

## Review Article

# The current status and applications of ureteral stents

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**Abstract:** Ureteral strictures and obstructions are common urinary diseases in modern society, and they cause great pain to patients. A ureteral stent (US) is a minimally invasive surgical device for the relief of obstructions and drainage from the kidney to the bladder. Ureteral stents have been used clinically for over 40 years. However, ureteral stent implantation may cause some complications, such as increased urinary frequency, urgency, infection, migration, etc. Up to now, no ureteral stent with ideal properties has been used clinically. Researchers and surgeons have been working to update and develop satisfactory devices. This paper summarizes the clinical research and the advantages and disadvantages of various US materials and configurations. Ureteral stents made of traditional polymer materials are inexpensive but are prone to encrusting and low strength, weaknesses which are not ideal for drainage and support in the ureter. Ureteral stents made of metal have better mechanical strength. However, with a stent implanted in the body for a prolonged time, the surface of the stent will become covered with stones and encrustation, leading to infections and ureter obstruction again. Ureteral stents made of biodegradable material avoid the trouble of secondary removal. However, it is difficult to control the degradation time of this type of stent, and some small fragments remain in the ureter after the stent degrades. Some novel technologies, such as anti-bacterial, encrustation-free, coating and drug-eluting, may be good ways to improve the performance of US.

**Keywords:** Ureteral stent, material, configuration, novel technology, complications

## Introduction

Ureteral stents are used for the short or long term placement of a ureter, usually after urological surgery and diseases, such as ureteroscopy, extracorporeal shock wave lithotripsy (ESWL), renal ureteral junction obstruction, and malignant ureteral obstruction, to maintain and promote the drainage of urine from the kidneys to the bladder, help heal the ureterostomy, and eliminate hydronephrosis and the leakage of urine [1, 2]. Compared with other surgical procedures, the placement of the ureteral stent is less traumatic, the recovery is fast, and the effect is apparently significant. Plenty of experiments and collaborations by researchers and surgeons on promoting the development of the ureteral tubes have been undertaken. In 1967, Zimskind et al. used silicone rubber to make a ureteral stent to relieve ureter-related diseases such as injury and stenosis [3]. In 1978, Finney introduced double-J and single-J stents in the

clinic, which solved the problem of stent displacement and shedding [4]. Since then, Finney's minimally invasive device has become an indispensable and standard medical device in urology. However, in any case, the ureteral stent is a foreign body for patients. In recent years, there have been many problems surrounding the use of ureteral stents, such as stent fractures, encrustation formation, urethral re-formations and obstructions, and urinary reflux, problems which are increasingly attracting the attention of patients and doctors. Novel technologies such as coating, drug-eluting, and tissue engineer stents are useful solutions to these problems mentioned above. A good ureteral stent has these advantages: (1) good mechanical, supporting, and drainage properties; (2) good biocompatibility and less damage to the urethral endothelium; (3) fewer recurrences of stones; (4) x-ray and B-ultrasound radiopaque for regular inspections after stent implantation.

## Current status and application of ureteral stents

In order to reduce patient discomfort and improve stent quality, researchers and surgeons (mainly urologists) have been constantly striving to explore better material properties and structure design of the ureteral scaffold. This paper gives a brief review of ureteral stent materials and summarizes the advantages and disadvantages of these materials and then discusses the design of ureteral stents and some novel technologies.

### Stent materials

The stent materials have a great influence on their efficacy, especially their mechanical and physicochemical properties. Since stents became available on the market, three types of materials have been used in the devices, namely, conventional polymers, metals, and biodegradable/bioabsorbable polymers [5, 6]. Ureteral stents made of traditional polymers are inexpensive and well-tolerated by patients, but such materials are prone to encrusting and are weak, properties which are not ideal for drainage and support in the ureter. After the stents are implanted, patients tend to forget they are inserted in their bodies. The surface properties of the material gradually changes, and the ureter's condition worsens. Metallic materials were used in the manufacture of early ureteral stents and had good mechanical strength. They are commonly used to treat malignant ureteral strictures and obstructions and to provide long-term internal support and drainage. However, with a stent implanted in body for a prolonged time, the surface of the stent becomes covered with stones and encrustation, leading to infections and ureter obstruction again. Ureteral stents made of biodegradable materials avoids the trouble of secondary removal and reduces the patient's pain and the burden of medical expenses. However, at present, the degradation time of this type of stent is difficult to control, and small fragments remain in the ureter after the stent degrades. **Table 1** summarizes the advantages and disadvantages of conventional polymer ureteral stents, metal ureteral stents, and biodegradable/bioabsorbable ureteral stents.

