Factors associated with recurrent urinary tract infections in spinal cord injured patients who use intermittent catheterization

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EVERETT RG, CHARLES DK, FOSS HE, O'CONNOR RC, GURALNICK ML. Factors associated with recurrent urinary tract infections in spinal cord injured patients who use intermittent catheterization. *Can J Urol* 2021;28(6):10920-10928.

Introduction: *Urinary Tract Infection (UTI) has been cited as the primary cause of morbidity in patients with history of spinal cord injury (SCI). Despite the significance of recurrent UTI (rUTI) in this population, the causative physiologic and patient characteristics are not well described. We sought to assess associations between demographic, clinical and urodynamic variables and rUTI.*
Materials and methods: *The records of 136 individuals with SCI who perform clean intermittent catheterization (CIC) were retrospectively reviewed. All had a video urodynamics study (VUDS) available for analysis. Individuals were divided into non-recurrent (< 3/year) or rUTI (≥ 3/year) groups. Differences between the cohorts were analyzed. Multivariable logistic regression was performed to determine associations between various demographic, clinical, and VUDS variables and rUTI.*
Results: *Self-reported rUTI were noted in 58 of 136 individuals. Of 124 individuals with urinary culture results, African American race (43.3% vs. 22.3%) and 'Other' race (13.3% vs. 8.5%) made up larger proportions in the rUTI group. Female gender (OR 4.96, 95% CI [1.44-17.13]) and African American race (OR 5.16, 95% CI [1.80-14.79]) were increasingly associated with rUTI on multivariable logistic regression. Shorter interval since injury was also significantly associated with recurrent infections with each year since injury indicating diminished likelihood (OR 0.91, 95% CI [0.82-0.99]). There were no significant differences in VUDS variables between groups and none were significant on regression as potential determinants of rUTI.*
Conclusions: *Patient race, gender, and time since SCI appear to have significant associations with rUTI in individuals with SCI using CIC. However, VUDS variables were not found to be significantly associated with rUTI.*

Key Words: spinal cord injuries, urinary bladder, neurogenic, urinary tract infections, urodynamics

Introduction

Adult neurogenic lower urinary tract dysfunction (ANLUTD) has been described as abnormal function of the urinary bladder secondary to pathology of the central nervous system or peripheral nerves involved in the process of micturition.[1-3] It may result from numerous neurodegenerative pathologies or neurologic insults, including spinal cord injury (SCI). Approximately 11,000 new SCI cases are reported annually in the United States and up to 24,000 are estimated throughout Europe.[4]

Urinary tract infection (UTI) significantly impacts emotional and social health and has been cited as the

Accepted for publication August 2021

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primary cause of morbidity in the SCI population.[4,5] Published literature demonstrates an approximate 20% prevalence of recurrent UTI in these individuals.[2,6] Despite the high impact of recurrent UTI in this population, predictive factors are not well described. Individual characteristics such as gender, age, and race have been found to predict recurrent UTI in some studies[7-9] but not others.[10,11] Similarly, urodynamic characteristics including detrusor overactivity, bladder compliance and bladder capacity, have inconsistently predicted recurrent UTI.[10,12,13] We sought to identify the relative strength of association between various individual demographic, clinical, and urodynamic factors and recurrent UTI in SCI individuals who manage their bladders with clean intermittent catheterization (CIC).

Materials and methods

Inclusion/exclusion criteria

Following Institutional Review Board approval, we retrospectively reviewed the charts of individuals referred to our tertiary academic hospital as outpatients between 2007 and 2017 for evaluation and management of ANLUTD. Many of these individuals had suffered a SCI relatively recently and had never been evaluated by a urologist, though some had previously been managed elsewhere and were transferring their care to our institution. All individuals had a history of SCI as the cause of ANLUTD and were using CIC for bladder management. Introduced in 1972 by Lapides et al, CIC refers to intermittent catheterization using "clean" but not sterile technique.[14] It is the practice of our department to encourage individuals to perform CIC with a new, single-use catheter with each catheterization. However, for this study, adherence to this technique could not be verified. We excluded non-SCI ANLUTD, persons not using CIC, and those with incomplete records, Figure 1.

