Percutaneous bladder catheterization in microgravity

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JONES JA, KIRKPATRICK AW, HAMILTON DR, SARGSYAN AE, CAMPBELL M, MELTON S, BARR YR, DULCHAVSKY SA. Percutaneous bladder catheterization in microgravity. The Canadian Journal of Urology. 2007;14(2):3493-3498.

Introduction: *Urinary obstruction (UO) or failure to void has been observed during several episodes of short-duration spaceflight, necessitating bladder catheterization. It should be considered a possible medical condition in long-duration space missions as well. Antiemetics used early in space flight add to the risk and severity of voiding problems, along with the sensory and psychological peculiarities of voiding without gravity and in the unusual setting of a spacecraft. Urolithiasis due to the above-normal calcium excretion increases the risk of UO in long duration space missions. Finally, the individual risk of UO is higher against the background of preexisting conditions such as benign prostatic hyperplasia (BPH) or urethral stricture. Both acute retention and ureteral obstruction are associated with substantial patient distress, and carry a risk of urosepsis and/or acute renal failure. If UO in orbital flight is unresolved or complicated, it would likely result in crew emergency return from orbit. Exploration missions, however, may require means for definitive treatment of urinary tract obstruction. This study documents successful ultrasound-guided percutaneous catheterization of the urinary bladder in microgravity. A porcine model of urethral occlusion was used. The results demonstrate an additional capability from our previous investigations describing endoscopic catheterization and stenting of the ureters in microgravity conditions.*

Methods: *In an anesthetized porcine model, a Foley catheter was placed in the bladder and clamped after instillation of 200 ml of colored liquid. The bladder was visualized and then drained under ultrasound guidance through suprapubic puncture, employing a 10.3 F pigtail catheter with introducer. The procedural elements were conducted only during microgravity portions of the parabolic flight.*

Results: *Ultrasound imaging was used to successfully perform image-guided percutaneous puncture through the anterior bladder wall with the catheter, without injury to adjacent organs. The percutaneous catheter was able to successfully drain the bladder in microgravity conditions.*

Conclusions: *Percutaneous bladder catheterization and drainage can be successfully performed in weightless conditions under ultrasound guidance. Ultrasound provides a low-power, portable means to safely conduct minimally invasive procedures in pertinent organs and tissues. Percutaneous bladder catheterization is a standard procedure when luminal bladder catheterization is not possible; this technique can be successfully modified for use in space medicine applications.*

Key Words: percutaneous bladder catheterization, ultrasound, microgravity, space medicine

Introduction

While essential medical care capability for early International Space Station (ISS) operations has been deployed, the medical systems for future "assembly-complete" ISS configuration and for exploration-class missions are still being defined.[1,2] Health risks to space crews include microgravity (μG) -related adaptation concerns as well as routine morbidity.[3,4] Of the many possible urologic disorders urinary infection, retention and calculi have been identified as the most likely to occur during flight,[5] and the latter two are most likely to result in mission impact if not treated definitively.[6]

Accepted for publication March 2007

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The risk of urinary retention is increased in older astronauts due to the possible pre-existing benign prostatic hyperplasia (BPH) or stricture disease, in addition to the diminished detrusor contractility in both genders.[7] Urinary retention may be provoked in any crewmember by Promethazine, which is often used to mitigate space motion sickness.[6] Pre-flight screening for urinary calculi reduces the early risk of calculus-induced urinary obstruction; however, elevated urinary calcium due to μG-induced bone resorption may lead to stone formation in long duration flights.[8-10] Another factor common to both genders, and especially prevalent in first-time space flyers, is the difficulty to initiate and perform voiding in the peculiar conditions of a space vehicle without the contribution of gravity.

