*American Journal of Clinical Medicine Research, 2016, Vol. 4, No. 1, 11-18*
Available online at http://pubs.sciepub.com/ajcmr/4/1/3

DOI:10.12691/ajcmr-4-1-3

# Intra-abdominal Pressure is Influenced by Body Position?

**António M. Lopes[1,2,*], Andreia Nunes[2], Maria M. R. E. Niza[3], António Dourado[1]**

[1]University of Coimbra – Department of Informatics Engineering, Center for Informatics and Systems of the University of Coimbra (CISUC), Polo II University of Coimbra, 3030-290 Coimbra, Portugal
[2]University Lusofona – Faculty of Veterinary Medicine, Avenida do Campo Grande, 3761749-024 Lisboa, Portugal
[3]University of Lisbon - Faculty of Veterinary Medicine, Avenida da Universidade Técnica, 1300-477 Lisboa, Portugal
*Corresponding author: antoniomcml@gmail.com

**Abstract** Background: Increased intra-abdominal pressure (IAP) is a complication related to physio pathological changes with high rates of mortality and morbidity. Abdominal surgery is consider one of the risk factors that can increased IAP. Measurement can be done by direct or indirect methods, being the most used the transurethral (TM). However this method continues to generate some controversy. This study tries to clarify the doubts of the effect of body position when we use different methods to measure IAP. Methodology: Study realized an anatomical model in order to eliminate the described variables that influence IAP: abdominal and gastric contraction, micturition reflex and breathing. IAP was measured, directly, via microsensor and, indirectly, by TM and intragastric manometry, in five different body positions. The study population consists in a population of 29 anatomical model, 14 males and 15 females, with an average weight of 12.04 ± 5.67 kilograms (Kg). The inclusion criteria consisted in the absence of abdominal disease that would. Principal Findings: IAP determination by direct method showed no differences in the five body positions (P=0.765). The indirect method with better correlation with the direct was TM (cc0.87). Indirect methods revealed statistically significant differences with the direct, only in the Trendelenburg and reverse Trendelenburg. Conclusions: The clinical impact of this study is to decrease the doubts in the measurements of IAP. This study improves the knowledge of the application of the direct and indirect methods to accesses IAP. IAP is not affected by body position and the direct pressure value measured in all positions is constant. Only if the indirect methods are used, in Trendelenburg and reverse Trendelenburg positions, they may underestimate or overestimate IAP value. For the first time it was explained why this phenomenon occurs.

***Keywords:*** *Abdominal surgery, Intra-abdominal pressure, transurethral method, intragastric manometry, body position*

**Cite This Article:** António M. Lopes, Andreia Nunes, Maria M. R. E. Niza, and António Dourado, "Intra-abdominal Pressure is Influenced by Body Position?" *American Journal of Clinical Medicine Research*, vol. 4, no. 1 (2016): 11-18. doi: 10.12691/ajcmr-4-1-3.

## 1. Introduction

Increased intra-abdominal pressure (IAP) is a complication related to physio pathological changes in cardiac, respiratory, renal, gastrointestinal, liver and nervous systems. Increased IAP may originate pathological changes, causing abdominal compartment syndrome [1,2,3,4]. These alterations influence vital functions of the patient, which lead to a high mortality and morbidity [3,5,6,7,8]. One of the main risk factors, is the diminished abdominal wall compliance caused by abdominal surgery [7,9,10]. Hernia and its surgical repair are also linked with elevated IAP [11,12,13].

The measurement of IAP may be performed through direct or indirect methods. Direct measurement of IAP is used as a reference to indirect methods [14,15] and can be measured with a solid microtranducer placed in the abdominal cavity [16]. The use of indirect methods has advantages due to it being less invasive, more cost efficient, and easier to use [17,18]. The transurethral method (TM) is the most commonly used for measuring IAP and it is considered the gold standard [17,19,20,21]. This method has already been clinically validated [22]. However, the measurement of IAP by TM continues to generate some controversy due to the large number of variables that can affect it, questioning its reproducibility [17,23-28]. Intragastric manometry (IGM) is other indirect method used to measure IAP by means of a nasogastric or gastrostomy tube when TM cannot be used. IGM also has already clinically validated [15,20,29]. Davies and co-workers compared the indirect methods, TM and IGM, with direct measurements via peritoneal dialysis catheter and conclude that the TM achieved better correlation coefficients in comparison with IGM [30]. There are also several studies comparing IAP measurement methods using animal models of rabbits, pigs and dogs [18,31,32]. Although the above studies show similar findings, they have poor experimental design and cannot fully explain the divergent results obtained in clinical practice.

Most patients in intensive care unit (ICU) are nursed with an head-of-bed elevation to reduce the risk of ventilator-associated pneumonia and pressure ulcers (33). Measuring IAP via the bladder in the supine position is still the accepted standard method but sometimes these measurements are made with head-of-bed elevation (34).

Several studies describe that the patient´s position influence the measurement of IAP [26,35,36,37].

The role of TM as the gold standard for IAP has become a matter of debate but in our days continues to be the most used to access IAP in clinical patients and experimental study´s worldwide [17,20]. The incorrect use and interpretation of TM can influence the IAP measurements. This study tries to clarify the doubts of the effect of body position when we use different methods to measure IAP. The value of IAP is also used to determine abdominal perfusion pressure (APP) which is an accurate predictor of visceral perfusion in patients. APP and IAP are booth clinical parameters used to classify the degree of abdominal hypertension. The accurate measurement of IAP is clinically relevant to not influence practician in the wrong way.