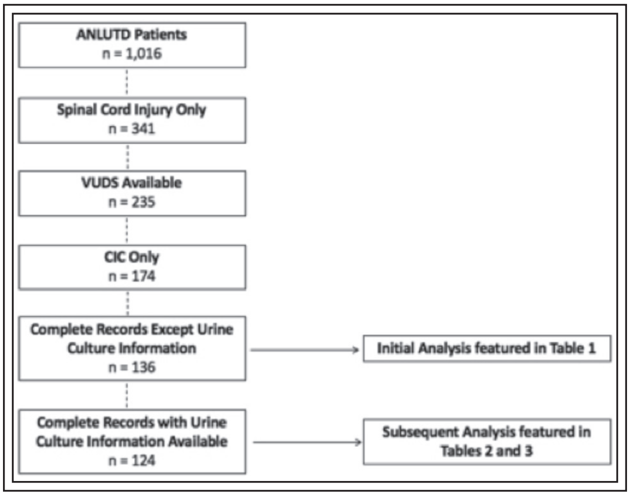

Figure 1. Stepwise patient exclusion diagram.

Demographic variables, comorbidities, and urine culture results for each individual were recorded. Video urodynamics study data, performed as part of the individual's initial work up, included cystometric capacity and bladder compliance/storage pressures. To best assess baseline individual physiologic and demographic parameters, the retrospective chart review only included data from the 12 months prior to each individual's initial presentation to our department.

Defining variables

Recurrent UTI (rUTI) was defined as ≥ 3 documented, culture proven (≥ 100,000 CFU/mL) urinary infections within the last 12 months.[15,16] Though our providers require symptomatic infection to diagnose UTI, the retrospective nature of this study limited the ability to ascertain symptoms at the time points of some cultures. Individuals were classified into the non-rUTI cohort if they had fewer than three positive cultures and/or if the individual denied having any previous infections when no cultures had been drawn.

Urodynamics

Video urodynamics was completed for each patient as part of routine assessment for an individual with ANLUTD and was performed in accordance with practices recommended by the International Continence Society during the study period.[17] Individuals had their bladders filled in the supine position at 30 mL/min with a low threshold to reduce the filling rate to 10 mL/min when the storage pressure appeared to increase, as with detrusor overactivity or impaired compliance.

Filling continued until: 1) the volume at which the patient felt a sensation of needing to empty as they would at home; 2) the volume at which terminal detrusor overactivity occurred with incontinence resulting in near total bladder emptying; 3) a volume as close as possible to maximum catheterized volume on bladder diary (if available); 4) the development of autonomic dysreflexia; or 5) an infused volume of 600 mL. Cystometric capacity was defined as the total catheterized volume at the end of the study rather than the infused volume, consistent with newer International Continence Society guidelines.[18] If an individual experienced incontinence during the study, capacity was defined as the greater of two values: the infused volume or the sum of the leaked volume (if able to be captured) and residual volume obtained with catheterization. Detrusor overactivity was defined as any increase in detrusor pressure that was associated with: 1) a sensation of urge/need for catheterization as the patient would at home; 2) incontinence or 3) fluoroscopic evidence of concomitant bladder neck funneling. We also considered any phasic detrusor

TABLE 1. **Characteristics for self-reported recurrent UTI (not confirmed by culture)**

