ISCoS The International Spinal Cord Society

www.nature.com/sc

ARTICLE

# A cost-effectiveness analysis of bladder management strategies in neurogenic lower urinary tract dysfunction after spinal cord injury: A publicly funded health care perspective

Samer Shamout[1,2], Sara Nazha[2], Alice Dragomir[2], Richard Baverstock[1], Jacques Corcos[2] and Lysanne Campeau[2]✉



**STUDY DESIGN:** Economic evaluation study.
**OBJECTIVES:** To investigate the long-term cost-effectiveness of clean intermittent catheterization (CIC) compared with suprapubic catheters (SPC) and indwelling urethral catheters (UC) among individuals with neurogenic lower urinary tract dysfunction (NLUTD) related to spinal cord injury (SCI) from a public healthcare perspective.
**SETTING:** University affiliated hospital in Montreal, Canada.
**METHODS:** A Markov model with Monte Carlo simulation was developed with a cycle length of 1 year and lifetime horizon to estimate the incremental cost per quality-adjusted life years (QALYs). Participants were assigned to treatment with either CIC or SPC or UC. Transition probabilities, efficacy data, and utility values were derived from literature and expert opinion. Costs were obtained from provincial health system and hospital data in Canadian Dollars. The primary outcome was cost per QALY. Probabilistic and one-way deterministic sensitivity analyses were performed.
**RESULTS:** CIC had a lifetime mean total cost of $ 29,161 for 20.91 QALYs. The model predicted that a 40-year-old person with SCI would gain an additional 1.77 QALYs and 1.72 discounted life-years gained if CIC were utilized instead of SPC at an incremental cost savings of $330. CIC confer 1.96 QALYs and 3 discounted life-years gained compared to UC with an incremental cost savings of $2496. A limitation of our analysis is the lack of direct long-term comparisons between different catheter modalities.
**CONCLUSIONS:** CIC appears to be a dominant and more economically attractive bladder management strategy for NLUTD compared with SPC and/or UC from the public payer perspective over a lifetime horizon.

*Spinal Cord* (2023) 61:269–275; https://doi.org/10.1038/s41393-023-00883-5

## INTRODUCTION

Neurogenic lower urinary tract dysfunction (NLUTD) is a prevalent unavoidable lifelong complication following spinal cord injury (SCI) which is commonly observed in 81% of individuals within the first year after injury [1]. Management of bladder dysfunction represents a significant economic and clinical burden for our health care system, caregivers and patient's quality of life [2].

Clean intermittent catheterization (CIC) is accepted worldwide as a standard of care for NLUTD related to SCI. Indwelling urethral (UC) or suprapubic catheters (SPC) have been frequently used in SCI individuals where self-catheterization is difficult, impossible or inconvenient [3]. Despite the complications related to chronic use of indwelling catheters, many SCI individuals switch from CIC to these catheters over time. The appropriate bladder management strategy should be tailored to individual patient needs such as anatomical factors, motor and cognitive functions, patient preference, and health-related quality of life [4]. SCI patients switch from CIC to SPC or UC for many different reasons such as recurrent UTIs, urethral damage, dependence on care givers, refractory incontinence and patient's preference [3]. Although CIC is a reliable, effective and widely advocated as a standard of care in selected SCI patients, the general use of indwelling catheters over the course of long-term urological management is still being considered for certain individuals. Literature data available focused mainly on the clinical and user perspectives, while the cost effectiveness and economic perspective of these approaches has not been studied so far.

The cost-effectiveness of the bladder management strategies for NLUTD in SCI adds evidence to the treatment decision made by physician in consultation with the patient, and to the policy makers especially in a publicly funded health care system. Therefore, the present study aimed to perform a health economic analysis with a lifetime perspective of CIC compared to UC or SPC in an adult SCI population from a Canadian publicly funded health care system perspective.

## MATERIALS AND METHODS

### Model design and population

A Markov model with Monte–Carlo microsimulations (Fig. 1) was created using TreeAge Pro Software 2020 (TreeAge, Inc, Williamstown, MA) to estimate the incremental cost per quality-adjusted life years (QALYs) of CIC versus SPC or UC for the treatment of NLUTD. We modeled a hypothetical

[1]Division of Urology, Department of Surgery, University of Calgary, Calgary, AB, Canada. [2]Division of Urology, Department of Surgery, McGill University, Montreal, QC, Canada. ✉email: lysanne.campeau@mcgill.ca

Received: 5 January 2022 Revised: 22 January 2023 Accepted: 23 February 2023
Published online: 9 March 2023