#### *Conventional polymer ureteral stents*

A satisfactory stent should be effective and have few less complications [7]. Unlike cardiovascular stents, ureteral stents are temporarily

implanted devices, which usually stay in the body for 15 to 60 days. Polymeric stents are commonly used in clinical practice [8, 9]. The current, conventional polymers widely used in ureteral stents include polyethylene, silicon rubber, and polyurethane [10]. Polyethylene was one of the first synthetic polymers used in the manufacture of ureteral stents. Although it was rigid, it was abandoned due its brittleness and tendency to fragment after implantation [11]. Adding polyethylene oxide to polyethylene can reduce bacterial adhesion and biofilm formation [12]. Subsequently, silicone became the gold standard material used for ureteral stents, due its biocompatibility and fewer infections and encrustations. Silicone is one of the most lubricious materials currently in use [13], and it is easy to shape and process. However, the silicone stent had a poor mechanical property: it is too soft to withstand tight ureters and extrinsic compression, making it less efficacious under such conditions. Commercial silicone ureteral stents used in the clinic include Black Silicone Ureteric Stent (Cook Medical, Bloomington, IN) and the Imajin Ureteral stent (Coloplast A/S, Humlebaek, Denmark). Polyurethane (PU) combines the rigidity of polyethylene and the elasticity of silicone, and along with the ethylene vinyl acetate (EVA) and polyvinyl chloride (PVC) are the most popular ureteral stent materials nowadays [14]. The stents produced by these materials, however, still have various complications and potential problems such as insufficient mechanical support, irritation to the bladder and kidneys, encrustation, all of which lead to ureteral obstruction and stenosis [7, 15]. Researchers, corporations, and surgeons (chiefly urologists) have always been exploring new materials with good physicochemical properties, excellent biocompatibility, and ease of use for the surgeons handling the devices during implanting.

#### *Metal ureteral stents*

Metal stents were invented to deal with the shortcomings of polymeric-based ureteral stents, such as the poor mechanical properties and short dwelling times [7]. Metal stents are commonly applied to treat cardiovascular disease, biliary tract and gastrointestinal tract diseases, and in 1972, they were first used for the treatment of ureteral stricture [16]. 20 years later, Pauer et al. introduced metal ureteral stents for malignant ureteral obstructions and

## Current status and application of ureteral stents

**Table 1.** Advantages and disadvantages of the different materials used in ureteral stents

	Materials	Advantages	Disadvantages
Conventional polymers	Polyethylene	Good flexibility, low water absorption, and good chemical stability	Easily becomes brittle, prone to breaking
	Silicone rubber	Smooth, flexible, less irritation	Easy to slip the ureter out
	Polyurethane	Hard and soft, good elasticity	Easy to cause ulcers, and the mucosa is easily damaged
Metals	Nickel-titanium memory alloy	Temperature memory, adaptation to ureter, easy implantation and removal	High cost and difficult preparation
	Stainless steel	Resistant erosion, durable use time	High price
	Super alloy	Low melting point, easy to manufacture, good tolerance, lightweight	-
Biodegradable polymers	Percuflex™	Provides long-term internal support	-
	Poly (L-lactide-co-glycolide) (PLGA)	Degradation time and rate can be controlled.	Adjustable degradation time
	Polycaprolactone (PCL)	High strength and good biocompatibility	Degradation >24 m
	Poly lactide (PLA)	Good mechanical properties and highly tensile	Degradation >24 m, adjustable degradation time
	Polyglycolide (PGA)	Good water absorption	Rapid degradation