	Total **n = 136**	**No (no reported rUTI)** **n = 78**	**Yes (reported rUTI)** **n = 58**	**p value**
Age, Mean ± SD	37.4 ± 13.6	37.4 ± 14.0	37.4 ± 13.2	0.891
Sex, (%)				0.089
Female	20 (14.7%)	8 (10.3%)	12 (20.7%)	
Male	116 (85.3%)	70 (89.7%)	46 (79.3%)	
BMI, Mean ± SD	25.5 ± 6.1	24.8 ± 6.3	26.4 ± 5.7	0.048
Race, (%)				0.271
Black	35 (25.7%)	16 (20.5%)	19 (32.8%)	
Other	13 (9.6%)	8 (10.3%)	5 (8.6%)	
White	88 (64.7%)	54 (69.2%)	34 (58.6%)	
SCI level of injury, (%)				0.299
Cervical	45 (33.1%)	30 (38.5%)	15 (25.9%)	
Thoracic	81 (59.6%)	43 (55.1%)	38 (65.5%)	
Lumbar	10 (7.4%)	5 (6.4%)	5 (8.6%)	
Years since SCI, Mean ± SD	5.6 ± 7.1	6.2 ± 7.7	4.9 ± 6.3	0.311
History of diabetes mellitus, (%)	6 (4.4%)	3 (3.8%)	3 (5.2%)	1.000
History of decubitus ulcers, (%)	29 (21.3%)	14 (17.9%)	15 25.9%)	0.265
Bladder stone(s) present, (%)	8 (5.9%)	6 (7.7%)	2 (3.4%)	0.466
Renal stone(s) present, (%)	15 (11.0%)	9 (11.5%)	6 (10.3%)	0.826
Hydronephrosis present, (%)	4 (2.9%)	1 (1.3%)	3 (5.2%)	0.312
Vesicoureteral reflux present, (%)	4 (2.9%)	3 (3.8%)	1 (1.7%)	0.636
Reports urinary incontinence, (%)	89 (65.4%)	48 (61.5%)	41 (70.7%)	0.267
Anticholinergic medication use, (%)	79 (58.1%)	44 (56.4%)	35 (60.3%)	0.726
Antibiotic prophylaxis use, (%)	13 (9.6%)	8 (10.3%)	5 (8.6%)	0.872
DO present, (%)	94 (69.1%)	54 (69.2%)	40 (69.0%)	0.974
Volume at first DO† Median (range)	250.0 (38-850)	229.0 (38-850)	279.5 (56-600)	0.804
Max Pdet during DO‡ Median (range)	50.0 (9-180)	49.0 (9-180)	53.0 (10-150)	0.447
Cystometric capacity, Median (range)	475.0 (35-1346)	459.0 (80-1200)	490.0 (35-1346)	0.874
End fill detrusor pressure, Median (range)	8.0 (1-74)	7.5 (1-74)	8.0 (1-56)	0.763
Compliance, Median (range)	43.6 (1.1-475.0)	42.4 (4.5-475.0)	47.2 (1.1-380.0)	0.770
3+ positive UCx in past year* (%)	30 (24.2%)	6 (7.7%)	24 (52.2%)	< 0.001

†volume at first DO corresponds to the infused volume during UDS at which the first uninhibited detrusor contraction occurred
‡max Pdet during DO corresponds to the maximum detrusor pressure obtained during an uninhibited detrusor contraction.
*3+ positive UCx in past year corresponds to the number of patients that had 3 or more positive (≥ 10,000 CFU/mL) urine cultures within the previous year leading up to their presentation to Urology. Notably, 12 patients who reported recurrent UTIs did not have urine culture information available.

pressure rise greater than 15 cm H_2O to be detrusor overactivity. Bladder compliance was calculated using the bladder volume at capacity divided by the end-fill detrusor pressure (not during detrusor overactivity). Video urodynamics variables such as capacity, compliance, maximal detrusor pressure with detrusor overactivity, and end-fill detrusor pressure were analyzed as continuous variables.

Analyses

Our study consisted of three main steps. We first divided participants into two groups, those with and those without self-reported rUTI independent of urine culture results, if available. Normal distribution was not assumed. We subsequently performed Mann-Whitney U tests and Fisher's exact tests to assess for differences between the two populations. These variables are listed in Table 1. Second, we separated individuals into cohorts with or without three or more culture-proven UTI and subsequently repeated our analysis. Last, we performed multivariable logistic regression to assess the relative strength of association between these variables and having three or more culture-confirmed UTIs. Statistical analysis was performed using IBM SPSS 24 and Stata 13.0. Significance was considered at $\alpha = 0.05$. Demographic and clinical factors were reported as mean ± standard deviation. Urodynamic variables were found to be more subject to outlier values and were consequently reported as median values with associated ranges.

Results

Records for 1,016 patients with ANLUTD were reviewed. Of the 341 individuals identified with SCI, 136 used CIC, had adequate medical records with video urodynamics, and were included in the initial analysis. Of these, only 124 had satisfactory urine culture information to be included in culture-specific analysis.