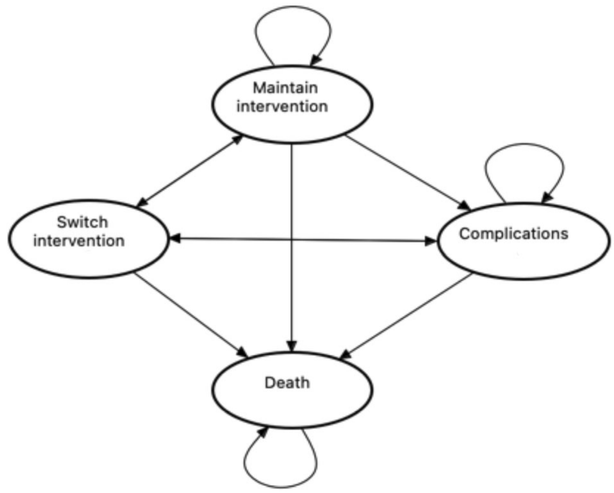


**Fig. 1 Schematic representation of the Markov model with four different health states.** The patient can progress to different states: maintain, switch, complications, and death. The arrows either represent "remain in health state" or the "progression to next health state".

population of adult participants with NLUTD related to SCI (Supplemental Table 1). The model was developed to estimate the long-term cost and outcomes of bladder management methods in people with SCI who had already completed initial SCI treatment and inpatient rehabilitation. We selected a lifetime horizon as this was the interval over which the SCI population would be likely to need NLUTD treatment and current bladder management options would remain relevant. Given the chronicity of the condition and the need for lifelong bladder drainage treatment, each Markov cycle was set at 1 year. Clinical guidelines indicated a yearly follow-up, urological evaluation, and surveillance algorithm for NLUTD based on patient risk-stratification [4].

## Model structure

Monte Carlo Simulations of 1000 participants were created to estimate the incremental cost-utility ratio (ICUR) in which the incremental cost is compared to the incremental health improvement expressed in the unit of quality adjusted life years (QALYs) of the three comparative treatment strategies. Our base-case presumed that all participants have equal access to all bladder management approaches, with the assumption that the SCI individual will continue in particular health state if treatment is effective. The model's target population reasonably represented the Canadian SCI data with 80% being males, and average age at injury of 40 years [5].

## Definition of health states

The Markov model consisted of different health states that a catheter dependent individual with SCI can experience. The model included four possible health states; 1) maintain intervention (defined as individuals assigned to their primary bladder management modality: CIC, SPC or UC), 2) switch intervention (defined as individuals who changed their primary treatment to a secondary treatment due to complications, inconvenience or change in underlying health condition and were diagnosed and recommended a different treatment modality by a treating physician), 3) complications (person/s developed one or more urological complications related to primary bladder drainage or deterioration in health condition), and 4) death (an absorbing state for general mortality in SCI population). Given the complexity of the model, and the availability of utility indices identified in the literature, we considered for our model the most frequent urological complications that patient with NLUTD would encounter over the short- and long-term periods, which need medical and/or surgical treatment. With respect to the complications, such as urinary tract infection [6], bladder or kidney stones [7] or urethral damage [8] were considered as short-term adverse events and were assumed to have been resolved with appropriate treatment. Given the fact that major renal impairment (calculated using stage $3+4$) and renal failure is irreversible conditions [9, 10], movement to a better renal health state was not possible. There are no transitions between different catheter-related complications. Baseline mortality rate was based on spinal cord injury age-specific standardised life tables derived from United States collaborative SCI survival study database (December 2019) [11].

## Data input

Transition between different treatment modalities within "switch" health state was permitted for a certain number of cycles based on assigned probabilities (Table 1). Patients with secondary complications after CIC, SPC or UC were able to maintain the same treatment or switch to another strategy. Of those undergoing a second CIC, SPC or UC, the same outcome algorithm was utilized, with the exception that no further CIC would be offered for patients switched from CIC. Similarly, individuals revert from SPC were offered CIC or UC placement rather than repeat SPC. In the scenario analysis, we assumed that participants only practice single-use disposable catheters (uncoated) similar to hydrophilic (coated) catheters. Guidelines advocate frequency of intermittent catheterization an average 4 to 6 times per day [12].

## Utility values

Utility indices in the model were obtained from the literature, and when not available, the expert panel of two experienced urology surgeons (LC and JC) with subspecialty experience in NLUTD and the study population provided input. Utility values anchored between 0 to 1, with 0 represents death and 1 indicates a perfect health state. These values were derived based on previously validated assigned utilities from a NLUTD condition [13–15]. Table 2 illustrates health utility values associated with catheter-related complications.