**Table 2.** Advantages and disadvantages of the different designs of ureteral stents

Innovation of design	Advantages	Disadvantages
Double J stents	Decreases the migration both in the proximal and distal ends	Bladder irritation
Expandable stents	Provides a higher ratio of intra-luminal flow, ease of implantation and retrieval	Prone to transformation in its radial direction
Magnetic stents	Facilitates the process of retrieval without a ureteroscopy	Hard to manufacture
Grooved stents	Makes the fragments flow efficiently through the ureter	Complicated manufacturing process
Dual-durometer stents	Different durometer materials in the proximal and distal ends, and decreases bladder irritation	-
Horn-shaped stents	Good anchoring property and less bladder irritation	Short indwelling time in the patients' ureters
Spiral stents	Has good mechanical properties, lumen, and fewer lower ureter symptoms	Loses efficacy easily

## Current status and application of ureteral stents

retroperitoneal fibrosis. He showed that metal stents can provide excellent radial support and better drainage from the kidney to bladder [17, 18]. Due to its resistance to deformation, metal stents are often used to treat complicated, malignant obstructions of the ureter and urinary diseases that are difficult to treat using conventional methods. Common complications of metal ureteral stents are tissue hyperplasia and the ingrowth of urothelial tissue throughout the process when implanted in patients' bodies. To deal with the issue of growing tissues in the ureteral tract, coated metal ureteral stents were introduced and applied. The Passenger stent (Boston Scientific Corporation, Oakland) was designed with a thin coating membrane on its surface, and showed little ureteral reaction and migration [19, 20]. Unlike polymers, metals are prone to erosion and can result in stent failure and infection. The ureteral metal stents currently available on the market are mostly made from nickel-titanium memory alloys and stainless steel. In the early stages of stent implantation, nickel-titanium memory alloy provided good radial support and treatment of the stenosis caused by malignant tumors [21], but the long indwelling of metal stents may lead to a potential risk of ureteral obstruction, and even renal failure due to the regrowth of tumors [22].

Metal ureteral stent designs include the traditional double J and the self-expandable. The two double J stent, the Silhouette stent (Applied Medical, Rancho Santa Margarita) and the Resonance stent (Cook Corporation) are commercially available. The Silhouette stent structure is a nitinol wire reinforcing the wall with a polymer coating on its surface. The outer polymer coating makes the nitinol skeleton vague, which provides excellent biocompatibility with the urothelial cells. A meta-analysis examining this type of ureteral stent found a superb ability to resist external compression and twisting [23, 24]. The Resonance stent is a classic and appealing device in urology, and it has been investigated in many research and clinical trials by scholars and urologists. The stents, armed with the double J configuration, are made of a nickel-cobalt-chromium-molybdenum alloy, which can be implanted in the ureteral tract for up to 12 months or even more indwelling time [25]. In a retrospective study examining a cohort of more than 40 patients,

the resonance stent indwelling time was 4 months longer than the polymer-based stents, which the data showed as 5.3 vs 1.7 months. No significant complications were reported in the process. Also, the efficacy and dwelling time in the benign and malignant scenarios had inconsistent results [26, 27]. Encrustation is still an issue, with encrustation found on 20% of removed stents. Detailed experiments need to be implemented to examine the efficacy of the US. Nowadays, the Resonance stent is the alternative device, which allow for a long implantation time and longer intervals between stent changes. The application of metal-based ureteral stents avoids the trouble of frequent replacement, but patients still need to go to the hospital regularly to check the stent with an x-ray or B-ultrasound, to check for displacement, encrustation or small fractures, so that the problem can be found in time and an immediate procedure can be undertaken to minimize any injury to patients. The design of the expandable ureteral stents is based on cardiovascular metal mesh stents. This kind of stent has the off-coil configuration and is cylindrical, and they fix themselves through deployment after implantation [28]. The Allium URS (Allium LTD, Caesarea, Israel) is a self-expanding US utilized in clinical scenarios. These stents anchor well in the bladder and are easily extracted in a completely unraveled condition. A trial examining 40 patients (49 ureteral tracts) with a more than 20 weeks follow-up period, found over 90% ureteral patency, and the migration ratio was 15% [29]. The Memokath 051 Stent (PNN Medical, Kvistgaard, Denmark) is also a self-expanding metal-based ureteral stent, composed of nickel and titanium. The stent is thermo-expandable, deploying in warm saline and shrinking in cool saline, which allows the stent to be implanted and extracted easily [30]. A recent report incorporated 5 studies, which the Memokath 051 Stent used in the malignant scenario, and the patency ratios ranged from 19% to 100% with a 10.6 to 22 months follow-up [31]. Complications included encrustation, migration, and infection, but the small number of samples made the results inaccurate and unconvincing. Though the metal used in the ureteral stents was also applied in cardiovascular diseases, the metal material utilized in the ureteral tract still needed to be investigated through masses of clinical applications and animal trials.