## 2. Materials and Methods

The methodology used in this study was chosen because of the difficulty of eradicating some of the variables that influence the method and all the ethical issues linked to experimentation. Using an analytical approach of breaking a problem down into smaller problems the study was realized in a cadaver anatomical model of the abdominal cavity. Like this, the large number of variables that affects IAP was reduced to a single variable: influence of body positon. The anatomic model of the abdominal cavity allowed the eradication of the described variables that influence IAP: abdominal and gastric contraction, micturition reflex and breathing [23,37-43]. The model of the abdominal cavity used was from dog, to maintain the similarity of the anatomical biology. To avoid changes in tissue tension and elasticity of the cavity´s the study was performed immediately after cadaver´s entry into the service of pathological anatomy.

The study population consists in a population of 29 dog cadavers, 14 males and 15 females, with an average weight of 12.04 ± 5.67 kilograms (Kg), received for necropsy at the Department of Pathology, Faculty of Veterinary Medicine. None of the animals used in this study were euthanized for this purpose. The inclusion criteria consisted in the absence of abdominal disease that would affect the abdominal cavity and its organs, which was confirmed by necropsy. All cadavers showing marked alterations of tension and elasticity of the abdominal cavity and its organs were eliminated from the study.

The IAP was measured by three methods - Direct, TM and IGM (Figure 1) - in five different positions – lateral, ventral and dorsal recumbency, Trendelenburg and reverse Trendelenburg (45 degrees angle). All measurements were performed before the necropsy and all the determinations were carried out in the framework of normal necropsy.

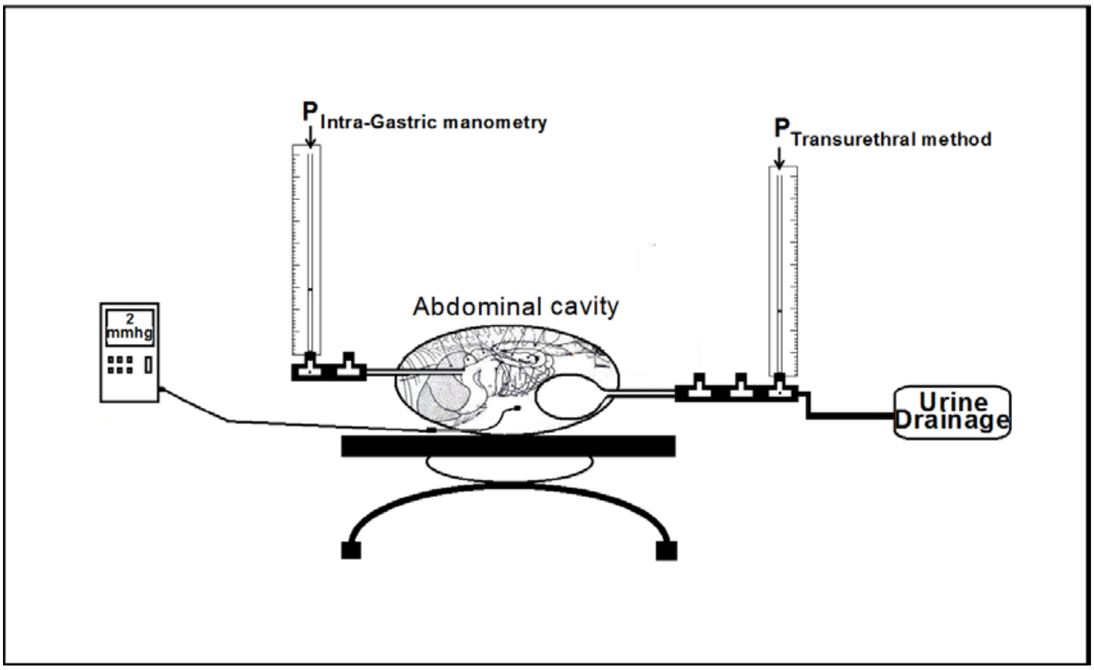


**Figure 1**.

### 2.1. Direct IAP Measurements

IAP measurement was held directly through an intra-peritoneal catheter of 16 G. The insertion of the catheter was performed at the midline near the umbilicus scar. Two sites of increased resistance were noted during cannula placement: the peritoneal aponeurosis and the peritoneal serosa. Once in the peritoneal cavity, the CODMAN sensor (Codman, Johnson & Johnson) was inserted inside the catheter, until it entered into the abdominal cavity [16]. Readings were carried out after the stabilization of the pressure [3]. Before introducing the catheter into the abdomen, the sensor was calibrated according to the manufacturer's instructions and the reference was adjusted to zero, the reference being atmospheric pressure [16].

### 2.2. Indirect IAP Measurements

The existing indirect methods to measure IAP are mostly based on the use of a water column metrically divided [17]. Indirect systems such as TM and IGM allow the connection between organic structures and a water column by urinary and gastric medical disposable catheters, extensions and three-way stopcock. Both systems allow IAP measurement after allowing, by means of the three-way stopcock, the dynamic balance between the water column and the fluid restrained in the bladder or stomach, respectively (Figure 1). The conversion to mmHg was done by multiplying by 0.736 [16].

