Voiding Prior to Parachuting

CPT Andrew B. Hall, USAF, MC,* Justin M. Sanders, PhD,† and CPT Brad Wheeler, USAF, MC*

*Keesler Medical Center, Keesler Air Force Base, Mississippi, and †Department of Physics, University of South Alabama, Mobile, Alabama

OBJECTIVE: Multiple incidents of isolated bladder ruptures have occurred in the military parachuting community after jumps. The aim of this article is to demonstrate the amount of energy it takes to rupture a distended bladder and encourage prejump voiding.

DESIGN: Euthanized pig abdomens were opened immediately postmortem, and the urethra and bladder were isolated. The urethras were attached to a water column, which was gradually increased in height until bladder rupture. During the course of expansion, the differences in water level height, bladder dimensions, and total volume were measured. An acceleration model was constructed by placing a bladder in a rigid cylinder with a soft top to replicate a pelvis. The bladder was then dropped from a standardized height after filling the bladder with gradually increasing volumes.

SETTING: 81st Medical Group Clinical Research Laboratory at Keesler AFB, Mississippi.

PARTICIPANTS: Pigs (*Sus scrofa domestica*) postuse in an Institutional Animal Care and Use Committee (IACUC)-approved protocol.

RESULTS: Mean pressure at rupture = 116 mm Hg (standard deviation [SD] ± 7), mean height = 193 mm (SD ± 42), mean width = 122 mm (SD ± 9), and mean volume = 963 (SD ± 124). Rupture occurred after deceleration at only maximum elasticity.

CONCLUSIONS: The pressure and amount of energy required to rupture a distended bladder is remarkably low, confirming the general application of Laplace's law to a bladder. It is our recommendation that parachutists be urged or required to void, when possible, before parachuting. (J Surg 68:218-221. © 2011 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: bladder rupture, parachute, military, trauma

COMPETENCY: Medical Knowledge, Practice Based Learning and Improvement, Patient Care

Correspondence: Inquiries to CPT Andrew B. Hall, USAF, MC, 301 Fisher Street, Keesler AFB, MS 39534; fax: 228 376 0128; e-mail: andrew.hall.2@us.af.mil

INTRODUCTION

Isolated bladder ruptures after parachuting have been an infrequent occurrence in the military population.[1] Because of their infrequency, little effort has been made to prevent future occurrences. It has been theorized that the failure to void is a contributing factor in isolated traumatic bladder ruptures. This article aims to demonstrate the ease of bladder rupture with distension and advocate for prejump voiding to eliminate isolated bladder ruptures in the parachutist population.

MATERIALS AND METHODS

Pigs (*Sus scrofa domestica*) were euthanized in accordance with an approved Institutional Animal Care and Use Committee protocol. The animal's undamaged bladder was freed of ventral attachments. Each pig's pubic ramus was divided and the urethra transected at the level of the pubic ramus. A nozzle with valve was secured to the urethra after decompression of the bladder (Fig. 1).

To measure the pressure at rupture, the valve was attached with clear plastic tubing to a container. After placement of the container's water column approximately at the level of the bladder, the container was elevated gradually using a pulley mechanism until the bladder ruptured. Straight edges were set adjacent to the bladder at both the inferior and ventral aspects with photographs taken at multiple points through expansion. At time of rupture, the valve was closed, fluid levels demarcated quickly, and the difference between the water column height in the container and bladder were measured. The total fluid administered and bladder maximal height and width at the time of rupture were also recorded. The total fluid was measured by establishing a water level equal to the distended bladder and adding premeasured quantities of water as the container was raised and the bladder distended. A total of 7 pigs with intact bladders was attempted, to include 5 with accurate bladder pressure measurements, 3 with accurate dimensions, and 2 with accurate volume measurements.

An acceleration model to replicate a deceleration injury was constructed by removing 2 bladders and ligating both ureters and urethras after filling with water. The bladders were then placed in a cylindrical housing with a secured soft top to simulate a pelvis. The containers were then dropped from a stan-

  1931-7204/$30.00 doi:10.1016/j.jsurg.2010.12.008

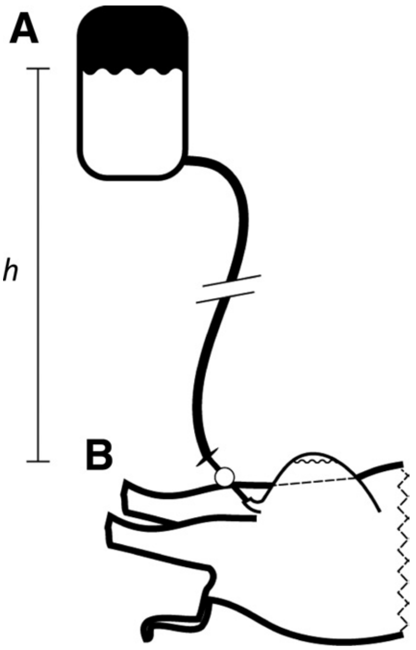

FIGURE 1. Depiction of bladder pressure setup, where A = water container on pulley. *B* = bladder attached to nozzle valve, and *h* = height of difference of water levels.

