Correlation between different methods of intra-abdominal pressure monitoring in varying intra-abdominal hypertension models

R D Wise,[1] MB ChB, FCA, Cert Crit Care, MMed, Dip Obst, Dip PEC; **R N Rodseth**,[1] MB ChB, FCA, Cert Crit Care, MMed, MSc, PhD; **L Correa-Martin**,[2] DVM, PhD; **F M Sanchez Margallo**,[2] DVM, PhD; **P Becker**,[3] PhD; **G Castellanos**,[4] MD, PhD; **M L N G Malbrain**,[5] MD, PhD

[1] *Pietermaritzburg Metropolitan Department of Anaesthetics, Critical Care and Pain Management, Pietermaritzburg, South Africa, and Discipline of Anaesthesiology and Critical Care, School of Clinical Medicine, University of KwaZulu-Natal, Durban, South Africa*
[2] *Laparoscopy and Anaesthesiology Research Department, Jesús Usón Minimally Invasive Surgery Centre, Cacères, Spain*
[3] *Department of Statistics, University of Pretoria, South Africa*
[4] *Department of Surgery, Virgen de la Arrixaca University Hospital, Murcia, Spain*
[5] *Medical and Surgical ICU and High Care Burn Unit, Ziekenhuis Netwerk Antwerpen, Antwerpen, Belgium*

Corresponding author: *R D Wise (robertwise@webafrica.org.za)*

Background. Advances in intra-abdominal pressure (IAP) measurement have enabled better monitoring and physiological manipulation of patients with intra-abdominal hypertension or abdominal compartment syndrome. This study aimed to determine the correlation between transvesical (TV), transgastric (TG) and direct transperitoneal (TP) IAP monitoring at different IAPs in porcine models.
Objectives. To assess the statistical agreement between TV, TG and TP pressure monitoring in a pneumoperitoneum and an intestinal obstruction intra-abdominal hypertension model at different IAPs.
Methods. Fifty-nine pigs were divided into six groups: a control group (Cr; *n*=5), three pneumoperitoneum groups at pressures of 20 mmHg, 30 mmHg, and 40 mmHg (Pn20, Pn30, Pn40; *n*=40), and two intestinal-occlusion groups at pressures of 20 mmHg and 30 mmHg (Oc20, Oc30; *n*=14). IAP was simultaneously measured in each pig using the three methods at different times. The control group did not have any intervention to increase the IAP. Intra-class correlation was used to assess agreement between the methods.
Results. At pressures >20 mmHg, all three methods showed good correlation with each other (Pn20=0.87; Pn30=0.96; Pn40=0.88; Oc20=0.69; Oc30=0.86). Correlation between TP and TG (Cr=0.0; Pn20=0.85; Pn30=0.94; Pn40=0.90; Oc20=0.78; Oc30=0.78); TP and TV (Cr=0.0; Pn20=0.83; Pn30=0.95; Pn40=0.86; Oc20=0.59; Oc30=0.88); and importantly between TV and TG (Cr=0.0; Pn20=0.95; Pn30=0.98; Pn40=0.88; Oc20=0.69; Oc30=0.91) was good.
Conclusion. All three measurement methods showed good correlation at pressures >20 mmHg and were unaffected by the type of IAP model. These results suggest that either transvesical or transgastric pressure measurements can be used for IAP measurement when TP pressures are >20 mmHg.

S Afr J Crit Care 2017;33(1):15-18. DOI:10.7196/SAJCC.2017.v33i1.327

Intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS) have been highlighted as major causes of morbidity and mortality in intensive care unit (ICU) patients.[1,2] Awareness of this clinical problem has improved through the publication of consensus documents, guidelines and the work of the World Society of Abdominal Compartment Society (WSACS, www.wsacs.org).[2] Recently, the introduction of the polycompartment syndrome concept, where increased compartment pressures in one region impact negatively on other regions, has been highlighted.[3]

Advances in IAP measurement have enabled better monitoring and physiological manipulation of patients with IAH or ACS. Accurately measured IAP (IAP) is central to the management of patients with IAH and ACS. IAP can be measured through direct intraperitoneal measurement, or indirect measures using a hollow viscus such as the bladder, stomach, rectum or uterus. Traditionally, the gold standard for measuring IAP has been via a Foley catheter in the bladder.[2] However, circumstances may arise where this method is not viable and alternative methods must be used.

