Urethral catheters

Catheterisation is an important and commonly performed clinical procedure. In this article we review types and indications for catheters and we discuss the major complications of catheter insertion, with the focus being on urinary tract infections (UTIs). We explore how advances in catheter technology and our understanding of biofilm formation may lead to the development of safer catheters with reduced risks of UTIs and other complications.

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Urinary catheterisation is often performed in acute and long-term settings for both therapeutic and diagnostic purposes. Despite this, up to 75% of all catheterised patients will suffer recurrent complications.[1]

In this article, we discuss the indications for urinary catheterisation, complications of catheter placement and the need for physicians and nursing staff to carefully weigh the benefits against the risks prior to insertion. We also review strategies for reducing the iatrogenic harm caused by urinary catheters.

Catheter types

A variety of catheters made of different materials are commonly available. Straight or coude tipped catheters are used only for intermittent catheterisation and do not have an anchoring balloon. Straight catheters are a straight piece of hollow tubing whilst Coude tipped catheters have a slight curvature that permite easier insertion. In contrast, the Foley catheter has an anchoring balloon that permits long-term retention within the bladder.[2,3]

Commonly used catheter materials include silicone, latex, PVC and PTFE. A number of additional coatings are also available, including those with non-stick or antimicrobial properties. Whilst no definitive guidelines exist regarding the choice of catheter materials, basic principles, such as the preference for antimicrobial catheters in patients at high risk of developing urinary tract infections (UTIs) and the avoidance of latex in those with allergies, should be adhered to where possible.[4]

The common therapeutic and diagnostic indications for urethral catheterisation are listed in Box 1.

Complications

By far the major and most extensively studied complication of urethral catheterisation is the development of UTIs. Other equally importan complications of catheterisation can be divided into functional and traumatic categories.

Box 1: Indications for urinary catheterisation[5]

Therapeutic
- Relief from acute or chronic urinary retention
- Bladder irrigation
- Management of urinary incontinence
- Bladder drainage during surgical procedures

Diagnostic
- Monitoring of urinary output as part of fluid balance
- Obtaining urine samples for laboratory investigations

Urinary tract infections

Urinary tract infections (UTIs) are the most common healthcare-acquired infections, accounting for 40% of all nosocomial infections.[6] Of this figure, up to 86% may be catheter associated, meaning that indwelling catheters are the single leading cause of nosocomial infections.[7] There is an important distinction to draw between bacteriuria and the presence of a UTI. Whilst bacteriuria relates

purely to the presence of bacteria within normally sterile urine, a UTI implies both the presence of bacteria and symptoms. Symptoms commonly segregating with the presence of a UTI include dysuria, back pain, haematuria and increased urinary frequency.[8]

A number of mechanisms may be responsible for infection associated with catheterisation, including:

1) transmission of bacteria colonising the distal urethra proximally during catheterisation
2) migration of bacteria colonising the distal urethra proximally following catheter insertion
3) intraluminal contamination and the migration of bacteria against the flow of urine into the bladder.

The relative contributions of these three routes to the pathogenesis of catheter associated UTIs remains unclear, but it appears that, with closed catheter systems, intraluminal contamination is less prevalent. Regardless of the mechanisms by which bacteria may gain access to the normally sterile urinary tract, a unifying means of bacterial colonisation appears to be the formation of biofilms.[9]

A biofilm on an indwelling catheter is a very complex environment of adherent bacteria, their extracellular products and host proteins. The precise mechanisms of bacterial adhesion differ between species. For example *Proteus mirabilis* uses mannose-resistant fimbrae, whilst *Escherichia coli* predominantly relies on electrostatic and Van der Waal's forces. Although stages of biofilm formation are complex, and beyond the scope of this article, the underlying reason that biofilms so readily form on indwelling catheters relates to both the inert nature of commonly used catheter materials and the survival advantage conferred to bacteria by forming colonies. Aside from reducing bacterial vulnerability to phagocytosis and shear forces (such as those caused by catheter movement or the flow of urine), biofilms have also been proven to enhance resistance to antibacterial agents. Possible reasons for this may include the slower growth rates of bacteria within biofilms and the transfer of antibiotic-resistant genes between multiple bacterial species.[9]

Interestingly the duration of catheterisation appears to be a critical risk factor for the development of a catheter-associated UTI. Whilst only 10–25% of patients catheterised in the acute setting develop a UTI (an incidence of around 3% per day),[10] UTIs are virtually ubiquitous in those with long-term catheters. Furthermore, studies have highlighted that the bacterial flora colonising indwelling catheters is continually changing, highlighting the dynamic nature of the biofilm.