### *Biodegradable/bioabsorbable ureteral stents*

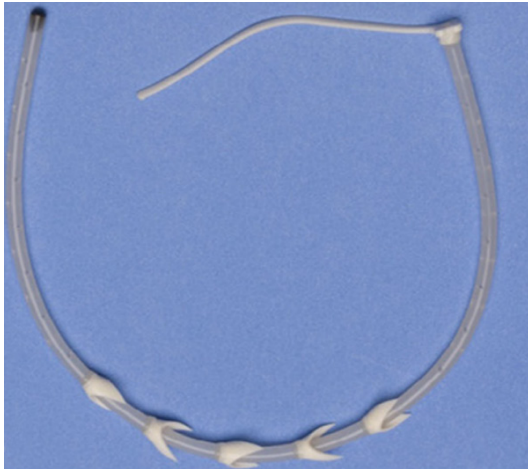
Despite the metallic ureteral stents' excellent mechanical properties in terms of drainage and stenosis therapy, complications, such as ureteric hyperplasia, encrustation, and urine reflux, made the stents unsatisfactory. Also, the "forgotten stent" has a negative influence on the patients' urinary systems, which can contribute to hydronephrosis and in the worst case lead to death. In order to solve the problem of stent-related complications and avoid the trouble of secondary removal, the biodegradable ureteric stent was introduced by Schlick and Planz in the 1990s. The stent was made of polymer blends, and the degradation of the stent can be triggered by changing the pH of the artificial urine solutions [9]. With the degradation, the polymer stent will be absorbed and eventually excreted in the form of water and carbon dioxide from the body. In addition, the biodegradable ureteral stents can prevent bacteria adhesion, encrustation, and the formation of biofilm, and they provide a more comfortable experience because of their soft properties.

Biodegradable materials commonly used for ureteric stents include polylactic acid (PLA), polyglycolide (PGA), polycaprolactone (PCL), and their copolymers. PLA degrades very slowly, and the complete degradation and absorption takes over 24 months depending on the size of the devices and the local environment. Therefore, it is not very suitable for ureteric stents because urethral recovery time is only about 6-8 weeks. After the stent function is realized, the incomplete degradation and fragmentation will lead to urethral obstruction and scratching. Researchers found that the copolymerization of glycolide (GA) into lactide (LA) can increase the degradation rate of individual polymers by about 8-10 times. By adjusting the proportion components of the monomers, it can effectively mediate and control the degradation rate and degradation time [32]. Hadaschik designed the three-generation stent Uriprene (Poly-Med Inc, Anderson) [33]. The first generation of Uriprene stents was made of PLGA. It began to degrade three weeks after implantation in the body, with 60% of the stent degraded at 7 weeks and the stent completely degraded after 10 weeks. For the above deficiency, the following stents add water-soluble material that improves the strength and reduc-