The initial analysis of 136 individuals compared baseline characteristics between individuals who self-reported (not culture proven) rUTI in the year prior to evaluation [n = 58 (42.6%)] and those who did not [n = 78 (57.4%)]. Individuals reporting rUTI had a higher mean (SD) body mass index than the cohort not reporting rUTI (mean difference 1.6, 95% CI [-0.5, 3.7]). No other significant differences in patient demographics, incidence of comorbidities present, or urodynamic variables between the two groups were noted, Table 1. Notably, the only other statistically significant difference between the cohorts was those reporting rUTI were more likely to have had three or more culture-proven infections. Of the 58 individuals who reported rUTI, culture information was available for 46. Among these, 24 (52.2%) did have three or more culture-confirmed infections. Of the 78 participants who denied rUTI, 6 (7.7%) individuals had evidence of three or more culture proven infections within the previous year.

The second analysis compared differences between individuals with [n = 30 (24.2%)] and without [n = 94 (75.8%)] three or more culture-proven infections in the year leading up to urology referral, Table 2. Race designated as African-American or Other was associated with a higher prevalence of rUTI. African Americans made up 13 of the 30 (43.3%) participants with rUTI compared to 21 of 124 (22.3%) without. Race designated as 'Other' also made up a larger proportion of the rUTI group (13.3%) compared to the non-rUTI group (8.5%). Additionally, individuals without rUTI had a longer period of time since their SCI compared to those with rUTI (mean difference 2.5, 95% CI [-0.2, 5.2]). While mean BMI appeared higher in the rUTI group, this finding did not achieve statistical significance at the determined confidence interval (mean difference 1.4, 95% CI [-1.2, 4.0]). Similarly, younger age (mean difference 4.4, 95% CI [-1.3, 10.1]) and female preponderance (23.3% vs. 10.6%) were more common with rUTI but failed to reach statistical significance. There were no significant differences in urodynamics variables between groups, all of which are shown in Table 2.

Lastly, multivariable logistic regression was performed to determine adjusted associations for those with three or more culture-proven UTIs in the previous year, Table 2. The regression analyzed the 136 individuals with culture data available and thus investigated the same group of individuals as Table 2. Notably, female gender (OR 4.96, 95% CI 1.44-17.13, p = 0.011), years since SCI (OR for each subsequent year 0.91, 95% CI 0.82-0.99, p = 0.036), and African American race (OR 5.16, 95% CI 1.80-14.79, p = 0.002) were the only statistically significant factors identified. Other variables included in the regression model, Table 3, were not significant.

Discussion

Our study aimed to investigate demographic and clinical factors that were closely associated with rUTI in individuals with SCI who manage their bladder with CIC. With 136 individuals in the initial analysis and 124 in the subsequent analysis, we believe our study represents one of the largest to date for individuals with SCI performing CIC.

TABLE 2. **Characteristics for recurrent UTIs (confirmed by 3 or more positive urine cultures in the previous year)**

