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Original Research

Objective Assessment of Rupture Parameters in Intact and Acute Post-Cystorrhaphy Cadaveric Bladders

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Abstract

Background: Certain procedures, particularly those used to treat symptoms of bladder pain syndrome/interstitial cystitis (BPS/IC), involve filling the bladder to or over its capacity for visualization and/or relief of symptoms. Rarely, if excessive pressure or volume is used, bladders may rupture causing significant harm to the patient. The purpose of this study was to identify baseline data for pressure and volume when hydrodistention is attempted in explanted cadaveric bladders, as well as determine bladder rupture pressure changes in the acute post-cystorrhaphy state. **Methods**: Eight explanted cadaveric bladders were filled using a systematic digital pump system. Intravesical pressure and volume were monitored during the filling phase until rupture. A two-layer cystorrhaphy was performed followed by bladder refilling to point of rupture. The pressure-volume correlations were developed for the explanted bladders, pre and post rupture. **Results**: The mean intact bladder rupture volume was 1186.3 mL ± 356.1 (range 450.0–1550.0) and mean pressure of 103.4 cm H_2O ± 45.9 (range 59.0–190.0). The mean bladder rupture volume following repair was 1051.9 mL ± 251.3 (range 500.0–1300.0) while the mean pressure dropped to 53.1 cm H_2O ± 44.0 (range 18.0–149.0). Compliance was noted to decrease significantly with a 54% drop in maximal pressure immediately prior to repeat rupture. Location of the initial rupture site did not have an impact on volume or pressures achieved. The weakest point post-cystorrhaphy consistently involved the original cystotomy site. **Conclusions**: This study provides *ex-vivo* bladder parameters that may guide providers in distention and post-rupture cases. Repeat rupture pressure (maximal bladder pressure achieved) and bladder compliance were noted to be significantly lower immediately post-cystorrhaphy.

Keywords: bladder; cadaver; cystorrhaphy; cystotomy; hydrodistention; rupture

1. Introduction

Bladder rupture is an uncommon event and usually occurs due to pelvic or abdominal trauma. However, bladder injury may also occur due to iatrogenic causes such as surgical or endoscopic procedures. The increasing use of cystoscopy for bladder assessment and treatment, e.g., bladder pain syndrome/interstitial cystitis (BPS/IC), may put patients at higher risk for bladder rupture [1–3].

Bladder hydrodistention is a diagnostic and therapeutic technique used to treat bladder pain syndrome [4]. Cystoscopy is also suggested after gynecologic surgery to identify urinary tract injuries that may not be detected with direct visual inspection [5]. Although urinary tract injury associated with pelvic surgery in women is low (ranging from 0.3 to 1 percent), performance of cystoscopy at the time of gynecologic surgery can successfully detect injury of the urinary tract with a sensitivity as high as 90% [6,7].

Increasing cystoscopy utilization, including the use of hydrodistention for diagnostic and therapeutic purposes, raises the need for better bladder compliance parameters and fluid instillation guidelines. The absolute risk of iatrogenic bladder trauma during procedures requiring bladder distention is unknown [6]. Additionally, when a bladder cystotomy is detected, repair may be indicated, and post-repair cystoscopy may be performed to ensure the integrity of the repair. A recommendation for pressure and volume during hydrodistention has been offered at a target range of 60–80 cm H_2O; however, bladder rupture has been noted to occur within this range. Additionally, there are no recommended pressure or volume parameters for post-surgical cystoscopy or post-repair cystoscopy [7].

Other methods for assessing bladder compliance, such as those used during urodynamics procedures (e.g., intravesical pressure and capacity defined as patient's strong desire to void) have not been reproducible [8]. In clinical practice, perceived bladder capacity and range of sensation during urodynamics vary widely in awake patients. Elucidating objective bladder pressures and volume at the time of rupture from cadaveric specimens would provide baseline parameters that could influence distention procedures and may offer an increased margin of safety. The purpose of this study was to identify pressure, volume, and compliance

values at the time of bladder rupture during fluid instillation in an *ex vivo* study of intact and post-cystostomy cadaveric bladders.