The TM was originally described by Kron and co-workers [44,45], but suffered some modifications [17]. One of the most commonly used modifications is the closed technique, proposed by Cheathman and co-workers [46]. This technique has some advantages over the initial method for which it was applied in this study [17]. IAP was measured via a transurethral bladder catheter. The bladder was emptied and a standard volume of sterile saline solution, 0.5 to 1 ml/kg of 0.9% saline, was instilled into the bladder to slightly distend it (too much saline in the bladder would elevate IAP) [19]. A three-way stopcock was connected to the transurethral bladder catheter and the other entrance was connected to a column of water, filled with sterile saline solution, to create a closed system. Once saline was instilled into the bladder, the three way stopcock was turned on, to allow the connection between the animal's bladder and the fluid column contained in the extension set. This led to the decrease in height of the fluid column, until its pressure was balanced with the pressure inside the bladder. The equilibrium point was considered to be the IAP. Its numerical value was obtained considering the zero point of the metric scale to be the level of the patient's symphysis pubis [19,47].

The IGM is similar to the TM, but the water column is connected to the stomach instead of the bladder. IAP pressure was measured via a standard nasogastric tube, which is positioned in the stomach. In this procedure, the volume of fluids instilled in the stomach was 50 ml per animal. We then allowed the connection between the fluid contained in the stomach and the water column, as to reach the equilibrium point. This point was considered to be IAP [17,32].

Consecutive measurements were carried out by indirect and direct methods in the five positions: lateral, ventral and dorsal recumbency, Trendelenburg and reverse Trendelenburg (Figure 2 - 45 degrees angle). All values were recorded in a database. Finally, necropsy was performed to confirm if the direct measurement catheter was inside the abdominal cavity and if the indirect catheters were in the bladder and stomach. It was also confirmed the non-existence of pathological alterations of the abdominal cavity. All dogs which revealed disease affecting the cavity and its organs were excluded.

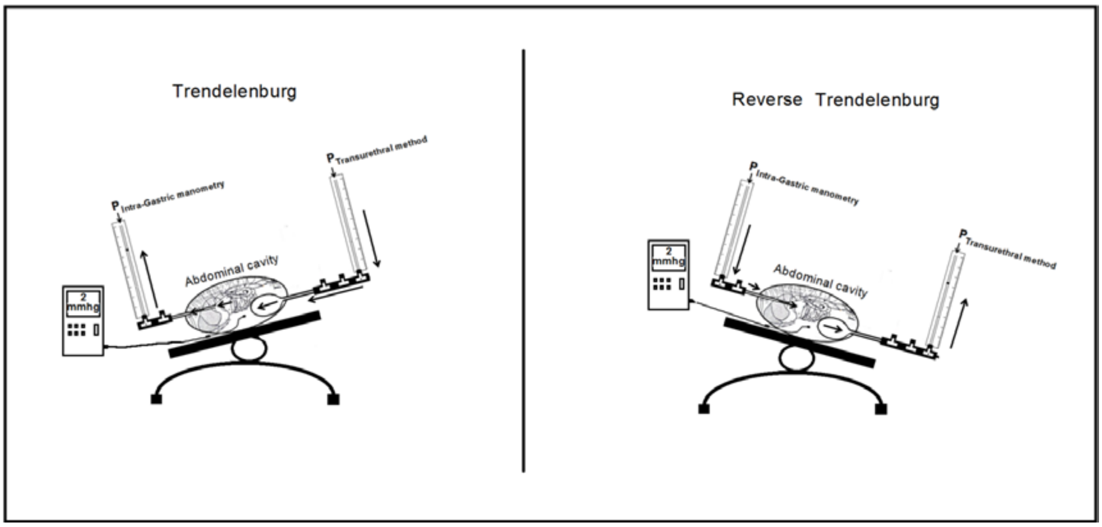


**Figure 2**.

## 2.3. Statistic

The data was analysed using the SPSS program (Statistical Package for the Social Sciences, 2010 version), which made a comparison between all variables. Analysis of variance (ANOVA) was used to identify significant differences between the averages of the groups. The Pearson coefficient correlation test was used to analyse relationships between the various pressures. Values are expressed as mean ± standard deviation and statistical tests of mean comparisons; differences were considered statistically significant when $P < 0.05$.

# 3. Results

## 3.1. Direct Values of IAP

The pressure measurements by direct sensor showed very constant readings in all positions. In lateral recumbency average, pressures were 3.1 ± 3.0 mmHg; in ventral recumbency, 2.3 ± 3.4 mmHg; in the dorsal recumbency, 1.9 ± 3.4 mmHg; in Trendelenburg position, 2.4 ± 3.2 mmHg; finally, in reverse Trendelenburg position, 2.2 ± 3.3 mmHg (Table 1).

**Table 1. Average IAP of the measured values by direct method in mmHg**

| Position | Lower limit | Upper limits | Mean ± Standard Deviation |
|---|---|---|---|
| Lateral | 0.00 | 13.00 | 3.07±3.04 |
| Ventral | - 2.00 | 13.00 | 3.31±3.38 |
| Dorsal | 0.00 | 14.00 | 1.93±3.44 |
| Trendelenburg | -2.00 | 13.00 | 2.34±3.22 |
| Reverse –Trendelenburg | -3.00 | 13.00 | 2.24 ± 3.52 |

The comparison of the direct values of IAP in the various positions did not reveal statistically significant differences (P = 0.765).

### 3.2. TM Values

The pressure measurements by TM showed stable readings in lateral, ventral and dorsal recumbency, but some differences in the Trendelenburg and reverse Trendelenburg position. In lateral recumbency, mean pressures were 4.5 ± 3.1 mmHg; in ventral recumbency, 3.6 ± 2.9 mmHg; in dorsal recumbency, 3.4 ± 3.4 mmHg; in Trendelenburg position, 2.6 ± 3.1 mmHg; in reverse Trendelenburg position, 4.6 ± 2.9 mmHg (Table 2).

