2015•2016
FACULTEIT GENEESKUNDE EN LEVENSWETENSCHAPPEN
master in de biomedische wetenschappen

Masterproef

Measuring intra-abdominal pressure using an intravaginal pressure tip balloon catheter: a pilot study

Promotor :
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Prof. dr. Marcel AMELOOT

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Scriptie ingediend tot het behalen van de graad van master in de biomedische wetenschappen

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List of abbreviations

Abbreviation	Explanation
ACS	Abdominal compartment syndrome
BMI	Body mass index
CO	Cardiac output
CS	Caesarean section
FMLV	Foley manometer low volume
GRV	Gastric residual volume
HOB	Head of the bed
IAH	Intra-abdominal hypertension
IAP	Intra-abdominal pressure
IAP_{Ves}	Intra-vesical pressure
IAV	Intra-abdominal volume
ICU	Intensive care unit
IGP	Intra-gastric pressure
IVBC	Intravaginal pressure tip balloon catheter
IVP	Intravaginal pressure
MAL	Mid-axillary line
PE	Preeclampsia
SPCC	Spearman correlation coefficient
UTI	Urinary tract infection
VEGF	Vascular endothelial growth factor
VRP	Vaginal resting pressure
WHO	World Health Organization
WSACS	World Society of the Abdominal Compartment Syndrome
ZOL	Ziekenhuis Oost-Limburg

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Samenvatting

Inleiding: Pre-eclampsie ontstaat mogelijks door een verhoogde intra-abdominale druk (IAP) boven 12 mmHg, die de veneuze terugstroom van het bloed verhindert. Door IAP te meten tijdens de zwangerschap kunnen deze verhoogde drukken gedetecteerd worden. Als gouden standaard wordt IAP gemeten via de blaas. Deze techniek is echter niet geschikt voor ambulant gebruik, omwille van de benodigde katheterisatie en een intrinsiek risico op urineweginfecties. Intra-vaginale drukmeting (IVP) zou de gouden standaard kunnen vervangen. Het doel van deze pilootstudie is het beoordelen van een intra-vaginale ballonkatheter (IVBC) voor IAP meting in zwangeren.

Materiaal & methoden: De herhaalbaarheid van IVBC metingen werd onderzocht in 20 vrouwen, waarbij IVP gemeten werd in 45° half-liggende positie op het einde van de ademhaling. IVP bepaling gebeurde telkens bij verschillende inflatievolumes van de katheter ballon (0 ml, 20 ml, 40 ml, 60 ml en 80 ml). Nadien werd IVP vergeleken met de gouden standaard (Foley Manometer Low Volume) door beide technieken uit te voeren in dezelfde positie, op het einde van de ademhaling, in 20 andere patiënten. Via SPSS werden Spearman correlatiecoëfficiënten (SPCCs) berekend voor gemiddelden van 2, 3 en 4 IVP metingen, alsook voor intravesicale druk (IAP_{Ves}) versus IVP bij verschillende ballonvolumes.

Resultaten: SPCC voor herhaalde IVP metingen waren ≥0.95 voor gemiddelden van ≥3 metingen. SPCC tussen IAP_{Ves} en IVP metingen waren ≥0.46 ($p<0.05$) bij inflatievolumes ≤40 ml, en <0.25 vanaf een inflatievolume ≥60 ml ($p>0.05$). Overeenkomst tussen beide technieken werd ook geïllustreerd in Bland-Altman plots.

Discussie en conclusie: De IVP meettechniek is sterk herhaalbaar vanaf ≥3 herhaalde metingen. Correlatie tussen IAP_{Ves} en IVP metingen was echter te laag om IVP als een geldig alternatief te beschouwen voor de gouden standaard.

Summary

Introduction: It is hypothesized that sustained increases in intra-abdominal pressure (IAP) above 12 mmHg might be associated with preeclampsia, by limiting the venous return. Measuring IAP could therefore be useful in prenatal care. Currently the gold standard to measure IAP is via the bladder, involving urethral catheterization with an intrinsic risk for urinary tract infections, and therefore restricted in ambulatory setting. Intravaginal pressure (IVP) measurements might be used alternatively. This pilot study aims to assess an intravaginal pressure tip balloon catheter (IVBC) for IAP monitoring in pregnant women.

Material & methods: Repeatability of IVBC measurement was investigated in 20 women: IVP was measured four times in 45° semirecumbent position at end-expiration using different balloon inflation volumes (0 ml, 20 ml, 40 ml, 60 ml and 80 ml). Comparison of IVP with the gold standard (Foley Manometer Low Volume) was performed by using both techniques in the same position at end-expiration in 20 other subjects. SPSS was used to calculate Spearman correlation coefficients (SPCCs) for means of 2, 3 and 4 IVP measurements, and for intra-vesical pressure (IAP_{Ves}) versus IVP at different balloon inflation volumes.

Results: SPCCs of repeated IVP measurements were ≥0.95 for means of ≥3 measurements. SPCCs between IAP_{Ves} and IVP measurements were ≥0.46 ($p<0.05$) at balloon inflation volumes ≤40 ml, and <0.25 at inflation volumes ≥60 ml ($p>0.05$). This was also illustrated in Bland-Altman plots.

Discussion & conclusions: The IVP measurement technique is highly repeatable at ≥3 repeated measures. However, correlation between IAP_{Ves} and IVP measurement was too low to consider IVP a valuable alternative for the gold standard.

1. Introduction

Preeclampsia (PE) is a pregnancy disorder, which is characterized by the de-novo development of hypertension (≥140/90 mmHg), measured two times a day with minimum six hours in between, combined with significant proteinuria (≥300 mg/day) (5). The disease affects 3-5% of pregnancies worldwide and arises mostly during the second half of pregnancy (5, 6). PE is the main cause of maternal and perinatal morbidity and mortality (6). The World Health Organization (WHO) reported that about 14% of maternal deaths between 2003 and 2009 were caused by hypertensive disorders (7). Furthermore, it is estimated that PE results yearly in 70 000 maternal and 500 000 new-born/fetal deaths worldwide (6). The disease is more prominent in developmental countries and will be often recurrent in subsequent pregnancies (8, 9). Many risk factors for PE have been described including the presence of insulin-dependent diabetes, obesity, chronic kidney disease and pre-existing hypertension (6). However, the etiology and pathogenesis of PE is still unclear (3). It is reported that inadequate cardiovascular and renal changes from the maternal body are associated with complications like PE (10).

1.1 Maternal changes during normal pregnancy

During the course of a normal pregnancy, the maternal body adapts physiologically to deal with increased metabolic demands. Cardiovascular changes include an increase in blood volume (1-2 litres) and preload, while vasodilatation reduces afterload (11). The maternal heart rate starts to increase early in pregnancy and will be 15-17% higher in the final trimester (11, 12). Consequently, the increase in stroke volume and heart rate both increase cardiac output (CO) up to 30-50% (11). The higher CO enhances mainly renal and uterine blood flow, although blood pressure decreases up to 20 weeks of gestation. This early hypotension results from a decrease in vascular resistances, provoked by progesterone and nitric oxide. However, vascular resistances and blood pressure subsequently increase again (13). In contrast to these physiological changes in normal pregnancy, CO decreases and peripheral resistance is found to increase with arising symptoms of PE (14).

In the kidneys, vasodilatation allows the glomerular filtration rate and renal plasma flow to increase. This enhances creatinine clearance and increases the urinary excretion of albumin and glucose (11). In addition to renal adaptations, the tidal volume and minute ventilation of the lungs increase both by 30-50% during pregnancy (13). Less air can be additionally exhaled after normal expiration (expiratory reserve volume) and the residual volume decreases too. Altogether, the functional residual capacity decreases with 10-25%, due to the growing fetus and the increasing abdominal pressure which moves the diaphragm upwards (11, 13). Since deviations from the normal (cardiovascular) physiology of pregnancy are associated with complications and the etiology of PE is still unclear, researchers recently have restarted investigating the role of intra-abdominal pressure (IAP) during pregnancy (15). It is hypothesized that a sustained increase in IAP might be involved in the process of PE by limiting the venous return (3, 15).

1.2 Intra-abdominal pressure

In 2006, the World Society of the Abdominal Compartment Syndrome (WSACS) defined the IAP as the steady-state pressure inside the abdominal cavity (16). The baseline IAP is related to the intra-abdominal volume (IAV) in proportion to the degree of abdominal expansion or compliance. Abdominal compliance in turn depends on the elasticity of the abdominal wall and diaphragm.

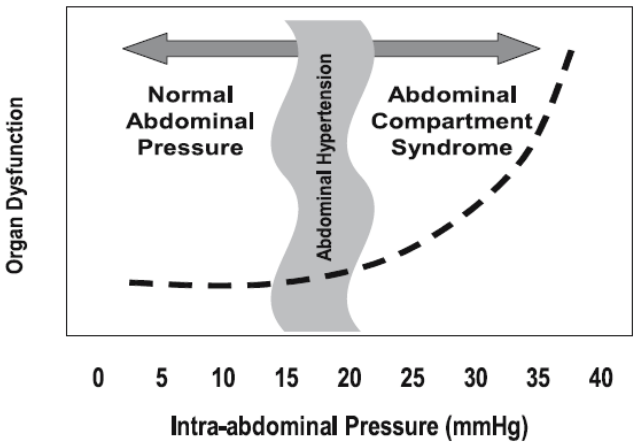


Figure 1: Range of intra-abdominal pressure (IAP). Increased IAP ≥12 mmHg or >20 mmHg is defined as intra-abdominal hypertension (IAH) and the abdominal compartment syndrome (ACS) respectively (4).

The IAP is found to be around 5-7 mmHg in healthy adults (17). However, an abnormally high IAP can cause intra-abdominal hypertension (IAH) or the abdominal compartment syndrome (ACS). IAH is defined by sustained or repeated elevations in IAP ≥12 mmHg and is graded into four levels: grade I, IAP of 12-15 mmHg; grade II, 16-20 mmHg; grade III, IAP 21-25 mmHg; and grade IV, IAP >25 mmHg. The ACS is characterised by pressures >20 mmHg and is associated with organ dysfunction (16, 18) (figure 1).

IAH and ACS are common among critically ill patients, and are identified as mortality predictors (19). Recently, Murtaza *et al.* measured the IAP in adult intensive care unit (ICU) patients who were mechanically ventilated and had an indwelling urinary catheter. The incidence and prevalence of IAH was reported to be 10% and 35% respectively. Therefore, measuring and diagnosing IAH timely and correctly is necessary to prevent progression towards ACS (20).

Risk factors for IAH and the ACS are related to diminished abdominal wall compliance (like surgery), increased intra-abdominal contents and/or to capillary leak and fluid resuscitation (appendix I) (16). Several management strategies exist to reduce IAP, depending on the etiology of IAH and the patient's condition. For example, intraluminal contents can be removed by inserting a nasogastric or a rectal tube. Apart from its use during surgery, sedation and analgesics in case of pain or inflammation can improve abdominal wall compliance by relaxing anterolateral abdominal muscles, which lowers IAP (1). The IAH/ACS medical management algorithm formulated by the WSACS is given in appendix II. Although most reports deal with the pathophysiologic implications of increased IAP in the ICU, the role of IAP in obstetrics has been less investigated (15).

1.2.1 Intra-abdominal pressure in pregnancy

In 1913, Paramore published the first report about IAP in pregnancy. He observed the pressure by means of a rectal catheter, and showed an increased IAP during the course of a healthy pregnancy (21). Staelens *et al.* recently investigated IAP in healthy term pregnancies one hour before and 24 hours after caesarean section (CS) by use of a Foley Manometer Low Volume (FMLV). Higher pressures were present before CS (14.0±2.6 mmHg), but significantly dropped to non-pregnant values after delivery (9.8±3.0 mmHg) (22). The findings are comparable with the research

performed by Fuchs *et al.*, who measured the IAP via a Foley catheter in 70 healthy women undergoing CS. They also found significant higher mean IAP values preoperative versus postoperative (14.2 vs. 11.5 mmHg). In addition, a significant higher preoperative IAP in obese pregnant women (15.7 mmHg) compared to non-obese (12.4 mmHg) was observed (23). Finally, Al-Khan *et al.* measured IAP through an intra-vesical catheter in 100 healthy pregnant women at term before and after CS. IAP was approximately 22 mmHg before delivery and decreased significantly to 16 mmHg postoperative (24). Altogether, 1) these studies indicate a higher mean IAP in obese women, 2) it demonstrates that IAP at term in a healthy pregnancy is >12 mmHg, and 3) IAP is significantly higher antepartum than after delivery. Consequently, IAP in term women without hypertensive disorders seems to equal the IAH criteria (15, 21-24).

The accumulating IAP during pregnancy can be explained by the progressive increasing abdominal volume. Besides the growing fetus, the amniotic fluid volume increases together with the placenta (15). It is reported that IAP is affected by birth weight and breech presentation (22). Furthermore, changes in maternal position and the restricted expansion capacity of the abdomen will influence IAP (15). The effect of body positioning on the IAP has been extensively investigated in the context of critical care. These patients have mostly an elevated head of the bed (HOB) to about 30°, which reduces the incidence of ventilation pneumonia (25). Rooban *et al.* showed that changing the position from supine to HOB30° increased the mean pressure from 12.3±4.5 mmHg to 15.8±4.9 mmHg (26). Significant differences between several HOB positions were also found by Vasquez *et al.*, who measured IAP in trauma patients at 0, 15, 30 and 45 degrees and concluded that the pressure increased with heightened HOB position (27). Since intra-abdominal contents may drop with HOB elevation, an external pressure is caused upon the bladder. Therefore, HOB elevation increases IAP indirectly when pressures are measured intra-vesically (25). In contrast, IAP measured in term pregnancy in the 10° left lateral tilt position (8.9±4.87 mmHg) was significantly lower compared to the supine position (10.9±4.67 mmHg). The result can be explained by the effect of the gravid uterus on the bladder, which might be eliminated in left lateral tilt (28).

Besides the effect of (maternal) body position, the lower abdominal compliance during gestation causes greater increases in IAP with any volume increase from the growing fetus (29). However it is unclear when the abdominal compliance reaches its maximum during pregnancy, the increasing IAP usually causes no organ dysfunction like in critically ill patients with ACS (15, 30). In normal pregnancies, hormonal influences allow the abdominal wall to stretch, thereby increasing compliance to adapt to the increasing IAP (30). However, normative IAP values during the course of pregnancy have not yet been defined. Additionally, it is speculated that IAH might have an important role in the occurrence of PE (15, 31).

1.2.2 Hypothesis: Intra-abdominal pressure as a cause of preeclampsia

Most hypotheses concerning the etiology of PE have been focussing on the placenta or the fetus. The strongest accepted hypothesis comprises the failure of the maternal spiral arteries to undergo vascular remodelling by a defective trophoblastic invasion, thereby reducing placental perfusion (32). Release of placental debris and other substances into the maternal circulation, evoked by the ischemic placenta, leads to maternal vascular endothelial dysfunction. Endothelial dysfunction then

increases the production of vasoconstrictors and reduces blood flow to multiple organs (10). However, it seems that the placenta and fetus are not essential for PE development, as the disease can occur in pseudopregnancies and in molar pregnancy without a fetus (33).

Paramore already suggested that high IAP might cause PE, because the fetus obstructs the venous return. Compared to the pressures in 22 normal pregnancies, much higher IAP values (18 and 22-37 mmHg) were observed in two patients with PE (21). However, his hypothesis never gained the necessary attention. Recently, few researchers have restarted exploring the role of IAH in pregnancy in order to find explanations for the origin of PE (15, 31). Several arguments have been proposed to support the hypothesis of increased IAP as cause for PE.