	Total n = 124	No (0-2 positive urine cultures) n = 94	Yes (3 or more positive urine cultures) n = 30	p value
Age, Mean ± SD	37.3 ± 13.9	38.4 ± 14.1	34.0 ± 13.0	0.142
Sex, (%)				0.123
Female	17 (13.7%)	10 (10.6%)	7 (23.3%)	
Male	107 (86.3%)	84 (89.4%)	23 (76.7%)	
BMI, Mean ± SD	25.7 ± 6.3	25.3 ± 6.1	26.7 ± 6.8	0.336
Race, (%)				0.033
Black	34 (27.4%)	21 (22.3%)	13 (43.3%)	
Other	12 (9.7%)	8 (8.5%)	4 (13.3%)	
White	78 (62.9%)	65 (69.1%)	13 (43.3%)	
SCI level of injury, (%)				1.000
Cervical	42 (33.9%)	32 (34.0%)	10 (33.3%)	
Thoracic	72 (58.1%)	54 (57.4%)	18 (60.0%)	
Lumbar	10 (8.1%)	8 (8.5%)	2 (6.7%)	
Years since SCI, Mean ± SD	5.0 ± 6.7	5.6 ± 7.0	3.1 ± 5.2	0.018
History of diabetes mellitus, (%)	6 (4.8%)	4 (4.3%)	2 (6.7%)	0.631
History of decubitus ulcers, (%)	26 (21.0%)	20 (21.3%)	6 (20.0%)	0.881
Bladder stone(s) present, (%)	8 (6.5%)	7 (7.4%)	1 (3.3%)	0.678
Renal stone(s) present, (%)	15 (12.1%)	13 (13.8%)	2 (6.7%)	0.358
Hydronephrosis present, (%)	4 (3.2%)	2 (2.1%)	2 (6.7%)	0.246
Vesicoureteral reflux present, (%)	4 (3.2%)	4 (4.3%)	0 (0.0%)	0.571
Reports urinary incontinence, (%)	80 (64.5%)	59 (62.8%)	21 (70.0%)	0.471
Anticholinergic medication use, (%)	68 (54.8%)	51 (54.3%)	17 (56.7%)	0.837
Antibiotic prophylaxis use, (%)	9 (7.3%)	7 (7.4%)	2 (6.7%)	1.000
DO present, (%)	88 (71.0%)	68 (72.3%)	20 (66.7%)	0.551
Volume at first DO†, Median (range)	262.0 (38-850)	275.0 (38-850)	225.0 (56-550)	0.287
Max Pdet during DO‡, Median (range)	50.0 (9-180)	50.0 (9-180)	55.0 (25-149)	0.240
Cystometric capacity, Median (range)	475.0 (35-1346)	486.5 (73-1346)	395.0 (35-1225)	0.424
End fill detrusor pressure, Median (range)	7.5 (1-74)	7.5 (1-74)	7.5 (1-46)	0.699
Compliance, Median (range)	44.7 (1.1-475.0)	42.4 (4.5-475.0)	50.0 (1.1-375.0)	0.641
Number of UTI in previous year* Mean ± SD	1.6 ± 1.7	0.8 ± 0.8	4.1 ± 1.7	0.000

†volume at first DO corresponds to the infused volume during UDS at which the first uninhibited detrusor contraction occurred
‡max Pdet during DO corresponds to the maximum detrusor pressure obtained during an uninhibited detrusor contraction. This was run as a continuous variable.
*number of UTI in previous year corresponds to the number of culture-proven infections within the previous year leading up to their presentation to Urology.

TABLE 3. **Adjusted associations with recurrent UTI* (stepwise logistic regression variables achieving or nearly achieving statistical significance)**

Effect	Odds ratio	Wald 95% confidence limit for adjusted odds ratio	p value
Sex			
Male	Reference		
Female	4.96	(1.44-17.13)	0.011
Race			
White	Reference		
Black	5.16	(1.80-14.79)	0.002
Other	3.91	(0.922-16.55)	0.064†
Years since SCI	0.91	(0.824-0.994)	0.036

†did not achieve statistical significance
*other variables included in the regression: age at presentation, BMI, presence of DO, volume at first DO, maximum detrusor pressure with DO, cystometric capacity, end fill detrusor pressure, calculated compliance, SCI level, history of decubitus ulcers, history of diabetes, presence of renal calculi, presence of bladder calculi.

Mean body mass index was found to be significantly higher (mean difference 1.6, 95% CI [-0.5, 3.7]) in those who self-reported rUTI. Apart from body mass index, there were no other significant differences in demographic or video urodynamics variables between the self-reported versus denied rUTI. Taken together, whether this particular finding bares any clinical significance as a predictor in patients reporting rUTI remains unclear. While a higher body mass index has been positively correlated with UTI risk, body mass index did not significantly differ between groups with culture information available.[19]

Our first analysis supports the findings of Linsenmeyer and Oakley who reported 32% of individuals with SCI falsely believed they had a UTI but were found to have a negative culture.[20] Urine culture information was available for 46 of 58 participants who reported rUTI. Yet only 52% of individuals had three or more positive cultures, reiterating the importance of obtaining urine cultures and upholding more specified definitions for UTI in the clinical management of SCI persons.

One major problem of studies regarding ANLUTD involves inconsistent and non-standardized definitions of UTI.[9,16] Typically, the diagnosis of UTI usually requires some combination of clinical symptoms and a degree of bacteriuria ± pyuria. Reliable thresholds for bacteriuria range from 10^2 CFU/mL to as high as 10^5 CFU/mL.[15,16] Associated symptoms can also vary widely and be somewhat open to interpretation. Some studies isolate UTI to infections of the bladder or upper tract. Others include pathologies such as prostatitis and epididymo-orchitis.[10,13] The most commonly reported characteristics of UTI were cloudy, malodorous urine and urinary incontinence.[4] However, other studies alluded to an array of vague symptoms.[4] As a retrospective study, we are limited in our ability to strictly define infection. Our initial analysis pertained to self-reported UTIs. However, it is expected that a subset of these could simply represent ANLUTD symptoms. The second analysis did utilize urine culture information. Yet, given the retrospective nature of the study, no standardized assessment of symptoms at the time of culture was utilized and some could simply be bacteriuria.

