as well as a standard UASh solely for irrigation inflow.

In an adult patient, the length of the UASh chosen is based on gender, height and stone location, with lengths varying between 20 and 55 cm. The choice of calibre is also important, between 9.5 and 14 Fr for internal diameter and 11.5–17.4 Fr for the external diameter. The majority of procedures are carried out using 12/14 Fr, with two studies favouring the 12/14 Fr Cook Flexor® UASh (Cook Urological, USA). Both of these studies took into account facilities and complications relating to placement, ease of passage for the instrument type used, stone extraction, and low failure rate. It is also worth noting that there was lower propensity to buckle with the use of this UASh [27, 28].

UAShs are currently emerging that allow suction during lithotripsy, meaning that small stone fragments can be drawn to the entrance of the UASh and continue to be pulverised using the LASER fibre, with great ease and reduced risk to the ureteral mucosa.

Devices to prevent stone migration

Stone or fragment migration can alter surgical strategy and increase operating time, due to the need for auxiliary procedures and increased morbidity. It can occur between 5 and 40% of the time during URS lithotripsy. One of the first devices developed to combat this was the use of a balloon dilator, which was used during dilation and simply raised above the stone, then re-inflated to prevent migration. The Stone Cone™ Nitinol (Boston Scientific, USA) was then developed, made from an inner coiled nitinol wire covered with an outer radio-opaque 3 Fr ch polytetrafluoroethylene cover. This device can prevent the migration of fragments over 2–3 mm [21, 29] and is resistant to EHL and pneumatic lithotripsy, although it can be damaged by a Holmium LASER. Its efficiency outweighs the additional cost of this device. Other variants then followed with a similar basis, such as the N-Trap®, a 7 mm umbrella that also has a nitinol base and is designed for the entrapment and extraction of a stone or fragments. Another example is the Accordion Stone Control Device, which is simple, useful and inexpensive. In addition to simple measures such as the reverse Trendelenburg position, lidocaine gel placed close to the radiopaque stone and reverse thermosensitive water-soluble polymers have also achieve the same effect of preventing stone migration.

Another idea that has been developed recently is the magnetisation of stone fragments using negatively charged amino acids combined with an iron oxide core matrix, coating the surface of the stones and removing them using a magnetic device. This procedure saves time by removing the need to extract multiple fragments individually [30].

Devices for stone retrieval

The reusable stainless steel baskets of the recent past have practically ceased to be used. Current baskets are single-use, sturdy and offer increased flexibility and memory. They are smaller, easily deployed and atraumatic, designed without tips and made of nitinol (nickel titanium) [22]. Some have a unique design that allows them to simultaneously grasp and LASER the stone with a 200 µm Holmium LASER fibre transmitted through the inner channel within the basket wiring [22]. They have low resistance, which preserves excellent irrigation flow during URS, and ex vivo studies show that baskets with a diameter less than 1.5 Fr have fewer negative effects on irrigation flow and scope deflection [31], while porcine studies have shown no advantage to using a complex wire configuration during stone retrieval [32]. The new designs of nitinol baskets vary in price and design, ranging from the simple to the more complex [33], and continue to be a useful tool when it comes to treating stones. Previous risks such as ureter avulsion and mucosal lesions have also been minimised. They make it possible to move calculi from the lower pole of the kidney to more easily accessible areas such as the upper calyx, where less stress is placed on the URS, protecting its lifespan.

Future developments

Recently, the role of URS has expanded, with it emerging as one of the most promising forms of treatment for upper urinary tract stones, tumours and other pathologies. The enthusiasm for this development is understandable when considering an increasingly obese population and the prevalence of kidney stones in such patients, as well as an increase in paediatric stone disease, bleeding diathesis, indications during pregnancy, and anatomical malformations [3, 4].

URS is the ideal choice for patients, justified by very low morbidity rates. Current guidelines supporting this view recommend URS as the most promising therapeutic option in obese patients [34], expectant mothers and children. Also contributing to this is the fact that LASER lithotripsy is often the elected choice for fragmenting stones during URS. Its efficiency and permitted modalities, ranging from pulverisation to fragmentation, make it capable of destroying any stone regardless of its composition. Indications of EHL, pneumatic and ultrasonic lithotripsy have all decreased for URS, due to their lower efficiency and associated high morbidity.

All of these factors are helping overcome new challenges of increased need for safety and efficiency, controlling the learning curve, and standardising procedures to reduce both time and cost, whether directly or indirectly.

In the same vein, introducing robotics to URS control and associated instruments can also offer benefits, such as within the fibre itself, during LASER-firing, in protecting against accidental LASER-firing within the working channel, for irrigation and pressure within the kidney and, last but not least, by removing the urologist to a console away from the patient, thus reducing radiation exposure during intervention.