Firstly, PE is a human-specific disease, which may be explained by the standing position of humans compared to other land animals. Animals carrying their abdomen in the inferior position are suggested to have lower IAP, as no obstruction of the venous return is observed (3). A recent analysis of Paramore's raw data from 1913 showed a mean pressure value of -2.4±6.8 mmHg for the knee-chest position. Inverting the abdomen via the knee-chest position may therefore ameliorate PE in emergency cases (15). A second argument for the relationship between increased IAP and PE is the time-point upon which PE develops. PE manifests mostly in the third trimester of pregnancy, when the highest IAP values are present (6, 30). Thirdly, some overlap exists between the characteristics of PE and the ACS. Besides the presence of abnormal intra-abdominal contents like a tumour or in pregnancy, the fetus, high body mass index (BMI) is a serious risk factor for ACS (18). Obesity is also a principal risk factor for PE, since it increases the risk with almost three times. In addition, nulliparity and twin pregnancies are together with a maternal age >40 years associated with a higher risk to develop PE (6). The higher risk for nulliparous women can be explained by their abdomen, which has not been previously stretched. In multiple pregnancies, IAP may be elevated because the space in the uterus and the abdomen becomes too confined (3). An older age is related to a decreased abdominal compliance, and therefore can imply an increased risk for ACS and PE (34). Next to obesity and older age as common risk factors, similar symptoms between ACS and PE exist. The ACS is characterised by reduced cardiac output, peripheral edema through vena cava compression and bowel ischemia. Limited renal blood flow results in oliguria and anuria, developing from 15 mmHg and 30 mmHg respectively. Consequently, the ACS ultimately affects every organ system (19).

The role of increased IAP in the pathophysiology of PE is recently described by Sugerman (appendix III). He postulated that an increase in IAP compresses the venous system and decreases the venous flow. This further leads to lower body edema, fetal and placental ischemia. Placental ischemia results in decreased placental growth factors like Vascular Endothelial Growth Factor (VEGF), and can affect fetal growth. Limited portal and splenic venous flow causes ischemia and necrosis, elevated liver transaminases and hypersplenism. The effects on the liver are due to compression of the portal vein and hepatic veins, together with an increase in intra-thoracic pressure (3). Gyselaers *et al.* found significant differences in hepatic vein doppler velocity between normal pregnancies and PE. The lower velocity in PE is explained by the backflow of blood into the venous compartment upon atrial contraction, thereby confirming the reduced venous flow (35).

Since the abdominal compartment is closely connected to the chest, abdomino-thoracic pressure transmission can result from cephalad deviation of the diaphragm (19, 36). Moreover, increasing intra-thoracic pressure causes pleural pressures to rise and CO to decrease. In contrast to lower body edema due to inferior vena cava compression, lung edema and upper extremity edema can arise from increased intrathoracic pressure. It is shown that preeclamptic women with eclampsia have elevated cerebrospinal fluid pressures. Therefore, it is suggested that seizures in eclampsia may result from increased intracranial pressure, which develops when IAP raises pleural pressure. Finally, a decreased renal venous flow could activate the renin-angiotensin axis. The release of aldosterone and angiotensin converting enzyme causes hypertension (3). In a study of Bloomfield *et al.*, the relationship of increasing IAP with high blood pressures has been demonstrated experimentally in dogs. An intra-abdominal balloon was placed into the animals, and slowly inflated over four weeks to 25 mmHg. The increasing IAV created systemic hypertension that resolved with balloon deflation (37).

Zhang recently emphasised the association of hypertension and proteinuria in PE with secondary renal injury, caused by increased IAP. In his model, PE results from the interaction of elevated IAP with several risk factors. T235 homozygosity of the AGT gene for example, is associated both with hypertension, nephropathy and PE. The presence of pre-existing renal injury or the genetically sensitivity towards renal injury are the main criteria to develop PE, resulting from an increased IAP. The model of Zhang therefore explains why most pregnant women will not develop PE, although an increased abdominal pressure is present (33).

A final argument to support proposed hypothesis is the way both diseases can be treated. The WSACS reported decompressive laparotomy to be the ultimate treatment option for ACS, as it immediately decreases IAP and improves organ function (16). For PE, the only treatment option is delivery of the fetus and placenta, and releasing the maternal body from its ballast (6). Therefore, the curative effects of the disease could be due to abdominal decompression (15).

In conclusion, the potential influence of IAP and IAH in pregnancy remains poorly understood. Furthermore, normal pressure values throughout the course of pregnancy have not been defined properly as there is no easy, safe and non-invasive way to measure the IAP. Measuring IAP is however of great relevance to define standard IAP values in a pregnant population, which might act as the fundamental start. Thereby making it possible to detect and manage elevated abdominal pressures in patients at risk for PE (31).

1.3 Strategies to measure intra-abdominal pressure

Around the year 1900, Emerson proved that the intraperitoneal pressure is equal in different parts of the abdomen, which can be explained by its fluid nature (17, 34). The phenomenon is attributed to Pascal's law, stating that the total pressure in an enclosed fluid is transmitted equally to all portions of the nearby fluid (15). As such, several strategies to measure IAP directly or indirectly have been described. A balloon-tipped abdominal drain can for example be inserted to measure IAP directly in a continuous way. However, a direct IAP measurement is often complicated with bleeding and infections and is therefore not suitable to perform, certainly not in a pregnant woman (34).

1.3.1 The gold standard

The current gold standard method to measure IAP indirectly is via the bladder at end-expiration. Subjects need to be in supine position and abdominal muscle contractions have to be avoided. The zero reference point of the pressure transducer is set at the mid-axillary line (MAL) at the level of the iliac crest (16, 17). This point remains constant during HOB elevation, and represents the place of the urinary catheter tip inside the bladder (38). According to the WSACS guidelines, a maximal instillation volume of 25 ml sterile saline should be used to measure IAP (2, 16). It is shown that larger instillation volumes result in increased IAP values, thereby overestimating the actual pressure (39). The overestimated IAP can be explained by the bladder compliance, which may be lower after prolonged drainage in critically ill patients (40). However, there is still debate about the optimal volume for reliable measurements. De Laet *et al.* recently measured IAP transvesically with instillation volumes of 2 ml, 10 ml and 20 ml in 25 critically ill patients at risk for IAH. Although the significant difference between $IAP_{2\ ml}$ and $IAP_{20\ ml}$ was not clinically relevant, they concluded even 2 ml saline was enough to obtain an IAP curve (41). Another study reported 10 ml of saline to be sufficient (40).

The intra-vesical pressure (IAP_{Ves}) measurement technique was originally developed by Kron. IAP could be measured after disconnecting the Foley catheter and instilling 50-100 ml saline via a syringe. A manometer or pressure transducer was connected, by which the symphysis pubis acted as reference point. However, the Kron open system measurement technique is reported to be time-consuming and complex (42). Consequently, this original method has been adjusted in past few years by Iberti, Cheatham and Malbrain (2, 42). Currently, the intra-bladder pressure method is considered to be reliable (22). However, there exists some anxiety about the potential increased risk for urinary tract infections (UTI). While Duane *et al.* first observed a greater risk of UTI with the open system technique, measurements were not associated with an increased risk when the drainage catheter stayed attached to the bag (43, 44). Nevertheless, the duration of urethral catheterization seems to be an important factor in assessing the UTI risk (45).

The FMLV (figure 2) is a new device to measure IAP without the use of saline and a pressure transducer. After inserting the manometer between the Foley catheter and drainage bag, IAP can be determined via the height of the urine column (46, 47). The technique is safe and does not change the UTI rate in critically ill patients. These findings seem reasonable as the FMLV is a closed system and urine normally is sterile (47). Furthermore, measuring IAP in pregnant women with the

FMLV has shown to be reproducible (22). The FMLV is in addition a very simple and cost-effective method. Finally, it is a fast technique since only 10 seconds are needed per IAP measurement (2).

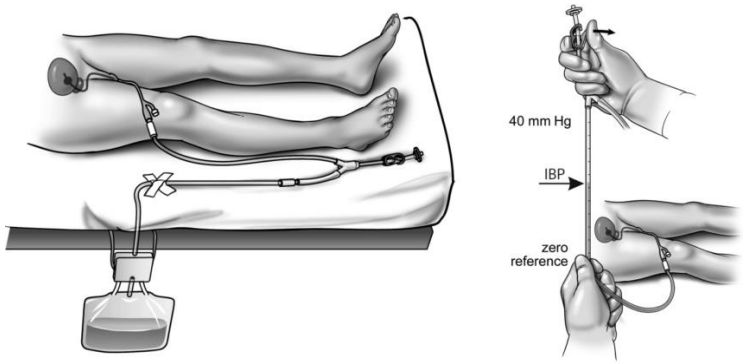


Figure 2: Intra- abdominal pressure measurement with the Foley manometer low volume (FMLV). The FMLV is placed between the urinary catheter and the drainage bag. Afterwards, the zero reference point is set at the MAL at the level of the iliac crest, while keeping the manometer in vertical direction. IAP can be measured by opening the clamp, after which the urine column drops according to the intra-vesical pressure. Finally, the pressure is read at end-expiration and the clamp is closed again (2). *MAL: Mid-axillary line.*

Although the FMLV technique in itself is easy to perform and does not increase the risk for UTI, IAP measurement via the bladder still has some drawbacks in the pregnant population. It is not a non-invasive technique as measuring pregnant women for IAH requires the placement of a urinary bladder catheter (48). Urethral catheterization is responsible for 70-80% of UTI and is not recommended to perform without prescribed indications (49, 50). Therefore, alternative indirect measurement methods have been investigated.

1.3.2 Alternative measurement methods

Previously, IAH was detected by physical observation and by measuring the abdominal perimeter. However, this approach is reported to be inaccurate because of a low inter-observer reliability and high variability risk (51). Van Mieghem *et al.* observed almost no correlation between IAP and the abdominal perimeter (R^2=0.12), and abdominal distension does therefore not always predict IAH (42).

Other ways to determine IAP by means of gastric, rectal, femoral vein, uterine or intra-peritoneal measurements have been described (2, 52). Recently, a novel device has been studied for simultaneous detection of gastric residual volume (GRV) and intra-gastric pressure (IGP) in critical care patients. This new device (GastroPV), which has to be placed between the nasogastric probe and the enteral nutrition feeding pump, showed good accuracy and precision (53). Turnbull *et al.* examined IGP measurement through a balloon catheter as strategy for continuous IAP monitoring. Although a linear relationship between IGP and IAP was seen, intra-gastric measurements are too invasive to perform in awake patients and consequently in pregnant women (54).

There is only scarce literature about the detection of IAP through rectal measurements. Our research group determined IAP rectally via a balloon-tipped catheter in 23 healthy term pregnant women. Another group of pregnant women underwent monthly IAP measuring starting from the first trimester. Good intra- and inter-observer correlations were found, but rectal IAP values

fluctuated within patients. Changing IAP values could be due to contractions and peristaltic bowel movements, switching positions of the fetus or the accumulation of stool (55). Therefore, the reliability of rectal measurements is rather unknown (15).

Femoral venous pressure measurement could be another way to represent IAP, which has been tested against bladder pressure. While an acceptable bias and precision of -1.5 and 3.6 mmHg were observed respectively, limits of agreement were too large (-8.7 and 5.7). However, with lower limits (-3 and 4.6), the femoral vein method might be useful when IAP is above 20 mmHg (56).

As none of these methods seems to be suitable for IAP measurement in pregnancy, a more simple and less invasive technique which correlates with the gold standard is desired. It is reported that IAP could be measured indirectly via the vagina, although this route is still experimental (2). Almost all studies about intravaginal pressure (IVP) measurement are aimed to investigate the role of IAP during physical activities in the occurrence of pelvic floor disorders (57, 58). Rosenbluth *et al.* developed a vaginal sensor and compared the pressures to rectal pressure in women undergoing urodynamic tests (filling cystometry). They found high correlations of 0.97, 0.94 and 0.97 between both methods after coughing, valsalva and squatting respectively (58). Even a wireless IVP transducer has been recently designed, which was comfortable and showed good correlation (r=0.97) with the conventional rectal balloon catheter used in urodynamics. However, the accuracy of the vaginal device in measuring absolute pressures was not determined because no comparison was made with a gold standard method (57).

In conclusion, the existence of a vaginal technique for IAP measurement specifically in pregnant women could be helpful. As such, standard IAP values in all phases of normal and complicated pregnancies can be determined safely and less invasively. This knowledge will further elucidate the potential presence and implications of IAH in pregnancy (31). In a future perspective, PE could be managed differently through IAP measurements and it might be a way to prevent or treat PE. Saving pregnant women from PE will furthermore improve both psychological and economic burden.

1.4 Aim

Since no reports exist about vaginal pressure measurements during pregnancy, the aim of this study is to assess an intravaginal pressure tip balloon catheter (IVBC) as a new method for IAP monitoring in pregnant women. It is hypothesized that measuring IAP using the less invasive IVBC is reliable, and that IVP values correlate with the gold standard. The first objective is to determine the repeatability and to investigate if the inflation volume influences the pressure. In addition, the effect of pelvic muscle contractions on the measured IVP will be investigated. Pressure values obtained after two weeks will be compared with the initial measurement to investigate reliability. The second objective is to determine the test-retest reliability of the gold standard method in patients admitted to the urology division. For the final objective, the reproducibility of the IVBC will be investigated compared to the gold standard.

2. Materials & Methods

2.1 Ethics

This observational pilot study was approved by the ethical committees of Ziekenhuis Oost-Limburg (ZOL, Genk, Belgium) and Hasselt University (Diepenbeek, Belgium) before study onset (12/084U) and confirmed to the Declaration of Helsinki (1964). Oral and written informed consent was obtained from all patients.

2.2 Validation of the intravaginal pressure tip balloon catheter

2.2.1 Patients

Three non-term pregnant and 23 non-pregnant women above 18 years old with a mean age of 43.8±13.6 years, who have been admitted at ZOL for a gynaecological consultation were included from November 2015 until January 2016. Exclusion criteria were the presence of a vaginal ring or a pessary, virgins, menstruating women and women with vaginal infections.

2.2.2 The intravaginal measurement device

The complete IVBC is a combination of an outer 2-way haematuria balloon catheter, 60-80 ml, 40 cm (Urovision, Bad Aibling, Germany) and an inner 18 T-DOC-7FA catheter (Laborie Medical Technologies Canada ULC, Mississauga, Canada), which is connected to the IVP detection machine (Ellipse Andromeda, Andromeda medizinische Systeme GmbH, Taufkirchen/Potzham, Germany) with 'Audact' software (figure 3A-B). The pressure channels of the Ellipse Urodynamic device were calibrated by Urotex Medical bv (Rhenen, The Netherlands) before delivery, in order that the measured values are valid. Due to the combination of both catheters, a preparation is necessary: the outer haematuria catheter tip is cut off up to the balloon thickening. In addition, a mark is applied on the inner catheter, at which the air-filled balloon could be brought outside the haematuria balloon catheter when its border equals the mark. The small air-filled balloon at the distal side of the inner catheter is charged with air, after which the monitoring device is zeroed with the air-filled balloon exposed to atmospheric pressure (figure 3B-C). Instead of mmHg as the accepted unit in literature, pressures are measured in cmH_2O.

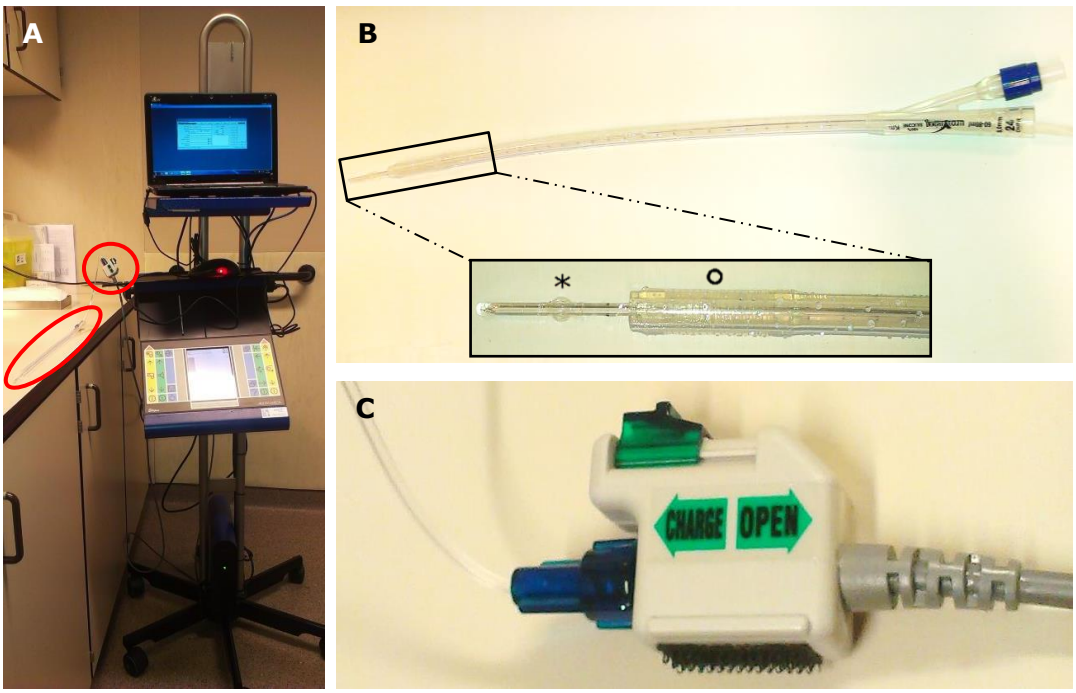


Figure 3: The intravaginal measurement device.
A) The IVP detection machine and laptop with 'Audact' software, to which the intravaginal catheter is connected via the charge-switch (red circles). B) The intravaginal catheter with the small air-filled balloon (*) and the balloon of the outer haematuria catheter that can be filled with water (°). C) The small air-filled balloon is charged with air by means of the charge-switch. *IVP: Intravaginal pressure.*

2.2.3 Protocol: intravaginal pressure measurements

In advance, the IVP measurement device was turned on and the IVBC was prepared as previously described. To facilitate IVBC introduction into the vagina, some lubricant was put on both the inner and outer catheter. Afterwards, the inner catheter was connected to the measurement device and the small air-filled balloon was charged with air. Finally, the device was zeroed with the air-filled balloon exposed to atmospheric pressure.