## Costs assignments

Estimated direct costs were assigned in 2020 Canadian dollars and calculated from the provincial public health system perspective (Quebec). Hospital and medical expenses were estimated based on the RAMQ (Régie de l'Assurance Maladie du Québec) and Ministère de la Santé et des Services Sociaux (MSSS) lists [16, 17]. Catheter, lubrication and acquisition costs were obtained from sales reports at the Jewish General Hospital in Montreal, Canada and commercial online sales websites specialized in continence products [18, 19]. Treatment-related adverse event expenditures were calculated in accordance with a clinically validated treatment pathway, based on those reported in Canadian Urological Association guidelines [4]. Costs related to renal health states (major renal impairment and renal failure) were calculated based on healthcare expenditures associated with nephrology care of pre-dialysis chronic kidney disease [9]. Annualized healthcare costs from a managed care perspective includes outpatient and inpatient services and medications costs (Table 3). Because of limited data, indirect, societal costs or out-of-pocket expenses related to sick leaves, early retirement, and early death are difficult to calculate in monetary terms and were not included in the scenario analysis.

## Model output

The Markov model outputs were incremental costs, quality-adjusted life years (QALYs), and life years gained (LYG). Following Canadian recommendations, an annual discount rate of 1.5% was applied to costs, QALYs, and LYG. Results are expressed as incremental cost-utility ratios (ICURs) for a lifetime perspective.

## Sensitivity analysis

To investigate the parametric uncertainty in the model, a probabilistic sensitivity analysis was conducted using a Monte Carlo simulations of 1000 iterations and presented through a scatterplot. The UC and SPC modality were compared, individually, to the CIC strategy. One-way deterministic sensitivity analyses were run with an input variable set to either its low (25% reduction) or high (25% increase) value relative to the base case value in order to determine key model parameters and the impact of variations and assumptions on the ICUR. The cost of catheterization, adverse events, the transition probabilities between health states and the utilities were included to evaluate their independent effects on the ICUR. We examined different discount rates of 0%, and 3% in the sensitivity analyses. Finally, a shorter 15- and 25-year time horizon were also explored.

# RESULTS

CIC had a lifetime mean total cost of $ 29,161 for 20.91 QALYs. While UC had a mean total cost of $31,657 for 18.95 QALYs, SPC

**Table 1.** Key input parameters to the model.

| Parameters | CIC | SPC | UC | Source |
|---|---|---|---|---|
| Annual transition probabilities to health state | | | | |
| Probability of maintain intervention | 0.9527 | 0.9436 | 0.9343 | [28] |
| Need to switch intervention | 0.0169 | 0.0114 | 0.0114 | [28] |
| Complications related to bladder management | 0.0175 | 0.0321 | 0.0414 | [22] |
| Death | 0.0129 | 0.0129 | 0.0129 | [11] |
| Annual transition probabilities to complications | | | | |
| UTI responding to initial treatment | 0.7050 | 0.5830 | 0.8330 | [6] |
| UTI not responding to initial treatment | 0.3120 | 0.1750 | 0.5000 | [6] |
| Bladder stones | 0.0165 | 0.0362 | 0.0202 | [7, 26] |
| Kidney stones | 0.0045 | 0.0208 | 0.0163 | [7] |
| Urethral damage | 0.0476 | 0.0159 | 0.0233 | [8] |
| Major renal impairment | 0.0159 | 0.0102 | 0.0247 | [10, 15, 30] |
| Renal failure | 0.004 | 0.004 | 0.004 | |
| Cost Components and Unit Costs (2019 Canadian dollars) | | | | |
| Hydrophilic coated catheter (single-use) | $4.89 | - | - | [18, 19] |
| Uncoated intermittent catheter (single-use) | $0.65 | - | - | [18, 19] |
| Daily acquisition cost (lubricant) | $0.15 | - | - | [18, 19] |
| Monthly dispensing fee | $8.15 | - | - | [18, 19] |
| Urethral indwelling catheter | - | - | $0.5 | [18, 19] hospital record |
| Suprapubic indwelling catheter | - | $1.32 | - | [18, 19] hospital record |
| Initial cost of insertion | $67.35 [a] | $622.58 [b] | $95.52 [a] | [16, 17] hospital record |
| Cost of monthly change (1catheter/month) [a] | - | $95.52 | $95.52 | [16, 17] hospital record |
| Follow-up (yearly thereafter) [c] | $109.3 | $109.3 | $109.3 | [16, 17] |
| Average cost (first year) | $1099.3 | $1768.82 | $1255.54 | |
| Average cost (yearly thereafter) | $1099.3 | $1255.54 | $1255.54 | |
| Other parameters | | | | |
| Catheterization frequency | 4.0 per day | 1.0 per month | 1.0 per month | [12] |
| Proportion of cohort with UTI not responding to initial treatment (complicated) | 31.2% (CI 26.8–35.8) | 17.5% (CI 11.2-25.5) | 50.0% (CI 26.0–74.0) | [6] |
| Length of hospitalization (UTI unresponsive to initial treatment) | 3.9 days | 3.9 days | 3.9 days | [30] |
| Cohort starting age | 40 | 40 | 40 | Assumption |

