Postoperative Urinary Retention: Risk Factors, Bladder Filling Rate and Time to Catheterization: An Observational Study as Part of a Randomized Controlled Trial

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Abstract

Background

Knowledge of risk factors for postoperative urinary retention may guide appropriate and timely urinary catheterization. We aimed to determine independent risk factors for postoperative urinary catheterization in general surgical patients. In addition, we calculated bladder filling rate and assessed the time to spontaneous voiding or catheterization. We used the patients previously determined individual maximum bladder capacity as threshold for urinary catheterization.

Methods

Risk factors for urinary catheterization were prospectively determined in 936 general surgical patients. Patients were at least 18 years of age and operated under general or spinal anesthesia without the need for an indwelling urinary catheter. Patients measured their maximum bladder capacity preoperatively at home, by voiding in a calibrated bowl after a strong urge that could no longer be ignored. Postoperatively, bladder volumes were assessed hourly with ultrasound. When patients reached their maximum bladder capacity and were unable to void, they were catheterized by the nursing staff. Bladder filling rate and time to catheterization were determined.

Results

Spinal anesthesia was the main independent modifiable risk factor for urinary catheterization (hyperbaric bupivacaine, relative risk 8.1, articaine RR 3.1). Unmodifiable risk factors were a maximum bladder capacity <500mL (RR 6.7), duration of surgery ≥60 minutes (RR 5.5), first scanned bladder volume at the Post Anesthesia Care Unit ≥250mL (RR 2.1), and age ≥60 year (RR 2.0). Urine production varied from 100 to 200mL/hour. Catheterization or spontaneous voiding took place approximately 4 hours postoperatively.

Conclusion

Spinal anesthesia, longer surgery time and older age are the main risk factors for urinary retention catheterization. Awareness of these risk factors, regularly bladder volume scanning (at least every 3 hours) and using the individual maximum bladder capacity as volume threshold for urinary catheterization may avoid unnecessary urinary catheterization and will prevent bladder overdistention with the attendant risk of lower urinary tract injury.

Dutch Central Committee for Human Studies registered trial database: NL 21058.099.07.

Current Controlled Trials database: Preventing Bladder Catheterization after an Operation under General or Spinal Anesthesia by Using the Patient's Own Maximum Bladder Capacity as a Limit for Maximum Bladder Volume. ISRCTN97786497 (https://doi.org/10.1186/ISRCTN97786497). Registered 18 July 2011 - Retrospectively registered. The original study started May 19th, 2008, and ended April 30th, 2009, when the last patient was included.
Introduction

Post-Operative Urinary Retention (POUR) followed by urinary catheterization is a well-known and frequent complication after surgery under general or spinal anesthesia.\textsuperscript{1-4} Since the introduction of routine bladder ultrasounds, the definition of 'POUR necessitating urinary catheterization' has gradually changed, in that it now relates more to a volume limit (=scanned bladder volume in mL) rather than a time limit (=patient must have voided within a certain time period). Reported bladder volume limits in the literature vary from 400mL to 600mL.\textsuperscript{5,6} We have previously demonstrated a large interindividual variation in maximum bladder volume, independent of age, gender and body mass index (BMI).\textsuperscript{7} The beneficial effect of assessing and evaluating the individual maximum bladder capacity (MBC) as a volume/capacity limit for POUR to prevent unnecessary urinary catheterization, was established in a large-scale randomized controlled trial (RCT) (Risk Reduction 0.73, 95%CI 0.55 to 0.96; p=0.025).\textsuperscript{1}

Even though urinary catheterization is the go-to solution to prevent bladder overdistention, it is an embarrassing procedure that most patients would like to avoid. It can cause urethral trauma, discomfort and urinary tract infection. On the other hand, bladder overdistention can cause temporary or even permanent damage to the lower urinary tract (LUT).\textsuperscript{4,7,8} LUT dysfunction can vary from mild (frequent voiding) to moderate (recurrent urinary tract infections) and can lead to severe adverse events (permanent bladder damage ending in life-long self-catheterization).\textsuperscript{9-11} It is unknown how many patients are affected annually by complications of urinary catheterization or long-term bladder overdistention (> 3 hours). Moreover, it is a clinical reality that POUR is handled by the nursing staff, out of sight from the anesthesiologists and surgeons. These facts could explain the lack of urgency and why preventing urinary catheterization and bladder overdistention is not highly ranked on the priority lists of surgeons and anesthesiologists. Executive prevention and management of POUR seems to vary between hospitals and/or countries. Thus, anesthesiologists might feel obliged to take responsibility, whereas POUR may be considered a surgical complication as well. Currently, The American Society of Anesthesiologists (ASA) and the Dutch Society of Anesthesiologists (NVA) have no practice guidelines for the management of POUR.