**Table 2. Average IAP of the measured values by transurethral method in mmHg**

| Position | Lower limit | Upper limits | Mean ± Standard Deviation |
|---|---|---|---|
| Lateral | 0.29 | 13.99 | 4.52±3.12 |
| Ventral | 0.00 | 11.55 | 3.59±2.94 |
| Dorsal | 0.00 | 12.65 | 3.40±3.43 |
| Trendelenburg | 0.00 | 11.25 | 2.57±3.14 |
| Reverse Trendelenburg | 0.00 | 11.18 | 4.55 ± 2.98 |

The comparison between the values of IAP obtained by TM in the various positions did not show statistically significant differences (P = 0.091).

### 3.3. IGM Values

The pressure measurements by IGM showed variable readings, with considerably different values in Trendelenburg and reverse Trendelenburg position. In lateral recumbency, mean pressures were 4.7 ± 2.2 mmHg; in ventral recumbency, 3.0 ± 1.6 mmHg; in dorsal recumbency, 2.6 ± 1.9 mmHg; in Trendelenburg position, 7.1 ± 2.7 mmHg; in reverse Trendelenburg position, 0.1 ± 0.3 mmHg (Table 3).

**Table 3. Average IAP of the measured values by intra-gastric manometry method in mmHg**

| Position | Lower limit | Upper limits | Mean ± Standard Deviation |
|---|---|---|---|
| Lateral | 1.47 | 10.67 | 4.73±2.16 |
| Ventral | 0.00 | 5.37 | 3.04±1.55 |
| Dorsal | 0.00 | 9.19 | 2.59±1.99 |
| Trendelenburg | 0.96 | 12.00 | 7.14±2.72 |
| Reverse Trendelenburg | 0.00 | 0.88 | 0.11 ± 0.28 |

The comparison between values of IAP obtained by IGM in the various positions revealed statistically significant differences (P = 0.0001).

### 3.4. Comparison of Methods

The measurements obtained by the three methods were subsequently compared with each other to see if there were differences between methods.

**Table 4. Level of significance between the measurements made by the three methods, in the five positions**

| Position | Significance level (P<0.05) |
|---|---|
| Lateral recumbency | 0.062 |
| Ventral recumbency | 0.207 |
| Dorsal recumbency | 0.186 |
| Trendeelenburg | 0.0001 |
| Reverse trendelenburg | 0.00001 |

It was observed that lateral, ventral and dorsal positions showed no statistically significant differences between them (P >0.05), with identical mean values obtained with through methods (Table 4). As for the efficacy of the direct IAP sensor, significant correlation coefficients (cc) were observed between the IAP measurements obtained directly versus indirectly: direct versus TM, cc. 0.87; direct versus IGM, cc. 0.28; TM versus IGM, cc. 0.25.

Regarding Trendelenburg and reverse Trendelenburg position, the IAP values obtained by the three methods showed statistically significant differences between groups (P< 0.05).

## 4. Discussion

The measurement of IAP can be useful for detecting early changes, such as intra-abdominal hypertension or alterations in APP. When IAP values are greater than 12 mmHg it is symptomatic of intra-abdominal hypertension, and compartment syndrome is generally considered when IAP values are greater than this in combination with at least one end-organ failure [4,48,49]. Abdominal compartment syndrome is the pathophysiological consequence of raised IAP, including reduction in perfusion, ventilation deficit, oliguria and other renal problems, and increased intra-cranial pressure [3,5,48,50]. Abdominal surgery is consider one of the risk factors that can increased IAP [7,21,31,50,51]. It is documented that hernioplasty and changes of anatomic stuctures in hernia´s are also responsible of IAP alterations [7,11,12].

Although there are several doubts regarding the measurements of IAP, the indirect methods used for determination of IAP are considered the most accurate to evaluate this parameter [17]. The choice of method usually points to the TM, since it is consider the gold standard [17,19,20,21]. In our study, we used the modified technique of Kron, proposed by Cheatham and Safcsak [17,46]. This technique minimizes the risk of urinary tract infections and sepsis, contrary to the original technique proposed, allowing the possibility of repeated measurements and reduced costs [17]. We also used the MIG to determine IAP since it is usually the alternative, when the TM cannot be used (urinary tract infection, pelvic trauma and cistotomy). This technique is also very cost efficient, it doesn't interfere with urine output and the risk of infection is absent, making this technique perfect to screening IAP, comparing its costs to the results [17].

The direct measurement through Codman´s micro sensor, micro miniature silicon strain gauge type sensor, was first used by Pracca and co-workers [16]. They concluded that these sensors allow continuous monitoring, without urinary tract manipulation, are simple to use and to calibrate and are minimally invasive. The problem with this sensor is its cost, for which it should be reserved for patients where standard techniques cannot be used [16].

The MT is widely used in ICU and scientific studies and sometimes the findings may be influenced by the method. In the literature there are several studies about the variables that affect IAP but none of them study each variable singly. In these studies all the variables that affect the IAP are always present. The type of methodology used in this study was chosen because three reasons: 1 - The difficulties linked to human experimentation and ethical issues (is not ethical rotate a patient to five positions, and measure IAP by three methods at the same time point); 2 - The difficulty of creating an artificial model of the abdominal cavity; and 3- The difficulty of eradicating some of the variables described that influence the measurement of IAP. Using an analytical approach of breaking a problem down into smaller problems, the study was realized in an animal anatomical model of the abdominal cavity. Like this we have an anatomical model of the abdominal cavity with scale and similarities to humans. The principal difference between the abdominal cavity of dogs and humans is the orientation of the organs because animals walk in prone position. This fact can influence abdominal compliance which affects IAP. These and other differences lead to different values of IAP between species. However the type of cavity, the anatomical constituents and the definition of abdominal pressure is similar. This type of study has many advantages, since it allows the elimination of variables that are identified in the literature as being liable for influencing IAP measurement [38-43]. For this reason, the following variables will not be present: abdominal and gastric contraction, micturition reflex and breathing [23,37-43]. Therefore we have a better explanation of the methods used, whilst maintaining the ethics of the study. Like this we only experiment the variable under study: the effect of body position.