*RAMQ* Régie de l'assurance maladie du Québec, *MSSS* Ministère de la Santé et des Services Sociaux, *CIC* Clean intermittent catheterization, *SPC* Suprapubic catheter, *UC* Urethral indwelling catheter.
[a]This amount includes material fees, nursing fees and hospital fees.
[b]This amount includes urologist fees, anaesthesia physician fees, procedure cost and hospitalization fees; day surgery (medications cost, nursing care, and therapeutic services).
[c]This amount includes physician fees and hospital fees.

mean cost was $ 29,491 for 19.14 QALYs (Table 4). At an incremental cost of $2496 per SCI individual, CIC confer 1.96 QALYs and 3 discounted life-years gained compared to UC, resulting in an ICUR of −$1273 per QALY gained and $832 per life years gained per individual. Similarly, CIC was dominant when compared with SPC, (1.77 higher incremental QALYs and 1.72 additional discounted life-years; ICUR, −$186). Consequently, the CIC is the dominant strategy over the indwelling UC or SPC over lifetime horizon.

One-way sensitivity analysis for CIC versus SPC or UC demonstrated that CIC dominance was most sensitive to catheter-associated complications (Fig. 2a, b). From a cost perspective, hydrophilic coated intermittent catheters (HCICs) were perceived as cost-effective strategy (improves clinical results at increased cost); when the cost per hydrophilic catheter estimated at $3.99 or $5.99, this resulted in an ICUR of $1295 and $2455 versus UC, and $2453 and $4812 versus SPC respectively. For the model parameters, the 15- and 25-year time horizon showed that the CIC strategy remains the dominant management option. When the CIC complications rate has increased, SPC is considered a cost-effective treatment resulting in an ICUR of $8388/QALY gained (Supplementary Table 2). The relative utility benefit (+0.05) of using hydrophilic catheters instead of conventional (uncoated) was also tested for the value of 0.881. When utility gain was assumed to be +0.05 using hydrophilic catheters, the ICUR becomes −$1440 and −$1068 versus SPC and UC respectively.

Probabilistic sensitivity analyses with 1000 simulations, indicated almost 100% probability of CIC being cost-effective versus

Table 2. Health utility associated with key health states.

| Health state | Mean value (95% CI) | Source |
|---|---|---|
| Baseline utility of catheterization | 0.831 (0.809–0.852) | [30] |
| UTI responsive to initial treatment | 0.782 (0.764–0.799) | [13] |
| UTI not responding to initial treatment | 0.760 (0.685–0.834) | [13] |
| Bladder stones | 0.80 (0.76–1.00) | Assumed same as kidney stones |
| Kidney stones | 0.80 (0.76–1.00) | [30] |
| Urethral damage | 0.738 (0.688–0.787) | [13] |
| Major renal impairment | 0.67 ± 0.31 | [15, 30] |
| Renal failure | 0.54 ± 0.33 (0.49–0.64) | [15, 30] |

*RAMQ* Régie de l'assurance maladie du Québec, *MSSS* Ministère de la Santé et des Services Sociaux, *UTI* Urinary tract infection.

Table 3. Main cost inputs.

| Healthcare costs | Mean | Source |
|---|---|---|
| UTI responding to initial treatment (per event) [a] | $164.3 | Calculated following; [13] RAMQ list [16], Quebec MSSS [17] |
| UTI not responding to initial treatment (per event) [b] | $5704.14 | Calculated following; RAMQ list [16], Quebec MSSS [17] |
| Bladder stones (per event) [c] | $1411.95 | RAMQ list [16], Quebec MSSS [17], hospital record |
| Kidney stones (per event) [c] | $2086.96 | Calculated following; RAMQ list [16], Quebec MSSS [17], hospital record |
| Urethral damage (per event) [d] | $975.68 | Calculated following Expert opinion; RAMQ list [16], Quebec MSSS [17], hospital record |
| Major renal impairment (per year) * | $21714 | Calculated using stages 3 and 4 following [9] |
| Renal failure (per year) * | $43915 | Calculated using stages 3 and 4 following [9] |

*RAMQ* Régie de l'assurance maladie du Québec, *MSSS* Ministère de la Santé et des Services Sociaux, *UTI* Urinary tract infection.
[a]This amount includes medications cost, urine test, physician fees, and hospital fees.
[b]This amount includes physician fees, and hospital admission fees (medications cost, nursing care, and therapeutic services).
[c]This amount includes (hospitalization fees, urologist fees, anaesthesia physician fees, technician fees and procedure cost for stones removal).
[d]This amount includes (hospitalization fees, urologist fees, anaesthesia physician fees, technician fees, dynamic studies of urinary tract and procedure cost; urethral dilatation, visual urethrotomy, urethroplasty).
*This amount includes (Outpatient and Inpatient services and medications costs).