Both ballooned and non-ballooned catheters are available in the Space Shuttle and ISS medical kits. They have been used on several occasions to treat acute urinary retention in Low Earth Orbit (LEO).[6] However, failure of the Crew Medical Officer (CMO) to pass a urinary catheter would present a significant medical and logistical problem. Reasons for such failure are many, including sphincteric spasm, urethral stricture, and BPH with bladder neck elevation. Percutaneous bladder catheterization is a standard of practice for such cases as an alternative access to the bladder for drainage. The technique can be reliably accomplished with minimum morbidity following modest training. This report documents the first ultrasound-guided bladder catheterization in an animal model during parabolic flight of the NASA Microgravity Research Facility.

Methods

Preparation

The procedures described herein conformed to the NIH Guidelines for the Care of Laboratory Animals and were approved by the NASA Johnson Space Center (JSC) and University of Texas Medical Branch-Galveston (UTMB) Animal Use Committees (ACUC), and the NASA JSC Institutional Review Board. The animal was prepared at an offsite animal facility (UTMB-Galveston) prior to transport to the airfield. Anesthesia was induced with intramuscular ketamine and mask-breathed halothane. After intubation, it was maintained with IV pentobarbital and fentanyl citrate. Arterial and venous catheters were inserted to monitor blood pressure and to provide intravenous access. A balloon catheter was inserted transurethrally and the bladder contents drained.

The μG studies were performed onboard the NASA KC-135 aircraft during parabolic flight. Each parabola consisted of 30-45 seconds of hypergravity (1.8 g), 10-15 seconds of transition, 20-25 seconds of μG, and another transition period. The animal, life support and monitoring equipment, and ultrasound equipment were secured to the aircraft floor prior to takeoff. After completion of the study protocol, the animal was euthanized by IV potassium chloride injection while still under anesthesia, per a procedure from NIH Guidelines approved by the ACUC.

Hardware

Two ultrasound imaging systems were used in this study. The first device was an HDI 5000 system (ATL/Philips, Bothell, WA) functionally identical to the rack-mounted ultrasound system of the ISS Human Research Facility. The output from this device was video-recorded and annotated for later analysis. A 2-5 MHz curved array transducer was used for this experiment. The second device was a portable, battery-powered and lightweight (5.4 lb) ultrasound device Sonosite-180 Plus (Sonosite, Inc., Bothell, WA) with a probe with similar characteristics.

In-flight procedures

A 1000 cc syringe was used to instill 200 cc of dyed saline into the bladder through the catheter, which was then clamped for the duration of the flight. Ultrasound imaging of the abdomen and pelvis was performed during all phases of the flight with both devices to evaluate human factors, ultrasound image quality, and visualization of the bladder for subsequent percutaneous bladder catheterization.

A 10.3 F hydrophilic pigtail catheter (Catalog # 27-135, Boston Scientific, Boston, MA) was used for percutaneous catheterization of the bladder. The bladder was visualized during the 2 g and transition portions of the flight and catheterized during the μG portion by a trained physician. Successful catheterization was confirmed by the flow of colored liquid into the drainage bag, and by insufflation of air into the bladder under ultrasound monitoring.

Following the procedure and with the catheter secured in place by adhesive tape, the abdominal cavity was inspected laparoscopically to evaluate catheter placement and to exclude abdominal visceral injury. Following the flight, a post-mortem examination was performed at the animal care facility to additionally verify laparoscopic findings.

Results

There was excellent visualization of the bladder in all phases of the flight. The ATL 5000 provided high image quality and definition of the pelvic structures, as seen depicted in Figure 1, taken during one of the early parabolas. The intraperitoneal bladder of the pig was noted to move in an anterior/posterior direction during gravity transitions. Only minor displacements of the bowel were noted during the gravity transitions, without any effect on the visualization or the catheter path to the bladder. The ultrasound probe was held at mid-sagittal plane with minimal pressure; excessive pressure on the probe resulted in lateral displacement of the bladder. These findings were similar to previous intra- and retroperitoneal porcine ultrasound imaging.[11]

Percutaneous catheter positioning for bladder puncture was done during μG phases of flight and the catheter was advanced under direct ultrasound guidance into the bladder. Figures 1 through 3 show that the image quality allowed intraperitoneal structures within the porcine abdomen to be readily visualized and identified. Confirmation of bladder catheterization in-flight was done with aspiration of previously instilled colored liquid and by injection of air under ultrasound visualization to cause easily identifiable turbulence.