After agreement, the following data were collected for each patient: age, weight, length, BMI, number of pregnancies and the corresponding way of delivery. Next, the patient was installed in a gynaecological chair, which was placed in the 45° semirecumbent position. The IVBC was gently introduced in the vagina at the level of the fornix posterior, with the small-air filled balloon inside the outer catheter (tip-to-tip). Subsequently, the IVBC was retreated a little while the inner catheter was moved up until the applied mark on the inner catheter equalled the border of the outer catheter. The air-filled balloon was thereby exposed to vaginal pressures.

Firstly, IVP was measured when the outer catheter balloon was empty. To investigate the effect of inflation volume on the obtained pressure value, the balloon was successively filled with 20 ml, 40 ml, 60 ml and 80 ml water. For each volume, IVP was determined in 45° semirecumbent position at end-expiration. In addition, pressures were measured after contracting the pelvic and abdominal muscles in a selected group of patients (n=17) (figure 4). While emptying the balloon in steps of 20 ml, pressure again was measured at each volume both after end-expiration and after muscle stretching. In order to determine test-retest reliability, the IVBC was inserted a second time if

possible. As such, four pressure values per inflation volume were obtained. When finally the balloon was empty, the IVBC was removed and the measurement was stopped.

Before leaving, patients were asked to complete a small questionnaire about the applicability of the new intravaginal technique (appendix IV). To investigate if IVP values could be measured confidentially, six non-pregnant and one pregnant women underwent the same protocol after two weeks.

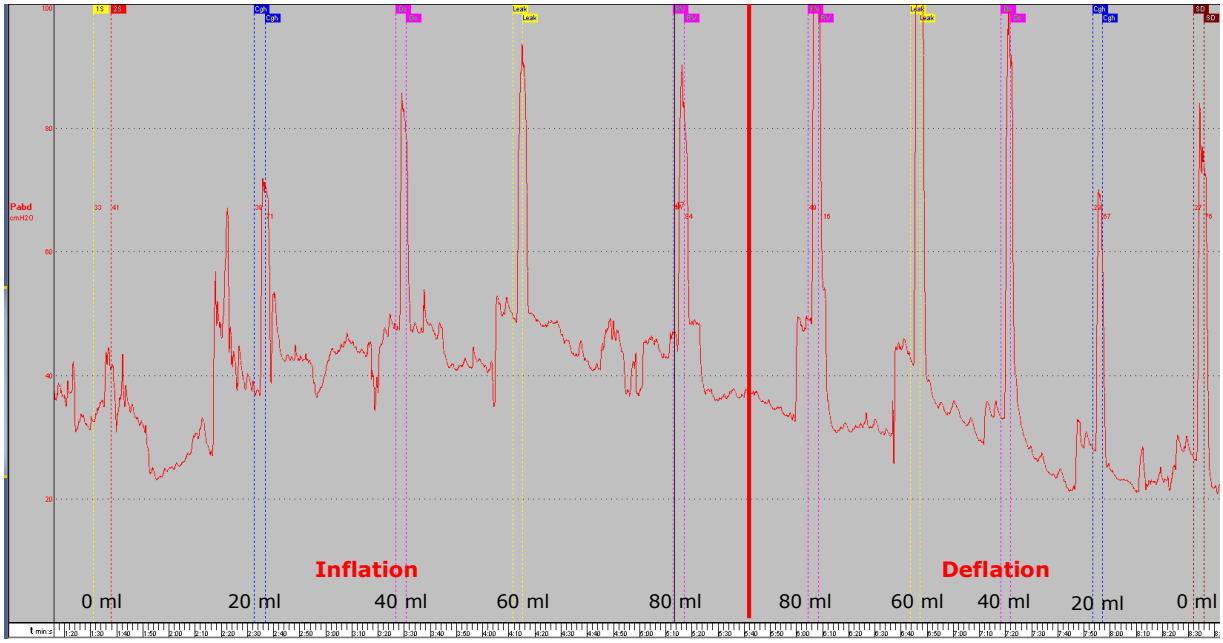


Figure 4: Intravaginal pressure measurements.
The graph shows vaginal pressures for only one cycle of balloon inflation (before red line) and deflation (behind red line). The dual lines represent IVP measured at end-expiration and after contracting pelvic and abdominal muscles respectively per inflation volume. S or SD (yellow, red, black lines): pressures at 0 ml, Cgh (blue lines): pressures at 20 ml, Dc (pink lines): pressures at 40 ml, 'Leak' (yellow lines): pressures at 60 ml and RV (pink lines): pressures at 80 ml. The x-axis represents time (seconds) while the y-axis represents the measured pressure in cmH_2O.

2.2.4 Statistics

IVP was measured in cm of water and converted to mm of Hg (1 mmHg= 1.36 cmH_2O). All data were registered in a Microsoft Excel database (Microsoft, Washington, USA) and statistical analyses were performed in IBM SPSS Statistics 23 (IBM Corporation, New York, USA) unless mentioned otherwise.

Normality was assessed using the Shapiro-Wilk test. For each inflation volume, repeatability was investigated by looking for correlations between the mean value of all four IVP measurements and the mean of one, two and three measurements performed at end-expiration using Spearman Correlation Coefficients (SPCCs). A Mann-Whitney test was performed to examine differences in mean pressures between women with low (BMI<25) and high BMI (BMI>25). The effect of balloon inflation on the observed IVP was investigated by means of a Friedman non-parametric test. In addition, a Dunn's Multiple Comparison post-test was done to compare all pairs of inflation volumes (GraphPad Prism 5.01, GraphPad Software, California, USA). IVP differences after contracting

abdominal and pelvic muscles compared to IVP values at end-expiration, were analysed using a Wilcoxon signed-rank test. The same test was performed to investigate IVP differences after two weeks. A p-value of <0.05 was considered significant for all tests.

2.3 Test-retest reliability of the gold standard method

2.3.1 Patients

During three weeks, test-retest reliability of IAP measurements through the Foley manometer (Bioengineering Laboratories SpA, Meda, Italy) was investigated in 10 patients with a mean age of 65.3±15.0 years, who have been admitted to the 'urology division' at ZOL. Patients were excluded if they did not have an indwelling urinary catheter or if the urine was too bloody due to a surgical intervention. Furthermore, exclusion criteria were contraindications to being placed frequently in the same position.

2.3.2 Protocol: intra-abdominal pressure measurements

After agreement, the Foley manometer was installed between the urinary catheter and the drainage bag, and the manometer was clamped distal to the sampling port. When the FMLV was filled with urine, the zero reference point was set at the MAL at the level of the iliac crest, while keeping the manometer in vertical direction. IAP was measured by opening the clamp, after which the urine column dropped according to the intra-vesical pressure. Finally, the pressure was read at end-expiration and the clamp was closed again *(ref. figure 2)*.

Besides one patient who was measured in the 45° semirecumbent position, because he was suffering from an operation, measurements were performed in supine position. The abdominal pressure was determined four times per patient, with a maximal time-interval of 85 minutes in between subsequent measurements. After each measurement, patients were replaced in their usual position. The following data were collected for each patient: age, gender, length, weight, BMI and diagnosis.

2.3.3 Statistics

IAP_{Ves} was measured in mmHg. All data were registered in a Microsoft Excel database (Microsoft, Washington, USA) and statistical analyses were performed by means of IBM SPSS Statistics 23 (IBM Corporation, New York, USA).

Normality was assessed using the Shapiro-Wilk test. Repeatability was investigated by looking for correlations between the mean value of all four IAP measurements and the mean of one, two and three measurements performed at end-expiration. Because of the small sample size (n<15), SPCCs were used. IAP_{Ves} values of patients with a BMI≤25 and a BMI>25, measured approximately in the supine position (n=9), were compared by means of a Mann-Whitney test. A p-value of <0.05 was considered significant for all tests.

2.4 Reproducibility against the gold standard method

2.4.1 Patients

From January 2016 until May 2016, 20 pregnant women above 18 years old with a mean age of 32.7±5.2 years, who have been admitted at ZOL for primary CS were included to compare the intravaginal method with the gold standard. Exclusion criteria were women with vaginal infections or complications, and patients with contra-indications for the placement of a bladder catheter. Furthermore, labour had to be absent and membranes had to be intact. One woman was measured at the maternity division after CS.

In addition to the pregnant women, four women above 18 years old (mean 47±9.6 years) admitted to the 'abdominal surgery division' at ZOL and having a bladder catheter were included. Exclusion criteria were a medical history of hysterectomy, the presence of a vaginal ring or a pessary, virgins, menstruating women and women with vaginal infections. Moreover, patients were excluded if they did not have an indwelling urinary catheter or if the urine was too bloody due to a surgical intervention.

2.4.2 Protocol: intra-abdominal pressure measurements

After agreement, women admitted for a primary CS were first measured with the intravaginal measurement technique before they received a bladder catheter *(ref. 2.2.3)*. Therefore, the IVP measurement device was turned on and the IVBC was prepared as previously described for the first part of the study. The device was zeroed with the air-filled balloon exposed to atmospheric pressure. Next, patients were measured at bedside in a position at which they felt most comfortable (usually 30° semirecumbent). The IVBC was gently introduced in the vagina as previously described, and the air-filled balloon was again exposed to vaginal pressures.

IVP was firstly measured when the outer catheter balloon was empty, and successively after inflation with 20 ml, 40 ml, 60 ml and 80 ml water. For each volume, IVP was determined at end-expiration. While emptying the balloon in steps of 20 ml, pressure again was measured at each volume. In total, the balloon was inflated two times if possible in order to obtain three pressure values per inflation volume, as determined in the first part of the study. When finally the balloon was empty, the IVBC was removed and the measurement was stopped.

Afterwards, the bladder catheter connected to the FMLV has been inserted to measure IAP via the bladder *(ref. 2.3.2)*. Vesical IAP measurements were performed like earlier described, in the same position adopted for the IVP measurements. The abdominal pressure at end-expiration was determined just once per patient, as determined in the second part of the study. Following data were collected for each patient: age, length, weight before pregnancy, weight before delivery, BMI, number of pregnancies (GPA-history) and the corresponding way of delivery, gestational age and the reason for CS.

For the patients admitted to the 'abdominal surgery division' and the woman at maternity, first the Foley manometer was installed between the urinary catheter and the drainage bag after

agreement. Subsequently, IVP was measured at the bedside in the most comfortable position at end-expiration, following the protocol stated above. Finally, IAP was measured once via the bladder in the same position. Following data were collected for each patient: age, length, weight, BMI, number of pregnancies (GPA-history), corresponding way of delivery and diagnosis.

2.4.3 Statistics

IVP was measured in cm of water and converted to mmHg (1 mmHg= 1.36 cmH_2O), while IAP_{Ves} was measured in mmHg. All data were registered in a Microsoft Excel database (Microsoft, Washington, USA) and statistical analyses were performed by means of IBM SPSS Statistics 23 (IBM Corporation, New York, USA).

Normality was assessed using the Shapiro-Wilk test. Outliers were detected by means of the Tukey method and visualised with boxplots. Next, linear regression analysis was performed to investigate the relationship between IVP and IAP_{Ves}. Vaginal pressure values (at every inflation volume) were transformed towards vesical pressures using the regression equation. Because of non-normality, SPCCs were calculated to determine correlations between calculated IAP_{Ves} and measured IAP_{Ves}. Differences between both techniques were analysed by means of Bland-Altman plots.

SPCCs were calculated between IVP or IAP_{Ves} and age, weight, length, BMI and gestational age to investigate influencing factors. Differences between the CS-group and the non-pregnant women measured at other divisions, between nulli- and multiparous women, between women with a delivery history of CS and those who underwent vaginal delivery, and between nulliparous and women with a delivery history of only CS were determined using a Mann-Whitney test. A p-value of <0.05 was considered significant for all tests.

3. Results

3.1 Validation of the intravaginal pressure tip balloon catheter

To determine the repeatability together with the effect of balloon inflation and pelvic muscle contractions on the observed pressure, IVP measurements have been performed in 26 patients of whom three non-term pregnant women (11.5%). However, insufficient data were obtained from six women (23.1%) because the catheter was not inserted a second time. The reasons for exclusion of the four non-pregnant women (66.7%) and two pregnant women (33.3%) are listed in table 1.

Table 1: Reasons for exclusion of patients.

Patient number	Pregnancy status	Explanation for exclusion
6	Non-pregnant	Experienced high pressure feeling at inflation volume of 80 ml.
7	Pregnant	Wanted to sit upright due to hot flushes.
11	Non-pregnant	Refused catheter replacement without specific reason.
14	Pregnant	Felt uncomfortable.
20	Non-pregnant	Technical problem; difficult to inflate the balloon with water.
26	Non-pregnant	Had little time.

3.1.1 Demographics

Data recorded from 19 non-pregnant women (95%) and one pregnant woman at a gestational age of 25 weeks (5%) were analysed. Demographic and clinical variables are shown in table 2. In total, the women had a median age of 45 years, and measured on average 165±7.3 cm. With a mean weight of 71.5±12.7 kg, BMI amounted 26.3±4.3. The non-pregnant group consisted of 15.8% nulli-, 26.3% primi- and 57.9% multiparous women. Altogether, 29 deliveries were counted from which one woman underwent two CSs (6.9%).

Table 2: Baseline characteristics of study patients.

Variables	Descriptive statistics (n=20)
Age (years)	45.0 (34.3; 47.0)
Length (cm)	165.0±7.31
Weight (kg)	71.5±12.7
BMI	26.3±4.3
Non-pregnant	19/20 (95%)
Nulliparous	3/19 (15.8%)
Primiparous	5/19 (26.3%)
Multiparous	11/19 (57.9%)
Vaginal delivery	15/16 (93.8%)
Caesarean section	1/16 (6.25%)
Pregnant	1/20 (5%)
Pregnancy number	1
Pregnancy duration (weeks)	25

Continuous data are demonstrated as mean ± standard deviation or as median (1^{st} quartile; 3^{rd} quartile) in case of non-normality. Categorical data are presented as proportion (percentage). *BMI: Body mass index.*

3.1.2 Repeatability

For each inflation volume (0 ml, 20 ml, 40 ml, 60 ml, 80 ml), repeatability of the IVBC was analysed by performing spearman correlations between the mean of one, two and three measurements and the mean value of all four IVP measurements (table 3). Therefore, IVP values at end-expiration were used. SPCCs increased with the mean number of IVP measurements performed towards a maximum SPCC of 1.000 (figure 5). For all inflation volumes, SPCCs above 0.950 were obtained with high significance ($p<0.01$) when IVP was measured three times, compared to mean values of all four measurements (figure 5). It is therefore suggested to perform triple IVP readings regardless the inflation volume. Together, these findings show that high repeatability of the intravaginal measurement technique is obtained. Data were further analysed using means of three pressure values for every inflation volume per patient, unless stated otherwise.

Table 3: Spearman correlation coefficients to investigate test-retest reliability.