2. Materials and Methods

This study was designated as Not Human Subject Research by the Miami Valley Hospital Human Investigation and Research Committee and by Wright State University Institutional Review Board. University and hospital guidelines for cadaver use were followed and no clinical information other than gender, age, and cause of death were recorded. Cadaveric exclusion criteria included males with prior prostatectomy, suspected bladder pathology, prior incontinence procedures not performed at the mid-urethra, and suspected history of suprapubic catheters. Eight bladders from male and female fresh frozen cadavers were explanted. Bladders were explanted by two fellowship-trained female pelvic medicine and reconstructive surgery (FPMRS) surgeons following standardized methodology while ensuring careful dissection of the bladder from its surrounding structures. Ureteral insertions were dissected proximally, then transected and suture ligated. The urethral insertion was dissected at the bladder neck, then cut. One bladder sustained inadvertent cystotomy at the time of dissection and was excluded. A foley catheter was placed in the urethra and securely tied distally with a 0-polyglactin suture to ensure a good seal. With the pretext of 1 mL of tap water weighing 1 gram, volume was assessed by filling the explanted bladder while placing it on a digital scale. The weight of the system was zeroed prior to starting each instillation. Each bladder was filled at a preset rate 200 mL/min in a standardized manner using a digital pump system. This method was chosen to approximate the fill rate of an unpressurized infusion system during routine cystoscopy. The Foley catheter was connected to both the digital pump and a manometer so that intravesical pressure could be assessed throughout the instillation process (Fig. 1).

Bladder pressure and volume were monitored during the instillation phase until rupture. Intravesical pressure and volume correlations were continuously recorded throughout each instillation at 10 mL increments. The primary outcome of this process was to assess the pressure and volume at the time of distinct bladder rupture.

Upon bladder rupture, a standard cystorrhaphy was performed. A layer of 2-0 polyglactin sutures was used to repair the cystotomy in running fashion, followed by a second imbricating layer consistent with standard practice [9]. The bladders were filled again at preset rate of 200 mL/min with water to the point of failure or leakage from the cystotomy site.

The pressure-volume correlations, indicating compliance, were developed for the explanted bladders, pre- and post-rupture. Descriptive statistics and nonparametric analyses were used, including the Mann-Whitney U test.

3. Results

A total of 8 fresh frozen cadavers were used for bladder assessment. Five female and three male cadavers were used. With the available data, fresh frozen cadaver age at time of death ranged from 69 to 80 years of age. Gender did not impact pre- or post-cystorrhaphy rupture volumes (p = 0.45 and p = 0.88, respectively).

For the primary outcomes, the mean bladder volume at rupture was 1186.3 mL $\pm$ 356.1 (median 1230.0; range 450.0–1550.0) and the mean pressure at rupture was 103.4 cm H_2O $\pm$ 45.9 (median 82.0; range 59.0–190.0). All but one bladder ruptured at or above 77 cm H_2O (Table 1).

For the secondary outcomes (after cystorrhaphy), the mean bladder volume at post-repair rupture was 1051.9 mL $\pm$ 251.3 (median 1070.0; range 500.0–1300.0) while the mean pressure at post repair rupture decreased to 53.1 cm H_2O $\pm$ 44.0 (median 38.0; range 18.0–149.0).

Compliance was affected after cystorrhaphy; there was a 54% mean decrease in maximal pressure noted immediately prior to post repair rupture/leakage. The location of the initial rupture site did not have an impact on volume or pressures achieved. Furthermore, all ruptures occurred in the dome of the bladder and were noted to be 2–3 cm in size. The weakest point post-cystorrhaphy consistently involved the original cystotomy site.

4. Discussion

This study adds to the current literature as it is the first reported study investigating the pressure and volume required for cadaveric bladder rupture in an *ex vivo* model. By performing the experiment *ex vivo*, we were able to control fluid extravasation by tying off the ureteral openings and urethra. We could also clearly confirm the time and point of rupture, along with the pressure and volume at that time. Our method shows that bladder pressure can be measured with a reliable manometer which may correlate to a margin of safety during bladder hydrodistention and cystoscopy procedures with estimated pressures using column of water determination. The use of fresh frozen cadavers appears to be a suitable model that addresses the challenges of a rare occurrence and the ethical concerns preventing *in vivo* experimentation.