Primary aim of the study

To identify risk factors for urinary catheterization in a controlled setting. To this end, we used the data from a previous RCT and considered the individual MBC (rather than a fixed bladder volume limit) as the threshold for urinary catheterization.\textsuperscript{1} The strength of the risk factors may vary based on how the need for catheterization is defined. In addition to the identification of risk factors, we calculated the bladder filling rate and analyzed the time to spontaneous voiding or catheterization. The results of these analyses may help health care providers in their decision making and, as such, prevent unnecessary urinary catheterizations and potential adverse effects on the LUT.

Methods
Type of study

This is an observational study analyzing risk factors for urinary catheterization as part of an RCT.¹

Participating patients

All patients enrolled in the RCT provided written informed consent, including permission to use data for additional analysis. Included patients were at least 18 years of age and scheduled to undergo a surgical intervention under general or spinal anesthesia. Peroperatively, there was no anticipated need for an indwelling urinary catheter. Patients were informed and asked to participate during their visit at the pre-assessment anesthesia clinic (PAC). After approval and informed consent, patients were requested to go to the restroom to assess the residual bladder volume by ultrasound. At home, the MBC was measured by postponing voiding as long as possible. When a strong urge occurred that could no longer be ignored, patients were encouraged to void in a calibrated bowl (supplied by the hospital) to measure their maximum voided volume; this procedure was repeated three times at different moments during the week. The individual MBC was calculated as the largest voided volume at home minus the residual volume measured at the PAC. All data were recorded in the database.

Postoperatively, the bladder of each included patient was scanned every hour until the MBC was reached, at which point the patient was asked to void. If spontaneous voiding was not possible, urinary catheterization was performed by the nursing staff. A research assistant performed the bladder scans using ultrasound (The BladderScan BVI 9400, Verathon, Bothell, WA, USA). The original aim was to evaluate the effectiveness of using the individual MBC rather than a fixed bladder volume limit of 500mL as an indicator of bladder overdistention, to prevent unnecessary urinary catheterization.

Outcome

The pre-planned secondary outcome consisted of analyzing risk factors for urinary catheterization, based on the data from the RCT.¹ Only the data of the MBC group was used for analysis, as they were considered new, implementing a revised definition for POUR to evaluate the need for urinary catheterization. The MBC group consisted of 893 patients who were analyzed in the original RCT for IPSS/QoL (international Prostate Symptoms Score/Quality of Life score) (figure 1), and 43 patients with missing data who were still eligible for risk factor analysis (total 936 patients). Pre- and perioperative patient and procedural characteristics, prospectively collected in the original RCT, were considered as potential risk factors/indicators for the need for urinary catheterization.⁴,⁸,¹⁰ Potential risk factors were divided in unmodifiable, not influenceable by anesthesiologists and surgeons, and modifiable, i.e. under direct control of anesthesiologists (Table 1); the relative risk (RR) was determined for each risk factor. Duration of surgery is not under direct control of anesthesiologists and is therefore considered not modifiable. For developing possible prediction models, the rate of bladder filling (mL/hour) was calculated and time to catheterization or spontaneous voiding was assessed.

Table 1. Unmodifiable and modifiable risk factors
Demographic variables, such as gender and age
BMI, Maximum Bladder Capacity, Co-Morbidity (Hypertension and Diabetes)
Drugs used, such as beta blockers, benzodiazepines and anti-depressive/anti-psychotic drugs.

Premedication with benzodiazepines and/or NSAID’s,
Bladder volume/residual volume before start of surgery, time since last voiding.

Type of Surgery, divided in Head-Neck, Thorax/Back/Breast, Lower Abdominal or Lower Extremities, Duration of Surgery.