Number of measurements	Inflation volumes				
	0 ml (n=17)	**20 ml (n=20)**	**40 ml (n=20)**	**60 ml (n=19)**	**80 ml (n=14)**
1 vs. 4	0.578*	0.820**	0.867**	0.942**	0.952**
	P=0.015	P=0.000	P=0.000	P=0.000	P=0.000
2 vs. 4	0.855**	0.970**	0.939**	0.951**	0.941**
	P=0.000	P=0.000	P=0.000	P=0.000	P=0.000
3 vs. 4	0.962**	0.992**	0.954**	0.989**	0.967**
	P=0.000	P=0.000	P=0.000	P=0.000	P=0.000
4 vs. 4	1.000	1.000	1.000	1.000	1.000

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

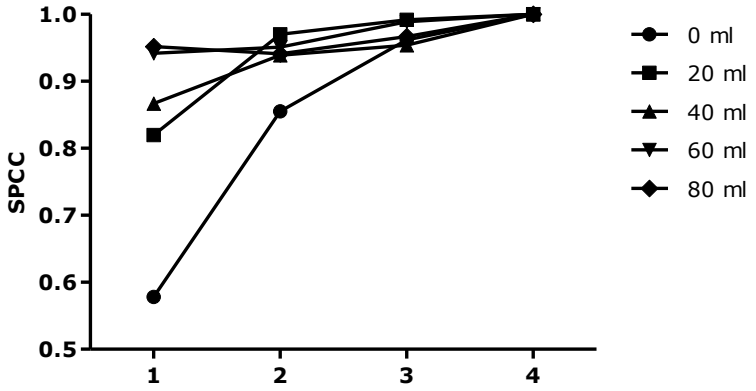


Figure 5: Spearman correlation coefficients related to the mean number of IVP measurements.
For each inflation volume, Spearman Correlation Coefficients (SPCCs) increased according the mean number of IVP measurements performed. When IVP is registered three times, SPCCs of 0.962, 0.992, 0.954, 0.989 and 0.967 were reached at inflation volumes of 0 ml, 20 ml, 40 ml, 60 ml and 80 ml respectively ($p<0.01$). To obtain high repeatability of the intravaginal measurement technique, it is suggested to measure IVP three times regardless the used inflation volume. *IVP: Intravaginal pressure*.

3.1.3 Effect of Body mass index

To investigate differences in mean pressure values between women with a low (BMI<25, n=11) and high BMI (BMI>25, n=9), Mann-Whitney tests were performed for every inflation volume. When the catheter balloon has not been inflated, women with a BMI<25 showed to have a mean IVP of 19.5±4.3 mmHg. In contrast, a higher, but not significant mean IVP (23.4±5.0 mmHg) was observed in the BMI>25- group (p=0.260, figure 6). By inflating the balloon to 20 ml, 40 ml, 60 ml and 80 ml, IVP increased similarly in both groups. Mean pressures of 26.6±7.7, 32.1±6.9, 40.3±10.7 and 43.8±19.1 mmHg were measured in women with a BMI<25 respectively (figure 6). Again, slightly higher pressures (20 ml: 30.7±10.1, 40 ml: 39.6±21.4, 60 ml: 46.6±21.2, 80 ml: 47.9±17.0 mmHg) were found with higher BMI (figure 6). However, differences between both groups were not significant with p-values of 0.503, 0.710, 0.710 and 0.679 at 20 ml, 40 ml, 60 ml and 80 ml balloon inflation respectively. In conclusion, these results indicate that although IVP differences between both groups were not significant, a higher BMI tends to increase the IVP.

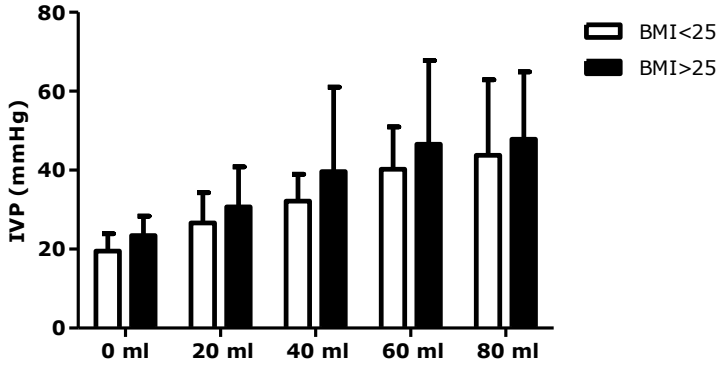


Figure 6: Mean IVP differences between high or low BMI- state.
For every inflation volume (0 ml, 20 ml, 40 ml, 60 ml, 80 ml), women with a BMI>25 (n=9) showed to have slightly higher mean IVP values compared to women with lower BMI (BMI<25, n=11). However, IVP differences between both groups were not significant (p>0.1).
Bars represent means + standard deviation. *BMI: Body mass index, IVP: Intravaginal pressure.*

3.1.4 Effect of balloon inflation

Since inflating the outer catheter balloon might influence the observed IVP, a Friedman test was performed to examine pressure differences between volumes. Therefore, data obtained from 15 women were analysed due to some missing values at 80 ml inflation. At the highest volume, five women felt uncomfortable or experienced a high pressure. Consequently, the volume of 80 ml during further measurements was avoided in these women.

The mean pressure value at end-expiration with an empty balloon was 21.8±5.0 mmHg. Overall, IVP significantly increased by inflating the catheter balloon with water (p<0.0001) (figure 7). At 20 ml, the pressure increased non-significantly to 29.0±8.9 mmHg (p>0.05). The IVP at 40 ml (36.7±16.0), 60 ml (43.1±16.8) and 80 ml (45.2±17.9) was significantly higher compared to 0 ml inflation (p<0.001). Furthermore, IVP at 60 ml and 80 ml differed significantly compared to the lower inflation volume of 20 ml (p<0.01). Altogether, these findings show that inflating the balloon with water gradually increases vaginal pressures.

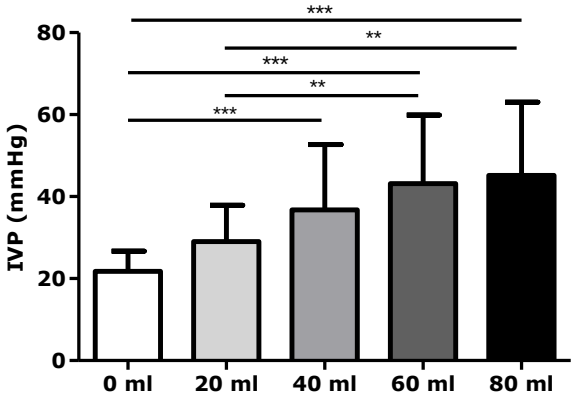


Figure 7: The effect of balloon inflation on measured vaginal pressures.
At zero inflation, measured IVP was on average 21.8±5.0 mmHg. By inflating the balloon with 20 ml, 40 ml, 60 ml and 80 ml, pressures significantly increased to 29.0±8.9, 36.7±16.0, 43.1±16.8 and 45.2±17.9 mmHg respectively (p<0.0001).
Bars represent means + standard deviation. *IVP: Intravaginal pressure.*
** Differences are significant at the 0.01 level, *** Differences are significant at the 0.001 level (2-tailed).

3.1.5 Effect of pelvic muscle efforts

Besides measuring IVP at end-expiration, pressures were monitored after contracting pelvic and abdominal muscles in a selected group of patients (n=17) to investigate the effect on IVP. From one woman with a weightlifting career in the past, results are discussed separately in a case study. Consequently, data from 16 women (BMI<25: n=8, BMI>25: n=8) were analysed by means of a Wilcoxon signed-rank test.

At end-expiration, mean IVP was 21.1±5.5 mmHg when the catheter balloon has not been inflated. Contracting the abdominal and pelvic muscles significantly increased the pressure up to 27.3±7.6 (n=16, p=0.001, figure 8). Comparable with the results above, IVP at end-expiration increased significantly to 29.1±9.0, 37.5±16.2, 46.1±16.2 and 48.1±15.7 mmHg after balloon inflation with 20 ml, 40 ml, 60 ml and 80 ml respectively (n=13, p=0.000). Consistently, significant increases in mean vaginal pressures were found after muscle contraction during respective balloon inflations to 39.0±12.4 (n=15, p=0.001), 47.5±15.8 (n=15, p=0.002), 54.9±17.5 (n=15, p=0.002) and 57.3±19.0 (n=13, p=0.002) mmHg (figure 8).

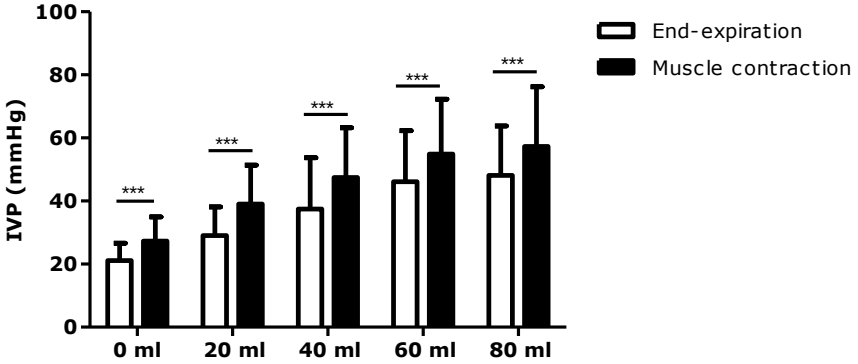


Figure 8: Mean vaginal pressure differences after abdominal and pelvic muscle contraction.
After contracting abdominal and pelvic muscles, mean vaginal pressures increased significantly compared to the values observed at end-expiration (0 ml: p=0.001, 20 ml: p=0.001, 40 ml: p=0.002, 60 ml: p=0.002, 80 ml: p=0.002). Bars represent means + standard deviation. *IVP: Intravaginal pressure.*
*** Differences are significant at the 0.001 level (2-tailed).

For a selection of women with a BMI<25, mean differences of 9.01±5.74, 13.6±10.5, 14.4±11.5, 11.1±11.6 and 12.9±13.1 between vaginal pressures at end-expiration and after muscle contraction at 0 ml, 20 ml, 40 ml, 60 ml and 80 ml inflation were observed. The pressure differences at end-expiration and after muscle contraction were smaller (0 ml: 3.37±3.22, 20 ml: 5.85±6.23, 40 ml: 4.84±6.95, 60 ml: 5.99±5.60 and 80 ml: 4.70±4.96) in women with a BMI>25. Only for the inflation volumes 0 ml and 40 ml, the pressure differences between both BMI-groups were significantly different ($p=0.036$ and $p=0.049$ respectively). IVP values for both BMI-groups at end-expiration and after muscle contraction are shown in appendix V. In conclusion, it is demonstrated that pelvic and abdominal muscle contraction have a significant impact on the measured IVP.

Intermezzo: a 45 year old woman with a professional weightlifting career.

On the 24th of November, a 45 year old woman came to the hospital on gynaecological consultation and agreed to participate in the study. In advance, Dr. Gyselaers told me she had a previous weightlifting career. Beside a world title and some European titles, she even took part at the Olympic games a couple of years ago.

Regarding the demographic variables, the patient measured 1.55 m and weighed 67 kg (BMI: 27.9). Her pregnancy state was nulliparous while declaring a conisation was performed. For an inflation volume of 0 ml, 20 ml, 40 ml, 60 ml and 80 ml, the mean IVP at end-expiration was 18.9, 23.1, 23.5, 34.6 and 28.0 mmHg respectively (figure 9). Instead of three measurements, IVP was only measured twice at 80 ml due to a high pressure feeling. The pressure values show to be lower, compared to the mean IVP at end-expiration from all other patients (n=16) previously described. However, enormously high pressures were found when the weightlifter contracted her abdominal and pelvic muscles. With mean IVP values of 122.4, 186.8, 162.6, 170.9 and 148.2 mmHg for each inflation volume (0 ml, 20 ml, 40 ml, 60 ml and 80 ml), she far exceeded the mean pressure values from all patients (n=16) after contraction (figure 9). Finally, both at end-expiration and after muscle contraction, pressures coming from the weightlifter showed no gradual increase with increasing inflation volume (figure 9).

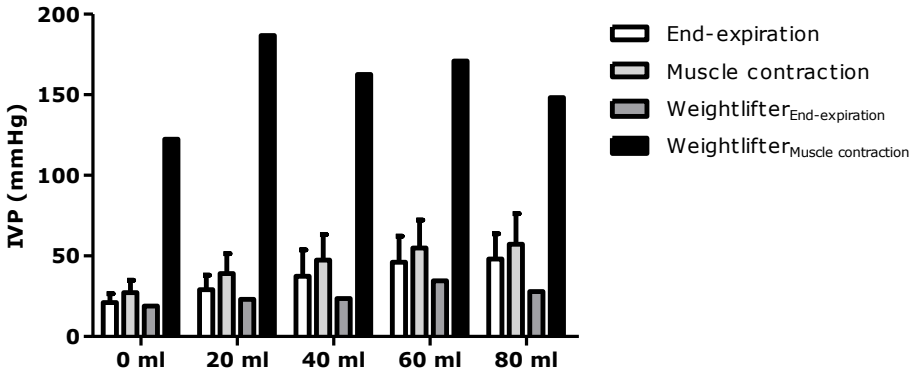


Figure 9: Vaginal pressures from a women with a previous weightlifting career.
Although this woman showed to have lower vaginal pressures at end-expiration (0 ml: 18.9, 20 ml: 23.1, 40 ml: 23.5, 60 ml: 34.6 and 80 ml: 28.0 mmHg) compared to the mean values from all other patients (n=16), pressures increased remarkably up to 122.4, 186.8, 162.6, 170.9 and 148.2 mmHg after contracting the abdominal and pelvic muscles. Bars represent means (+ standard deviation). *IVP: Intravaginal pressure.*

In conclusion, this case confirmed the influence of abdominal/pelvic muscle strength on vaginal pressure. The fact that this woman her muscles have been trained during the weightlifting career, explained the high pressure values observed after contraction. Therefore, IVP monitoring might be useful to examine abdominal/pelvic muscle strength.

3.1.6 Difference in time

To investigate if the intravaginal measurement technique is reliable when using a longer time-interval between subsequent measurements, six non-pregnant and one non-term pregnant women from the 26 women included (26.9%) underwent the same protocol after two weeks. Initially an appointment was made with 12 patients (46.2%), although five patients (41.7%) never came back to repeat the measurements. Two of them cancelled their appointment because of illness (40%), one woman because of menstruation (20%) and two women just not arrived (40%).

In total, no significant differences in mean IVP at end-expiration were found between the initial measurements and the measurements repeated after two weeks (figure 10). When the outer catheter balloon was empty, mean IVP was initially 19.9±3.5 mmHg and amounted 20.3±4.5 mmHg after two weeks (n=7, p=0.735). The first day, on average 28.3±6.6 (n=7), 33.5±6.9 (n=7), 40.9±13.4 (n=7) and 49.8±23.1 mmHg (n=5) was measured at 20 ml, 40 ml, 60 ml and 80 ml inflation. Approximately the same pressures were observed after two weeks (31.7±15.5, 37.7±20.3, 42.0±21.1 and 45.8±25.4) with p-values of 0.612, 1.000, 0.735 and 0.893 per inflation volume (figure 10). Altogether, it seems that the IVP measurement technique is reliable since IVP would not have changed drastically in two weeks.

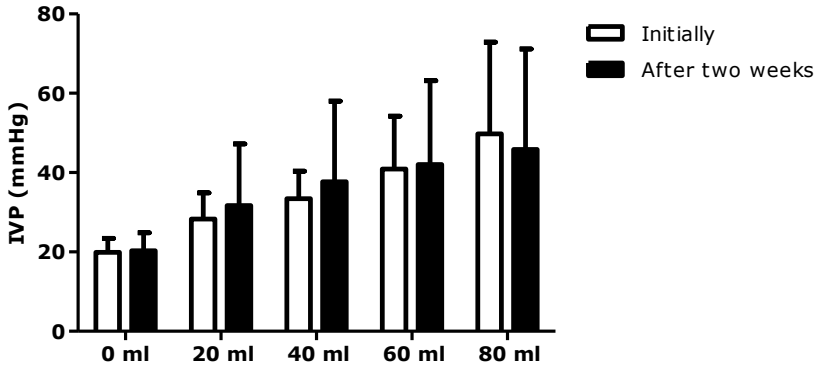


Figure 10: Vaginal pressure measurements with a time-interval of two weeks.
For each inflation volume (0 ml, 20 ml, 40 ml, 60 ml and 80 ml), the mean IVP measured after two weeks differed not significantly from the values obtained initially (p>0.05). While first pressures were on average 19.9±3.5, 28.3±6.6, 33.5±6.9, 40.9±13.4 and 49.8±23.1 mmHg, they showed to be respectively 20.3±4.5, 31.7±15.5, 37.7±20.3, 42.0±21.1 and 45.8±25.4 mmHg next time.
Bars represent means + standard deviation. *IVP: Intravaginal pressure*.