dardized height of 1.5 m (9 in) to result in a velocity of 5.9 m/s after contact with the ground. The first bladder was filled to maximum elasticity (approximately 450 ml) by elevating a water column gradually as described previously. The second bladder was filled sequentially with 200 ml, 300 ml, and finally 350 ml (maximum elasticity), and it was dropped at each fill point.

A pig model was used because of availability and size similarity to humans. A single, anatomically unremarkable pig bladder was removed from a euthanized pig, insufflated with a 10% formalin solution, and allowed to fix, submerged in formalin for 2 weeks. Eight representative, full-thickness sections of bladder wall as well as 3 sections of ureter were taken and processed, embedded in paraffin, and cut into 4-μm sections onto standard glass slides. The tissue was then stained with hematoxylin and eosin.

RESULTS

Using the equation $P = \rho g h$, where P equals pressure, ρ is equal to the fluid density, g is the acceleration of gravity, and h is the difference in height of both water columns the pressure at bursting was calculated. Additional measurements were also recorded (Table 1). The mean bladder pressure at rupture was 116 mm Hg (SD ± 7) after conversion from water to mercury. The mean bladder height at rupture was 193 mm (SD ± 42), width 122 mm (SD ± 9), and volume 963 ml (SD ± 124). By integrating the area under the pressure versus volume curve (Fig. 2), the total energy required to distend the bladder was found to be approximately 2 J.

Assuming the bladders can be approximated as spherical. For each of the volumes given, the diameter can be computed. The speed at impact, dropped from a height of 1.5 m (9 in), is 5.9 m/s. Assuming that the bladder decelerates to rest over a distance comparable to its diameter, the formula for calculating deceleration is $a = v^2/2nd$, where a equals acceleration, v equals velocity, and d equals diameter. The results of the calculation were tabulated (Table 2). Both bladders ruptured at maximum distension.

Like human bladders, the pig bladders have 4 anatomic layers, including the transitional epithelium, fibrous lamina propria, muscularis externa, and the adventitia. We noted some microscopic differences, including the transitional epithelium, which was consistently 3–5 cell layers thick compared with 5–7 in humans. The lamina propria appeared thinner as well. The muscularis externa included 3 layers of smooth muscle as seen in human bladders, and the adventitia was also similar.

DISCUSSION

Approximately 96% of the ruptures observed are to the result of traumatic or iatrogenic causes, with the remaining 4% occurring from over distension or unknown mechanisms.[1] Of the traumatic bladder ruptures, most are associated with pelvic fractures.[2] It has also been shown that the location of rupture is most commonly the trigone region because of the lack of rigid support and developmental weakness in the area, and this was observed in all experimentally ruptured bladders.[3] The propensity to rupture during trauma has been theorized to correlate to the level of distension at the time of the incident, but little data have been used to support this. This concept is important in the rare but occasional isolated bladder rupture after parachute jumps.

The concept, that structures are weaker with dilation, is important in medicine. Laplace's law is used to demonstrate the increased risk of rupture as structures expand. Commonly, the law is described as $T = (P \times R)/M$, where T = wall tensile stress, P = pressure, R = radius, and M = wall thickness. For the mean bladder parameters given in Table 1 (p = 116 mm Hg, $R = 45$ mm) and an estimated wall thickness (M) of 1 mm, a tensile strength of 700 kPa was obtained. As a comparison, arterial tensile strength has been estimated at 1000 kPa.[4]

The low tensile strength for bladder rupture is important because during a parachute landing, the stresses on the human body can be significant. Currently, in the U.S. Army, parachutes are designed to create a rate of descent of 6.7 m/s and are

TABLE 1. Bladder Dimensions, Pressure, and Volume at Bursting, *n* = Number of Successful Measurements

	Range	Mean
Maximum height	152–235 mm	193 mm (*n* = 3)
Maximum width	115–132 mm	122 mm (*n* = 3)
Burst pressure	110–128 mm Hg	116 mm Hg (*n* = 5)
Volume	875–1050 ml	963 ml (*n* = 2)