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Evaluating intra-abdominal pressures in a porcine model of acute lung injury by using a wireless motility capsule

Authors' Contribution:

- A** Study Design
- B** Data Collection
- C** Statistical Analysis
- D** Data Interpretation
- E** Manuscript Preparation
- F** Literature Search
- G** Funds Collection

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Summary

Background:

Intra-vesical pressure measurement as the reference standard for assessing intra-abdominal pressures is mainly indirect and discontinuous. We therefore evaluated a motility capsule for continuous intra-abdominal pressure measurement in an animal model with a high probability for capillary leakage and intestinal edema.

Material/Methods:

Motility capsules were inserted into the stomachs of 8 anesthetized and ventilated pigs. Stomach pH, pressure, and temperature data were wirelessly transmitted to a recorder attached to each animal's abdomen. Intra-gastric pressures measured by the capsule were compared to intra-vesical pressures measured by a pressure transducer system.

Results:

The intra-abdominal pressures ranged from 3 to 15 mmHg (7.8±2.4 mmHg [mean ±SD]) measured via the bladder. The capsule pressure recordings ranged from 1 to 3 mmHg (1.7±0.5 mmHg [mean ±SD]). Bland-Altman analysis revealed an unacceptable bias between the 2 methods. The test bias was 6.2 (±1.4) mmHg and the limits of agreement were from 3.3 to 8.9 mmHg.

Conclusions:

Pressures in the stomach as measured by motility capsule underestimated the intra-vesical pressures. Discrepancies between gastric and intra-vesical pressures could be caused by gastric dilatation or different position of the 2 devices to the zero reference point.

key words:

motility capsule • intra-abdominal pressures • animal model

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BACKGROUND

Intra-abdominal hypertension has become a widely known complication that is associated with increased morbidity and mortality [1,2]. It can lead to decreased abdominal perfusion pressure with inadequate renal perfusion and subsequently to intra-abdominal pressure-induced renal failure. The clinical reference standard for assessing intra-abdominal pressure is the intermittently measured bladder pressure via Foley catheter [3,4]. A newly developed motility capsule (Figure 1) for assessing gastric emptying and colon motility in patients with suspected gastroparesis and constipation has been available since 2006 [5–11]. It is a wireless capsule that transmits pH, pressure, and temperature data to a recorder. A potential application for the motility capsule is the continuous monitoring of intra-abdominal pressures in critically ill patients. We therefore compared the intra-gastric pressures of the motility capsule with the intra-vesical pressures in a large animal model of acute lung injury over 24 hours. Specifically, we tested the hypothesis that the 2 devices show sufficient agreement to be used interchangeably.

MATERIAL AND METHODS

This experimental study was approved by the Laboratory Animal Care and Use Committee of the District of Unterfranken, Germany and adhered to the NIH guidelines for ethical animal research. The experiments were part of a study investigating different ventilation strategies in a large animal model of ARDS that has been validated and recently published [12]. The experiment was performed on 8 healthy female Pietrain pigs (54±4 kg) over 24 hours. Shortly after intramuscular premedication with ketamine (10 mg/kg), an intravenous line was obtained and the animals were anesthetized with continuous infusion of 5–10 mg/kg thiopental and 0.01 mg/kg/h fentanyl throughout the experiment. They were paralyzed by continuous infusion of 0.1 mg/kg/h pancuronium. The trachea was intubated with a cuffed 8.5 mm ID endotracheal tube (Rüschelit®, Rüsch, Kernlen, Germany). Severe ARDS was induced by bilateral pulmonary lavages with 30 mL/kg isotonic saline (38°C), repeated every 10 minutes until PaO₂ decreased to less than 60 mmHg and remained stable for 60 minutes with unchanged ventilator settings. An average of 7±2 lavages with approximately 12,000 mL saline per animal was necessary for ARDS induction. The lungs were ventilated with low tidal volumes (4–6 mL/kg body weight). PEEP levels were maintained at around 25 cmH₂O. All animals were placed in a supine position (Figure 2). Baseline measurements were done after an equilibration period of 1 hour. Thereafter, pressure readings were recorded simultaneously every hour. The recordings from the capsule and the urinary bladder were synchronized by setting time marks on the data recorder and on the pressure recording of the monitor at the same time. It was assured that the intra-vesical measurement worked adequately by observing a change of pressure level in synchronicity with respiration. All pressure recordings were done during expiration. A total of 192 pressure measurement pairs were recorded over 24 hours. The animals were sacrificed after 24 hours per protocol.