Type of Anesthesia; General or Spinal (divided in short-acting articaine and long-acting bupivacaine), cardiovascular drugs such as atropine, ephedrine and/or phenylephrine, opioids.

Bladder volume after arriving at PACU, Total sum of opioids needed, Drugs given such as cardiovascular therapeutics, opioids, anti-emetics, Total volume infused or taken.

Statistical analysis

Categorical data are presented as counts and percentages. Continuous variables are presented as mean with SD or medians with interquartile ranges, depending on normality of the data. For each potential risk factor, differences in the incidence of postoperative urinary catheterization were estimated using a univariate log-binominal regression model. In case of failure to converge, a “modified Poisson” approach was applied with robust error variances to estimate crude relative risks and confidence intervals. After univariate analysis of all potential risk factors, those with a P-value <0.10 were included in the initial multivariable model. A backward elimination strategy was used to achieve the most suitable model to estimate the adjusted relative risks with the final multivariable model, only including risk factors associated with postoperative urinary catheterization at a level of P <0.05. In this regard, first order interactions were also taken into consideration. A two-tailed P-value <0.05 was considered to indicate statistical significance. All analyses were performed using SAS software, version 9.4 (SAS institute, Inc, Cary, NC).

Results

A total of 936 surgical patients with complete data on maximum bladder volume entered the study. The average preoperative determined MBC was 611mL (SD ±209mL, range 150 to 1400mL). The incidence of urinary catheterization was 9.1% (85/936) (Table 2).

Table 2. Demographic and clinical characteristics of the study patients
| **MBC group** | N = 936 |
|---------------|---------|
| **Patient data** | |
| Women, No. (%) | 493 (53) |
| Age, mean (SD), y | 47.9 (15) |
| Height, mean (SD), cm | 176 (10) |
| Weight, mean (SD), kg | 81.4 (17) |
| BMI, mean (SD), kg/m² | 26.3 (5) |
| **Type of Surgery, No. (%)** | |
| Head/Neck | 209 (22) |
| Thoracic/Breast | 77 (8) |
| Spine | 33 (4) |
| Abdominal | 273 (29) |
| Extremities | 344 (37) |
| **Study Data** | |
| MBC, mean (SD), ml | 611 (209) |
| Residual volume, mean (SD), ml | 33 (53) |
| Voided before surgery, No. (%) | 877 (94) |
| Time before surgery, mean (SD), min | 59 (48) |
| Volume at Holding, mean (SD), ml | 52 (81) |
| General Anesthesia, No. (%) | 639 (68) |
| Spinal Anesthesia, No. (%) | 297 (32) |
| Articaine, No. (%) | 235 (79) |
| Bupivacaine, No. (%) | 62 (21) |
| Total volume infused, mean (SD), ml | 1,492 (647) |
| Procedure time, mean (SD), minutes | 61 (40) |

BMI – Body Mass Index, MBC – Maximum Bladder Capacity, SD – Standard Deviation

**UNIVARIATE RISK FACTORS FOR URINARY CATHETERIZATION**

*Modifiable risk factors*

Figure A shows all identified (un)modifiable risk factors potentially associated with urinary catheterization (p <0.10). Spinal anesthesia was the strongest modifiable risk factor for urinary catheterization. Coupled to spinal anesthesia, and therefore not displayed in Figure A-C, was the regression of the sensory block. If the sensory block was higher than dermatome T12, voiding was difficult and 69% of these patients had to be catheterized (RR 12.8, 95%CI 8.4 to 18.3; p<0.0001). When the sensory block had regressed below dermatome S3, the incidence was 5.7% (RR 0.8, 95%CI 0.4 to 1.6; p=0.49). A preoperative bladder volume of 150mL or more represented another modifiable risk factor (RR≥150mL 2.4, 95%CI 1.6 to 3.5; p<0.02). The total infused volume exceeding 1 liter was not a significant risk factor for urinary catheterization (RR 0.7, 95%CI 0.4 to 1.1, p=0.09). Other non-significant risk factors included drugs used perioperatively, e.g. the opioid piritramide (i.v. or s.c.) (RR 1.0, 95%CI 0.7 to 1.6; p=0.91), ephedrine (RR 1.3, 95%CI 0.8 to 2.0,
P=0.33) and atropine (RR 1.2, 95%CI 0.7-1.9, p=0.5). For phenylephrine the numbers were too small to analyze.