The normal values in humans for IAP are 0.2-12.2 mmHg [1,7] and the normal interval in dogs is between 0 and 3.75 mmHg, however, in animals submitted to ovariohysterectomy, IAP values can reach up to 11.25 mmHg, without symptoms of hypertension [7,19,47]. Recently Way and co-workers (2014) found in dogs higher average IAP values (5.9 ± 1.0 mmHg) than those previously described [52]. Although the present study was performed in cadavers, IAP values established are within the limits defined for the species, as shown in Table 1, Table 2 and Table 3. The fact that IAP values in cadavers are similar to live animals is directly linked with the definition of IAP, which is nothing more than a pressure state. The pressure state of the abdominal cavity is determined by body mass index, posture, muscular activity of the wall and breath [48,50,53]. This definition of IAP is precisely the reason why we decided to carry out a cadaver study. Nevertheless the IAP values obtained can be considered low. Lower values of IAP in this study can be due to loss of tissue tension, the non-existence of respiratory movements and a complete absence of abdominal muscles contraction. It is documented that only the variable muscle contraction may lead to a decrease in 25% of IAP if exists neuromuscular blocking in abdominal surgery [54]. The effect of respiratory movements in IAP was studied by Wilson (1933) and he concluded that there is a rise in IAP during inspiration proportional to the depth of inspiration [55]. He also concluded that no rise of IAP occurs in normal expiration [55]. As in this study there are no respiratory movements will be no change in IAP, independently of the physiological mechanism.

In this study, it was concluded that IAP measurement through the bladder, using urethral or intra-gastric catheter, is, in both cases, an accurate method for measuring IAP in lateral, ventral and dorsal positions in dogs. In these body positions, the three methods showed no statistically significant differences between them ($P < 0.05$), with identical average values obtained with both methods (Table 4). As for the efficacy of the direct IAP sensor, significant correlation coefficients (cc) were observed between the IAP measurements obtained directly versus indirectly: direct versus TM, cc. 0.87; direct versus IGM, cc. 0.28; TM versus IGM, cc. 0.25. The correlation coefficients found for the different methods are in accordance with the literature, although showing lower values [32]. In the study of Engum and co-workers the objective was to compare gastric tonometry with direct IAP in a canine model with simulated abdominal compartmentalization syndrome. The dogs were submitted to laparotomy and a bag of fluid was positioned inside the abdomen. The issue occurred with the anaesthetic protocol. They induced the dogs with thiopental and the anaesthesia was maintained with isoflurane. In the experimental design of this study, the animals were without any analgesia when undergoing laparotomy. This means that the animals could demonstrate pain and, consequently, there could have been abdominal contraction, which is one of the factors that may result in IAP increase [38,40]. This fact can explain the differences between the correlation values of our study and Engum work. Another fact that may explain the difference between the correlation coefficients is the absence of contraction by abdominal muscles [54]. Despite these small differences, this study demonstrates that the best indirect method for measuring IAP in dogs is the TM, similar to what happens in humans [30,56].

The IAP values obtained by direct method were quite constant in all the positions studied and no statistically significant differences were obtained ($P = 0.765$). This presupposes that there is no difference in IAP when body position is altered. This fact is contrary to what is described in the literature, which contradicts the previously described [26,36,37]. These studies conclude that IAP values are different depending of the body position. However, all IAP values were determined by indirect methods, namely the TM. We mustn't forget that TM is based on fluids mechanic and in the principles of hydrostatic. The pressure value obtained depends on the dynamic balance between columns of water, between the bladder and the stomach (17). This type of system has some disadvantages linked to being a fluid-filled system. The displacement of the fluid from an upper pressure to a lower pressure influences the system, as observed in this work. We believe that this fact explains why these studies refer that IAP is influenced by body position. In our work, statistically significant differences were demonstrated between direct measurements and IAP values obtained by indirect methods (TM and IGM) in the Trendelenburg and reverse Trendelenburg position. We believe this to be directly related to the dynamic equilibrium of the fluid column pressures. In such positions, the patient is placed in an inclined plane leading to fluid movement as Figure 2 illustrates. In our study, although measurements are being collected simultaneously by the three methods, we observed that the water in both columns (TM and IGM) demonstrates several alterations when we change the body position, with the direct measurement remaining equal. Thus, in the Trendelenburg position, the TM tends to have values close to zero, since the water column will move in the cranial direction, with the average values decreasing by 50%, 2.6 ± 3.1 mmHg, when compared with the average in lateral, ventral and dorsal recumbency. On the other hand, IGM rises whit a gain of approximately 40%, 7.1 ± 2.7 mmHg. The fluid column, due to the inclination, tends to move anteriorly. Hence, the IAP will be underestimated by TM and overestimated by IGM. In the reverse Trendelenburg position, the opposite occurs, because, as the slope is the opposite, the fluid column movement will be as well, presenting a direction of the fluid flow. Thus, the IAP value reflected a decrease of average values close to zero, 0.1 ± 0.3 mmHg in IGM. Similarly, the movement of the fluid column in this position led to an increase in the IAP value for TM, to mean 4.6 ± 2.9 mmHg. This fact had already been described by De Keulenaer and co-workers when observed that patients with the head of the bed elevated to 30 and 45 degrees had IAP increased [36]. Therefore, in reverse Trendelenburg position, IAP by IGM will be underestimated and by TM will be overestimated. This type of change is not linked to the type of patient (human, dog or cat) or if the study was realized in a living or non-living animal model. This change is directly related to the TM and the principles of fluid mechanics and is going to happen in all species and in any type of model.