Continuous intra-gastric pressure measurement (motility capsule)

A pH, pressure and temperature sensing capsule (SmartPill™, SmartPill Corp., Buffalo, NY) (Figure 1) was

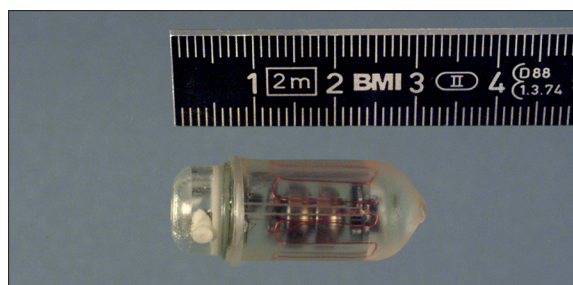


Figure 1. SmartPill® GI Monitoring Capsule (SmartPill, Inc.; Buffalo, NY, USA). The capsule measures 30 mm x 13 mm, consists of a solid plastic head and a soft polyurethane body incorporating the batteries and sensors.

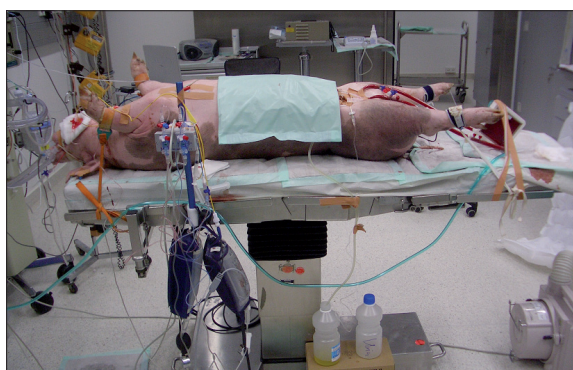


Figure 2. Experimental setup of an anesthetized, ventilated Pietrain pig in supine position.

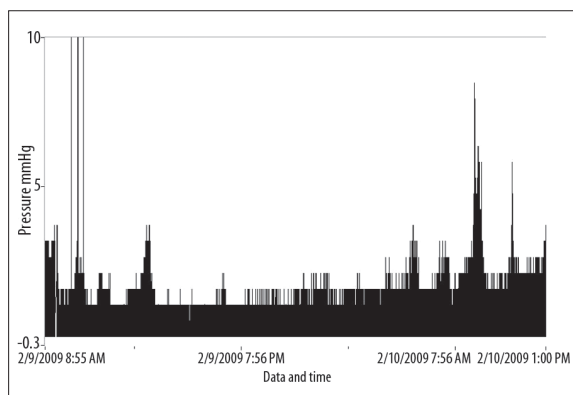


Figure 3. SmartPill® pressure tracing in one pig over 24 hours.

positioned endoscopically with a capsule delivery device (AdvanCE™, US Endoscopy, Mentor, OH) into the corpus of the stomach. The capsule measures 13 by 30 mm and has a relatively soft body consisting of polyurethane. The capsule data were transmitted wirelessly to a recorder attached to the abdomen. MotiliGI software (MotiliGI 1.3.1, SmartPill, Inc.) was used to calculate intra-gastric pressures (Figure 3).