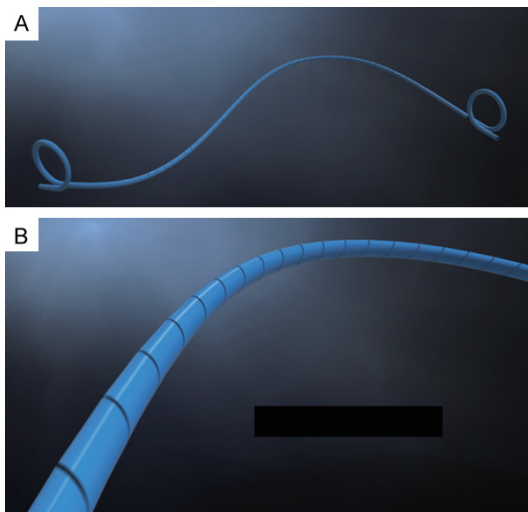
es the degradation time of the stent. Experiments show that the second-generation stent began to degrade at the second week and completely degraded in 10 weeks, while the third-generation stent degraded entirely within four weeks [6]. The ureteric stent based on copolymer of lactide and glycolide (PLGA20: 80) achieved a good effect [34]. Lumiaho designed a degradable ureteral stent utilizing PLA [35, 36]. Implanting the stents into porcine ureteral tracts showed good drainage efficacy, but blockage was found in the degrading process and showed a deficient biocompatibility. Li reported that PLA can prevent hydronephrosis in the canine groups. Zhang conducted a study using a braided biodegradable US with the multifilament of PGA and PLGA. The degradation began at the first week and finished the process within four weeks. It was unclear in the research whether there existed small blocks in the ureteral tract. In addition, biodegradable ureteral stents designed with the natural polymer alginate showed excellent drainage and biocompatibility [37, 38]. Complete degradation was achieved in half a month, but small degradation fragments were found in patients' bodies up to three months or more, and sometimes surgical operations were needed [7]. An experiment with gelatin-based ureteral stents implanted in several porcine models showed that the degradation was completed within 10 days [39], and the histopathologic scores showed good tolerance in patients' bodies compared with the control group. However, the rapid degradation of the natural polymer sacrificed the biostability integrity and the function maintenance of the ureteral stent before it could achieve its clinical purpose.

Degradable and bioabsorbable metals and alloys are promising materials in the development of ureteral stents. Magnesium (Mg) is a lightweight and biodegradable metal. A trial with a different proportion of Mg in an artificial urine solution (AUS), showed that it decreased the bacteria unit formation. The SEM showed the cracks on the surface of the ureteral stent on the first day of degradation, and the degradation time was not stated in the report. The Mg ureteral stent showed excellent performance in resistance radial compression, bacteria and encrustation, but its efficacy in vivo still needs to be tested and confirmed.

## Current status and application of ureteral stents



**Figure 1.** Gibbons ureteral stent [45].



**Figure 2.** Spiral ureteral stent [47].

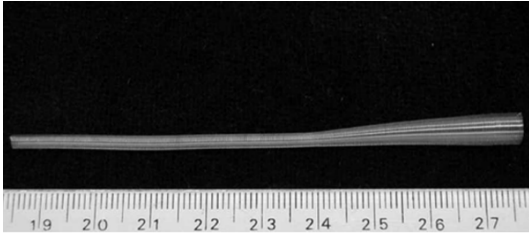
### *Design of ureteral stents*

The design of ureteral stents has undergone many scientific approaches and a series of extensive modifications [34, 40]. Gustav was the first person to implant a tube into patients' ureteral tract during a cystotomy. In 1885, Joaquin invented the first ureteral catheter for the drainage [41-43]. Dr. Paul Zimskind in 1967 first invented the silicone stent and proved its efficacy with regard to durability [3]. And in 1970, Marmar innovated a ureteral catheter with a closed end in the kidney direction, facilitating retrograde implantation. The modification of Marmar allowed surgeons to push the stent upward to the ureter [44]. Dr. Zimskind reported several implanted ureteric catheters.

Inspired by the Zimskind's lecture in 1966, Dr. Gibbons as an urologist made several modifications of the stent in order to solve the problems he found in clinical practice, such as migration, obstruction, and its poor ability to keep its configuration [45]. Gibbons added a collar at 1-2 cm distance to the end of the stent thus greatly improving the migration problem, and small holes were bored along the stent to prevent blockage in the ureter tracts. In 1974, Gibbons incorporated the coil into his design to improve the anchoring effect, and a flange was added to the distal end to prevent proximal end migration. Furthermore, a tail was added at the distal end, facilitating the extraction of the stents. This is the famous "Gibbons stent" (**Figure 1**). Moreover, in order to cope with the distal migration, Dr. McCullough invented a stent with a proximal polyethylene curl, dealing with the migration to some extent [46]. Finney in 1978 described the double-J stent, which met demand of ideal ureteral stents: a stable diameter, good anchoring property, resistance to compression, and easily passing the ureter [4]. The Finney stent was invented more than 40 years ago, and it is still the prototype of modern ureteral stents. In addition to the appearance of double-J stents, other types of stents have been developed in large quantities by researchers.