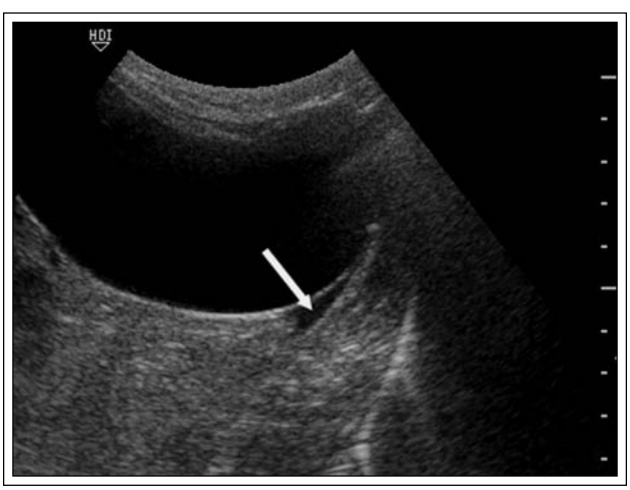

Figure 1. Suprapubic sagittal ultrasound image (HDI 5000, ATL/Philips) of the liquid-filled porcine bladder. Real-time sonography demonstrated movement of the bladder in antero-posterior direction during 0 G/ 1.8 G transitions and upon probe pressure, and lateral displacement when probe pressure further increased. A stable, small amount of retrovesical liquid (arrow) was present since trocar placement in the laboratory.

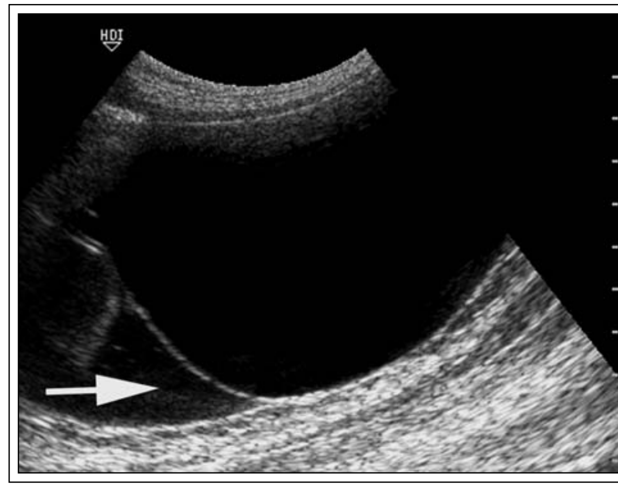

Figure 2. Suprapubic midline transverse ultrasound demonstration (HDI 5000, ATL/Philips) of liquid in the pelvis (arrow), during the simulation of bladder perforation/perforated viscus. Note the distinct white curvilinear outline of the bladder wall between the extravesical and intravesical liquid (dark spaces).