Aside from providing a means of bacterial entry and colonisation, indwelling catheters may also impair the normal host immune response by either the physical effect of traumatising and damaging the uroepithelium or by triggering an inflammatory response, both of which increase susceptibility to bacterial invasion.[9] Local inflammatory responses may do this because they can trigger damage to the uroepithelium and provoke increased vascular permeability, which may increase susceptibility to bacterial infection.

Box 2: Risk factors for UTI

Cather-related factors

- Increased period of catheterisation
- Poor hygiene of catheter insertion and catheter care
- Open drainage systems

Patient-related factors

- Previous catheter associated infections
- Female gender
- Increasing age
- Postpartum state
- Difficulty in maintenance of personal hygiene, eg, owing to dementia or psychiatric disorders

Common patient- and catheter-related factors that increase susceptibility to bacteriuria and UTIs are listed in Box 2.[7]

The most common causative organisms for catheter-associated UTIs include: *Escherichia coli*, and *Klebsiella, Proteus, Enterobacter, Enterococcus, Pseudomonas,* and *Candida* species.[7] The diagnosis of infection, however, is particularly difficult in catheterised patients and relies on the presence of both symptoms and bacteriuria. It is important to note, however, that the symptoms – including fever, confusion or anorexia – can be very subtle or non-specific particularly in elderly patients. It may therefore not be possible to pin the diagnosis until they have resolved following the initiation of empirical antibiotic therapy.

Most trials of non-pregnant individuals have shown that asymptomatic bacteriuria does not warrant antibiotic therapy whereas

a course of antibiotics is the management of choice for symptomatic UTIs.[5] The issue of changing the indwelling catheter following diagnosis of a UTI remains contentious. One study has demonstrated that catheter change prior to the initiation of antibiotic therapy is associated with improved clinical status, reduced time to afebrile status and a reduced risk of symptomatic relapse. The results of this study are certainly intuitive in light of the fact that removing the biofilm is likely to improve outcome.

Although catheter-associated UTIs are generally benign, complications can occur and include pyelonephritis, cystitis, prostatitis and epididymitis. The most serious complication, gram negative septicaemia, is fortunately rare with an incidence of 1%, but warrants special attention as there is often little time to act in the acutely septic patient.[5,7]

UTI prevention

A number of strategies have been suggested to reduce the incidence of catheter-associated UTIs. Broadly speaking, these strategies aim to either: reduce the total number of catheterised patients by reducing either insertion rates or the duration of catheterisation, or reducing the occurrence of bacterial colonisation and infection from existing catheter devices.

In terms of reducing the insertion of urinary catheters, clear evidence suggests that 21–38% of initial catheter insertions are unjustified.[11–13] Furthermore, following insertion catheters may be kept *in situ* for longer than needed. It is not uncommon for physicians to forget that patients have a catheter *in situ* and that computerised reminder systems can successfully prompt removal.[14] Moreover a study of catheterised patients in long-term care facilities has highlighted that up to 50% of catheters can be successfully removed with return to normal continence.[15]

Clearly these data underscore the importance of carefully considering the

clinical need for a catheter both prior to and following insertion. Once a catheter is no longer clinically needed, it should be removed promptly. Another important consideration is the use of alternative drainage devices where possible. Condom catheters for example ensheath the penis and should be considered over intraurethral devices when the clinical indication is to monitor fluid output. Suprapubic catheters are also useful, particularly when urethral catheterisation proves difficult due to stricture formation. Another option to consider is intermittent urethral catheterisation, which has proven to be particularly effective in managing the neurogenic bladder. Although little data has compared the incidence of UTIs associated with these different means of catheterisation, some valid evidence suggests that all three strategies may result in lower rates of infection compared with standard intraurethral devices.[16–20]

Basic measures, including maintaining good catheter hygiene, are logical and advocated by most authorities, but generally there is a lack of evidence from trials. One development in catheter hygiene for which there is substantial evidence is the development of closed drainage systems.[7,21] Closed drainage systems are those in which all drainage compartments are isolated from the external environment and preferably sterile. The purpose of this is to prevent bacterial entry into the urinary tract. The implementation of closed drainage systems has probably been the single most effective means of reducing the incidence of catheter-associated UTIs. Beyond basic measures, a number of antimicrobial strategies have been proposed to reduce biofilm formation and the risk of infection.