**Unmodifiable risk factors**

A smaller MBC was associated with an increased incidence of urinary catheterization. Of the 300 patients with an MBC <500mL, 14% was catheterized as compared to 9% of 398 patients with an MBC between 500 and 800mL and 2% of 199 patients with an MBC ≥800mL (MBC <500mL RR 7.0, 95%CI 2.5 to 19.1; p<0.001). In addition, age ≥60 years increased the risk of catheterization (RR 3.3, 95%CI 2.2 to 4.9; p<0.0001), and, when considering the univariate analysis, a higher IPSS was a risk factor as well. In patients with ‘severe’ symptoms (IPSS 20-35 points) the incidence of urinary catheterization was 22% (RR 2.7, 95%CI 1.5 to 5.2, p=0.002).

The strongest unmodifiable risk factor ‘related to surgery’ was the duration of surgery (RR_{30-60} 4.5, 95%CI 1.8 to 11.3, RR_{>60} 5.1, 95%CI 2.1 to 12.8; p<0.001). For the location of surgery, comparing surgeries on head/neck/thoracic (general anesthesia) with those on the abdomen or extremities (general or spinal anesthesia), the incidence increased from 4.9 to 11.8 and 10.2%, respectively (RR_{abdomen} 2.4, 95%CI 1.3 to 4.4; p<0.004 and RR_{lower extremity} 2.1, 95%CI 1.1 to 3.7; p=0.012). Another unmodifiable risk factor was bladder volume ≥250mL on the first postoperative scan at the PACU (incidence 18.6% compared to 6.3% <250mL)(RR 3.0, 95%CI 1.9 to 4.4; p<0.001).

Interestingly, ‘having no urge to void’ when the MBC was reached turned out to be an unmodifiable risk factor as well. Of the 84 patients who were catheterized, 60 patients had no urge to void (71%) (RR 4.8, 95%CI 3.1 to 5.9; p<0.001). The influences of gender (RR 0.8, 95%CI 0.5 to 1.2, p=0.31) and existing preoperative hypertension (RR 1.6, 95%CI 1.0 to 2.5, p=0.07) did not reach statistical significance in any of the analyses. Anti-depressant drugs were used by 58 patients (6%) of which 18% was catheterized (RR 2.8; p< 0.001), and 61 patients used diazepam (6.5%) of which 23% was catheterized (RR 1.8; p=0.02). For diabetes, the numbers were too small to analyze (26 patients =3.1%).

**FULL MULTIVARIABLE ANALYSIS**

Figure B shows the full multivariable analysis for urinary catheterization in the MBC group and includes all potential risk factors with a level of p<0.10 (as determined by the univariate analysis). Using the backward elimination strategy, location of surgery and ‘severe’ IPSS were not identified as independent risk factors in the multivariable analysis.

**FINAL MULTIVARIABLE ANALYSIS**

The final multivariable model is displayed in Figure C. Spinal anesthesia was the main modifiable risk factor with RR values of 8.1 and 3.1 for hyperbaric bupivacaine and articaine, respectively. The unmodifiable risk factors MBC (RR 6.7), duration of surgery (RR 5.5), first scan at PACU ≥250mL (RR 2.1) and age ≥60 (RR 2.0) were identified as independent risk factors for catheterization.
TIME OF VOIDING or CATHETERIZATION and RATE of BLADDER FILLING

Table 3 displays the elapsed time from the start of anesthesia to when patients voided or were catheterized. The rate of bladder filling over this period was estimated by subtracting the preoperative scanned bladder volume from the final scanned bladder volume before spontaneous voiding or catheterization. Both for general and spinal anesthesia, spontaneous voiding occurred after 280min (4.5hrs). The scanned bladder volume amounted to approximately 450mL with a filling rate of 100mL/u. Catheterization after general anesthesia was performed significantly later than after spinal anesthesia (352 ±157min versus 205 ±74min, p<0.001). Spinal anesthesia patients who were catheterized (203 ±94 mL/hour, p=0.005) produced almost twice the amount of urine as those who voided spontaneously (107 ±63mL/hour).