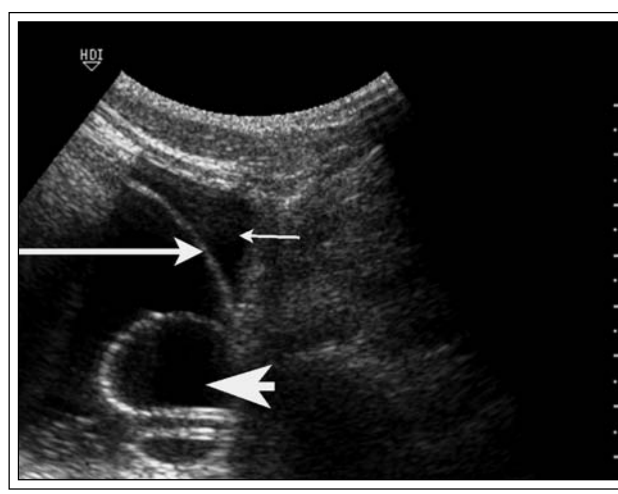

Figure 3. Suprapubic mid-sagittal ultrasound image (HDI 5000, ATL/Philips) of the distended porcine bladder with catheter balloon (arrowhead) visible in the lumen. Bladder wall (long arrow) and antevesical pelvic liquid (small arrow) are visible. Interposition of liquid (therefore, peritoneal space) between the anterior wall of a distended bladder and the abdominal wall is characteristic of the intraperitoneal porcine bladder. In the human pelvis, a distended bladder pushes the peritoneal fold with the urachus cephalad, leaving only adipose tissue in the path of the catheter between the abdominal wall and the bladder.

Comparison of the image quality between the ATL 5000 and the Sonosite revealed that there was some appreciable, but not significant, difference in image quality between the two devices. Sonosite images, although inferior to the ATL, were adequate for abdominal and pelvic structural interpretation, and therefore for conducting the procedure. On the other hand, portability of the system and its power autonomy offered greater operational flexibility. A sample image of a human urinary bladder is shown in Figure 4.

The catheter was then connected to direct drainage and secured to the abdominal wall. A laparoscope was introduced through an infra-umbilical trocar and the abdomen was insufflated with air. Direct visualization of the percutaneously placed catheter confirmed placement into the bladder without visceral injury, Figure 5.

Defined quantities of fluid were introduced into the pelvic space, to simulate a bladder rupture and subsequent urinary extravasation, and then imaging performed to determine threshold of detection. Of special interest was detection during the 0-g phases of flight, when gravitational pooling effects are eliminated. Figure 2 shows detection of 250 cc of abdominal fluid in 0-g. The bladder wall is clearly defined in the image, with both intraluminal fluid (urine) and pelvic fluid visible.

Figure 4. A mid-sagittal ultrasound image of a human (male) urinary bladder, taken with a portable ultrasound system. The double arrow shows an example of the needle path for bladder catheterization, which does not penetrate the peritoneal space when the bladder is distended.

Figure 5. Photograph of laparoscopic view of the percutaneous bladder catheter passing through the anterior abdominal wall and entering the bladder.

The animal was euthanized at the conclusion of the flight and an autopsy performed at the animal care facility. The bladder catheter was demonstrated to directly enter the superior dome of the bladder anteriorly. There was no extravasation of colored fluid into the peritoneal cavity or evidence of bowel or other pelvic structure injury.

Discussion

Operational medical procedures for the ISS are described in a document called "ISS Medical Checklist".[2] Medical procedures for orbital missions are continually reviewed and updated as new knowledge is gained and opportunities for optimization arise; capabilities and procedures for exploration-class missions are currently in the definition phase by operational medical and clinical experts at JSC.[12-15] The medical support systems for orbital spaceflight and for exploration space missions must meet substantially different requirements, including prevention, diagnosis, and therapy of many contingencies of higher probability or potential for severe mission impact.

Acute urinary system problems during spaceflight could have significant mission impact or even mission-ending consequences, if they occur in LEO and require emergency return to Earth for definitive care.[16-18] Although the baseline risk of urolithiasis in the astronaut population is controlled by the routine screening for stones and abnormal renal stone risk index, long duration spaceflight modifies the risk through elevation of urinary calcium excretion due to bone calcium resorption.[8-10] The potential for acute urinary retention due to urethral obstruction is enhanced by pharmacologic interventions used in some astronauts to combat space motion sickness. Balloon (e.g. Foley) catheters are flown in the Shuttle and ISS medical kits, and are expected to be included in exploration medical kits as well. However, failure to catheterize an astronaut with acute urinary retention must be planned for, since during exploration missions to the moon or to Mars such acute issues would have to be resolved in-flight due to the distance from Earth, time to return, and the added technical risks of a major change of the mission.