### *Spiral ureteral stents*

The spiral ureteral stent is a good stent for anchoring following the double pigtail stent. The traditional ureteral stent, under the condition of good positioning, will lead to obstruction and poor drainage. This kind of stent has both good positioning characteristics and unique internal support and drainage. Percuflex Helical™ (Boston® scientific, USA) is a typical spiral urinary stent tube (as shown in **Figure 2**) that provides a stable and long-lasting support lumen for the urethra [47]. There is no opening at the end of the ureter, and the urine mainly exits around the spiral stent. In addition, there are some other types of stents used in clinical therapy. The dual-durometer stent is a tube that has different hardnesses at the distal and proximal ends. Compared with a conventional stent, this one reduces the irritation to the bladder and can be stably anchored in the ureteral system. Percuflex® Bracket (Boston® Scientific, USA) is a common dual-durometer stent



**Figure 3.** Horn-shaped ureteral stent [52].

[48]. Grooved stents were first proposed by Finney in 1981 for postoperative lithotripsy. To improve the clearance rate of stones and facilitate the excretion of urine [49, 50], the grooves on the surface provide multiple paths for small gravel. The LithoStent™ stent is a grooved stent manufactured by Olympus (USA). The horn-shaped stent was designed with L-poly-lactic acid [51] and is mainly used for obstructions of the ureteropelvic junction. The unique structure of the stent makes it difficult to slide out of the ureter tract, and patients have an uncomfortable feeling after the operation, which indicates that the stent has good biocompatibility and tolerance [52]. **Figure 3** is a horn-shaped stent, which is shaped like a long trumpet and has good anchoring performance in the ureter. **Table 2** summarizes the advantages and disadvantages of the different designs of ureteral stents.

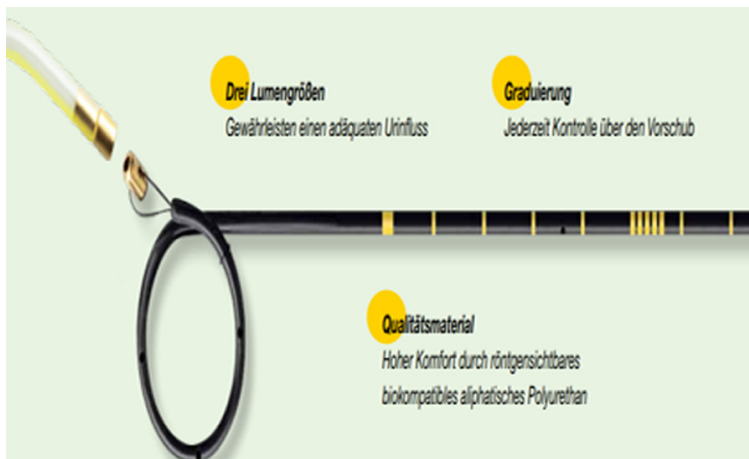
### *Novel technology in ureteral stents*

**Drug-eluting:** Drug-eluting stents were first used in the cardiovascular field to treat endometrial growth and coronary restenosis [53], which were used in ureteral stents afterwards. The stent is loaded with specific targeted drugs to treat some urinary tract diseases such as urinary tract infections and encrustations. Drug-eluting stents direct the delivery of the drug to the bladder, which can reduce bladder irritation and pain, relieve a patient's pain and prolong the stent replacement time. Elayarajah used vitamin E as a carrier for drug stents, accompanied by drugs such as norfloxacin and metronidazole. The results showed that the stent had the ability to release drugs locally and reduced bacterial adhesion and inhibited urethral bacterial growth [54]. Chew performed stent implantation in the urethras of pigs [55]. Compared with other types of stents, they found drug-eluting stents have a stable drug release ability. Kallidonis implanted a zotarolimus-eluting

stent in rabbit and pig urethras [56]. The results showed a certain degree of urothelial hyperplasia, but it did not cause urethral obstruction. Drug-eluting stents are a good advancement in reducing ureteral disease and promise to reduce the complications associated with stents.