SPC or UC for cost-utility threshold of $50,000 per QALY gained [20, 21]. Probabilistic sensitivity analyses with 1000 simulations, indicated that CIC was cost-effective versus UC > 99% of the time and versus SPC > 86.8% of the time at a willingness-to-pay threshold of $50,000/QALY (Supplementary Fig. 1a, b).

## DISCUSSION

Optimal bladder management modalities remain of paramount importance for catheter-related adverse events as well as health-related quality of life. To the best of our knowledge, this is the first study evaluating the cost-utility of different bladder management techniques in a publicly funded health care system context. From a lifetime perspective, CIC is a dominant management strategy as compared with SPC or UC, which is within the Canadian threshold of $50,000 per QALY. The base-case analysis demonstrated an ICUR of −$2,496 /QALY when comparing CIC versus UC, and −$186/QALY when implementing CIC instead of SPC. These low ICURs were driven by marginal differences in costs but significant relative increases in QALYs across bladder management modalities. The results of this economic analysis are valid for our provincial public health care system and used Quebec as the reference province for costs and resources, we believe it may translate to other publicly funded health care systems and can be used to guide rationale decision-making about the urological management in SCI populations.

We considered for our model the most frequent urological complications that people with NLUTD would encounter over the short- and long-term periods, which need medical and/or surgical treatment. The quoted incidence of overall urological complications for CIC bladder drainage over 18 years was 27%, compared to 44% and 53% for SPC and UC, respectively [22]. However, the reported frequencies of complications according to bladder management strategies are heterogeneous. Other studies have reported lower (17–20%) [23, 24] or higher (29–45%) [25, 26] CIC complication rates. The discrepancies are related to variation in the study populations and design, utilized intermittent catheterization type, reported complications, outcome measures and follow-up duration between the studies.

In the present model, we assumed that 60% of SCI individuals would maintain CIC over lifetime, which is in accordance with other reports [27]. Other authors documented lower compliance rate with CIC over the long-term. These studies reported about 20% compliance rate at 30 and 45 years follow-up [28, 29]. On the contrary, approximately two-third of SCI participants would maintain indwelling SPC or UC over the long run [27, 28]. In spite of established efficacy of CIC, the greater rate of changing to another assisted bladder management strategy has a strong impact on their overall elevated cost. Our cost-utility analysis showed that increased cost-effectiveness of CIC versus SPC or UC was due to the higher rate of catheter associated complications in both SPC and UC, resulting in increased costs and therefore a higher ICUR of CIC versus comparators. This might also explain why the overall cost of CIC were almost comparable to other bladder management options.

The present study revealed a rather high average additional life expectancy of 25.15 years and 20.91 gained LYG when using CIC in SCI cohort with a starting age of 40 years. This relatively high average life expectancy might be explained by the absence of disease specific mortality in this model, which is a potential limitation of this study. Given that the data used for the estimations are built upon combined hospital and community settings, the findings are similar to the actual life expectancy found for SCI population [11].

**Table 4.** Base-case scenario (lifetime horizon).

| | Cost | Δ Cost | QALY | Δ QALY | LGY | Δ LGY | |
|---|---|---|---|---|---|---|---|
| CIC | $ 29161 | | 20.91 | | 25.15 | | Dominant |
| SPC | $ 29491 | −$330 | 19.14 | 1.77 | 23.43 | 1.72 | |
| UC | $ 31657 | −$2496 | 18.95 | 1.96 | 22.15 | 3 | |

*CIC* Clean intermittent catheterization, *SPC* Suprapubic catheter, *UC* Urethral indwelling catheter, *QALYs* Quality-Adjusted Life Years, *LGY* Life year gained.