Utilizing this model, we offer potential baseline data that supports previous recommendations for bladder hydrodistention pressure and volume during cystoscopy and other diagnostic procedures. The technique for hydrodistention includes recommendations for bladder pressures in the range of 60–80 cm H_2O and our study indicates that this is likely a reasonable target range [1,2]. Most iatrogenic bladder injuries occur during gynecologic surgery and are intraperitoneal. These injuries vary by location and size which dictates the type of repair required. Prior studies suggest the dome is the weakest part of the bladder, the location of most spontaneous/traumatic bladder ruptures, and the area most vulnerable to injury during bladder distention

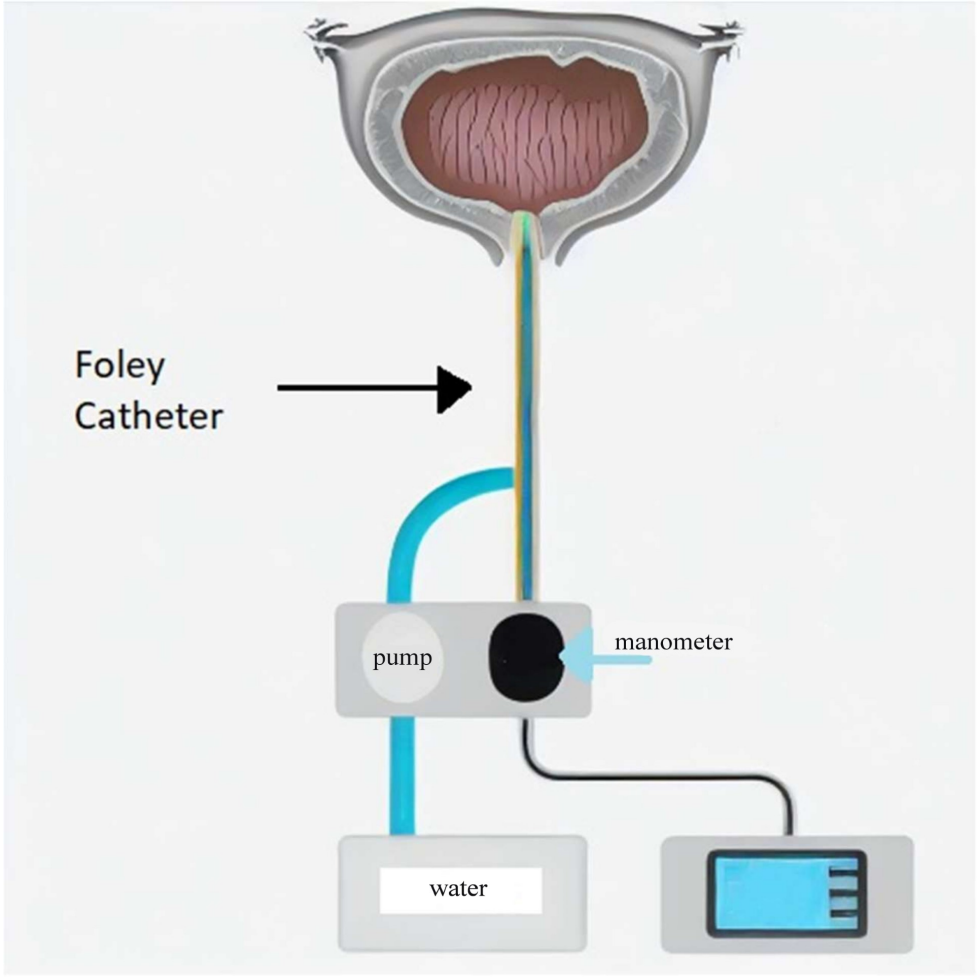

Fig. 1. Diagram of bladder pressure apparatus. Materials included plastic tubing, a pump, a Foley catheter, a manometer and a pressure gauge.

[10,11]. As most of the cadaveric bladder ruptures in our study were also located at the bladder dome and caused a 2 cm or greater tear, our study is consistent with prior studies and supports the conclusion that the dome is the most likely site of bladder vulnerability and the impact of such a rupture. In addition, most of our cadaveric bladders ruptured with pressures over 77 cm H_2O. Our findings are consistent with earlier publications advising surgeons to keep bladder pressures beneath the patient's mean arterial pressure to avoid tissue necrosis (usually 60–120 cm H_2O) [11,12].