Using robotics also reduces the stress on the URS during procedures, helping to avoid exaggerated curvatures and allowing the device to rotate more easily and with a broader range than if controlled by a human hand. Initial results suggest that robotisation could also allow for faster inspection of calyces by standardising the procedure. When comparing robotic and conventional URS, the former allows for a greater range of movement, instrument stability and improved ergonomics. As far as virtual reality training is concerned, robotics also allow for the development of models that reduce the urologist's learning curve and less radiation for the patient and the urologist.

Robotisation already allows for the use of instruments from various manufacturers and is likely to be adapted to the new disposable fURS options already on the market.

Semi-disposable flexible URS and disposable digital URS

The fURS is extremely fragile, not only during procedures, but also before and after use, during cleaning, sterilisation and storage. Pre and post-procedural damage, resulting in high repair and maintenance costs, is a key issue. Additionally, new demands regarding washing and sterilisation to minimise risks of cross-contamination have presented new challenges and further maintenance costs.

With this in mind, new models began to be designed with the aim of overcoming these difficulties and, above all, the costs.

The PolyScope system was the first modular design of the semi-disposable URS, presented by Lumenis as a more cost-effective option. Clinical studies demonstrated that it was simple to use, effective and reliable, as well as being compatible with a semi-rigid ureteroscope [35, 36].

These have been well-received, as they are inexpensive, require no maintenance or sterilisation, and ensure that the surgeon is always working with undamaged materials. This paves the way for the use of devices that are entirely disposable.

Disposable digital URS

The idea of disposable dURS is not new in the medical field, and there are various examples of its evolution. Disposable laryngo-, broncho- and oesophagoscopes are today a reality. Disposable intubation scopes are also a clear example. Regarding laryngoscopes and bronchoscopes, a comparison of reusable versus disposable scopes by Perbet et al. has shown that "costs of disposable [are] not superior to reusable" [37]. In the field of urology, disposable Isiris® cystoscopes for JJ stent removal have already been used in many offices, avoiding the need to send the patient to hospital.

There is not currently a great deal of comparative data regarding new disposable and existing reusable fURS, as to date only Lithovue (Boston Scientific) has been comparatively evaluated.

Proietti et al. recently compared reusable URS and disposable fURS, demonstrating two key points. Firstly, Lithovue combines the enhanced image resolution of the digital complementary metal oxide semiconductor image with the smaller size of fibre-optic scopes. Secondly, deflection is maintained even with the use of thicker LASER fibres (365 mcm), concluding that Lithovue is comparable with conventional scopes in terms of visibility and manoeuvrability [38].

New developments regarding disposable digital fURS have to take into account key factors such as size, weight, deflection, image quality, ergonomic handling and manoeuvrability of the dfURS, which must be at least as good as that of the rURS. Recently, the author had the opportunity to treat ureteral and kidney stones with a Pusen disposable dfURS PU3022. Global performance, ease of use, response and sturdiness in situations of sustained stress in difficult positions were surprisingly positive. Automatic block of a maintained deflection position, reduce weight of around 330 g and image quality should also be emphasised.

In initial stages costs may be higher, but widespread use would reduce costs and bring advantages, such as a perfect view every time and full performance without the need for processing, as well as a guarantee for patients that there will be no cross-contamination due to failures in the sterilisation process. For the hospital, it would mean less investment in sterilisation centres and in transport, as well as in training and certifying personnel for these tasks. However, it would require a large amount of space for new materials, as well as for those that have been used and will be discarded. The manufacturer must also be able to recycle the final product of all the components, to reduce the costs of hospital waste for each unit.

During this transitional period, there are two clear pathways available. New units can begin immediately with the disposable philosophy, rather than investing in the logistics and resources needed for conventional appliances. Established units that have already made these investments can consider disposable options as resources for exceptional or particularly difficult situations in which great stress would be placed on conventional devices. For example, this could include stone occurrence in the lower pole. Disposable devices can be used to treat these cases, as irreversible damage is contained. For small clinics and offices with in-house facilities for ambulatory surgery these disposable devices will be advantageous, at least for diagnosis under intravenous sedation.

Nowadays, indications for fURS have broadened and it has achieved an ever-growing place in the treatment of urinary tract stones and other issues such as urothelium tumours. Due to its particular characteristics, the fURS has become the sole indication for certain situations, such as where pregnancy, obesity and skeletal deformation are concerned. Minimally invasive surgery, with low morbidity and high efficiency, has become established as a clear future technique for both adults and children. This development is not only due to technological advancements, but also to the use of the Holmium: YAG LASER for intracorporeal lithotripsy, capable of destroying any stone regardless of its composition or location, surpassing the ability of any other lithotripter. It is also due to the development of devices that allow access to the ureter and kidney, as well as auxiliary aids to assist in the handling of stones during treatment.

New LASERs, robotics and digital imaging, as well as disposable devices, have had and, indeed, continue to have a unique impact on future development in this field. However, success will continue to depend on the careful choice of fURS, energy source and ancillary instruments obtained by the urologist during both real and virtual training.

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