Table 3. Time to catheterization/voiding after general or spinal anesthesia, scanned bladder volumes, and bladder filling rates.

|                  | N   | MEAN  | STANDARD DEVIATION | MINIMUM | MAXIMUM |
|------------------|-----|-------|--------------------|---------|---------|
| **GENERAL ANESTHESIA** |     |       |                    |         |         |
| Spontaneous      |     |       |                    |         |         |
| Time (minutes)   | 580 | 282#  | ±117               | 70      | 808     |
| Scan volume (mL) | 595 | 412   | ±206               | 0       | 1000    |
| Rate (mL/hour)   | 569 | 100   | ±66                | 0       | 388     |
| Catheter         |     |       |                    |         |         |
| Time (minutes)   | 26  | 352** | ±157               | 178     | 710     |
| Scan volume (mL) | 31  | 602   | ±216               | 298     | 1000    |
| Rate (mL/hour)   | 25  | 137   | ±84                | 32      | 317     |
| **SPINAL ANESTHESIA** |   |       |                     |         |         |
| Spontaneous      |     |       |                    |         |         |
| Time (minutes)   | 238 | 273^  | ±82                | 99      | 712     |
| Scan volume (mL) | 238 | 452   | ±224               | 49      | 999     |
| Rate (mL/hour)   | 234 | 107§  | ±63                | 11      | 379     |
| Catheter         |     |       |                    |         |         |
| Time (minutes)   | 44  | 205^* | ±74                | 99      | 397     |
| Scan volume (mL) | 52  | 626   | ±179               | 330     | 999     |
| Rate (mL/hour)   | 43  | 203§  | ±94                | 94      | 469     |

N, with missing data
Time = time to catheterization or voiding
Scan volume = scanned bladder volume before voiding or catheterization
Rate = bladder filling rate from start of anesthesia till voiding or catheterization

# General anesthesia spontaneous (282min) versus catheterization (352min), p=0.032
^ Spinal anesthesia spontaneous (273min) versus catheterization (205min), p< 0.001
* Spinal anesthesia (205min) versus general anesthesia (352min) with catheterization, p<0.001
& Spinal anesthesia bladder filling rate, catheterization (203mL/hour) versus spontaneous (107mL/hour), p=0.005

Discussion
To the best of our knowledge, this is the first study that uses the individual maximum bladder capacity (MBC) to estimate the risk of urinary catheterization after general or spinal anesthesia. In accordance with the literature\textsuperscript{1,2,8}, the most important \textit{modifiable} risk factor for postoperative urinary catheterization was spinal anesthesia. The risk to be catheterized after hyperbaric bupivacaine and articaine was eight times and three times higher, respectively, as compared to general anesthesia. Available literature comparing general anesthesia with spinal anesthesia and its association with urinary catheterization is limited.\textsuperscript{13-16} More specifically, there are no recent studies regarding POUR or urinary catheterization after general anesthesia, let alone comparing their incidence with spinal anesthesia. Most studies about postoperative urinary catheterization are performed in orthopedic patients after spinal anesthesia. During spinal anesthesia, the local anesthetics block the nerves necessary for spontaneous micturition (S2-S4). The spinal block has to regress below dermatome S3 before voluntary control over the external urethral sphincter returns. By then most patients are already able to walk. For bupivacaine, the inability to void may last up to eight hours.\textsuperscript{14} Therefore, if one wishes to reduce the risk for postoperative urinary catheterization (e.g. in day case surgery), it may be justified to change the anesthesia technique. For example, consider using a short-acting local anesthetic for spinal anesthesia, or if possible, use a regional technique (e.g. a femoral or popliteal nerve block), or choose general anesthesia.