There are, however, some indirect systems that accomplish the IAP measurement with an air-pouch localized in the stomach. These systems use air and not liquid, eliminating the disadvantages related with the water column [17,20,25]. The problem of this systems is that are not indicated to screening, but is best for continuous fully automated monitoring for a long period of time [17,20].

Abdominal perfusion pressure has been demonstrated to be an accurate predictor of visceral perfusion and an end-point for resuscitation [5,48,49,57]. The calculation of the APP is performed by subtracting the value of IAP to the mean arterial pressure (MAP) [48,49,57]. As the most widely used method for measuring the IAP is the MT, when the patient is inclined, measurement may be erroneous leading to false judgments of APP. This false assumption can lead the practician to wrong therapeutic decisions.

The clinical impact of this study is improves the knowledge in the measurements of IAP in ICU and surgery blocks allowing proper use of the direct and indirect methods. Direct and both indirect methods to measure IAP in humans and animals have been validated clinically and they are used worldwide in ICUs [15,16,19,20,22,29,37]. Although this study was conducted in a non-living animal model, results provide a better explanation of the IAP. Only a study with this experimental design allows eradicate the variables described of influence the measurements and maintain the ethics of the study. The use of a non-living animal model to realize the study and measure IAP may be controversial. However, the IAP measurements obtained have similar values in live dogs and the physical definition of pressure was not changed.

## 5. Conclusions

For the first time, is given the explanation why body position can influence the measurement of IAP. The measurements of IAP via the bladder through a urethral catheter, and the measurement via intra-gastric catheter, are both accurate methods for measuring IAP in lateral, ventral and dorsal position. All measurements carried out in Trendelenburg and reverse Trendelenburg position by indirect methods show differences regarding the direct method. This fact can be explained by the movement of the water column, which is the base of the indirect methods.

The values obtained from direct method measurements in different positions (lateral, ventral, dorsal, Trendelenburg and reverse Trendelenburg) have no statistically significant differences. This fact assumes that there are no differences of IAP in different body positions. In the literature it is described that position can alter the IAP because in these studies they use indirect methods based in water manometers. Therefore, in Trendelenburg position the IAP by TM will be underestimated and overestimated by IGM, and in reverse Trendelenburg position the IAP by IGM will be underestimated and the TM will be overestimated.

The indirect methods to obtain IAP are valid methods that give valid information to the practician. However the clinician must know the variables that affect the method to obtain the most reliable information.

## Acknowledgments

### Competing interests

The author(s) declare(s) that there is no conflict of interest.

### Funding statement

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

### Authors' contributions

- Guarantor of the integrity of the entire study: AML, MMREN, AD
- Study concepts and design: AML, MMREN, AD
- Literature research: AML, AN, LM
- Experimental studies: AML, AN
- Data acquisition: AML, AN
- Data analysis/interpretation: AML, AN, AD
- Statistical analysis: AML
- Manuscript preparation: AML, MMREN, AD
- Manuscript definition of intellectual content, editing, revision/review and final version approval: AML, MMREN, AD

### List of abbreviations

IAP- intra-abdominal pressure
TM – Transurethral method
IGM- Intra-gastric manometry
ANOVA – Analysis of variance
CC - correlation coefficients
mmHg - millimeters of mercury (mmHg)
ICU - Intensive care unit

## References

[1] Balogh Z, Moore F a., Moore EE, Biffl WL. Secondary abdominal compartment syndrome: A potential threat for all trauma clinicians. Injury. 2007;38(3):272-9.

[2] Unit IC. Intraabdominal hypertension and abdominal compartment syndrome in the intensive care unit. 2006;1(1):13-5.

[3] Aspesi M, Gamberoni C, Severgnini P, Colombo G, Chiumello D, Minoja G, et al. The abdominal compartment syndrome. Clinical relevance. Minerva Anestesiol [Internet]. 2002;68(4):138-46.

[4] Joubert KE, Oglesby P a., Downie J, Serfontein T. Abdominal compartment syndrome in a dog with babesiosis. J Vet Emerg Crit Care. 2007;17(2):184-90.

[5] Cheatham ML. Abdominal Compartment Syndrome: pathophysiology and definitions. Scand J Trauma Resusc Emerg Med [Internet]. 2009;17(1):10. Available from: http://www.ncbi.nlm.nih.gov/pubmed/19254364.

[6] Bosch L, Rivera del Alamo MM, Andaluz a., Monreal L, Torrente C, Garcia-Arnas F, et al. Effects of ovariohysterectomy on intra-abdominal pressure and abdominal perfusion pressure in cats. Vet Rec [Internet]. 2012;171(24):622-622.

[7] Kirkpatrick AW, Roberts DJ, De Waele J, Jaeschke R, Malbrain MLNG, De Keulenaer B, 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):1190-206.

[8] Ameloot K, Gillebert C, Desie N, Malbrain MLNG. Hypoperfusion, Shock States, and Abdominal Compartment Syndrome (ACS). Surg Clin North Am. 2012;92(2):207-20.