Intermittent intra-vesical pressure measurement (AbViser Autovalve®)

A suprapubic bladder catheter was placed under ultrasound guidance. It was connected to the AbViser Autovalve® (Wolf Tory Medical, Inc., USA) intra-abdominal pressure

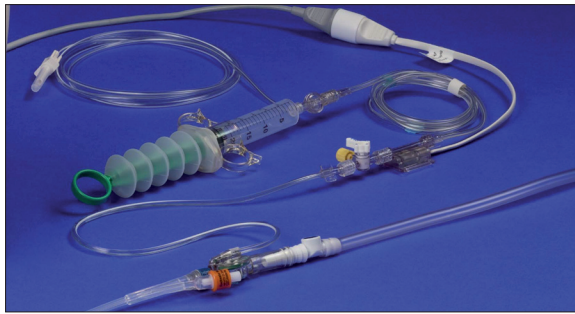


Figure 4. AbViser Autovalve® (Wolf Tory Medical, Inc., USA). Closed tubing system with a pressure transducer and an automatic valve connected between the Foley catheter and the drainage system to measure intra-abdominal pressure via the bladder. Photo with courtesy of Wolf Tory Medical.

monitoring device to record intra-vesical pressures. The pressure transducer was levelled to the upper edge of the symphysis, which served as the reference height for the measurements. According to the guidelines, an intra-vesical instillation volume of 25 mL was chosen (Figure 4).

Statistical analysis

Demographic results are expressed as means \pm standard deviations (SD) or counts. Pressures are characterized as means \pm SDs and ranges. Intra-vesical measurement of intra-abdominal pressures (IAP) was regarded as the clinical reference standard and intra-gastric measurements as the method of comparison. The mean value of each animal over 24 hours was used in a Bland-Altman assessment for agreement to compare the 2 methods. The bias was defined as mean difference between 2 measurements. A range of agreement was defined as mean bias \pm 1.96 SD. The precision was defined as the standard deviation of the bias. The method was considered acceptable if the bias did not exceed 1 mmHg and the precision was not greater than 2 mmHg. The cut-offs for acceptable bias have been determined and published in recommendations for research from the international conference of experts on intra-abdominal hypertension and abdominal compartment syndrome. Analysis was conducted with SAS 9.1.3 (The SAS institute, Cary, NC).

RESULTS

The intra-gastric pressure recordings ranged from 1 to 3 mmHg (1.7 ± 0.5 mmHg [mean \pm SD]). The intra-vesical measurements ranged from 3 to 15 mmHg (7.8 ± 2.4 mmHg [mean \pm SD]). The test bias was $6.2 (\pm 1.4)$ mmHg and the limits of agreement were from 3.3 to 8.9 mmHg. The precision was 1.4 mmHg. The 2 methods were precise enough but the Bland-Altman analysis revealed an unacceptable (too large) bias between the 2 methods (Figure 5). Intra-gastric pressure readings were on average lower than those obtained by the intra-vesical method.

The mean fluid intake was 7.5 ± 1.3 L, 140 mL per kg body weight, respectively. The fluid balance was positive with 6.2 ± 0.9 L, 110 mL per kg body weight.

The capsules remained in the stomach during the entire study period of approximately 24 hours in all 8 cases and

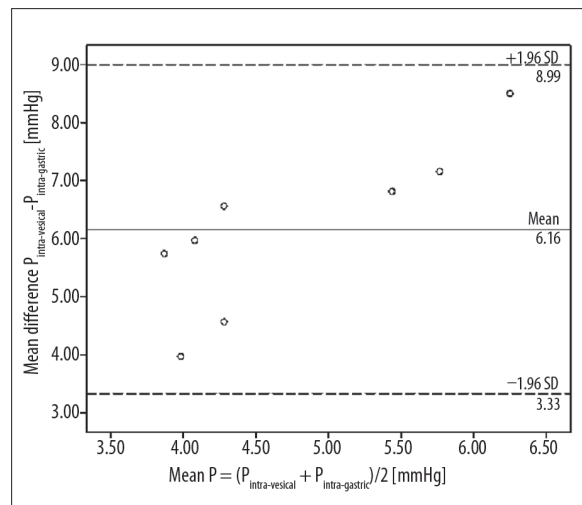


Figure 5. Bland-Altman plot for intra-vesical and intra-gastric pressure. Mean P = mean over 24 hours in each animal. X-axis: mean P = $(P_{\text{intra-vesical}} + P_{\text{intra-gastric}})/2$; Y-axis: mean difference $P_{\text{intra-vesical}} - P_{\text{intra-gastric}}$. Dashed lines Lower and upper limit of agreement (bias \pm 1.96*standard deviations).

the location was confirmed by autopsy. All animals had ascites and a bloated stomach, confirmed by autopsy as well.