As expected, our secondary outcomes also demonstrated decreased pressure and volume ranges that occur during a rupture after cadaveric cystotomy repair. After most live bladder injuries, post-cystostomy repair is usually performed with a two-layer closure. A post-repair cystoscopy or distention is often done to verify the repair is water-tight. Postoperative management consists of an indwelling foley catheter for 5 to 14 days to allow the bladder to heal and prevent overdistention and potential compromise of the repair. Thereafter, a cystogram may be performed 10–21 days later with instillation of around 300 mL of dye. In our study, despite a 2-layer repair as consensus guidelines recommend, the repair site at the dome remained the most susceptible to re-injury. And though repeat rupture pressure (maximal bladder pressure achieved) and bladder compliance were significantly lower immediately post-cystorrhaphy, the lowest volume of repeat rupture identified in our experimentation was 500 mL. The volume used during post-repair cystoscopy, post-repair filling, and interval cystograms would likely all be lower than that threshold. While our data does not take into account any healing time between repair and repeat distension, this data does support the practice of continuous bladder drainage following cystotomy repairs until complete healing is achieved and the avoidance of excessive distention early in the healing process. Further research will be necessary to confirm these findings.

Use of cadaveric bladders has inherent limitations but resolves the ethical concerns preventing *in vivo* live experimentation. Normal *in vivo* bladders in live patients may have numerous physiologic traits that protect against spontaneous iatrogenic rupture. We hypothesize that bladder

Table 1. Bladder volume and pressure at time of rupture.

		N	Minimum	Maximum	Median (IQR)	Mean (SD)	p†
Intact Bladder							
Volume at Rupture (mL)							
	All Cases	8	450.0	1550.0	1230.0 (1002.5–1480.0)	1186.3 (356.1)	0.45
	Male	3	950.0	1420.0	1160.0 (950.0–1420.0)	1176.7 (235.4)	
	Female	5	450.0	1550.0	1230.0 (840.0–1525.0)	1192.0 (440.6)	
Pressure at Rupture (cm H_2O)							
	All Cases	8	59.0	190.0	82.0 (78.0–143.5)	103.4 (45.9)	0.88
	Male	3	81.0	159.0	81.0 (81.0–159.0)	107.0 (45.0)	
	Female	5	59.0	190.0	83.0 (68.0–143.5)	101.2 (51.5)	
Post-Cystorrhaphy							
Volume at Rupture (mL)							
	All Cases	8	500.0	1300.0	1070.0 (1002.5–1253.7)	1051.9 (251.3)	0.88
	Male	3	1010.0	1190.0	1100.0 (1010.0–1190.0)	1100.0 (90.0)	
	Female	5	500.0	1300.0	1040.0 (750.0–1287.5)	1023.0 (321.9)	
Pressure at Rupture (cm H_2O)							
	All Cases	8	18.0	149.0	38.0 (25.5–75.5)	53.1 (44.0)	0.88
	Male		30.0	87.0	37.0 (30.0–87.0)	51.3 (31.1)	
	Female		18.0	149.0	39.0 (21.0–95.0)	54.2 (53.9)	
Observed Change							
Difference in Volume$^+$ (mL)							
	All Cases	8	–410.0	150.0	–195.0 (–263.7–45.0)	–134.4 (190.5)	0.65
	Male	3	–410.0	150.0	30.0 (–410.0–150.0)	–76.7 (294.8)	
	Female	5	–275.0	50.0	–200.0 (–252.5 to –70.0)	–169.0 (126.8)	
Volume Percent Change$^+$							
	All Cases	8	–15.8%	28.9%	14.4% (46.5%–67.5%)	8.1% (15.9)	0.65
	Male	3	–15.8%	28.9%	–2.6% (45.0%–63.0%)	3.5% (22.9)	
	Female	5	–11.1%	18.7%	15.4% (36.5%–69.0%)	12.4% (12.4)	
Difference in Pressure* (cm H_2O)							
	All Cases	8	41.0	72.0	47.5 (41.3–56.7)	50.3 10.8)	0.29
	Male	3	44.0	72.0	51.0 (44.0–72.0)	55.7 (14.6)	
	Female	5	41.0	58.0	42.0 (41.0–55.5)	47.0 (8.0)	
Pressure Percent Change*							
	All Cases	8	–69.5%	–21.6%	–57.1% (–67.4% to –46.6%)	–54.1% (15.5)	0.65
	Male	3	–63.0%	–45.3%	–54.3% (–63.0% to –45.3%)	–54.2% (8.8)	
	Female	5	–69.5%	–21.6%	–59.8% (–69.2% to –36.1%)	–54.0% (19.7)	