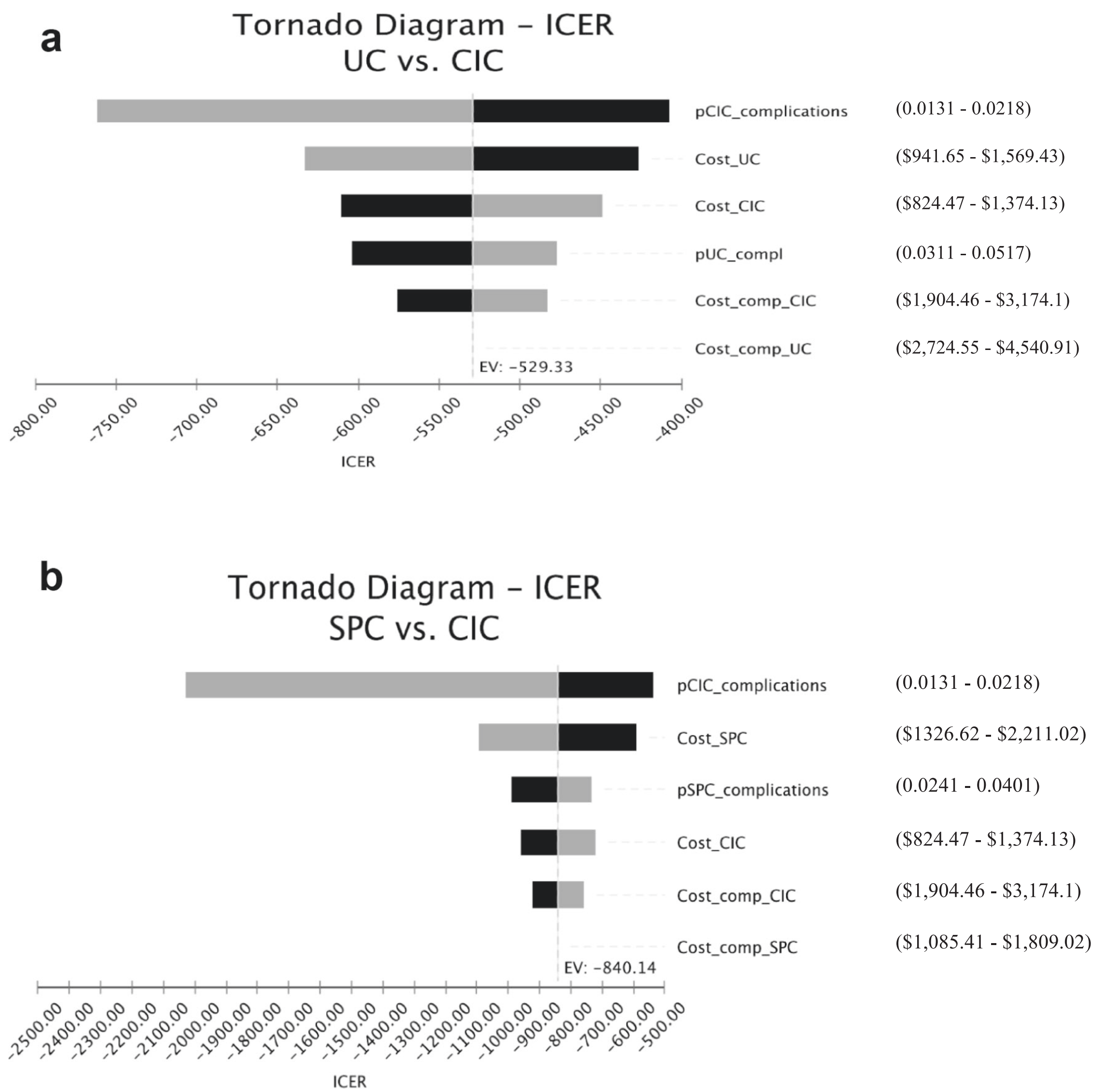


**Fig. 2 Schematic Tornado diagram, One-Way sensitivity analyses. a** Schematic Tornado diagram, One-Way sensitivity analyses: Intermittent Catheters Versus Indwelling Urethral Catheters. The ICUR calculations were based on a willingness to pay corresponding to the Base-Case ICUR, that is, $50 K/QALY. CIC Clean intermittent catheter, Compl Complications, UC Urethral catheterization. **b** Schematic Tornado diagram, One-Way sensitivity analyses: Intermittent Catheters Versus Indwelling Suprapubic Catheters. The ICUR calculations were based on a willingness to pay corresponding to the Base-Case ICUR, that is, $50 K/QALY. CIC Clean intermittent catheter, Compl Complications, SPC Suprapubic catheterization.

Several studies have investigated the economics of the CIC treatment for NLUTD. Welk et al analyzed the cost-effectiveness of two different types of intermittent catheterization (hydrophilic coated vs uncoated) from a Canadian societal perspective including direct and indirect costs; their base-case result identified a lifetime expenditure of $72,622 for 5.37 QALYs by using uncoated catheters compared to $120,639 for 6.09 QALYs with hydrophilic catheters [30]. In another study, the average lifetime treatment cost for CIC was £59,000 for 6.58 QALYs for the SCI population utilizing two different single-use intermittent catheter designs from a UK perspective. The model further predicted an additional 22.5 years when using CIC (uncoated catheters), which increases to 23.9 years with HC catheters [15]. Similar to the results presented in previous cost-effectiveness studies [13, 15, 30], CIC using hydrophilic catheters was perceived as a cost-effective treatment strategy over a lifetime perspective. Despite the weak correlation between long-term compliance and catheter type/design [27], it is often recommended that SCI participant should be offered HC catheters when possible, given a lower risk of urinary tract infection and urethral complications and improved bladder related QoL [4].