Percutaneous bladder catheterization is a commonly employed procedure where urethral catheterization is not possible.[19-26] Numerous percutaneous bladder catheterization kits are available and in routine use. The technique of percutaneous bladder catheterization is well-established and requires only modest training. The traditionally used "blind" approach requires delineation of urinary bladder contour using palpation and percussion only, with complication rates ranging between 1%-5%.[27] Physical examination in μG is challenging as a precise urinary bladder palpation may not be possible and the high levels of ambient noise make percussive evaluation difficult.[28,29] Although trained personnel can accomplish percutaneous bladder catheterization following focused instruction, ultrasonic visualization and guidance can provide an additional element of safety during the procedure.[27] In medical practice sonography has been used to guide suprapubic bladder needle aspiration in children, as well as in emergency department suprapubic cystostomies in adults, and has been shown to both promote success and lower complication rates.[27,30] NASA-Medical Operations have demonstrated the utility of diagnostic abdominal, retro-peritoneal, and thoracic ultrasound in experiments on animal models during parabolic flight on KC-135 aircraft,[31-33] and the feasibility of ultrasonic imaging in human space flight has been demonstrated with diagnostic hardware that has been flown and successfully operated on United States and Russian spacecraft, by both physician and non-physician astronauts.[6,34-38] These investigations have confirmed that good quality sonographic imaging is possible in μG with minimal to no degradation, even when performed by non-medical personnel.

This report demonstrates that the obstructed bladder is readily visualized by ultrasound during μG maneuvers and will provide an on-board, real time support for catheter placement. Ultrasound also provides confirmation of catheter location after placement by visualization of the catheter or by air bubbles introduced through the catheter. Use of sonographically reflective (echogenic) needles is recommended, to aid in observation of the catheter advancement vector during the procedure and as an additional confirmation of correct catheter location upon penetration into the bladder. It is also desirable to use a sterile clip-on needle guide, which is small and lightweight enough to become part of the on-board ultrasound setup. Such needle guide would further reduce the risk of complications such as bowel perforation[39] or misplacement of the catheter, especially when a non-physician CMO does the procedure. It would likely prove beneficial for a variety of other minimally invasive procedures or biopsies as well. Non-physician CMOs have limited medical training, only 2 hours of which involve familiarization with sonography.

In this study, gravity transitions during parabolic flight maneuvers caused the intra-peritoneal pig bladder to displace during gravity transitions and upon excessive probe pressure. Percutaneous catheterization of the human bladder is facilitated by the fixed pelvic/retro-peritoneal location of the bladder, which has very limited freedom of displacement. Therefore, catheterization of a human bladder is easier than in the animal model employed in this study and safer since the needle/catheter path in the case of a distended bladder lies well outside of peritoneal space.

The outcome of a medical contingency may be changed drastically, and an unnecessary evacuation from the ISS may be prevented, if clinical decisions are guided by objective imaging information. However, the power, mass and electromagnetic emission properties associated with imaging modalities other than ultrasound currently prevent their use on either ISS or the near- term Constellation exploration vehicle. The ISS Human Research Facility includes a multipurpose ultrasound system for research, and is expected to augment the ISS medical support system to significantly enhance the ability to timely diagnose, stage, and intervene for a wide variety of medical conditions. The procedure validation completed with the ISS ultrasound system provides a sound basis of evidence on which to design exploration medical systems. Exploration-compatible sonographic systems will most likely be smaller portable units. In our experience, a portable system produced images of quality comparable to those from the full-capability unit and fully sufficient for the given purpose. From these findings, it appears that portable imagers are acceptable for percutaneous lower abdominal and pelvic organ access procedures, instead of fixed multipurpose systems.

Conclusions

Percutaneous bladder catheterization provides a rapid, safe, and effective method of bladder drainage in patients with urinary retention who are unable to be catheterized. The technique can be readily accomplished in μG, with ultrasound imaging enhancing procedural safety by allowing precise needle/catheter insertion planning and imaging support in all phases of the procedure. □

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