This study aimed to compare the statistical agreement between transvesical (TV), transgastric (TG) and direct transperitoneal (TP) IAP monitoring. Measurements were taken in two different porcine IAH models (i.e. a pneumoperitoneum model and an intestinal obstruction mode) at different IAPs.

Methods

This study was carried out in strict accordance with the recommendations in the Royal Decree 1201/2005 of 10 October 2005 on the protection of animals used for experimentation and other scientific purposes. All experimental protocols were approved by the Committee on the Ethics of Animal Experiments of Minimally Invasive Surgery Centre Jesús Usón, and by the Council of Agriculture and Rural Development of the Regional Government of Extremadura (ref. no. ES100370001499).

Fifty-nine white female pigs (24.1 kg; range 17.3 - 33 kg) were fasted for 24 hours before receiving premedication with intramuscular atropine (0.04 mg/kg), diazepam (0.4 mg/kg) and ketamine (10 mg/kg). Induction and anaesthesia were the same as described previously by Correa-Martin *et al.*[4] Briefly, the animals were pre-oxygenated with a factional inspired oxygen of 1.0 (fresh-gas flow of 3 - 5 L/min), before administration of propofol 1% (3 mg/kg), after which their tracheas were intubated and their lungs mechanically ventilated. Anaesthesia was maintained with isoflurane (minimum alveolar concentration of 1.25) and 0.9% sodium chloride intravenous fluids (2 mL/kg/h). Intraoperative analgesia was provided with an infusion of remifentanil (0.3 µg/kg/min). On completion of the study, the animals were euthanised following the guidelines of the American Veterinary Medical Association Panel on Euthanasia[5] using potassium chloride (KCl, 1 - 2 mmol/kg).[4]

Study design

The pigs were divided into six groups: a single control group (Cr; *n*=5), three pneumoperitoneum groups with IAP of 20 mmHg, 30 mmHg, and 40 mmHg (Pn20, Pn30, Pn40; *n*=40) and two mechanical intestinal-occlusion groups with IAP of 20 mmHg and 30 mmHg (Oc20, Oc30; *n*=14). Correa-Martin *et al.*[4] have previously described the pneumoperitoneum and mechanical obstruction models. The pneumoperitoneum model was achieved using an insufflation technique with laparoscopy, while the mechanical obstruction model was achieved by placing a laparoscopic suture at the ileocaecal valve, with 0.9% saline infused into the bowel. The subjects were then maintained at the required IAP for up to 5 hours.

IAP was measured simultaneously using the three different methods under investigation. Multiple physiological parameters, together with blood samples, were measured every 30 minutes. Measurements were initiated (parameter T1) once IAP stabilised.[4] The control group received the same anaesthetic as the experimental groups, with the same 30-minute physiological measurements as the experimental groups. The control group did not have any intervention to increase the IAP.

Data collection

IAP was measured simultaneously at 30-minute intervals in each pig using the 3 methods (i.e. TP, TV and TG). The direct TP technique, a direct measure of IAP, was considered the gold standard. TP measurements were achieved using a Jackson-Pratt catheter inserted laparoscopically into the abdominal cavity and placed on the liver.[4] TV measurements were achieved using a manual manometer system with a Foley catheter in the bladder and urine drainage bag. TG measurements were made through a gastric balloon catheter (placed endoscopically) connected to an electronic pressure transducer (Spiegelberg Pharma, Germany).[6] The TG measurements were graphically recorded in real time.

Statistical analysis

Intra-class correlation was used to assess agreement between the three pressure measurement methods. This inferential method was selected because the quantitative measurements of IAP were made on grouped subjects. It was used to identify how closely the groups resembled each other. Correlation could therefore be investigated based on the varying pressure models. In addition, the subjects had a fixed degree of relatedness.