Multiple-use uncoated PVC-catheters are still widely used, which may be due to the fact that initial cost and reimbursement is in favor of PVC catheters rather than the HC design, or possibly patient preference. The evidence for endorsing the use of uncoated PVC-catheters (multiple-use) remains inconclusive. If the multiple-use CIC scenario was applied in our analysis, the results would have been even more favorable for CIC approach. This highlights the need for more RCTs comparing different intermittent catheterization designs/materials.

As with any cost-effectiveness model, the limited availability of data and inherent hypothetical design were the most obvious limiting factors, therefore results are entirely dependent on the quality of available evidence. A potential weakness of the current study was the lack of RCTs evaluating different bladder management techniques from clinical and user perspective. Furthermore, the reported data concerning the rate of associated complications and long-term compliance are even more diverse. Therefore, we have limited our findings to the accuracy of our assumptions. While various types and designs of catheters are available, the model only examined the most frequently used catheters in Canada. Another potential weakness is that estimates on the transition rate between catheter modalities over time was scarce in the literature and were the largest assumptions in the model, thereby we are limited by the accuracy of our speculations. Additionally, the variability among catheter-associated complication rates are significant determinants of the outcome in this model. Therefore, the results of this economic analysis are greatly driven by the frequency of catheter-associated complications and the transition rate between different bladder management strategies over long-term. Precise data regarding less frequent catheter-associated complications was not available (e.g., difficulty to do CIC, urethral trauma requiring an indwelling catheter, and catheter blockage). Obviously, catheter-related problems could involve emergency visits which are costly. Finally, additional analysis of SCI subpopulations was not feasible due to limited availability of data on female SCI population, coping and level of neurological impairment and bladder management directed by caregivers.

This economic analysis demonstrates that CIC is a dominant treatment strategy (offering increased benefits at lower cost) to manage SCI individuals with NLUTD compared to indwelling UC or SPC over lifetime horizon, from a publicly funded health care system perspective. Despite high ongoing cost of using HCICs; it was perceived as a cost-effective technology. That being said, SCI individuals with chronic retention often switch to these catheters over time. This remains an ongoing debate for health care providers and patients alike. Future research should strive to address the implications of various bladder care practices among different SCI subpopulations.

## DATA AVAILABILITY

Datasets analyzed during the current study are publicly available and cited in the reference section. Makov Model used this study are available from the corresponding author [LC] on request.

