Catheter Designs to Minimize UTI Risk

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Introduction

UTIs are among the commonest healthcare-associated infections.[1] It is estimated that catheter-associated UTIs (CAUTIs) make up about 80% of hospital-acquired UTIs.[2] The risk factors for CAUTI include female gender, extremes of age, prolonged duration of catheterization, and diabetes.[1]

An Indian study assessed the factors associated with UTIs in a hospital-based setting. The rate of CAUTIs was found to be 9.4 per 1000 urinary catheter days. The risk factors identified included being female, diabetes, and catheterization duration. CAUTIs were largely observed in the age group of 51 to 70 years. The incidence was the highest in the 3rd week of catheterization.[1]

Patients requiring bladder management can be subjected to either an indwelling Foley catheter or clean intermittent catheterization (CIC).[2] An indwelling catheter can result in bacteriuria which can occur via periurethral or intraluminal introduction during catheter placement, bacterial entry from the drainage bag, and biofilm formation.[2]

Bacteria can enter during catheter insertion and result in colonization of the intraluminal and extraluminal catheter surfaces. Around 20% of CAUTI patients have been reported to have bacterial adherence and colonization during insertion of the catheter. The creation of biofilm by host proteins on the surface of the catheter also facilitates bacterial adhesion. Biofilm maturation on the device results in increased risk of CAUTI.[3]

Eliminating biofilms formed on the surface of a urinary catheter in CAUTI patients is challenging. Hence, it is crucial to design a biomaterial capable of effectively managing biofilm-related infections in medical devices.[3]

Catheter encrustation and blockage is another issue encountered in patients with long-term catheterization. Encrustation risk is linked to the duration of catheter use. With time, there is increased accumulation of mineral deposits on the catheter surface.[2]

Considering this, modifications in catheter design and material are needed to help reduce the risk of CAUTIs. This article covers some of the design modifications in catheters aimed at reducing the risk of UTIs.

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Catheter Design Modifications

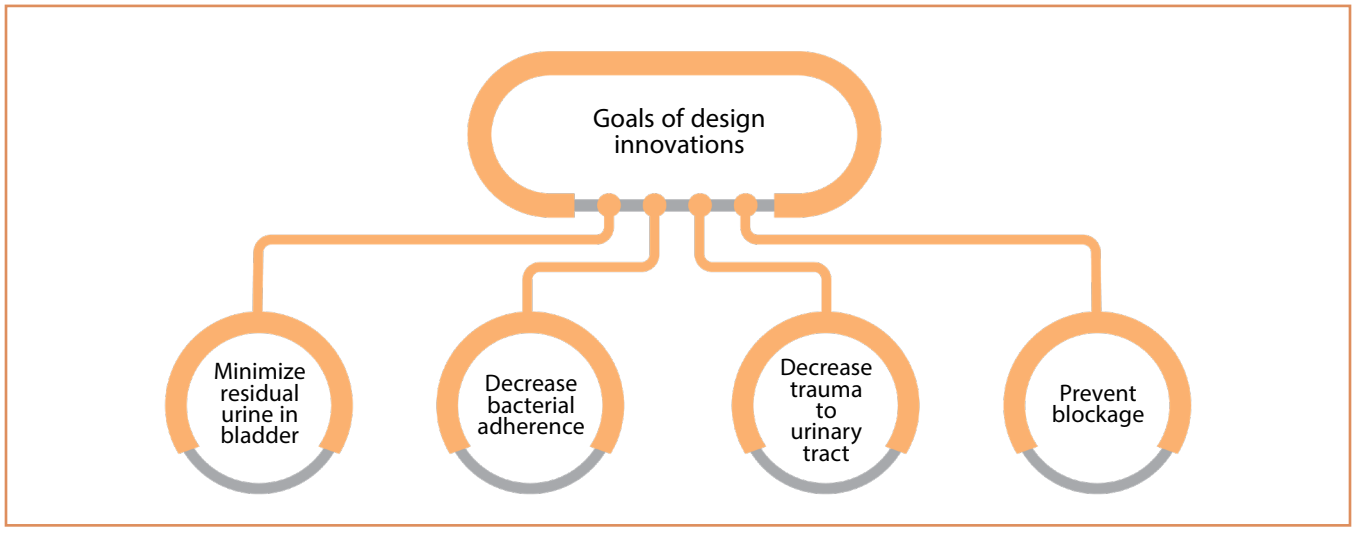
A recent article discussed design changes in urinary catheters as a means to minimize UTI risk. Catheter design modifications have aimed at minimizing undrained urine accumulation, injury to the urinary tract, and limiting bacterial adherence (Figure 1).[4]

Considering the design of a Foley catheter, the drainage holes are positioned above the retaining balloon. Inflating the balloon moves the holes away from the bladder base. This can result in a residual pool of urine. This stagnant urine could create a favorable environment for bacterial growth, increasing the risk of UTIs.[4]

A catheter design with protected tip and eyeholes at the base of the balloon has been evaluated*. The tip is protected with the retaining balloon when inflated and the drainage eyeholes are close to the bladder neck. In Stage 1 testing with 10 patients, balloon inflation, drainage, retention and removal were confirmed and

there were no serious adverse events. The catheter performed well in preclinical blockage and balloon tests.[5] The impact of this catheter use in decreasing UTI risk cannot be commented on yet.