[9] Reintam Blaser A, Parm P, Kitus R, Starkopf J. Risk factors for intra-abdominal hypertension in mechanically ventilated patients. Acta Anaesthesiol Scand [Internet]. 2011;55(5):607-14. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21418151

[10] Balogh ZJ, Martin A, van Wessem KP, King KL, Mackay P, Havill K. Mission to eliminate postinjury abdominal compartment syndrome. Arch Surg [Internet]. 2011;146(8):938-43.

[11] Zhou T, Yang B, Zhang Y, Zhang L, Chen S. Study on intra-abdominal pressure in indirect inguinal hernia patients. Zhonghua Wai Ke Za Zhi. 2007;45:1455-7.

[12] Peker K, Isik A, Inal A, Demiryilmaz I, Yilmaz I, Emiroglu M. How Lichtenstein hernia repair affects abdominal and anal resting pressures: a controlled clinical study. Int J Clin Exp Med [Internet]. 2014;7(2):363-9.

[13] Lyons M, Mohan H, Winter DC, Simms CK. Biomechanical abdominal wall model applied to hernia repair. Br J Surg [Internet]. 2015;102(2):e133-9.

[14] Suominen PK, Pakarinen MP, Rautiainen P, Mattila I, Sairanen H. Comparison of direct and intravesical measurement of intraabdominal pressure in children. J Pediatr Surg. 2006; 41(8): 1381-5.

[15] Turnbull D, Webber S, Hamnegard CH, Mills GH. Intra-abdominal pressure measurement: validation of intragastric pressure as a measure of intra-abdominal pressure. Br J Anaesth [Internet]. 2007;98(5):628-34.

[16] Pracca FF, Biestro AA, Moraes L, Puppo CB, Calvo SM, Gorrasi J, et al. Direct measurement of intra-abdominal pressure with a solid microtranducer. J Clin Monit Comput. 2007;21(3):167-70.

[17] Malbrain MLNG. Different techniques to measure intra-abdominal pressure (IAP): time for a critical re-appraisal. Intensive Care Med. 2004;30(3):357-71.

[18] Lee SL, Anderson JT, Kraut EJ, Wisner DH, Wolfe BM. A simplified approach to the diagnosis of elevated intra-abdominal pressure. J Trauma [Internet]. 2002;52(6):1169-72.

[19] Drellich, Sharon (University of California D. Intraabdominal Pressure and Abdominal Compartment Sydrome. Compend Contin Edu. 2000;22: N.º 8(Small Animal/Exotics):764-8.

[20] Wauters J, Spincemaille L, Dieudonne AS, Van Zwam K, Wilmer A, Malbrain MLNG. A novel method (CiMON) for continuous intra-abdominal pressure monitoring: Pilot test in a pig model. Crit Care Res Pract. 2012;2012.

[21] Ece I, Vatansev C, Kucukkartallar T, Tekin A, Kartal A, Okka M. The Increase of Intra-Abdominal Pressure Can Affect Intraocular Pressure. 2015;2015(08).

[22] berti TJ, Lieber CE, Benjamin E. Determination of intra-abdominal pressure using a transurethral bladder catheter: clinical validation of the technique. Anesthesiology [Internet]. 1989;70(1):47-50.

[23] Johna S, Taylor E, Brown C, Zimmerman G. Abdominal compartment syndrome: does intra-cystic pressure reflect actual intra-abdominal pressure? A prospective study in surgical patients. Crit Care. 1999;3(6):135-8.

[24] Hunter JD, Damani Z. Intra-abdominal hypertension and the abdominal compartment syndrome. Anaesthesia. 2004;59(9):899-907.

[25] Soler Morejón CDD, Lombardo TA, Tamargo Barbeito TO, Sandra BG. Effects of zero reference position on bladder pressure measurements: an observational study. Ann Intensive Care [Internet]. Springer Open Ltd; 2012;2 Suppl 1(Suppl 1):

[26] Yi M, Leng Y, Bai Y, Yao G, Zhu X. The evaluation of the effect of body positioning on intra-abdominal pressure measurement and the effect of intra-abdominal pressure at different body positioning on organ function and prognosis in critically ill patients. J Crit Care [Internet]. Elsevier Inc.; 2012;27(2):222.e1-222.e6.

[27] Fusco MA, Martin RS, Chang MC. Estimation of intra-abdominal pressure by bladder pressure measurement: validity and methodology. J Trauma. 2001;50(2):297-302.

[28] Smith SE, Sande AA. Measurement of intra-abdominal pressure in dogs and cats. J Vet Emerg Crit Care. 2012;22(5):530-44.

[29] 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 [Internet]. 1993;19(8):478-80.

[30] Davis PJ, Koottayi S, Taylor A, Butt WW. Comparison of indirect methods of measuring intra-abdominal pressure in children. Intensive Care Med. 2005;31(3):471-5.

[31] Lacey SR, Bruce J, Brooks SP, Griswald J, Ferguson W, Allen JE, et al. The relative merits of various methods of indirect measurement of intraabdominal pressure as a guide to closure of abdominal wall defects. J Pediatr Surg. 1987;22(12):1207–11.

[32] Engum S a., Kogon B, Jensen E, Isch J, Balanoff C, Grosfeld JL. Gastric tonometry and direct intraabdominal pressure monitoring in abdominal compartment syndrome. J Pediatr Surg. 2002; 37(2): 214-8.

[33] Metheny N a, Frantz R a. Head-of-bed elevation in critically ill patients: A review. Crit Care Nurse. 2013;33(3):53-67.

[34] Pinsky MR (University of PMC, Laurent B (Hopital HM, Mancebo J (Hospital de SP, Antonelli M (Universita C des SC. Applied Physiology in Intensive Care Medicine 2. Third edit. Springer Heidelberg New York Dordrecht London; 2012. 220-224 p.