As the test subjects were organised into related groups, we used intra-class correlation to assess the degree of agreement between the three pressure-measurement methods. This allowed the determination of the correlation between the three groups. TV and TG measurements were compared with the TP measurements that were considered the most accurate. Analysis was performed using STATA 13 (Stata Corp., USA).[7]

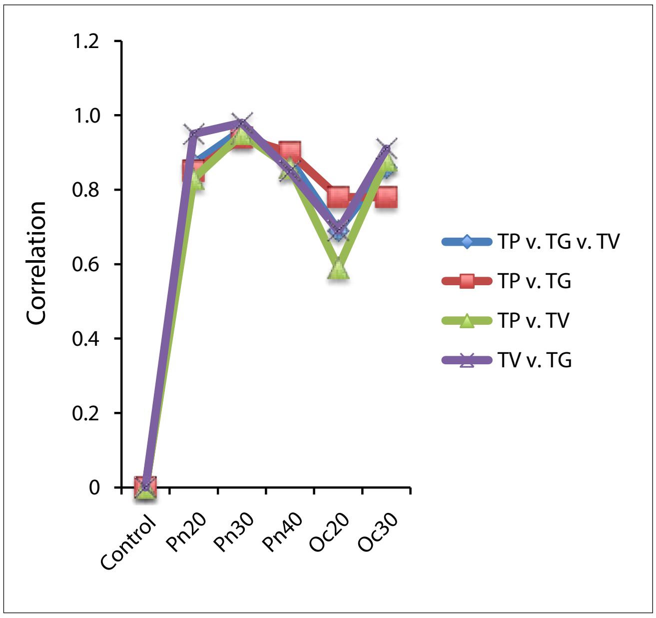

Fig. 1. Comparison of intra-class correlation between three modalities (transperitoneal, transgastric, transvesical) used for the measurement of IAP in two different porcine models. (IAP = intra-abdominal pressure; TP = transperitoneal; TG = transgastric; TV = transvesical; Pn20 = pneumoperitoneum model, pressure 20 mmHg; Pn30 = pneumoperitoneum model, pressure 30 mmHg; Pn40 = pneumoperitoneum model, pressure 40 mmHg; Oc20 = intestinal obstruction model, pressure 20 mmHg; Oc30 = intestinal obstruction model, pressure 30 mmHg.)

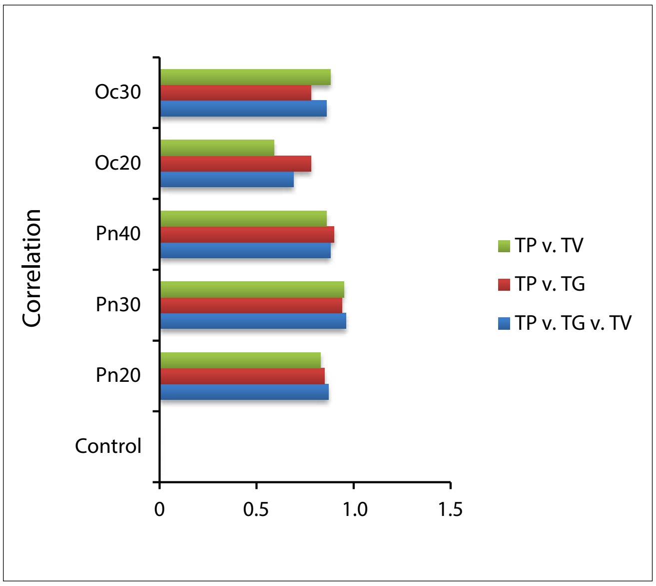

Fig. 2. Comparison of intra-class correlation between the different IAP measurement techniques in the different models of ACS. (ACS = abdominal compartment syndrome; TP = transperitoneal; TG = transgastric; TV = transvesical; Pn20 = pneumoperitoneum model, pressure 20 mmHg; Pn30 = pneumoperitoneum model, pressure 30 mmHg Pn40 = pneumoperitoneum model, pressure 40 mmHg; Oc20 = intestinal obstruction model, pressure 20 mmHg; Oc30 = intestinal obstruction model, pressure 30mmHg.)