Continuous antibiotic prophylaxis for catheterisation is generally not recommended, because of the risk of emergence of drug-resistant flora and the relative difficulty of preventing biofilm formation with systemic therapy. Despite this, promising results have been demonstrated in a recent trial of the effect of long-term prophylaxis with norfloxacin.[22] This study demonstrated both a reduction in the occurrence of UTI and an improvement in clinical outcomes. The issue of administering a few doses of prophylactic antibiotics immediately prior to or following catheterisation has also been studied but remains more controversial. NICE guidelines suggest that prophylaxis prior to catheterisation should be considered in those at high risk of catheter-associated UTIs. Regarding prophylaxis on catheter removal, a recent study has shown that three doses of co-trimoxazole (trimethoprim-sulfamethoxazole) given after removal decreased the relative risk of UTI by an impressive 17%.[23]

Importantly, there have been a number of advancements in catheter technology, which aim to reduce biofilm formation.[24] These include impregnating catheters with antiseptic or antibiotic agents.[25] The antiseptic agent that has been the subject of much interest is silver in the form of either silver alloy or silver oxide. A meta-analysis in 2008, designed to compare the effects of different catheter types on the short-term incidence of asymptomatic or symptomatic bacteriuria found no significant beneficial effect of silver oxide catheters over standard catheter types. In contrast, silver alloy impregnated catheters significantly reduced rates of bacteriuria with catheters *in situ* for less than seven days (relative risk reduction = 0·54) and to a lesser extent with catheters *in situ* for longer than seven days (relative risk reduction = 0·64) without a significant change in the reported incidence of side-effects.[26] Interestingly, one trial pointed to an estimated cost reduction of 3·3–35·5% resulting from use of silver alloy catheters, indicating that this may be a safer and more cost-effective alternative than standard catheter types.[27]

Schumm et al also analysed trial data of two different antibiotic-impregnated catheters, the first impregnated with a combination of minocycline and rifampicin and the second impregnated with nitrofurazone. Both catheter types significantly reduced the incidence of bacteriuria for catheterisation durations of up to, but not beyond, one week. Other antibiotics that have been impregnated into catheter materials with some success at preventing bacteriuria include gentamicin and norfloxacin.[28,29] It is important to note that, although both antibiotic-impregnated and antiseptic catheters inhibit biofilm formation in the short term, particularly for durations of up to one week, they are not an effective means of preventing biofilm formation and hence the risk of UTIs for patients with long-term catheters. Furthermore, the issue of microbial resistance to these catheter materials has not been fully addressed and will

undoubtedly play an important role in their long-term efficacy.[25]

Whilst eliminating the formation of biofilms on indwelling catheters will undoubtedly prove a challenge, there are a number of promising areas for future research.[30,31] Preliminary studies suggest that catheters containing iron-chelating compounds may be effective at reducing the risk fo UTI since iron appears to be a critical component for the formation and growth of biofilms.[32] Another important stage in biofilm formation appears to be the production of quorum sensing molecules, which regulate gene expression in a manner that facilitates biofilm formation.[33] Disruption of this process by chemicals such as furanone has been shown to reduce the ability of bacteria to form biofilms in in vitro studies and may be useful for preventing UTIs.[34–36] An additional strategy, bacterial interference, aims to prevent colonisation by pathogenic organisms by the artificial formation of a non-pathogenic biofilm. Therefore the aim is not to prevent biofilm formation, but rather to change the composition of the biofilm so that it is composed primarily of non-pathogenic rather than pathogenic organisms.[37, 38]