## REFERENCES

1. Ku JH. The management of neurogenic bladder and quality of life in spinal cord injury. BJU Int. 2006;98:739–45.
2. Krueger H, Noonan V, Trenaman L, Joshi P, Rivers C. The economic burden of traumatic spinal cord injury in Canada. Chronic Dis injuries Can. 2013;33:113–22.
3. Feifer A, Corcos J. Contemporary role of suprapubic cystostomy in treatment of neuropathic bladder dysfunction in spinal cord injured patients. Neurourol Urodyn. 2008;27:475–9.
4. Kavanagh A, Baverstock R, Campeau L, Carlson K, Cox A, Hickling D, et al. Canadian urological association guideline: diagnosis, management, and surveillance of neurogenic lower urinary tract dysfunction–full text. Can Urol Assoc J. 2019;13:E157.
5. White BAB, Dea N, Street JT, Cheng CL, Rivers CS, Attabib N, et al. The Economic burden of urinary tract infection and pressure ulceration in acute traumatic spinal cord injury admissions: evidence for comparative economics and decision analytics from a matched case-control study. J Neurotrauma. 2017;34:2892–900.
6. Krebs J, Wöllner J, Pannek J. Risk factors for symptomatic urinary tract infections in individuals with chronic neurogenic lower urinary tract dysfunction. Spinal Cord. 2016;54:682–6.
7. Katsumi H, Kalisvaart J, Ronningen L, Hovey R. Urethral versus suprapubic catheter: choosing the best bladder management for male spinal cord injury patients with indwelling catheters. Spinal cord. 2010;48:325.
8. Krebs J, Wöllner J, Pannek J. Urethral strictures in men with neurogenic lower urinary tract dysfunction using intermittent catheterization for bladder evacuation. Spinal cord. 2015;53:310.
9. Vekeman F, Yameogo N-D, Lefebvre P, Bailey RA, McKenzie RS, Piech CT. Healthcare costs associated with nephrology care in pre-dialysis chronic kidney disease patients. J Med Econ. 2010;13:673–80.
10. Ku JH, Choi WJ, Lee KY, Jung TY, Lee JK, Park WH, et al. Complications of the upper urinary tract in patients with spinal cord injury: a long-term follow-up study. Urol Res. 2005;33:435–9.
11. Center NSCIS. National Spinal Cord Injury Statistical Center Annual Statistical Report. Birmingham, AL, University of Alabama at Birmingham. 2019.
12. Groen J, Pannek J, Diaz DC, Del Popolo G, Gross T, Hamid R, et al. Summary of European Association of Urology (EAU) guidelines on neuro-urology. Eur Urol. 2016;69:324–33.
13. Bermingham SL, Hodgkinson S, Wright S, Hayter E, Spinks J, Pellowe C. Intermittent self catheterisation with hydrophilic, gel reservoir, and non-coated catheters: a systematic review and cost effectiveness analysis. BMJ. 2013;346:e8639.
14. Ontario HQ. Intermittent Catheters for chronic urinary retention: A health technology assessment. Ont Health Technol Assess Ser. 2019;19:1.
15. Clark JF, Mealing SJ, Scott DA, Vogel LC, Krassioukov A, Spinelli M, et al. A cost-effectiveness analysis of long-term intermittent catheterisation with hydrophilic and uncoated catheters. Spinal Cord. 2015. https://doi.org/10.1038/sc.2015.117.
16. Régie de l'assurance maladie du Québec: Manuel des médecins spécialistes. http://www.ramq.gouv.qc.ca/fr/professionnels/medecinsspecialistes/manuels/Pages/remuneration-acte.aspx (2019). Accessed June 2019.
17. Gouvernement du Québec: Ministère de la Santé et des Services sociaux. www.informa.msss.gouv.qc.ca (2015). Accessed June 2019.
18. SCI supply inc.: https://www.scisupply.ca/intermittent-catheters (2019). Accessed May 2019.
19. CathetersPLUS™: https://www.cathetersplus.com/ (2019). Accessed May 2019.
20. Laupacis A, Feeny D, Detsky AS, Tugwell PX. How attractive does a new technology have to be to warrant adoption and utilization? Tentative guidelines for using clinical and economic evaluations. CMAJ: Can Med Assoc J. 1992;146:473.
21. Griffiths E, Vadlamudi NK. Cadth's $50,000 cost-effectiveness threshold: Fact or fiction? Value Health. 2016;19:A488–A9.
22. Weld KJ, DMOCHOWSKI RR. Effect of bladder management on urological complications in spinal cord injured patients. J Urol. 2000;163:768–72.
23. Bennett CJ, Young MN, Adkins RH, Diaz F. Comparison of bladder management complication outcomes in female spinal cord injury patients. J Urol. 1995;153:1458–60.
24. Wyndaele J-J, Maes D. Clean intermittent self-catheterization: A 12-year followup. J Urol. 1990;143:906–8.
25. Gao Y, Danforth T, Ginsberg DA. Urologic management and complications in spinal cord injury patients: A 40-to 50-year follow-up study. Urology 2017;104:52–8.
26. Chai T, Chung A, Belville W, Faerber G. Compliance and complications of clean intermittent catheterization in the spinal cord injured patient. Spinal Cord. 1995;33:161–3.
27. Afsar S, Yemisci O, Cosar S, Cetin N. Compliance with clean intermittent catheterization in spinal cord injury patients: a long-term follow-up study. Spinal Cord. 2013;51:645.
28. Cameron AP, Wallner LP, Tate DG, Sarma AV, Rodriguez GM, Clemens JQ. Bladder management after spinal cord injury in the United States 1972 to 2005. J Urol. 2010;184:213–7.
29. Krebs J, Wöllner J, Pannek J. Bladder management in individuals with chronic neurogenic lower urinary tract dysfunction. Spinal Cord. 2016;54:609–13.
30. Welk B, Isaranuwatchai W, Krassioukov A, Husted Torp L, Elterman D. Cost-effectiveness of hydrophilic-coated intermittent catheters compared with uncoated catheters in Canada: a public payer perspective. J Med Econ. 2018;21:639–48.

## AUTHOR CONTRIBUTIONS

SS was responsible for conception and design, data acquisition, data analysis, manuscript drafting, and revision. SN was responsible for data acquisition and interpretation, data analysis, and manuscript drafting. AD was responsible for conception and design, data management, manuscript revision, and supervision. RB participated in data analysis and management, manuscript revision, and supervision. JC participated in data analysis and management, manuscript revision, and supervision. LC was responsible for conception and design, data management, manuscript revision, and supervision.

## COMPETING INTERESTS

The authors declare no competing interests.

## ETHICAL APPROVAL

This study does not require Research Ethics Board Review as it is a health economic model analysis involving information freely available in the public domain, and no intervention is staged by the researcher or direct interaction with the individuals or groups.

## ADDITIONAL INFORMATION

**Supplementary information** The online version contains supplementary material available at https://doi.org/10.1038/s41393-023-00883-5.

**Correspondence** and requests for materials should be addressed to Lysanne Campeau.

**Reprints and permission information** is available at http://www.nature.com/reprints

**Publisher's note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.