**Coating:** Coated stents are coated with different materials to improve the lubricity of the stent and to prevent some complications such as infection and encrustation [53]. Materials commonly used to coat stents are hydrogel, heparin, phosphorylcholine, triclosan, and polytetrafluoroethylene. Hydrogel is a special hydrophilic polyurethane coating that expands with water, which improves the lubricity of the stent and facilitates the placement of the stent. Studies have reported that hydrogel coatings can reduce or increase biofilm formation and infection compared to other uncoated stents [57, 58]. Heparin-coated stents are promising stents that effectively reduce stent replacement and resist bacterial adhesion. Cauda implanted heparin-coated stents in humans and found significant improvements in stent encrustation [59]. However, in vitro experiments of heparin's ability to resist bacterial adhesion have not been implemented [60]. Widely used in coronary stents, phosphocholine coated stents have been shown to reduce platelets and endothelial cell growth and serve as a platform for releasing drugs [61]. Stickler implanted a phosphocholine coated stent into 44 patients and tested their biofilm, encrusting, and bacterial adhesion for 12 weeks [53]. The stents showed lower visible biofilms (36% vs 61%) and associated visible bacteria (36% vs 54%) compared to uncoated control scaffolds. Triclosan is a common bacteria-preventing drug used to decrease urinary tract infections. The triclosan coated stent was implanted into 8 patients and placed for three months [53]. The result showed its good antibacterial efficacy and decreased systemic infection. Triclosan-coated stents will not perform anti-infection and anti-bacterial adhesion effects in a short period of time (10-15 days), but they can reduce the pain during the patient's activity and improve the patients' quality of life [62]. Long-term placement of triclosan-coated stents does not reduce the possibility of bactericidal urine and infection, but it significantly reduces the amount of oral administration [63]. The

## Current status and application of ureteral stents



**Figure 4.** Magnetic ureteral stents [65].

Teflon-coated stent has a small coefficient of friction and van der Waals force, which is effective against bacterial adhesion and growth [48, 64]. These coated stents can reduce the adhesion of bacteria, infections, and the incidence of encrustation, but there are diverse problems that need to be solved.

### *Magnetic ureteral stent*

The magnetic stent is a new type of stent tube described by Taylor and McDougall, with stainless steel columns that can be attached to the distal end of the stent with a magnet catheter, and the stent is removed without the guidance of cystoscopy or ureteroscopy [65]. Magnetic Black-Star (Urovision, Germany) is a typical magnetic stent. During the implantation and removal process, the stent is magnetically suctioned. The stent tube is placed according to the urinary tract direction, which reduces the use of extra equipment and improves the safety and accuracy of the stent placement. In the future, the effects of this kind of stent need to be evaluated by a large number of clinical experiments. **Figure 4** shows a magnetic ureteral stent.

### **Discussion**

Since Zimskind implanted a silicone rubber stent into patients for ureteral obstruction in 1967, ureteral stents have been used in urology for 52 years. Some of the complications caused by ureteral stents, such as urine frequency, urgency, hematuria, lower urinary tract symptoms, stent displacement, stent failure,

and so on, have also plagued patients and designers in recent years. The clinical efficacy of the stent tube seems to be unsatisfactory. At present, research on ureteral stents mainly focuses on the optimization of material and the stent configuration design. Ureteral stents will likely respond to more indications and resist various complications in the future. The advancement of cardiovascular stents provides the basis and possibility for the development and progress of urinary stents. Urinary stents

combine the characteristics and mechanisms of cardiovascular stents and propose more creative ideas and new designs. Some researchers have administered some questionnaires to patients after stent implantation, and the patients visually evaluated their levels of pain, which can be used as indicator for improving the discomfort caused by the stent. The mechanisms of some complications have been clarified, but some complications are still unclear. Advancement in the medical area and in scientific technology will promote the development of ureteral stents. Improvements for better stents require a detailed study on the causes of various complications. For stents available in the open market, researchers need to examine their effects and characteristics through extensive in vivo and in vitro experiments.