[35] McBeth PB, Zygun DA, Widder S, Cheatham M, Zengerink I, Glowa J, et al. Effect of patient positioning on intra-abdominal pressure monitoring. Am J Surg. 2007;193(5 SPEC. ISS.):644-7.

[36] De Keulenaer BL, De Waele JJ, Powell B, Malbrain MLNG. What is normal intra-abdominal pressure and how is it affected by positioning, body mass and positive end-expiratory pressure? Intensive Care Medicine. 2009. p. 969-76.

[37] Rader RA, Johnson JA. Determination of normal intra-abdominal pressure using urinary bladder catheterization in clinically healthy cats. J Vet Emerg Crit Care. 2010;20(4):386-92.

[38] Cresswell AG. Responses of intra-abdominal pressure and abdominal muscle activity during dynamic trunk loading in man. Eur J Appl Physiol Occup Physiol. 1993;66(4):315-20.

[39] De Waele JJ, De Laet I, De Keulenaer B, Widder S, Kirkpatrick AW, Cresswell AB, et al. The effect of different reference transducer positions on intra-abdominal pressure measurement: A multicenter analysis. Intensive Care Med. 2008;34(7):1299-303.

[40] Davis KG, Marras WS. The effects of motion on trunk biomechanics. Clin Biomech. 2000;15(10):703-17.

[41] Hodges PW, Gandevia SC. Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. J Appl Physiol. 2000;89(3):967-76.

[42] Ahmadi-Noorbakhsh S, Malbrain ML. Integration of inspiratory and expiratory intra-abdominal pressure: a novel concept looking at mean intra-abdominal pressure. Ann Intensive Care [Internet]. Springer Open Ltd; 2012;2 Suppl 1(Suppl 1):S18. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3527153&tool=pmcentrez&rendertype=abstract.

[43] Malbrain MLNG, Deeren DH. Effect of bladder volume on measured intravesical pressure: a prospective cohort study. Crit Care. 2006;10(4):R98.

[44] Kron IL, Harman PK, Nolan SP. The measurement of intra-abdominal pressure as a criterion for abdominal re-exploration. Ann Surg [Internet]. 1984;199(1):28-30. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1353253&tool=pmcentrez&rendertype=abstract.

[45] Harman PK, Kron IL, McLachlan HD, Freedlender a E, Nolan SP. Elevated intra-abdominal pressure and renal function. Ann Surg [Internet]. 1982;196(5):594-7. Available from: http://www.ncbi.nlm.nih.gov/pubmed/7125746.

[46] Cheatham M. Intraabdominal Pressure: A Revised Method for Measurement. J Am Coll Surg [Internet]. Elsevier; 1998 May 5 [cited 2015 Oct 9];186(5):594-5.

[47] Conzemius MG, Sammarco JL, Holt DE, Smith GK. Clinical determination of preoperative and postoperative intra-abdominal pressures in dogs. Vet Surg VS Off J Am Coll Vet Surg. 1995;24(3):195-201.

[48] Papavramidis TS, Marinis AD, Pliakos I, Kesisoglou I, Papavramidou N. Abdominal compartment syndrome - Intra-abdominal hypertension: Defining, diagnosing, and managing. J emergencies, trauma Shock. 2011;4(2):279-91.

[49] Al-Dorzi HM, Tamim HM, Rishu AH, Aljumah A, Arabi YM. Intra-abdominal pressure and abdominal perfusion pressure in cirrhotic patients with septic shock. Ann Intensive Care [Internet]. Springer Open Ltd; 2012;2(Suppl 1):S4. Available from: http://www.annalsofintensivecare.com/content/2/S1/S4.

[50] Bosch L, del Alamo MMR, Andaluz A, Monreal L, Torrente C, Garcia-Arnas F, et al. Effects of ovariohysterectomy on intra-abdominal pressure and abdominal perfusion pressure in cats. Veterinary Record. 2012.

[51] Mahajna A, Mitkal S, Krausz MM. Postoperative gastric dilatation causing abdominal compartment syndrome. World J Emerg Surg. 2008;3:7.

[52] Way LI, Monnet E. Determination and validation of volume to be instilled for standardized intra-abdominal pressure measurement in dogs. J Vet Emerg Crit Care. 2014;24(4):403-7.

[53] Castellanos G, Piñero A, Fernández JÁ. La hipertensión intraabdominal y el síndrome compartimental abdominal: ¿qué debe saber y cómo debe tratarlos el cirujano? Cir Esp. 2007;81(1):4-11.

[54] Van Wijk RM, Watts RW, Ledowski T, Trochsler M, Moran JL, Arenas GW. Deep neuromuscular block reduces intra-abdominal pressure requirements during laparoscopic cholecystectomy: a prospective observational study. Acta Anaesthesiol Scand. 2015;59(4):434-40.

[55] Wilson WH. <Effect of Breathing on the Intra Abdominal Pressure.Pdf>. J Physiolo. 1933;Oct 25; 79:481-6.

[56] Gudmundsson FF, Viste A, Gislason H, Svanes K. Comparison of different methods for measuring intra-abdominal pressure. Intensive Care Med. 2002;28(4):509-14.

[57] Cheatham ML, White MW, Sagraves SG, Johnson JL, Block EF. Abdominal perfusion pressure: a superior parameter in the assessment of intra-abdominal hypertension. J Trauma [Internet]. 2000;49(4):621-6; discussion 626-7. Available from: http://www.ncbi.nlm.nih.gov/pubmed/11038078.