In our analysis of patients with urine culture results we found race to be a significant individual demographic variable associated with rUTI. African Americans and other non-Caucasian races were both more likely to have had rUTI (OR 5.16 and 3.91, respectively). However, overlap existed in the confidence intervals for other non-Caucasian race. Similarly, Waites et al also found African American race to correlate with UTI in persons with SCI.[7] Their investigation also investigated other socioeconomic status variables such as income and level of education and included these on multivariable analysis. Our study, however, did not.

On multivariable regression, our findings demonstrated female gender had a significant, adjusted association with rUTI. However, the role of gender can be hard to interpret as males disproportionately make up the bulk of the SCI population.[12] In our study, only 20 of 136 (14.7%) patients were female. Gender has previously been investigated as a predictor for UTI. However, the findings of previously published reports vary widely. Neither Waites et al nor Edokpolo et al found sex to be a predictor.[7,11] However, Bennett et al, who specifically looked at differences in UTI rates between SCI men and women who performed CIC, found females to have a significantly higher infection rate.[8] Siroky also reported a female preponderance for UTI in the SCI population.[6] Conversely, Mukai et al reported male gender to be a significant risk factor on univariate and multivariate analysis (HR 3.08) for febrile UTI in individuals with SCI performing CIC.[10]

Age has also proven to be a demographic factor of interest. Chaudhry et al reported age to be protective on multivariate analysis, with decreased odds of UTI within the past year by 7% for every additional year of age in 194 patients with spina bifida or tethered cord.[9] Our participants with rUTI appeared younger on average (mean difference 4.4, 95% CI [-1.3, 10.1]) although overlap did exist within the ranges of confidence intervals. Perhaps the age related findings may be attributed more to experience in dealing with ANLUTD issues, rather than age itself. However, our study was not appropriately designed to assess causation. Given our patient variables were collected as they were first evaluated by our department, many of these individuals were novices regarding the management of urologic sequelae of their injuries. Consequently, age would not necessarily indicate further experience with disability as it would in a spina bifida population. The idea of experience is supported by our finding that time since SCI was inversely associated with rUTI, with every additional year since SCI showing a 9% decrease in chance of rUTI. We postulate the experience individuals and their caretakers accumulate when managing their conditions provides benefit. However, we are unable to propose a causal pathway and the factors that might improve with such experience and provide benefit remain unclear.

Notably, we did not identify any significant impact of UDS findings on the risk for rUTI. Video urodynamics characteristics have been investigated previously with mixed results. Neyaz et al studied recent (< 1 year) SCI persons performing CIC and compared those with detrusor overactivity to those with detrusor areflexia. They reported 70% of UTIs occurred in individuals with detrusor overactivity and attributed infection risk to higher bladder pressures.[12] On the other hand, Mukai et al did not directly investigate urodynamics factors but found no difference in UTI rates in 259 ANLUTD patients taking versus not taking overactive bladder medications.[10] This is consistent with our study in which approximately 50% in each group was taking overactive bladder medication.

Several studies have supplied at least indirect evidence of urodynamic variables as predictors for infection. Gamé et al studied the effect of onabotulinumtoxin A injection on 30 patients with ANLUTD and detrusor overactivity. They found the mean rate of UTI was significantly lower (0.20 vs. 1.75 infections/patient) 6 months following injection compared to 6 months prior.[13] Though only three participants had UTIs after injection, they did identify that less improvement with injection regarding volume at first detrusor overactivity, maximum detrusor pressure, and cystometric capacity were predictors of infection later on. Similarly, Jia and colleagues compared rates of UTI 6 months before and after onabotulinumtoxin A injection in 41 male SCI persons performing CIC.[21] They found the rate of UTI significantly decreased for those with detrusor overactivity pre-operatively but not for those with normo-active detrusor. Taken together, the findings suggest that bladder hyperactivity and increased bladder pressure may be a risk factor for rUTI.