Figure 1. Goals of design innovations in urinary catheters



Another catheter design includes two eyes for drainage. One of these is below the balloon while the other in a reduced profile tip#.[4]

A novel micro-hole zone catheter has been developed which has shown lower residual volumes. The catheter features a distinct drainage zone incorporating more than 80 micro-holes. The catheter was compared with conventional eyelet catheter in a study in an *ex vivo* pig lower urinary tract model and *in vivo* in pigs. Regardless of the diameter of the micro-hole, the novel catheter was noted to have higher flowrates and significantly lower residual volumes at the first flow-stop. Table 1 shows the residual volumes with conventional eyelet catheter and micro-hole zone catheters of different hole diameters. Irrespective of the depth of insertion or simulated intra-abdominal pressures resembling those in sitting or standing individuals, there appeared to be no mucosal suction with the 0.4 mm micro-hole diameter.[6]

It was shown that the bladder gradually folds around the catheter drainage tip without obstruction to the flow. As opposed to the conventional eyelet catheter, sharp pressure changes and flow-stops were absent during voiding. *In vivo*, there were no flow-stops necessitating repositioning of the catheter with the novel catheter use. The novel catheter thus demonstrated superior performance over a conventional eyelet catheter and decreased the residual volume. Thus, it may have the potential to lower UTI risk.[6]

A novel micro-hole zone catheter demonstrated superior performance over a conventional eyelet catheter and decreased the residual volume.

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Table 1. Residual volumes with conventional eyelet catheter and micro-hole zone catheters of different hole diameters

Catheter	Residual volume (mL)
Conventional eyelet catheter	38.1±26.7
Micro-hole zone catheters 0.7 mm 0.6 mm 0.5 mm 0.4 mm	 2.2±2.6 4.8±6.5 5.2 ±6.1 3.6 ±3.9

Conventional Foley catheters seem to lead to irritation and damage to the bladder mucosal lining. This could heighten the risk of CAUTI. A novel dual-balloon urinary catheter has been evaluated in a study which showed only 1 CAUTI with the dual-balloon catheter vs. 6 CAUTIs with the conventional Foley catheter. The infection rate was 1.1 per 1000 catheter-days in the dual-balloon catheter group compared to 5.5 per 1000 catheter-days in the conventional catheter group.[7]

A novel low-profile catheter has shown potential in reducing CAUTI occurrence in patients with indwelling catheters.[8] This design eliminates the tip, providing direct access to the lumen from the proximal end of the catheter.[4] The Foley catheter group had a higher percentage of patients with raised colony counts in comparison with the low-profile catheter group.[8] The dual-balloon design incorporates an additional balloon alongside the retaining balloon at the catheter's tip. This design protects the tip, minimizing trauma, and shields the drainage holes.[4]

Another novel design aimed at removing standing urine in the bladder and drainage system through an active drain line urine clearance and having an automated intra-abdominal pressure monitoring has been evaluated in an observational study. This novel catheter system was found to be associated with decreased CAUTIs. Before implementation, the incidence of CAUTI events was 0.030, which significantly decreased to 0.002 after introducing an automatic drain line clearing urine output monitoring system.[9]

A novel dual-balloon urinary catheter has shown only 1 CAUTI vs. 6 CAUTIs with the conventional Foley catheter in a study.

There is a need for design modification incorporating angulation of the catheter tip in order to minimize the risk of a false passage. Additionally, novel stent designs have been put forward to enhance shear stresses. This may have the potential to minimize bacterial adhesion and encrustation.[4] Another design that incorporates triangular obstacles to upstream swimming of the bacteria with an artificial intelligence (AI) model has been introduced that may help diminish retrograde spread within the catheter lumen.[4]

It has also been suggested that catheter designs can include features that support techniques aimed at preventing blockage. The drainage balloon seems to offer a mode for delivering antibacterial compounds. Additionally, antibacterial compounds could be placed in the catheter lumen. It has been proposed that methods could be devised to attain surface strain selectivity in the lumen of the catheter. Using a soft robot, controlled by a magnetic field, has also been proposed to remove biofilm.[4]

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Conclusion

Advancements in catheter design can help decrease mucosal trauma and residual urine volumes, thus playing a role in decreasing the risk of CAUTIs. However, it must be borne in mind that these innovations do not give rise to any new problems.

Additionally, the advantages of the novel design innovations need to be evaluated in real-life scenarios to understand their impact on reducing UTIs.

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