+ Volume difference and percentage change between the intact bladder and the post-cystorrhaphy cases; negative values represent a decrease in volume at second rupture.

* Pressure difference and percentage change between the intact bladder rupture pressure and the post-cystorrhaphy pressures; negative values represent a decrease in pressure at second rupture.

† p values listed are from Mann-Whitney U tests comparing male and female bladders.

IQR, interquartile range; SD, standard deviation.

elasticity, compliance and thus the rupture pressure and volumes may all be higher with an intact live bladder due to an existing vascular supply and normal smooth muscle tone. Further, spontaneous detrusor contractions with increasing pressure may be protective from further increased pressure. This is demonstrated during some hydrodistension procedures by observed leakage of fluid around the cystoscope as the maximum capacity under anesthesia is approached. While cadaveric bladder testing is not ideal, this research may set the stage for further cadaveric or live human studies. We also acknowledge that using explanted cadaveric bladders cannot account for the influence that the abdominal body cavity could have on delay or prevention of rupture at these bladder volumes and pressures. It is possible that the explanted cadaveric bladder readings may not adequately correlate with *in vivo* readings, however our model required explant for proof of concept and precise volume measurement. It is not known whether the abdominal organs and baseline detrusor pressure provide a protective environment against bladder rupture. A protective environ-

ment could be evident if *in vivo* measurements are found to differ predictably (higher) from our *ex vivo* values. Our rupture location (the dome) is consistent with existing literature suggesting that the abdominal cavity does not likely affect the most vulnerable location for rupture. This lends confidence to our findings.

Though it has limitations, including the small sample size, this study can guide future research on measuring the bladder's pressure and volume in *ex vivo* settings and perhaps future *in vivo* studies. We have demonstrated a standardized setup, measurement methodology, assessment intervals, and repair techniques to increase reproducibility and thus the reliability of this model in future research. In addition, we used non-parametric statistics that are more reliable when sample sizes are small. Further research is needed to determine other factors, e.g., patient age, race, and comorbid conditions, that may impact bladder rupture, including *in vivo* cadaveric studies examining the impact of the abdominal cavity on rupture pressure. In addition, further studies to determine bladder compliance in patients with bladder pathologies such as bladder pain syndrome or overactive bladder would prove useful to determine differences in potential bladder rupture pressures and volumes in these patients versus the general population.

5. Conclusions

Our study provides baseline cadaveric *ex vivo* bladder pressure and volume parameters that may assist physicians to better understand and manage intact and post-rupture bladder cases to reduce associated case complications. Our findings support the need for vigilance in bladder distention procedures and indicates that rupture may be possible at pressures less than those typically employed (60–80 cm H_2O). Opportunities for further research could include assessing explanted bladders with ureters intact to evaluate whether vesicoureteral reflux could function to relieve bladder capacity, perform studies on the intact genitourinary system in cadavers, or potentially perform *in-vivo* studies in animal models.

Availability of Data and Materials

The dataset used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author Contributions

GT, DZ, and JY designed the study. GT, DZ, and AR processed specimens/collected data. RM and AR analyzed data. GT, DZ, JY, and JM interpreted the data. GT, DZ, RM, AR, JY, and JM wrote and edited the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This project was determined to be Not Human Subjects Research by the Miami Valley Hospital Human Investigations Research Committee (HIRC; Study #20-163), and by Wright State University IRB (IRB# 2022-167). Institutional guidelines and procedures related to using cadavers in research were followed. Global informed consent was obtained from families of cadaver donations by the University. This project did not require additional consent.

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Conflict of Interest

The authors declare no conflict of interest.

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