3.1.7 Applicability of intravaginal pressure measurements

The applicability of the intravaginal measurement technique was examined by means of a small questionnaire, which has been completed by 25 women. Only one of them (4%) reported to experience some inconveniences associated with inserting the IVBC. Although 22 women (88%) had no inconveniences with balloon inflation, one woman (4%) did at 60 ml and two women (8%) at 80 ml. Often an increased pressure was felt or a smarting feeling was recognised. Furthermore, one woman (4%) felt slight pain when the balloon was maximally inflated. In general, all patients were satisfied about the examination progress and indicated the intravaginal technique to be appropriate for standard use within pregnant women.

3.2 Test-retest reliability of the gold standard method

During three weeks, IAP_{Ves} measurements have been performed in 10 patients admitted to the 'urology division' to investigate the test-retest reliability of the gold standard intra-vesical technique. Data from all patients were used for repeatability analysis, whereas data from one patient measured in the 45° semirecumbent position was left out for general IAP analysis.

3.2.1 Demographics

Demographic and clinical variables are shown in table 4. In total, IAP was measured in six men and four women, with a mean age of 65.3±15.0 years. The mean length and median weight was 170.5±8.6 cm and 68.5 (63.4; 82.3) kg respectively, resulting in a median BMI of 24.2 (22.8; 27.5)

Table 4: Baseline characteristics of study patients.

Variables	Descriptive statistics (n=10)
Age (years)	65.3±15.0
Gender	
Men	6/10 (60%)
Women	4/10 (40%)
Length (cm)	170.5±8.6
Weight (kg)	68.5 (63.4; 82.3)
BMI	24.2 (22.8; 27.5)
Clinical diagnosis	
Abdominal pain	1/10 (10%)
Anterior resection	1/10 (10%)
Bladder infection	2/10 (20%)
Kidney stones	1/10 (10%)
Nephrectomy	1/10 (10%)
Prostate	2/10 (20%)
Ureterectomy	1/10 (10%)
Unknown	1/10 (10%)

Continuous data are demonstrated as mean ± standard deviation or as median (1^{st} quartile; 3^{rd} quartile) in case of non-normality. Categorical data are presented as proportion (percentage). *BMI: Body mass index.*

3.2.2 Repeatability

Repeatability of the gold standard was analysed by making spearman correlations between the mean of one, two and three measurements and the mean value of all four IAP measurements. Therefore, IAP values at end-expiration were used. SPCCs of 0.895, 0.933 and 0.963 were obtained with high significance ($p<0.001$), with increasing number of IAP measurements performed. When IAP was measured once, already a high correlation was observed compared to all four measurements. In conclusion, only one single measurement with the gold standard seems reliable. Mean IAP was therefore analysed using one pressure value per patient.

3.2.3 Intra-abdominal pressure at the urology division

From the patients measured in approximately the supine position (n=9), five had a BMI≤25 and four had a BMI>25. Mean IAP at end-expiration amounted 8.7±1.3 mmHg and 10.8±1.5 mmHg in the low and the high BMI-group respectively. IAP differences were not significant, but tend towards significance (p=0.080). This means that BMI might have an influence on the mean IAP.

3.3 Reproducibility against the gold standard method

Initially, 25 women of whom 20 admitted for primary CS (80%), four at the abdominal surgery division (16%) and one at maternity (4%), were included to compare the IVBC against intra-vesical measurement using the FMLV. However, only 20 women were used for analysis: two women undergoing CS, the bladder measurement failed due to time emergency; leakage of the balloon catheter disturbed IVP measurement in another woman at the abdominal surgery division. In addition, pressure values derived from one woman undergoing CS and from a woman at the abdominal surgery division did not lie between the lower and upper pressure limits ($IVP_{0\ ml}$: 6.61-36.1 mmHg, $IVP_{20\ ml}$: 11.6-36.6 mmHg, $IVP_{40\ ml}$: 10.4-40.8 mmHg, $IVP_{60\ ml}$: 6.75-48.9 mmHg, $IVP_{80\ ml}$: 4.4-49.5 mmHg, IAP_{Ves}: 8-108 mmHg). According to the Tukey method, these two patients were labelled as outliers (table 5 and appendix VI).

Table 5: Reasons for exclusion of patients.

Patient number	Hospital division	Explanation for exclusion
4	Delivery-room	Failed bladder measurement; Time emergency
6	Delivery-room	Failed bladder measurement; Time emergency
25	Abdominal surgery	Leakage of the IVBC
11	Delivery-room	Outlier; $IVP_{40\ ml}$= 43.4 and $IVP_{80\ ml}$= 65.8 mmHg
24	Abdominal surgery	Outlier; $IVP_{20\ ml}$= 70.6, $IVP_{40\ ml}$= 89.3, $IVP_{60\ ml}$= 66.2 and IAP_{Ves}= 4 mmHg

IVBC: Intravaginal pressure tip balloon catheter, IVP: Intravaginal pressure, IAP_{Ves}: Intra-vesical pressure.

Remark: Separated outlier detection for the 'section'-group (n=18) also revealed patient N°11 to be an outlier. However, separated detection for patients at both other divisions (n=4) found no outliers, due to the small sample size. Therefore, outliers were calculated for all patients together (n=22).

3.3.1 Demographics

Data recorded from the remaining 20 patients of whom 17 pregnant women undergoing CS (85%), one woman at maternity (5%) and two women at the abdominal surgery division (10%) were analysed. Demographic and clinical variables are shown in table 6. Mean age and BMI amounted 32.5±4.3 years and 31.5±6.1 respectively for the CS-group, while women at the other divisions were on average 45.3±11.0 years and had a median BMI of 28.4 (n=3). Except for one twin pregnancy, all women in the CS-group were going to have a single baby.

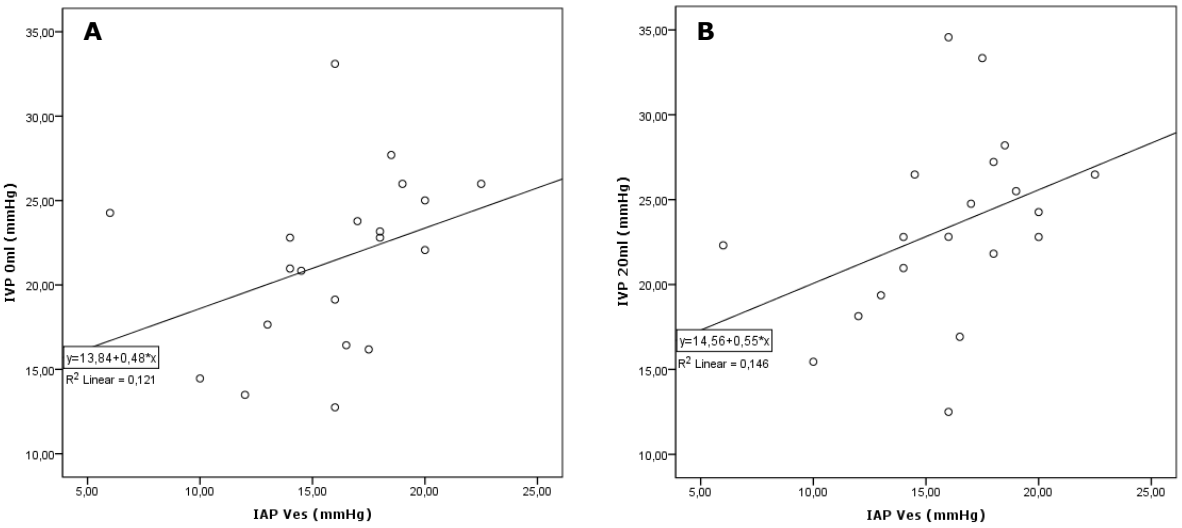
Table 6: Baseline characteristics of study patients.

Variables	Descriptive statistics	
	Women before CS (n=17)	**Other divisions (n=3)**
Age (years)	32.5±4.3	45.3±11.0
Length (cm)	163.8±6.3	163.3±4.7
Weight (kg)		78.5 (/)
Before pregnancy	70.3±14.9	
Before delivery	84.5±17.0	
BMI	31.5±6.1 (Before delivery)	28.4 (/)
Pregnancy history		
Nulliparous	3/17 (17.6%)	1/3 (33.3%)
Multiparous	14/17 (82.4%)	2/3 (66.7%)
Vaginal delivery	5/14 (35.7%)	1/2 (50%)
CS	8/14 (57.2%)	1/2 (50%)
Both	1/14 (7.1%)	0/2 (0%)
Gestational age	38w6d (38w1d; 39w0d)	/
Indication primary CS		
Breech presentation	5/17 (29.4%)	
Cervical rupture in history	1/17 (5.8%)	/
CPD	2/17 (11.8%)	
Repeat	7/17 (41.2%)	
Other	2/17 (11.8%)	

Continuous data are demonstrated as mean ± standard deviation or median (1st quartile; 3rd quartile) in case of non-normality. Categorical data are presented as proportion (percentage). *BMI: Body mass index, CS: Caesarean section, CPD: Cephalo-pelvic disproportion.*

3.3.2 Relation between intravaginal and intra-vesical pressure measurement

For every inflation volume (0 ml, 20 ml, 40 ml, 60 ml and 80 ml) used for vaginal pressure measurements, scatter plots were drawn to investigate the relationship between IVP and IAP_{Ves} (figure 11). IVP at 60 ml and 80 ml inflation has been measured in 19 and 17 patients respectively, instead of in all 20 women (due to high pressure feelings or discharge of the balloon). The slope and intercept of the regression line were calculated, assuming a linear relationship between IVP and IAP_{Ves}. The determination coefficient R^2 amounted 0.121, 0.146, 0.124, 0.019 and 0.053 respectively for the different inflation volumes. Changes in IVP can therefore be explained for only 12%, 14.6%, 12%, 1.9% and 5.3% by changes in vesical pressure.



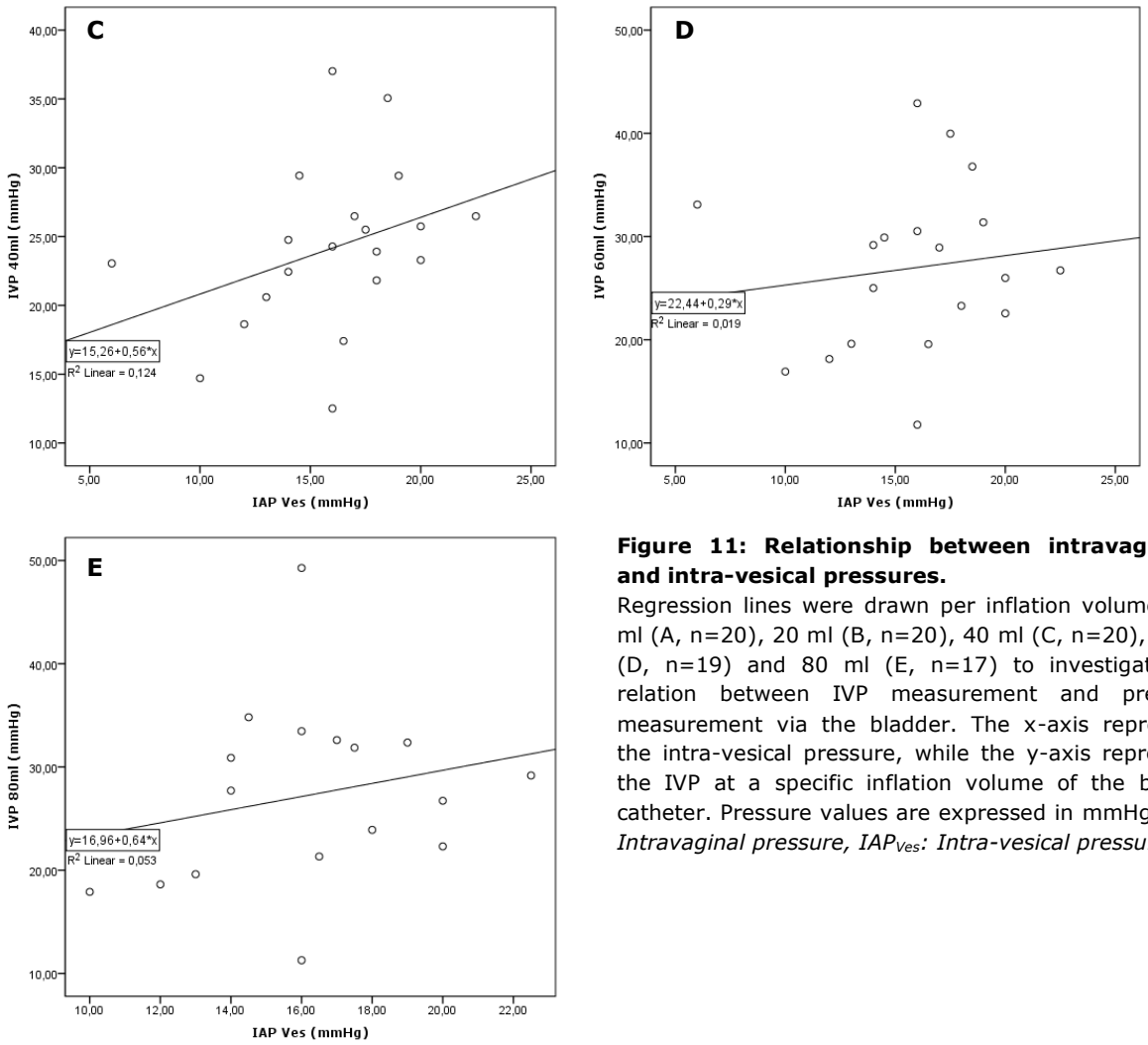


Figure 11: Relationship between intravaginal and intra-vesical pressures.
Regression lines were drawn per inflation volume of 0 ml (A, n=20), 20 ml (B, n=20), 40 ml (C, n=20), 60 ml (D, n=19) and 80 ml (E, n=17) to investigate the relation between IVP measurement and pressure measurement via the bladder. The x-axis represents the intra-vesical pressure, while the y-axis represents the IVP at a specific inflation volume of the balloon catheter. Pressure values are expressed in mmHg. *IVP: Intravaginal pressure, IAP_{Ves}: Intra-vesical pressure.*

SPCCs between calculated IAP_{Ves} values (using the regression equations above) and measured bladder pressures demonstrated weak correlations between both techniques (table 7). Without inflation of the vaginal catheter balloon, a significant correlation of 0.497 (p=0.026) with the measured vesical pressure is obtained. Inflation of the balloon up to 20 ml and 40 ml, also showed small but significant correlations of 0.511 (p=0.021) and 0.462 (p=0.041) respectively. Transformed IVP at 60 ml (SPCC=0.196, p=0.421) and 80 ml (SPCC=0.248, p=0.336) inflation demonstrated almost no correlation with measured bladder pressure.

Table 7: Spearman correlation coefficients between calculated and measured bladder pressures.

SPCC	**Transformed values**				
	$IAP_{Ves\ (0\ ml)}$	**$IAP_{Ves\ (20\ ml)}$**	**$IAP_{Ves\ (40\ ml)}$**	**$IAP_{Ves\ (60\ ml)}$**	**$IAP_{Ves\ (80\ ml)}$**
	N=20	**N=20**	**N=20**	**N=19**	**N=17**
Measured IAP_{Ves}	0.497	0.511	0.462	0.196	0.248
	P=0.026	P=0.021	P=0.041	P=0.421	P=0.336

SPCC: Spearman correlation coefficient, IAP_{Ves}: Intra-vesical pressure.