Though our study did not find urodynamics characteristics to be significant risk factors for rUTI, we believe several variables warrant further discussion. Particularly, the median volume at first detrusor overactivity was 262.0 mL and median cystometric capacity in our population was 475.0 mL. Both values are higher than previous reports in ANLUTD populations. Moslavac et al published mean capacity of 239 ± 107 mL and 227 ± 125 mL in individuals with complete and incomplete SCI, respectively.[22] Variables such as participant positioning for urodynamics, bladder fill rate, and patient use of anti-muscarinic medication were not mentioned. Participant positioning can affect the detection of detrusor overactivity on urodynamics with it being less commonly identified in the supine as opposed to upright positions.[18] Our urodynamics were done in the supine position as this is easier for our technical staff. It is possible, however, that had we performed the studies in the seated position the findings might have been altered. Ockrim et al investigated the urodynamics results of SCI men and identified an average capacity of 310 mL and volume at first detrusor overactivity of 212 mL.[23] Again, the proportion of patients on antimuscarinic therapy was not specified. Additionally, they filled the bladder at a rate of 50 mL/min and capped capacity at 500 mL. Taken together, it may be that supine positioning, our slower filling rate, and the significant proportion of our participants on antimuscarinic therapy (54.8%) may account for the higher than expected capacities in these individuals. Wöllner et al found a capacity more in line with our population.[24] Their study examined SCI persons with detrusor overactivity and the effect of mirabegron on urodynamics variables. Twelve of fifteen participants were already on anticholinergic medications. They reported bladder capacities increased from 365 mL pre-therapy to 419 mL, although neither filling rates nor capacity were defined. A recent best practice paper by the International Continence Society Urodynamics Committee recommended a filling rate between 10-100 mL/min in SCI persons.[25] Consequently, the impact of rate of filling within this range likely warrants further exploration by future studies. Additionally, 42 of our 136 (30.9%) did not have detrusor overactivity on urodynamics. The median cystometric capacity for these individuals was 750 mL (35-1346). While these individuals were not included in the volume at first detrusor overactivity calculation, they did skew the findings for capacity. The median capacity for those with detrusor overactivity present was 385.5 mL (73-1029).

A low proportion (28.2%) of the studied participants had bladder diary evaluations sufficient for inclusion. However, of those included, individuals with rUTI did have a lower 24-hour urine output (1343.1 mL vs. 1878.2 mL). While this did not achieve statistical significance ($p = 0.130$) further inquiry into fluid management and rUTI rates in SCI populations may be warranted.

Our findings are subject to limitations of a retrospective chart review that should be considered. While our sample size is relatively large compared to many of the other cited studies, it likely remains underpowered to assess differences in various variables of interest. Given the retrospective nature of our investigation, no formal power analysis was performed. Rather, we included all eligible patients as described previously. Accurate differentiation of factors with wide ranges such as urodynamic variables would certainly be improved with increasing sample sizes. These variables will also benefit from a standardized method of collection given results can vary significantly between studies depending on how they are ascertained. As we previously alluded, UDS variables are particularly prone to non-standardized assessment. For these reasons, we have attempted to meticulously describe our methods for testing and collection. Additionally, the majority of urine cultures in these individuals were ordered by physicians outside of our department. Consequently, we were unable to confirm the symptoms present at the time of each culture as to provide stringent definition of infection within the study. We also cannot account for any cultures/infections that might not have been documented in our electronic medical record (e.g. patient went elsewhere) which may underestimate the number of UTIs. Although we reviewed individuals as part of their initial work up with our department, we were unable to account for any treatment initiated by other providers prior to each individual's presentation to Urology.

In summary, we found that demographic factors such as female gender and African American race were positively associated with culture-proven rUTI on adjusted analysis in persons with SCI using CIC for bladder management while a greater length of time since SCI was negatively associated. We did not identify any urodynamic parameters that were significantly associated with rUTI. With improved predictive capabilities, it is our hope that individuals with SCI can be stratified into different categories for surveillance and possibly intervention. However, future studies are needed to assess casual pathways for infection and effective ways to mitigate these. ☐

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