Our analysis revealed that an MBC of less than 500mL was an \textit{unmodifiable} risk factor for urinary catheterization (RR 6.7). Bjerregaard et al (2015), studying orthopedic patients after fast-track hip or knee surgery, compared a threshold for POUR of 800 versus 500mL. They found an incidence of 13.4\% versus 32.2\%. They concluded that a threshold of 800mL can be set safely, without increasing urological complications.\textsuperscript{18} Of note, their patient group consisted of ‘older’ patients, with unknown MBC and voiding history. A threshold of 800mL may lead to complications in patients with lower MBCs (e.g. <500mL) or in patients with pre-existing LUT complaints. In general, a strict POUR protocol should be implemented to prevent bladder overdistention. When the MBC is known, the need for urinary catheterization can be precisely determined and this may prevent unnecessary application of the procedure.

Duration of surgery constituted a strong \textit{unmodifiable} risk factor (RR 5.1) in all analyses, consistent with similar studies.\textsuperscript{19-21} This could be due to a higher cumulative dose of anesthetic drugs, longer unnoticed bladder filling, or, when using long-acting local anesthetics for spinal anesthetics, an inability to void persisting for more than eight hours. Obtaining shorter surgery times can help to lower the incidence of urinary catheterization.

Not voiding before the start of surgery is considered a \textit{modifiable} risk factor for POUR followed by urinary catheterization. In the univariate analysis a \textit{preoperative} bladder volume $\geq 150$mL was a significant risk factor, but this significance was not sustained in the final multivariable model. Joelsson-Alm found in her prospective study on bladder distention in orthopedic surgery, that a higher preoperative bladder volume is a risk factor for POUR and urinary catheterization.\textsuperscript{22} She concluded that encouraging patients to void before leaving for operating theatre does not necessarily mean an empty bladder at the start of surgery. Our results confirmed that observation. Patients were at risk for large bladder volumes postoperatively, if they already had a considerable bladder filling at the start of surgery. Indeed, a postoperative bladder
volume $\geq 250\text{mL}$ after the first scan at the PACU was an important *unmodifiable* risk factor.\textsuperscript{23} Measuring bladder volumes shortly before surgery in the holding area and urging patients to void if needed, can thus contribute to preventing large postoperative bladder volumes.\textsuperscript{25} Interestingly, the absence of urge does not mean an empty bladder; of the patients who felt no urge to void but reached POUR, 71\% needed to be catheterized.

In patients $\geq 60$ years of age the incidence of urinary catheterization amounted to 18.5\%, compared to just 5.7\% in subjects <60 years. Increasing age is a well-known *unmodifiable* risk factor for postoperative urinary catheterization (RR 2.0).\textsuperscript{1,4-26,28} This could be due to higher IPSS scores in older patients. Or possibly the different types of surgery performed in more senior patients (e.g. more surgery on lower abdomen or lower extremities, longer operation times, use of long-acting spinal anesthesia, and the use of ephedrine/atropine). The impact of age $\geq 60$ was evident in the univariate analysis but did not reach significance in the final multivariable analysis (Figures A and C).

The *modifiable* risk factor ‘volume infused and taken orally’ volume exceeding one liter appeared to have a small risk reducing effect, but this was not significant (RR 0.7, p <0.09). Patients had received on average 1.5 liter of fluid at the time of voiding or catheterization. In the literature, the amount of fluids infused was considered a *modifiable* risk factor for urinary catheterization.\textsuperscript{23-25} More recent studies confirmed that the amount of fluids given or taken perioperatively is not a significant risk factor for urinary catheterization.\textsuperscript{1,16,21}

Possible *modifiable* risk factors for catheterization are drugs given peroperatively.\textsuperscript{2,3,28} Opioids can have a dual effect on voiding; direct- by partially inhibiting the parasympathetic nerves that innervate the bladder, and indirect - by decreasing the awareness of a full bladder and the sensation of urge. Our results could not confirm that piritramide had an effect on the incidence of urinary catheterization (RR 1.0, p=0.91). We did not register pain scores as they were titrated below a VAS of four (Visual Analogue Scale), following protocol. Cardiovascular drugs may also affect bladder function through interactions with the sympathetic and parasympathetic nerve system. For atropine and ephedrine this effect was not significant. However, preoperative use of anti-depressant drugs or diazepam did have a significant effect on POUR, although the numbers were relatively small. These patients may need to be monitored more closely.