The design of the ureteral stent, starting from the first generation of double pigtail stents, has been slowly evolving into other types of stents in clinical applications, including coated stents, drug-eluting stents, magnetic stents, self-expanding stents, spiral stents, and dual-durometer stents. The design principle of the stent is to reduce the displacement and decrease bladder irritation. The bladder triangle is a sensitive and fragile part of the human urinary system that controls the contraction and relaxation of human urination and the corresponding muscle. Rane and his colleagues found that when the stent passed through the midline of the bladder, it increased the probability of urgency, and the distal end caused more severe hematuria, pain, and frequent urination [66]. The length and diameter of the



stent also has a great impact on the patients' feelings. Researchers found that when comparing stents with large diameters and stents with small diameters, although there was little reduction in pain or complications, the stents with large diameters were not easily displaced and provided better support for ureter. Drug-eluting stents and coated stents are mainly used to cope with complications such as infection, bacteriuria, and encrustation. The material on the surface of a coated stent provides the stent a smoother surface and facilitates its implantation into the ureter. Common coating materials are heparin, carbon, hydrogel, triclosan, and silver. In addition to the triclosan, the rest of the material is primarily responsible for the production of biofilms and encrustation [67-69]. While triclosan mainly inhibits epithelial mucosal hyperplasia and bacterial growth, the Food and Drug Administration (FDA) is concerned about the effects of triclosan resistance to bacteria [70]. Drug-eluting stents are commonly used in the cardiovascular field to prevent new intimal growth and coronary restenosis. The magnetic stent allows for a more efficient implantation and the removal of the stent without a cystoscope. The magnetic stent on the market is Magnetic Black-Star (Urovision, Germany). Self-expanding stents have a high ratio of inside to outside diameter, and they have a high intraluminal flow. The spiral stent is not prone to be displaced in the body and has good anchoring properties. It is reported that this stent can reduce the occurrence of upper urinary tract symptoms [71]. The dual-durometer stent is placed in the kidney as a hard material, while the material placed in the bladder is a softer material in order to reduce irritation to the bladder triangle and reduce patient discomfort.

The materials of the ureteral stent have a tremendous impact on the performance and mechanical properties of ureteral stents. The material of the stent has been experienced by artificial non-degradable polymers, metals and degradable materials. Artificial polymers were first used in the manufacture of urinary stents, mainly polyethylene, silicone rubber and polyurethane. Stents made of these materials need to be replaced regularly, and sometimes a stent implanted in the patient that prolonged positioning in the ureter may cause re-obstruction, infection, or even severe complications. One study found that the accumulation of urinary

salts caused by silicon was severe, and that stent tubes made of the material were too smooth and soft, so they were slowly abandoned. Metal stents have also been widely used in recent years. Nickel-titanium alloys and stainless steel are commonly used metals. Metal stents have good mechanical properties and are often used in cases of malignant obstruction and invalidation in conventional treatment. However, in recent years, the metal stents easily migrate in the ureter, and the long-term effect is not ideal, so the use has gradually decreased. The use of degradable materials for manufacturing stents is of great significance, because it eliminates the trouble of forgetting the stents in the ureter and avoiding a secondary removal of them. However, the degradation condition of the stent is not ideal, and in the degradation, the time and direction are uncontrollable. Small fragments generated by degrading stents are hard to discharge out of the urethra and need to be taken out by surgery. In view of these problems, researchers should analyze the stents through the extensive experimental exploration of their comprehensive properties.

Future ureteral stents should be designed with better anchoring properties and low potential migration in mind. The shape of ureteral stents should be in accordance with the anatomical structure of kidney-ureter-bladder, which avoids bladder irritation. The material used to make ureteral stents should have a suitable hardness, one which provides good mechanical and tensile strength. Stents with different degradation cycles will also appear on the market to accommodate different demands. The use of eluting stents and coated stents reduces stent-related complications such as infection, encrustation formation, biofilm formation, and stone re-formation. The combination of eluting drugs and degradable properties, coupled with good anchoring features, are the future trends of ureteral stents, and they will bring more convenience and comfort to patients.

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## Current status and application of ureteral stents

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### Disclosure of conflict of interest

None.

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