DISCUSSION

Increased intra-abdominal pressures are a well-known problem in critically ill patients. Different animal models have been designed to simulate abdominal compartment syndrome and were summarized in a recent review article [13]. The porcine model is considered to be close to humans due to comparable size and physiology. Most of the animal models for intra-abdominal pressure research under the condition of pneumoperitoneum, intra-abdominal fluid instillation or bag inflation do not reflect the clinical situation of organ dysfunction. Following the recommendation for research on intra-abdominal hypertension, we have chosen a different animal model with at least 2 risk factors for increased intra-abdominal pressures, namely high fluid intake, organ failure and ventilation with high PEEP levels [14]. This “pathological” model has a high probability for capillary leakage and intestinal edema.

Apart from those research models, different methods and locations have been reported to measure intra-abdominal pressures in humans and animals [13,] [15,] [16]. The current standardized technique for intra-abdominal pressure monitoring is the intermittent intra-vesical pressure measurement with an instillation volume of 25 mL [3].

Schachtrupp et al. evaluated 2 different techniques for direct and continuous measurement of intra-abdominal pressures. They compared a piezoresistive and water-capsule technique in a porcine model [17]. Although the water-capsule pressure readings systematically underestimated the intra-abdominal pressures, both methods were more precise than intermittent intra-vesical measurements. A disadvantage is that the probes have to be placed surgically into the abdominal cavity, with the risks of infection and probe fragmentation.

Becker et al. measured intra-abdominal pressures in cirrhotic patients using a nasogastric tube with an intra-gastric balloon [18]. They compared the continuous measurements from the balloon-tipped probe with the direct intra-peritoneal measurements in 10 patients with ascites who underwent an intermittent paracentesis. Although it has been shown that the device offers reliable measurements of pressures, with a bias of $-0.2 (\pm 0.4)$ cmH₂O, corresponding to an error of 5.9% in an *in vitro* model, the authors could not further confirm the results with their study [19]. Intra-gastric measurements of intra-abdominal pressures were not precise enough, with a test bias and limits of agreement of $-4.9 (\pm 6.8)$ mmHg. The study from Davis et al. in children and Collee et al. in adults found better agreement between intra-peritoneal or urinary bladder and intra-gastric pressure measurements [20,21]. Our results are thus generally consistent with previous work suggesting that intra-gastric pressure measurements do not consistently correlate well with intra-vesical pressure measurements, depending on the applied technique.

Our study is limited by the fact that this is not an established animal model for evaluating intra-abdominal pressures and we only investigated the natural course of the intra-abdominal pressures due to high fluid intake and organ failure. Although 50% of our pressure values exceed 12 mmHg, we did not reach intra-abdominal pressures above 20 mmHg. We only measured intra-abdominal pressures for 24 hours; therefore, we can only speculate about the course of intra-abdominal pressures later in the critical illness. We also did not perform any intervention to increase and control the intra-abdominal pressure up to abdominal compartment levels. It would also be helpful if we had validated *a priori* the capsule pressures in a static model (eg, a water tank with the height of the water column) as a reference.

CONCLUSIONS

Our results indicate that intra-gastric pressures underestimate the intra-vesical pressures in this large animal model with Pietrain pigs. The discrepancies between gastric and intra-vesical pressures could be caused by gastric dilatation leading to inadequately conveying pressures to the capsule, with false low readings or different positions of the 2 devices to the zero reference point. Pigs are known to be susceptible to acute severe gastric dilatation under stressful situations, which can be a cause of sudden death. Therefore, it is rather the location than the devices that leads to the insufficient agreement. Future studies must address the concern that we did not apply controlled pressures in a range to achieve abdominal compartment syndrome. We also need to evaluate the usefulness of motility capsules in detecting intra-abdominal hypertension and guiding treatment in the clinical setting.

Conflict of interest

None of the authors has a personal financial interest related to this research.

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