To estimate the rate of bladder filling after surgery, the time from the start of anesthesia to catheterization or spontaneous voiding was calculated (Table 3). A similar approach has been applied previously by Kreutziger et al.\textsuperscript{26} They studied time to voiding in 86 patients after spinal anesthesia. On average, catheterization was performed after 200 minutes and voiding occurred after 270 minutes (3.5 hrs.), comparable with our findings for spinal anesthesia. In our study catheterization after general anesthesia was performed later, after almost 6hrs. This difference in time to catheterization between spinal and general anesthesia can possibly be explained by a difference in bladder filling rate. In patients who were catheterized the bladder filling rate following spinal anesthesia was almost 70mL/hour higher than during general anesthesia (203mL/h versus 137mL/h). Bladder filling rate does not only depend on the anesthesia technique, but likely on factors such as age, amount of fluids infused, antidiuretic hormone
production, blood pressure, and is probably not linear. More targeted studies are necessary to confirm or refute our results. Yet, considering urine production, and time to catheterization, it is highly recommendable to scan the bladder within 3 hours (180 minutes) after the end of surgery to prevent bladder overdistention. When assessing bladder filling state within this timeframe, some patients may have already reached their MBC, with bladder volumes varying from 300 to 540mL. This is still a safe margin for urinary catheterization if the MBC is unknown; the procedure may be performed a bit prematurely, but, more importantly, not too late. A full bladder extended beyond its maximum capacity for 2 to 3 hours can damage the detrusor muscle and should therefore be avoided at all times.\textsuperscript{29}

In conclusion, in the present study we identified important independent risk factors for urinary catheterization. We used the individual maximum bladder capacity as the cut-off bladder volume limit for catheterization. Spinal anesthesia was the most important \textit{modifiable} risk factor, whereas a MBC <500mL, duration of surgery $\geq$ 60 minutes, the first scan at the PACU $\geq$ 250mL, and age $\geq$ 60 years constituted significant \textit{unmodifiable} risks. Awareness of these risk factors for POUR can help anesthesiologists, surgeons and the nursing staff to decide when catheterization is necessary.\textsuperscript{30} On average, voiding or catheterization took place four hours after surgery and the bladder filling rate varied between 100 and 200mL per hour, depending on the anesthesia technique. To prevent injury to the lower urinary tract, a simple algorithm can be considered: (1) preoperatively, at the pre-assessment clinic, ask patients at risk to measure their MBC at home; (2) use this individual MBC as a bladder volume limit throughout the postoperative phase; (3) preoperatively, at the holding area, check if patients have voided before surgery and consider measuring residual bladder volume with bladder ultrasound; (4) if possible, prevent long-acting local anesthetics for spinal anesthesia; (5) postoperatively, perform bladder ultrasound at regular intervals and estimate when the MBC will be reached, knowing bladder filling rate; and (6) implement a POUR protocol at the PACU and the surgical wards, until spontaneous voiding or urinary catheterization is deemed necessary.

Anesthesiologists and surgeons together, should raise awareness among the nursing staff how to recognize POUR and when to perform urinary catheterization when necessary.

**List Of Abbreviations**

- RCT \hspace{1cm} \text{Randomized Controlled Trial}
- POUR \hspace{1cm} \text{Postoperative Urinary Retention}
- LUT \hspace{1cm} \text{Lower Urinary Tract}
- MBC \hspace{1cm} \text{Maximum Bladder Capacity}
- PAC \hspace{1cm} \text{Pre-assessment Anesthesia Clinic}
- PACU \hspace{1cm} \text{Post Anesthesia Care Unit}
Declarations

Ethical approval and consent to participate:

The RCT was approved by the Ethical Review Board of the Medical Center Leeuwarden on May 14th, 2008 [protocol no. TPO 523]. The RCT was registered in the Current Controlled Trials database no: ISRCTN97786497 (https://doi.org/10.1186/ISRCTN97786497).

Consent for publication:

Not applicable

Availability of data and materials:

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request (t.brouwer@mcl.nl).

Competing interest:

The authors (TAB, ENR, PFWMR, CJK, NV) declare that they have no competing interests.

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Authors’ contributions:

TB - data analysis, interpretation of data, writing manuscript

ENR - interpretation of data, writing manuscript

PFWMR - interpretation of data, writing manuscript

CJK - writing manuscript

NV - data analysis, interpretation of data, writing manuscript

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