Results

In the first comparison among TP v. TG v. TV v. control, there were 2 087 observations. When comparing TP against TG, there were 1 392 observations. Likewise, when comparing TV against TG there were 1 392 comparisons.

The first comparison between all three methods of pressure measurement (TP v. TG v. TV) showed very poor correlation in the control group (variance fraction = 0.0). Therefore the relationship between the variables measured was weak, with variability in the changes in IAP between the groups.

Comparison amongst the other groups showed good correlation (Pn20=0.87; Pn30=0.96; Pn40=0.88; Oc20=0.69; Oc30=0.86). A comparison between TP and TG had similar results with good correlation (Cr=0.0; Pn20=0.85; Pn30=0.94; Pn40=0.90; Oc20=0.78; Oc30=0.78). The analysis between TP and TV also showed good correlation (Cr=0.0; Pn20=0.83; Pn30=0.95; Pn40=0.86; Oc20=0.59; Oc30=0.88).

Good correlation was shown between the TV and TG models (Cr=0.0; Pn20=0.95; Pn30=0.98; Pn40=0.88; Oc20=0.69; Oc30=0.91). All models correlated better at higher pressures.

Discussion

IAH and ACS negatively impact morbidity and mortality in ICU patients.[8-10] The 2013 updated WSACS guidelines recommend IAP monitoring when there is any known risk factor for the development of IAH/ACS in critically ill or injured patients.[2] The findings of Cheatham *et al.*[1] support the routine monitoring of IAP, as this allows the implementation of early management protocols, thereby improving patient survival. Finding a simple, reliable and reproducible measuring technique for the measurement of IAP is important, as it is well recognised that clinical examination is not reliable.[11,12] Repeated or continuous IAP pressure monitoring via the trans-bladder route is recommended by the WSACS, and is probably still the most commonly used technique.[13-15]

This study found good correlation between TP, TG and TV methods at IAPs >20 mmHg. This supports the hypothesis that IAPs can be accurately measured for intermittent readings via any of these routes.

TV pressure monitoring is ideal for most patients at risk of developing IAH/ACS because a urinary catheter is likely to have been placed. The bladder's anatomical position, compliance and relatively low wall tension when drained or filled with a small volume (25 mL) of room or body temperature saline makes it suitable for indirect pressure measurements.[2,16,17] Like all available techniques, none are without limitations, and the stimulation of detrusor contraction should always be considered, with a 60-second pause after instillation of saline before reading the pressure. The results from the TV and TP comparisons confirm this route as reliable when compared with direct IAP measurements.

However, it may not always be possible to use the TV route. Alternative techniques to TV pressure measurements should also be simple and cost-effective. These different methods are simply classified into direct and indirect techniques.[16] Alternative invasive and non-invasive techniques have been explored, with the TV route maintaining popularity.[18,19] Invasive (direct) measurement usually only occurs after placement of an intraperitoneal catheter, such as in continuous peritoneal dialysis, continuous paracentesis or experimentally in laboratory research.[16]

Other routes that have been considered include both rectal and uterine, but these costly and often complicated methods have obvious practical limitations in critically ill patients. Inferior vena cava pressure is another direct technique, but introduces additional risks of bloodstream infections, bleeding and additional costs and risks of needle-stick injuries.[15] Microchip transducer-tipped catheters, although able to provide alternative solutions to continuous IAP monitoring, are expensive and are not frequently used.[15]

The TG route for IAP monitoring has also been investigated. Its appeal is similar to that of the bladder – most patients at risk will already have access to this hollow organ via a nasogastric tube, placement is easy, it is relatively inexpensive and there is no needle-stick risk. However, previous studies examining the TG route have been small, with limited numbers of paired readings being analysed.[6,20-22] Gastric tonometry balloons and regular nasogastric tubes have also been used. Disadvantages compared with the bladder include the need to remove air before instillation of fluid, contractility of the muscular stomach wall, an exit through the pylorus, a dependence on the patient achieving enteral tolerance, and difficulty with continuous monitoring.

However, if this route correlates well with TV readings, it may provide a very useful method for intermittent IAP monitoring when bladder monitoring is not possible. Such a scenario may occur during surgical procedures. Predicting the likelihood of a polycompartment syndrome using IAPs provides useful additional information when deciding on abdominal closure.