3.3.3 Agreement between intravaginal and intra-vesical pressure measurement

Mean IVP was 21.4±5.18 mmHg at zero inflation, while further balloon filling increased IVP to 23.3±5.46 mmHg (20 ml), 24.1±5.98 mmHg (40 ml), 27.0±8.04 mmHg (60 ml) and 27.3±8.73 mmHg (80 ml). Mean bladder pressure amounted 15.9±3.78 mmHg. Bland-Altman plots were performed to compare the intravaginal technique with the gold standard (figure 12). At 0 ml inflation, mean difference (bias) between IVP values and IAP_{Ves} values was 5.5±5.25 mmHg (n=20) with limits of agreement from -4.78 to 15.8 mmHg. Further inflating the catheter balloon up to 20 ml, 40 ml, 60 ml and 80 ml increased the bias between both techniques respectively to 7.41±5.32 (n=20), 8.20±5.84 (n=20), 11.1±8.43 (n=19) and 11.1±8.58 (n=17) mmHg. In addition, limits of agreement slightly increased with balloon inflation (20 ml: -3.02-17.8 mmHg, 40 ml: -3.25-19.7 mmHg, 60 ml: -5.37-27.7 mmHg and 80 ml: -5.76-27.9 mmHg). In conclusion, even without balloon inflation IVP differed from IAP_{Ves} measurement. Therefore, both techniques cannot be used interchangeably.

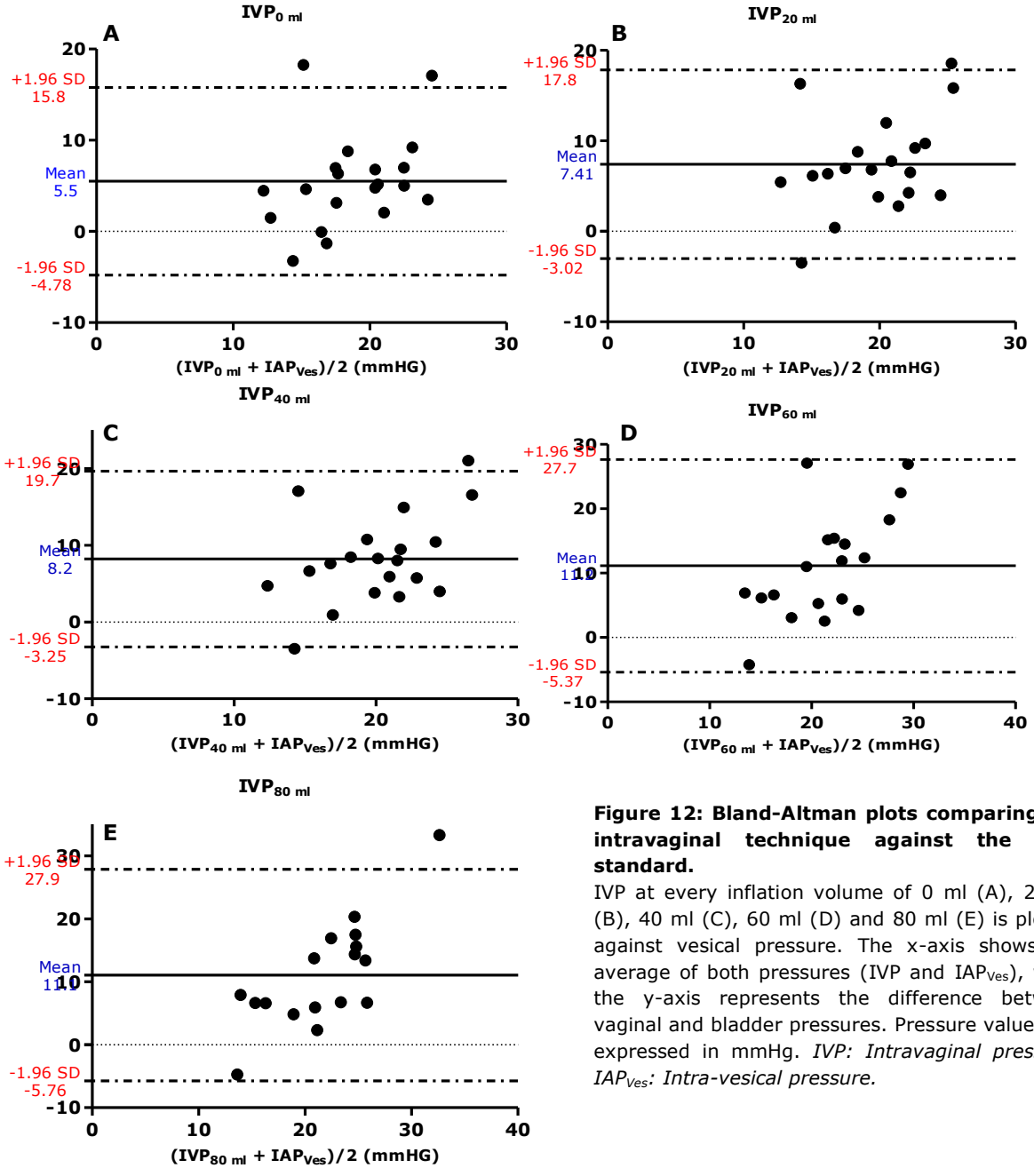


Figure 12: Bland-Altman plots comparing the intravaginal technique against the gold standard.

IVP at every inflation volume of 0 ml (A), 20 ml (B), 40 ml (C), 60 ml (D) and 80 ml (E) is plotted against vesical pressure. The x-axis shows the average of both pressures (IVP and IAP_{Ves}), while the y-axis represents the difference between vaginal and bladder pressures. Pressure values are expressed in mmHg. *IVP: Intravaginal pressure, IAP_{Ves}: Intra-vesical pressure.*

After transformation of IVP towards IAP_{Ves} using the regression equations, the mean difference between calculated and measured bladder pressures was 0 mmHg for every original inflation volume. However, standard deviations were 10.2, 9.15, 10.0, 27.9, and 13.4 mmHg at 0 ml, 20 ml, 40 ml, 60 ml and 80 ml inflation respectively, being higher than before transformation (appendix VI). Therefore, correction of IVP values towards bladder pressures did not improve the association between both techniques.

3.3.4 Factors influencing intravaginal or intra-vesical pressure

In total, no correlations were found between IVP or IAP_{Ves} and age, weight, length or BMI ($p>0.05$, $n=20$). Women in the CS-group ($n=17$) differed significantly in age (32.5±4.3 vs. 45.3±11.0 years, $p=0.029$) compared to non-pregnant women measured at the other divisions ($n=3$). Although the pregnant women seemed to have slightly higher pressures, differences were not significant (figure 13). Mean IVP for both groups were respectively 21.8±5.34 vs. 19.5±4.51 mmHg (0 ml), 23.4±5.47 vs. 23.1±6.59 mmHg (20ml), 24.4±5.92 vs. 22.7±7.44 mmHg (40 ml), 27.4±8.10 vs. 23.4±9.19 mmHg (60 ml) and 27.4±8.77 vs. 26.4±12.0 mmHg at 80 ml inflation. In the CS-group, mean bladder pressure was 16.2±3.78 mmHg compared to 14.2±4.01 mmHg in the non-pregnant women ($p=0.396$).

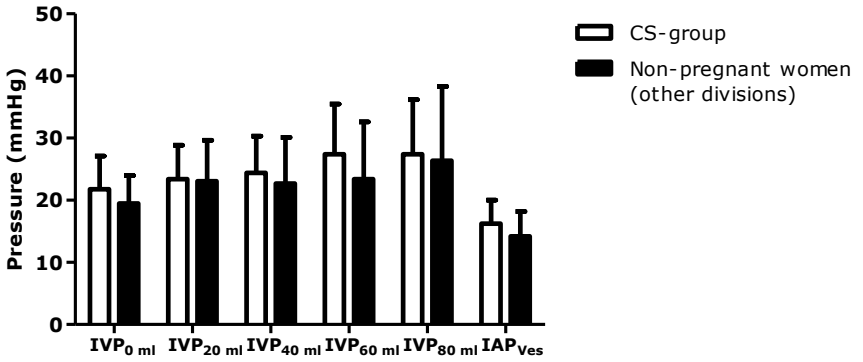


Figure 13: Intravaginal and intra-bladder pressures in women undergoing caesarean section versus non-pregnant women.

Both IVP (at all inflation volumes) and IAP_{Ves} were not significantly different ($p>0.05$) between pregnant women in the CS-group ($n=17$) and non-pregnant women measured at the other divisions ($n=3$).

Bars represent means + standard deviation. *CS: Caesarean section, IVP: Intravaginal pressure, IAP_{Ves}: Intra-vesical pressure.*

Within the CS-group, nulliparous women had significantly higher bladder pressures (20.5±1.8 mmHg, $n=3$) compared to multiparous women (15.3±3.47 mmHg, $n=14$) with a p-value of 0.014. Higher IVPs were also seen in nulliparous women compared to multiparous, however results were not significant yet, $IVP_{0\ ml}$ and $IVP_{40\ ml}$ tended towards significance ($p_{IVP0\ ml}=0.058$, $p_{IVP20\ ml}=0.166$, $p_{IVP40\ ml}=0.089$, $p_{IVP60\ ml}=0.705$, $p_{IVP80\ ml}=0.564$). IVP was respectively 25.7±0.57, 25.4±1.11, 27.2±1.95, 28.0±2.92 and 29.4±2.83 mmHg at increasing inflation volumes for nulliparous women, compared to 20.9±5.55, 23.0±5.95, 23.8±6.35, 27.2±8.91 and 26.9±9.74 mmHg for multiparous women (figure 14).

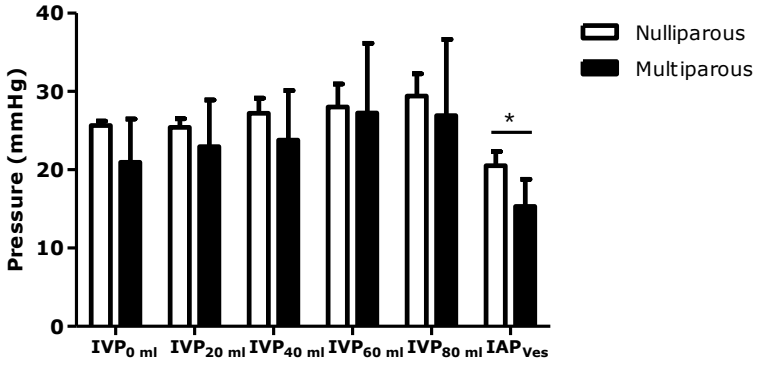


Figure 14: Intravaginal and intra-bladder pressures in nulliparous versus multiparous women.
At all inflation volumes, IVP seemed to be slightly higher in women who were pregnant for the first time (nulliparous, n=3) compared to multiparous women (n=14). However, IVP differences were not significant ($p>0.05$). Mean IAP_{Ves} in contrast was significantly different between nulliparous (20.5±1.8 mmHg) and multiparous women (15.3±3.47 mmHg) with a p-value of 0.014.
Bars represent means + standard deviation. *IVP: Intravaginal pressure, IAP_{Ves}: Intra-vesical pressure.*
* Correlation is significant at the 0.05 level (2-tailed).

From the multiparous women undergoing a CS, six women have been given birth vaginally in history while eight women underwent only CS. Mean IVP were 18.1±3.65, 21.6±7.01, 21.2±5.14, 26.0±9.7 and 26.1±8.43 mmHg at increasing inflation volume for women delivered vaginally in the past. Pressures differed not significantly ($p>0.05$) from those of women who gave birth only by CS ($IVP_{0\ ml}$: 23.1±5.93, $IVP_{20\ ml}$: 24.0±5.27, $IVP_{40\ ml}$: 25.7±6.76, $IVP_{60\ ml}$: 28.2±8.83 and $IVP_{80\ ml}$: 27.7±11.7 mmHg). However, there was a trend towards significance for IVP at 0 ml inflation ($p=0.061$). Mean IAP_{Ves} was 15.7±1.40 vs. 15.1±4.55 mmHg respectively for women delivered vaginally vs. those delivered by CS ($p=0.795$) (figure 15).

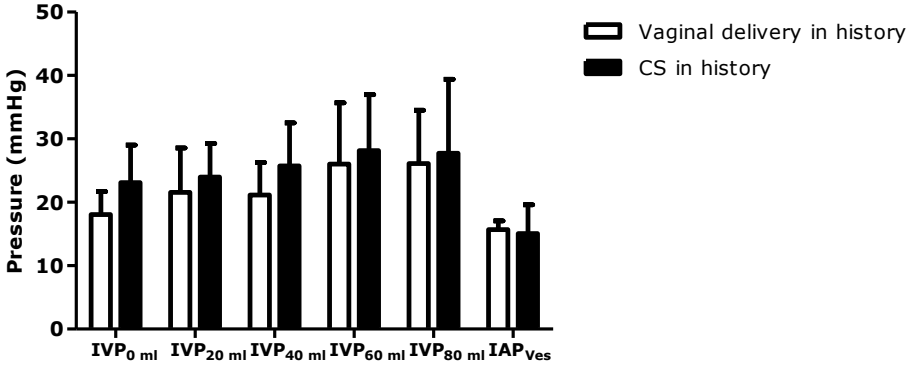


Figure 15: Intravaginal and intra-bladder pressures in women who delivered vaginally versus women who gave birth only through caesarean section in history.
Although IVP seemed to be lower in women who delivered vaginally (n=6) during previous pregnancies, no significant differences in IVP and IAP_{Ves} were found compared to women who gave birth only through CS (n=8) ($p>0.05$).
Bars represent means + standard deviation. *CS: Caesarean section, IVP: Intravaginal pressure, IAP_{Ves}: Intra-vesical pressure.*

Comparing pressures between nulliparous women (n=3) and women who gave birth only through CS (n=8) in history, revealed significantly higher IAP_{Ves} of 20.5±1.8 vs. 15.1±4.55 mmHg respectively for nulliparous women ($p=0.032$). In contrast, IVP was not significantly different between both groups at all inflation volumes ($p>0.05$).

In conclusion, pregnant women seemed to have slightly higher IVP and IAP_{Ves} compared to non-pregnant women. Furthermore, from the women undergoing CS, nulliparous women had significantly higher bladder pressures than multiparous women, which could not be showed yet significantly with vaginal pressures. Although not significant, vaginal delivery in pregnancy history seemed to decrease IVP. Finally, the influence of a previous pregnancy on the abdominal pressure was confirmed since nulliparous women had significantly higher intra-bladder pressures than women who gave birth only through CS in the past.

4. Discussion

In this study, an IVBC was developed and assessed as a new method for IAP monitoring in women at risk for PE. Before testing the intravaginal device against the current gold standard method via the bladder, its test-retest reliability was investigated in a first validation step.

4.1 Validation of the intravaginal pressure tip balloon catheter

In total, measurements were performed in 26 women of whom six women were excluded due to the inability obtaining four pressure values per inflation volume (0-80 ml). Solely in one woman failure was caused by a problem of the technique itself, since it was difficult to inflate the balloon with water. Subject-related problems like high pressure feelings at 80 ml, the presence of hot flushes or having limited time for the experiment were the culprit in other cases. Consequently, only complete and successful measurements derived from one pregnant and 19 non-pregnant women were analysed.

Repeatability

The intravaginal measurement method showed high repeatability when IVP was measured three times for every inflation volume. Compared to mean values of all four measurements, SPCCs above 0.950 were obtained with high significance using means of three pressure values. To avoid inter-observer variability, pressure monitoring was performed by a single researcher.

For all measurements, the IVBC was placed in the vagina at the level of the fornix posterior and zeroed to atmospheric pressure. Since the vagina is about 10 cm long, it is reported that different pressure zones exist along the vaginal length. While the distal zone should reflect atmospheric pressure, the deepest segment located above the pelvic diaphragm might represent IAP. The IVBC was therefore placed minimally 5 cm within the vagina (59). Although at second insertion the exact location of the catheter tip could have been changed, correct IVBC placement was assumed by the resistance felt upon moving the catheter ahead. Furthermore, exposure to vaginal pressures was confirmed by moving the inner catheter up until the applied mark equalled the border of the outer balloon catheter.

The WSACS recommends measuring IAP in the supine position at end-expiration (16). However, IVP was usually measured in the 45° semirecumbent position, which is known to increase IAP but was more comfortable (27). Since the same position was used for repeated measurements within a patient, repeatability could not have been affected by subject position. Moreover, respiratory variations were excluded by asking the patients to indicate when they had fully expired. A limitation of this strategy is that not everyone is able to perform the protocol correctly with a normal breathing pattern, for example by expiring too deeply. However, the lowest IVP values at end-expiration could be easily identified as pressures were continuously registered. Overall, it is suggested to perform triple IVP readings when all requirements are met.