Complications

Functional

Another very important and widespread complication of long-term catheterisation, which is related to bacterial biofilm formation, is encrustation and blockage. Some studies suggest that this may occur in up to 50% of all patients.[39] Infection with *Proteus mirabilis* is believed to play a key role in the initiation of encrustation. This organism forms biofilms and produces a urease enzyme that raises the pH of both urine and the biofilm. Under these conditions, struvite and apatite crystals are formed and become embedded in the biofilm polymer matrix. These crystals can result in trauma to the epithelium, especially on catheter removal, and they have the potential to block the lumen of the catheter resulting in obstruction and the associated complications of retention and UTIs. Furthermore calculi within the bladder can predispose to recurrent UTIs and also an increased risk of squamous cell carcinoma. A recent study has demonstrated that encrustation occurs most extensively at or just below the eye hole of the catheter, largely because of the irregularities of the catheter surface at these sites.[39]

Given that encrustation is a process mediated by bacteria, interventions designed to prevent bacterial colonisation should generally reduce rates of encrustation. In line with this, evidence reveals that filling the retention balloons of catheters with antibacterial or antibiotic solutions capable of diffusing through the balloon and on to the surrounding catheter material significantly impairs the growth of *P. mirabilis* and prolongs catheter patency. Antibacterial agents found to be particularly effective include triclosan and nalidixic acid.[40–43] Interestingly, in a model of bacterial infection with proteus species, catheters primed with triclosan were particularly effective at resisting biofilm formation and the rise in urinary pH induced by urease production. Consequently, encrustation measured by electron microscopy was reduced and catheter patency prolonged. Despite the bactericidal properties of silver, the hydrogel/silver coated latex catheter did not effectively prevent the rise in urinary pH induced by proteus, consequently leading to a microcrystalline foundation layer of calcium phosphate, which potentially allowed biofilm formation by shielding bacteria from the underlying silver.[44] Although triclosan has proven to be a very effective measure against *Proteus mirabilis* encrustation, its ability to restrict colonisation and encrustation by other species, including *Pseudomonas, Enterococcus* and *Providencia rettgeri* is less clear.[45, 46]

Other noteworthy complications of urethral catheters include an impairment of sexual function and incontinence caused by leakage of urine around the catheter. These can to some extent be prevented by intermittent catheterisation or suprapubic catheterisation. Antispasmodic medications, and encouraging the use of wide-bore catheters, may also prevent leakage.[5]

Traumatic and reactive

Traumatic complications of urinary catheters can occur during or even after catheter insertion. During insertion, it is not uncommon for the delicate uroepithelium of the bladder or the urethra to be damaged, resulting in bleeding and pain. A study by Barford and colleagues confirmed this at a cellular level by finding that catheter materials induce epithelial cell damage, as measured by lactate dehydrogenase concentration.[47] In the long term, urinary catheters

may also result in chronic reactive histological changes in the bladder epithelium, including squamous metaplasia and cystitis glandularis, which predispose to the development of squamous cell carcinoma.[48–50] Reported rates of squamous cell carcinoma in patients with indwelling catheters have been as high as 10%.[51]

An added complication of repeated or ongoing urethral trauma is stricture formation. The presence of a stricture makes voiding difficult and may in severe cases necessitate the insertion of a suprapubic catheter. Strategies that have proven effective at reducing stricture formation include urethral lubrication prior to catheter insertion, the use of hydrophilic catheter materials and minimally traumatic insertion techniques.[52–55]

A final and very important cause of trauma is the inflated balloon of the catheter. If the balloon was inflated whilst positioned incorrectly within the urethra, severe urethral injury could result. Furthermore, it is not uncommon for confused patients to forcefully remove their catheters, or for balloons to fail to fully deflate upon attempted catheter removal, again resulting in potentially severe urethral and bladder injury.[53]

Conclusion

Since urinary catheters are extremely useful devices for both therapeutic and monitoring purposes, clinicians are often keen to have patients catheterised. In this review we discuss the frequent complications of catheters that lead to significant morbidity and mortality and urge clinicians to carefully consider the possible harm prior to proceeding to catheter insertion. We have also outlined the possible alternatives to catheter insertion, and have discussed current and future strategies to reduce morbidity from indwelling catheters. In particular targeting the formation of biofilms will be an important strategy for reducing the occurrence of both UTIs and catheter encrustation.

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