Correlation between TG and TV measurements was good at pressures >20 mmHg. This supports the hypothesis that IAP can be accurately measured for intermittent readings via the TG route. Clinically applicable routes (TV and TG) can therefore be used for intermittent intra-abdominal measurements. Despite limitations, both techniques may be useful in different settings. Continuous IAP measurements are probably easiest using the TV technique, whereas intermittent measurements can be achieved using either TV or TG methods. In this study, the intra-abdominal hypertension model did not influence correlation. Future studies should investigate intraoperative IAP limits (measured via the nasogastric tube) when closing the abdomen following surgery to provide clinical guidance for surgeons and anaesthesiologists when faced with this clinical dilemma.

Limitations

Despite being a large-animal study, limitations include the small number of subjects studied and the limited duration of measurements: the design of the study was not tested beyond 5 hours of initiation of IAH. Furthermore, a gastric balloon tonometry device was used and not a standard nasogastric tube, but it seems unlikely that this would make a difference to pressure readings.

Conclusions

Correlation between all three methods of IAP measurement (TP, TG and TV) was good at pressures >20 mmHg. However, correlation was poor at low IAPs. These findings were independent of the IAP model used. TG and TV techniques both have utility in the clinical setting, with TG pressure monitoring offering an attractive alternative for intermittent pressure monitoring when the TV route is not possible. The TG route may be most useful in patients undergoing surgery where the TV route is not accessible.

Acknowledgements. None.

Conflict of interest. MLNG Malbrain is the founding president and member of the executive committee of the WSACS and current treasurer. He is a member of the medical advisory board of Pulsion Medical Systems (Maquet Getinge Group) and consults for ConvaTec, Acelity, Spiegelberg and Holtech Medical. He is a member of the executive committee of the International Fluid Academy (IFA). The IFA is integrated within the not-for-profit charitable organisation iMERiT (International Medical Education and Research Initiative) under Belgian Law. The IFA website (http://www.fluidacademy.

org) is now an official SMACC (Social Media and Critical Care)-affiliated site and its content is based on the philosophy of FOAM (Free Open Access Medical Education – #FOAMed). All other authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this paper.

Author contributions. RW, RNR, GC, MLNGM contributed to analytical design and manuscript drafting and review. LC-M, FMSM, GC contributed to experimental design, data collection, and manuscript review. PB contributed to analytical design, statistical analysis and the manuscript.

Funding. This work was supported by one grant from Extremadura Regional Government through the Plan Regional de Investigación de Extremadura (PRI09A161 to Minimally Invasive Surgery Center Jesús Usón). The funder had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