Effect of Body mass index

Next, the validation tests showed slightly higher pressures in women with a BMI>25 compared to those with a BMI<25. However, our results were not significant which might be explained by the small sample size in both the high and low BMI-group. Possibly, if more women would have been measured, significant differences in IVP would be expected. Nevertheless, the results are similar to those of Sanchez *et al.*, who found significant higher IAP in patients with higher BMI. They measured IAP in 77 hospitalized patients (36 females, 41 males) through the procedure described by Kron, using an indwelling Foley catheter. Individuals with a normal BMI had a mean IAP of 5.0±2.9 mmHg vs. 8.9±3.5 mmHg in obese patients (60). Even though they placed patients in the supine position during IAP measuring, approximately the same differences in vaginal pressures between both BMI-groups are found in our study, and this for every inflation volume. In addition, Fuchs *et al.* reported significant higher preoperative IAP in obese pregnant women (15.7 mmHg) compared to non-obese (12.4 mmHg). Pressure was measured in 70 healthy women undergoing CS through a Foley catheter following the WSACS guidelines (23). Because we measured all patients in 45° HOB position with the new intravaginal technique, absolute IVP values cannot be compared to these studies. Moreover, Fuchs *et al.* measured IAP in term pregnant women, who had higher BMI and were found to have higher IAP compared to non-pregnant women (23). By inflating the balloon to 80 ml, IVP increased similarly in women with a BMI<25 and a BMI>25. Therefore, it is suggested that BMI has no effect on balloon inflation. Van Mieghem *et al.* observed almost no correlation between IAP and the abdominal perimeter (R^2=0.12) in 12 ICU patients, indicating that an increase in IAP is not necessarily caused by an increased abdominal perimeter (42). Sugerman *et al.* found significant different pressures of 5.1±1.2 mmHg vs. 13.2±0.5 mmHg in surgical patients with low vs. high BMI respectively. In contrast to the study of Van Mieghem, the observed correlation between IAP and the abdominal perimeter suggests that an increased IAP can cause hypertension, diabetes or other risks associated with obesity (25). Obesity and accordingly IAH are furthermore reported to be a principal risk factor for PE (6, 15). In conclusion, a slightly increased IVP was observed in women with higher BMI, thereby possibly confirming the link between obesity and IAH.

Effect of balloon inflation

At zero inflation, a mean IVP of 21.8±5.0 mmHg in the 45° semirecumbent position was found. Overall, IVP gradually increased by inflating the intravaginal catheter balloon with water up to 20 ml, 40 ml, 60 ml and 80 ml. Significant pressure differences were observed between zero inflation and the three highest inflation volumes (40 ml, 60 ml and 80 ml). Furthermore, the IVP at 60 ml and 80 ml differed significantly compared to the lower inflation volume of 20 ml. Although in the context of assessing pelvic floor muscle strength, squeeze pressures are usually measured in another vaginal segment, it is reported that different probe sizes give various results (59, 61). Applied to our study, the increasing IVP with inflation can be explained by an autonomic vaginal muscle reflex when the catheter balloon becomes larger. Recently, Broens *et al.* investigated the existence of a vaginal sphincter mechanism in asymptomatic nulliparous women. By inflating an intravaginal balloon, an autonomic reflexive process of vaginal and/or other muscles was noticed (62). Vaginal constriction due to this smooth muscle response might therefore be responsible for

the observed increasing IVP. Even some women experienced a high pressure feeling or felt uncomfortable at 80 ml inflation, and were not further measured at the highest volume. Their data therefore have not been analysed for investigating the inflation effect on IVP. Since the high balloon size may indeed provoke anxiety or discomfort, it is believed that a smaller balloon volume is more acceptable.

However, while in most women IVP clearly increased with balloon inflation, IVP remained relatively constant in some others (data not shown). This observation explains the higher standard deviation of IVP when the catheter balloon was more inflated. Individual differences in IVP increase might be dependent on the vaginal opening size or on the compliance of the vaginal wall (61). It is therefore suggested that a small opening or a low compliance of the vaginal wall results in higher IVP increases by inflating the catheter balloon. These subject dependent differences might also bias our later analysis when comparing the golden standard technique with IVP.

Altogether, inflating the balloon with water gradually increased vaginal pressures. The question remains which inflation volume is most optimal for IVP measurement and if the balloon has to fit the size of the vagina. In addition, the inflation volume at which the IVP measurements might truly reflect IAP needs to be elucidated. Vasquez *et al.* measured 45 trauma patients with a mean BMI of 28.3 via their indwelling Foley catheter. In the 45° HOB position, IAP values of 16.7 mmHg were observed at end-expiration (27). In contrast, IVP in our 15 non-pregnant women at zero-inflation was slightly higher (21.8±5.0 mmHg) whereas they had a lower BMI of 25.5±1.13. Since the zero reference point was not defined, Vasquez *et al.* might have measured IAP at the level of the symphysis pubis instead of using the recommended point at the MAL (16, 27). It is shown that IAP with the reference level at the symphysis pubis is significantly lower compared to IAP measured with the reference point at the MAL (63). Therefore, their observed IAP_{Ves} might approach the IVP values measured in our study. The results are equally comparable with the research of McBeth *et al.*, who measured IAP in 37 critically ill intubated patients (mean BMI: 30±13) in different HOB positions. With the pressure transducer placed in-line with the iliac crest at the MAL, mean IAP amounted 21.5±5.0 mmHg in the 45° HOB position (64). Regarding these studies, IVP measured with the IVBC might reflect IAP measured through the gold standard. However, we included healthy women compared to the trauma and critically ill patients measured in the other studies. Since the latter are often at risk for IAH and the ACS, no strict conclusions can be drawn about the IVP values found in our healthy study population (65).

Effect of pelvic muscle efforts

After measuring IVP at end-expiration, pressures were registered after contracting pelvic and abdominal muscles. Muscle contraction significantly increased IVP as expected, and this approximately in the same amount for every inflation volume. The squeeze pressures lie in the range of 30-60 mmHg observed by Kegel, who was the first to determine vaginal pressures in order to evaluate pelvic floor strength (66). However, since the mid high-pressure zone of the vagina is speculated to reflect pelvic floor muscle contraction, and we placed the IVBC in the proximal zone, no assumptions about pelvic floor muscle strength can be made (59). Jung *et al.*

proposed that the puborectalis muscle, located caudal to the pubococcygeus, is responsible for the constrictor function of the pelvic floor (67). Furthermore, our study subjects were not instructed to contract the pelvic floor correctly and no vaginal examination was performed to ensure contraction of the levator ani. Even inward movement of the catheter for validation of correct pelvic floor muscle contractions was not evaluated (61). Instead, patients were only asked to contract their abdominal or pelvic muscles, since it was not aimed to test pelvic muscle strength. Due to the proximal location of the IVBC and the incorrect instructions, it is suggested that the observed IVP increases are mainly caused by abdominal muscle contractions. In addition, inter-subject variation exists because of individual differences in abdominal muscle strength. Nevertheless, our new intravaginal measurement method might be useful for measuring pelvic floor muscle strength if the catheter is placed correctly in the high pressure zone, and if all mentioned requirements are accomplished.

Guaderrama *et al.* found the vaginal pressure in the proximal zone to be 7 mmHg at rest and 12 mmHg after pelvic muscle contraction. Using a four-channel water-perfused manometry catheter, IVP was measured in 14 nulliparous women with a mean age of 42 years (59). Their results are different from the pressure values measured with the IVBC, which were on average 21.1±5.5 mmHg at end-expiration and 27.3±7.6 mmHg after muscle contraction (zero inflation). Although the absolute pressure values in our study are higher, about the same IVP increase after contraction is observed (5.0 vs. 6.2 mmHg). However, it is difficult to compare the results since Guaderrama reported no information about BMI and measurement position (59). Another limitation that could have biased our IVP values might be the fatigue of the abdominal and/or pelvic floor muscles as the test proceeded. This could have been solved by recording the maximum squeeze pressure instead of calculating the mean IVP value of all three muscle efforts.

Difference in time

Six non-pregnant women and one pregnant woman underwent the same measurements after two weeks, in order to investigate differences in IVP values. However, about the same IVP values at end-expiration for all inflation volumes of the catheter balloon were found on both measurement days. The pressure within the abdominal cavity is only tended to increase when risk factors for IAH or the ACS, like abdominal surgery or sepsis are present (68). Since healthy subjects without known risk factors were measured, no IVP differences were expected. Furthermore, no IVP changes were observed in the pregnant woman, although it is reported that IAP increases during the course of a healthy pregnancy (21). It is suggested that abdominal pressure might not have increased rapidly, since the third trimester was not reached yet (25 weeks pregnant) and therefore the abdomen still had some capacity to expand. In addition, the absence of pressure differences could be explained by the relatively small time period in between the measurements, in which potential pressure changes might not have become significant. Assuming that IVP remained quite stable during this time period, it seems that the vaginal measurement technique is reliable in detecting the same pressures. However, a limitation is the low number of subjects that was measured after two weeks.

Applicability of intravaginal pressure measurements

In general, the intravaginal pressure measurements were accompanied with minimal discomfort. Most women had no complaints with balloon inflation, while a minority did at the highest inflation volumes (60-80 ml). It seems therefore more acceptable to measure IVP at a lower inflation volume. Compared to the placement of a bladder catheter, a rather invasive procedure, inserting the IVBC is not painful and less inconvenient. In conclusion, we proved that the IVP monitoring method has a good applicability for its use within pregnant women.

4.2 Test-retest reliability of the gold standard method

Next, the test-retest reliability of the gold standard method was determined in patients admitted to the urology division. One IAP measurement showed a high correlation compared to the mean of all four measurements. The results confirm the high intra-observer correlation of IAP measurements according to the bladder pressure method, previously shown by our research group (22).

The IAP_{Ves} measurements were performed with irregular time intervals in between, although most measurements could have been performed every 10-20 minutes. These irregularities were caused by individual velocity differences for filling the FMLV with urine. Depending on the patient his/her condition, urine might have been produced at a higher or lower rate. Nevertheless, all individual IAP recordings were taken within a four hour period, to reduce the potential for confounding due to a change in clinical status.

Besides one patient, who was uncomfortable due to surgery, all patients were measured in approximately the supine position. Although the supine position was not exactly specified, significant IAP increases ≥2 mmHg just occur starting from 20° HOB elevation (69). IAP was furthermore recorded at end-expiration by observing the lowest level of the urine column. Using the MAL at the level of the iliac crest as zero reference, the current guidelines for IAP_{Ves} measurement were followed (2). Among these circumstances, a mean IAP of 8.7±1.3 mmHg and 10.8±1.5 mmHg was found for patients with a low and a high BMI respectively. Although these IAP values were not significantly different, probably because of the low sample size, they support the relationship between IAP and BMI (25).

It is reported that IAP in healthy individuals is around 5-7 mmHg, whereas pressures ≥12 mmHg characterise IAH (17). The IAP_{Ves} values measured at the urology division as such were found to be increased, although no IAH was observed. Similarly, critically ill patients are known to have pressures of approximately 10 mmHg (17). Van Stappen *et al.* compared a combined method for GRV and IGP measurement, to bladder pressure measurement via a FMLV in 37 ICU patients. Mean IAP_{Ves} amounted 10.7±4.1 mmHg, accompanied with a mean BMI of 26.2±6.3 and supposing pressures were measured in the supine position (53). The increased IAP may be explained by conditions like ascites, bowel edema, the accumulation of blood or other space-occupying lesions, which may induce IAH (65). The elevated IAP in our patients at the urology division can also be explained by the risk factors associated with IAH. A lot of them underwent surgery, which can diminish the abdominal wall compliance (16). In addition, pain may increase the thoracoabdominal muscle tone leading to an increased IAP (69).

4.3 Reproducibility against the gold standard method

The final part of this pilot study aimed to compare IVBC measurement with IAP_{Ves} monitoring (FMLV), using both techniques in women admitted for primary CS, at the abdominal surgery division or at maternity. The pregnant women experienced a healthy course in pregnancy. In total, two patients were labelled as outliers having IVP or IAP_{Ves} outside calculated pressure ranges: 1) IVP in the woman undergoing CS might not have been measured correctly at end-expiration and was only recorded twice per inflation volume (lack of time). Therefore, IVP might have fluctuated resulting in deviate pressure values at 40 ml and 80 ml inflation. 2) The outlier detected at abdominal surgery was characterized by a low BMI of just 15.4. Although her intra-bladder pressure (4 mmHg) was comparable with the pressures found by Sanchez *et al.* for mild nourished and normal subjects (4.9±2.9 mmHg), it is unclear why IVP at 20 ml, 40 ml and 60 ml was quite high (60).

Relation and agreement between intravaginal and intra-vesical pressure

Scatter plots investigating the relationship between IVP and vesical IAP showed low determination coefficients for all inflation volumes, indicating only a weak linear association between both techniques. Therefore, when IVP would be measured to calculate IAP_{Ves} using the regression equations, little variance in vesical pressure can be predicted by IVP. SPCCs between measured intra-vesical and calculated bladder pressures were slightly positive but significant at balloon volumes ≤40 ml. However, IVP at inflation volumes ≥60 ml showed no correlation (SPCC<0.25). Lower correlations at high inflation volumes (60 ml and 80 ml) could be explained by the individual differences in IVP increase upon balloon inflation earlier explained. In addition, Bland-Altman analysis showed increasing bias between both techniques with increasing inflation volume. The observation confirms the increase in mean IVP with inflation, also found in the first part of the study. Two methods can be used interchangeably if R^2 is >0.6 (53). WSACS recommends furthermore a bias of <1 mmHg with a precision of 2 mmHg and limits of agreement between -4 and 4 mmHg (2). Even without inflating the catheter balloon, R^2 was 0.121 and bias amounted 5.5±5.25 mmHg, resulting in limits of agreement from -4.78 to 15.8 mmHg. Consequently, correlation between IAP_{Ves} and IVP measurement was too low and bias too high to consider IVP a valuable alternative for the gold standard. IVBC measurement might therefore not represent true IAP. Transforming IVP towards IAP_{Ves} still increased standard deviations from the bias (0 mmHg), indicating that correction of IVP towards IAP_{Ves} is not very reliable.

HOB elevation significantly increases measured IAP (27, 38). However, it is unlikely that HOB elevation has affected pressure measurement, since both techniques were performed in the same position. Low correlation between IVP and vesical pressure measurements may be caused by different urine volumes within the bladder at the moment of FMLV placement (in CS patients). Malbrain *et al.* reported significantly increasing intra-bladder pressures with increasing instillation volumes (39). Therefore, as no previous drainage has occurred, variable filling status could have influenced IAP_{Ves}. In addition, IVP measurement was sometimes not feasible to be repeated three times, limiting reliability of some IVP values. Another explanation for low correlation and agreement between both measurement techniques are characteristics of the local subject

dependent environment like smooth muscle pressure, which influences pressures measured from each location (70).

Factors influencing intravaginal or intra-vesical pressure

Besides these factors, other parameters possibly affecting IVP or IAP_{Ves} were investigated. Although it is reported that IAP is influenced by BMI, no correlation with IVP or bladder pressure was found (25). Comparing the CS-group ($IVP_{0\ ml}$: 21.8 and IAP_{Ves}: 16.2 mmHg) with the non-pregnant women ($IVP_{0\ ml}$: 19.5 and IAP_{Ves}: 14.2 mmHg) revealed slightly higher pressures in the pregnant women, although not significant, probably due to the low sample size of the non-pregnant group. In a study of Chun *et al.*, IAP of twenty term pregnant women was 10.9±4.67 mmHg in the supine position at end-expiration, as measured via the bladder (28). Staelens *et al.* measured IAP before CS in the supine position using a FMLV and found IAP to be 14.0±2.6 mmHg (22). Compared to these studies, IAP_{Ves} we observed (16.2±3.78 mmHg) was slightly higher maybe because pressures were not recorded in the supine but usually in the 30° HOB position, which was more comfortable. Consequently, IAP in our term women, as well as in the women measured at other divisions, seemed to equal the IAH criteria (IAP ≥12 mmHg) (16). However, results have to be interpreted very carefully since position may have differed between patients. It is therefore difficult comparing pressure values from the CS-group with those from non-pregnant women, and to draw conclusions about the results obtained.