1. Cheatham ML, Safcsak K. Is the evolving management of intra-abdominal hypertension and abdominal compartment syndrome improving survival? Crit Care Med 2010;38(7):402-407. http://doi.org/10.1097/CCM.0b013e3181b9e9b1
2. Kirkpatrick AW, Roberts DJ, De Waele J, et al. Intra-abdominal hypertension and the abdominal compartment syndrome: Updated consensus definitions and clinical practice guidelines from the World Society of the Abdominal Compartment Syndrome. Intensive Care Med 2013;39(7):1190-1206. http://doi.org/10.1007/s00134-013-2906-z
3. Malbrain ML, Roberts DJ, Sugrue M, et al. The polycompartment syndrome: A concise state-of-the-art review. Anaesthesiol Intensive Ther 2014;46(5):433-450. http://doi.org/10.5603/AIT.2014.0064
4. Correa-Martin L, Parraga E, Sanchez-Margallo FM, et al. Mechanical intestinal obstruction in a porcine model: Effects of intra-abdominal hypertension. A preliminary study. PloS One 2016;11(7):e0148058. http://doi.org/10.1371/journal.pone.0148058
5. American Veterinary Medical Association: Guidelines for the Euthanasia of Animals. 2013 edition. Schaumburg, United States: American Veterinary Medical Association.
6. Correa-Martin L, Castellanos G, Garcia M, Sanchez-Margallo FM. Renal consequences of intraabdominal hypertension in a porcine model. Search for the choice indirect technique for intraabdominal pressure measurement. Actas Urol Esp 2013;37(5):273-279. http://doi.org/10.1016/j.acuro.2012.06.001
7. StataCorp: Stata Statistical Software: Release 13. College Station, TX: StataCorp LP.
8. Malbrain ML, Chiumello D, Pelosi P, et al. Prevalence of intra-abdominal hypertension in critically ill patients: A multicentre epidemiological study. Intensive Care Med 2004;30(5):822-829. http://doi.org/10.1007/s00134-004-2169-9
9. Zhang HY, Liu D, Tang H, Sun SJ, et al. Prevalence and diagnosis rate of intra-abdominal hypertension in critically ill adult patients: A single-center cross-sectional study. Chin J Traumatol 2015;18(6):352-356. https://doi.org/10.1016/j.cjtee.2015.11.015
10. Malbrain ML, Chiumello D, Pelosi P, et al. Incidence and prognosis of intraabdominal hypertension in a mixed population of critically ill patients: A multiple-center epidemiological study. Crit Care Med 2005;33(2):315-322. http://doi.org/10.1097/01.CCM.0000153408.09806.1B
11. Kirkpatrick AW, Brenneman FD, McLean RF, Rapanos T, Boulanger BR. Is clinical examination an accurate indicator of raised IAP in critically injured patients? Can J Surg 2000;43:207-211.
12. Castillo M, Lis RJ, Ulrich H, Rivera G, Hanf C, Kvetan V. Clinical estimate compared to intra-abdominal pressure measurement. Crit Care Med 1998;26((Suppl 1)):78A.
13. Cheatham ML, Malbrain ML, Kirkpatrick A, et al. Results from the International Conference of Experts on intra-abdominal hypertension and abdominal compartment syndrome. II. Recommendations. Intensive Care Med 2007;33(6):951-962. http://doi.org/10.1007/s00134-007-0592-4
14. Malbrain ML, Cheatham ML, Kirkpatrick A, et al. Results from the International Conference of Experts on intra-abdominal hypertension and abdominal compartment syndrome. I. Definitions. Intensive Care Med 2006;32(11):1722-1732. http://doi.org/10.1007/s00134-006-0349-5
15. Malbrain ML. Different techniques to measure intra-abdominal pressure (IAP): Time for a critical re-appraisal. Intensive Care Med 2004;30(7):357-371. http://doi.org/10.1007/s00134-003-2107-2
16. De Keulenaer BL, Regli A, Malbrain ML. Intra-abdominal measurement technique: Is there anything new? Am Surg 2011;77(July Suppl):S17-S22.
17. De Waele JJ, De Laet I, Malbrain ML. Rational intra-abdominal pressure monitoring: How to do it? Acta Clin Belg 2007;62(Supp1:16-25). http://doi.org/10.1179/acb.2007.62.s1.004
18. Van Ramshorst GH, Salih M, Hop WC, et al. Noninvasive assessment of intra-abdominal pressure by measurement of abdominal wall tension. J Surg Res 2011;171(7):240-244. http://doi.org/10.1016/j.jss.2010.02.007
19. Kim KS, Seo JH, Kang JU, Song CG. Implementation of a multi-functional ambulatory urodynamics monitoring system based on newly devised abdominal pressure measurement. J Med Syst 2010;34(6):1011-1021. http://doi.org/10.1007/s10916-009-9318-1
20. Debaveye Y, Bertieaux S, Malbrain M. Simultaneous measurement of intra-abdominal pressure and regional CO_2 via a gastric tonometer. Intensive Care Med 2000;26(Suppl3):S324.
21. Sugrue M, Buist MD, Lee A, Sanchez DJ, Hillman KM. Intra-abdominal pressure measurement using a modified nasogastric tube: Description and validation of a new technique. Intensive Care Med 1994;20:588-590.
22. Collee GG, Lomax DM, Ferguson C, Hanson GC. Bedside measurement of intra-abdominal pressure (IAP) via an indwelling naso-gastric tube: Clinical validation of the technique. Intensive Care Med 1993;19:478-480.