Within the CS-group, nulliparous women had slightly higher IVP and significantly higher bladder pressures compared to multiparous women. It is suggested that IAP, and accordingly the risk for PE, may be elevated in nulliparous women since their abdomen has not been previously stretched (3). Up to now, no other studies were found comparing IAP between nulli- and multiparous women. Although mean IAP_{Ves} measured in nulliparous women (20.5±1.8 mmHg) even equalled the ACS criteria (IAP >20 mmHg), hormonal influences might have stretched the abdominal wall, thereby increasing compliance to adapt to the increasing IAP (30). In contrast to IAP_{Ves}, the insignificant IVP differences might explain the low correlation of IVP with the gold standard. In conclusion, lack of position standardisation and the low sample size of the nulliparous women again limits correct interpretation.

The effect of delivery mode on IAP_{Ves} and IVP showed slightly lower IVP values for women delivered vaginally in previous pregnancies compared to women who gave birth only by CS. However, IVP difference at 0 ml inflation maybe could have become significant if more patients were included. Hilde *et al.* studied the impact of delivery mode on vaginal resting pressure (VRP), and found significant reduction (29%) of VRP after normal vaginal delivery. In addition, while pelvic floor muscle strength was not reduced in women after CS, significant reductions were observed for vaginal delivery (71). However, they used an air-filled balloon placed 3.5 cm inside the introitus, while we positioned the water-filled balloon minimally 5 cm within the vagina to measure IAP (71). It is furthermore possible that muscle strength recovers completely at one year postpartum (72). Even if our results would have been reliable, comparison with studies investigating pelvic floor function is not allowed. Finally, IAP_{Ves} was higher in nulliparous women than in women delivered

only by CS, while IVP remained similar. Although results might not have been reliable, we carefully suggest that nulli- vs. multiparity has a major effect on IAP_{Ves} and that IVP might mainly be influenced by delivery mode.

5. Conclusion & Synthesis

This pilot study aimed to assess an IVBC as a new and less invasive method for IAP monitoring in pregnant women. We showed that IVP measurements were highly repeatable starting from three repeated measures. Inflating the catheter balloon with water gradually increased IVP, and higher pressure values were observed after (abdominal) muscle contraction. The present study was the first comparing vaginal pressure measurements with the gold standard. Although the new technique was reliable, correlation between bladder and IVP measurement was too low to consider IVP a valuable alternative for the gold standard.

However, some limitations were encountered during the study. First, recording IVP could have occurred incorrectly at end-expiration since patients sometimes changed their normal breathing pattern. Second, since repeatability was investigated in the 45° HOB position, nothing is known about repeatability of the IVBC in the supine position. In addition, measuring in the supine position would allow comparing the results with other research. Third, fatigue of the (abdominal) muscles could have biased IVP after muscle contraction. It would therefore be better to record maximum squeeze pressure in future research. IVP measurement was sometimes not feasible to be repeated three times, limiting reliability of some IVP values in the final study part. Together with low sample sizes and different measurement positions between patients, no strict conclusions could be drawn about factors affecting intravaginal or intra-vesical pressure.

Although IVBC measurement seems not representing true IAP, vaginal measurements were safe, less invasive and comfortable. In addition, our technique allowed continuous pressure monitoring instead of intermittent recordings. Further research is therefore recommended to deal with the above limitations and to optimize the IVBC. For example, the IVBC design could be adapted to remove pressure increase with balloon inflation, making it possible investigating IVP during body movements. Including more patients and measuring them in the supine position will simplify comparison with other research, and might confirm the observed factors affecting intravaginal or intra-vesical pressure. Adding these factors in the regression equation might then improve the relationship between both techniques.

In conclusion, this pilot study proved that IVBC measurement is no valuable alternative for IAP monitoring. Future research has to improve the vaginal technique or will investigate other ways for minimal invasive IAP monitoring during pregnancy, making it possible to confirm the hypothesis of increased IAP as a cause of PE.

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Appendix

I. Risk factors for increased IAP (18)

Table 1. Risk factors for the development of intra-abdominal hypertension and abdominal compartment syndrome

A. Related to diminished abdominal wall compliance
- Mechanical ventilation, especially fighting with the ventilator and the use of accessory muscles
- Use of positive end-expiratory pressure (PEEP) or the presence of auto-PEEP
- Basal pleuropneumonia
- High body mass index
- Pneumoperitoneum
- Abdominal (vascular) surgery, especially with tight abdominal closures
- Pneumatic anti-shock garments
- Prone and other body positioning
- Abdominal wall bleeding or rectus sheath hematomas
- Correction of large hernias, gastroschisis, or omphalocoele
- Burns with abdominal eschars

B. Related to increased intra-abdominal contents
- Gastroparesis
- Gastric distention
- Ileus
- Volvulus
- Colonic pseudo-obstruction
- Abdominal tumor
- Retroperitoneal/abdominal wall hematoma
- Enteral feeding
- Intra-abdominal or retroperitoneal tumor
- Damage control laparotomy

C. Related to abdominal collections of fluid, air, or blood
- Liver dysfunction with ascites
- Abdominal infection (pancreatitis, peritonitis, abscess, and so on)
- Hemoperitoneum
- Pneumoperitoneum
- Laparoscopy with excessive inflation pressures
- Major trauma
- Peritoneal dialysis

D. Related to capillary leak and fluid resuscitation
- Acidosis[a] (pH <7.2)
- Hypothermia[a] (core temperature <33°C)
- Coagulopathy[a] (platelet count <50,000/mm^3 OR an activated partial thromboplastin time more than two times normal OR a prothrombin time <50% OR an international standardised ratio >1.5)
- Polytransfusion/trauma (>10 units of packed red cells per 24 hours)
- Sepsis (as defined by the American-European Consensus Conference definitions)
- Severe sepsis or bacteremia
- Septic shock
- Massive fluid resuscitation (>5 L of colloid or >10 L of crystalloid per 24 hours with capillary leak and positive fluid balance)
- Major burns

[a] The combination of acidosis, hypothermia, and coagulopathy has been forwarded in the literature as the deadly triad leading to abdominal compartment syndrome.

II. Medical management strategies to reduce IAP

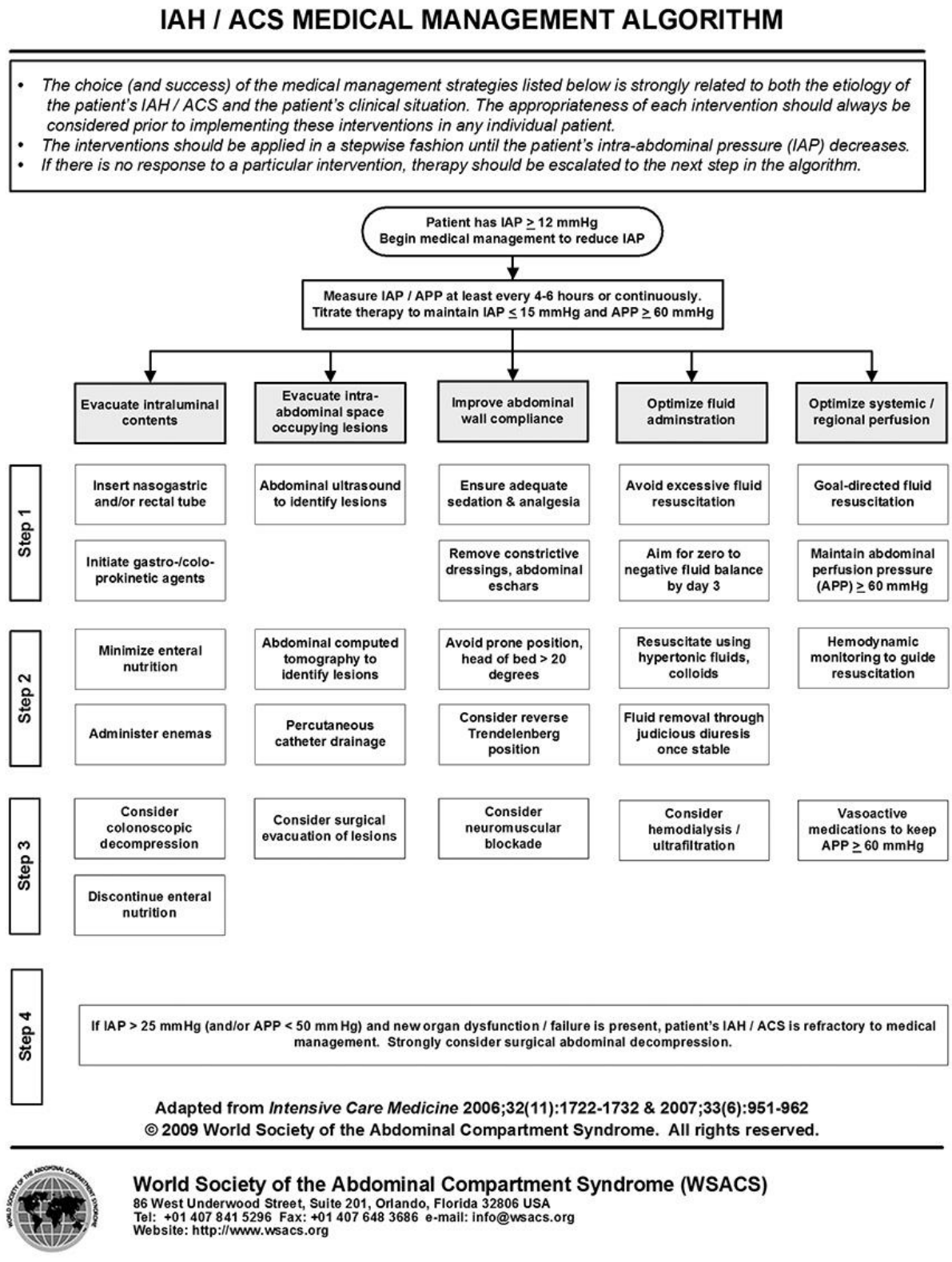

Figure 1: The WSACS IAH/ACS medical management algorithm (1).

III. Role of increased IAP in the pathophysiology of preeclampsia

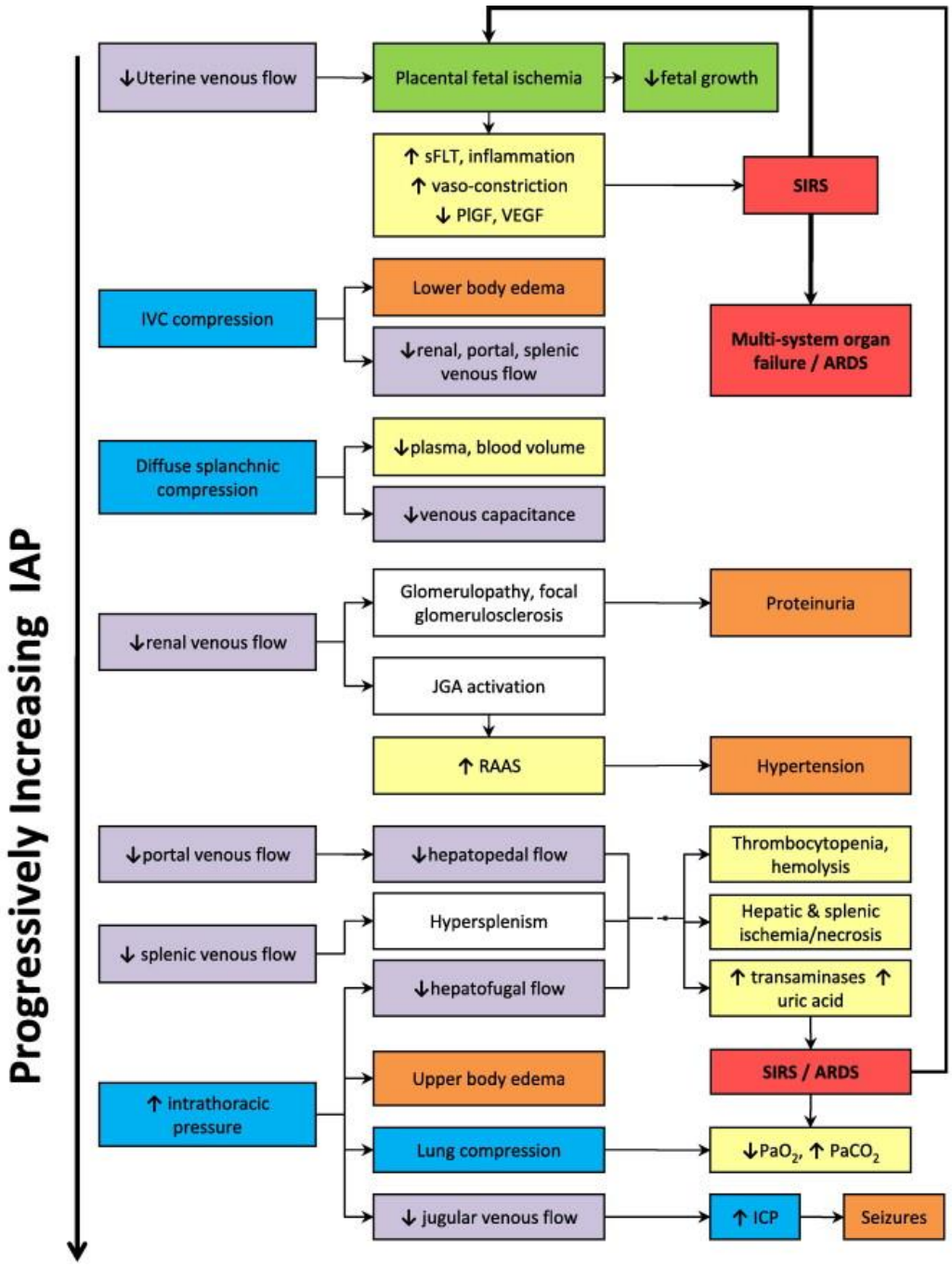

Figure 2: The role of increased IAP in the pathophysiology of preeclampsia.
Purple: direct effects on venous flow, **Blue**: increased pressures, **Green**: direct effects on the fetus, **Orange**: clinical signs, **Yellow**: end effects of increased IAP, **Red**: life-threatening systemic outcomes.

ARDS: adult respiratory distress syndrome, IAP: intra-abdominal pressure, ICP: intra-cranial pressure, IVC: inferior vena cava, JGA: juxtaglomerular apparatus, PIGF: placental growth factor, RAAS: renin angiotensin aldosterone system, sFLT: soluble fms tyrosine kinase 1, SIRS: septic inflammatory response syndrome, VEGF: vasoactive endothelial growth factor (3).

IV. Questionnaire: applicability of the intravaginal measurement technique

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KNOWLEDGE IN ACTION

Vragenlijst ter evaluatie van de intra-vaginale drukmeting

A) Informeren van de patiënte (Bij 'NEE', gelieve uw antwoord te verklaren)

1. Was u tevreden over de informatie die u werd gegeven over het doel van deze studie?

JA / NEE

2. Was het aan de hand van de verkregen informatie voor u duidelijk hoe het onderzoek ging verlopen?

JA / NEE

B) Drukmeting via de vagina

3. Heeft u enig ongemak ervaren bij het inbrengen van de sonde in de vagina?

JA / NEE

4. Heeft u enig ongemak ervaren wanneer het ballonnetje van de sonde groter werd (na vulling met water)? Indien ja, vanaf welk volume? (omcirkel wat van toepassing is)

JA (20 ml, 40 ml, 60 ml, 80 ml) / NEE

5. Heeft u pijn ervaren wanneer het ballonnetje van de sonde groter werd (na vulling met water)? Indien ja, vanaf welk volume? (omcirkel wat van toepassing is)

JA (20 ml, 40 ml, 60 ml, 80 ml) / NEE

6. Was u algemeen tevreden over het verloop van het onderzoek? (Bij 'NEE', gelieve uw antwoord te verklaren)

JA / NEE

7. Vindt u deze vaginale techniek voor het meten van de buikdruk geschikt om standaard bij zwangere vrouwen toe te passen?

JA / NEE

8. Andere opmerkingen i.v.m. het onderzoek en/of de vaginale techniek:

Tot slot wilt het onderzoeksteam onder leiding van Prof. Dr. Gyselaers u hartelijk bedanken voor uw deelname aan deze studie!

V. Validation of the intravaginal pressure tip balloon catheter

Table 2: Effect of pelvic muscle efforts in women with low and high BMI.

	0 ml	20 ml	40 ml	60 ml	80 ml
BMI<25 (n=8)					
$IVP_{End\text{-}expiration}$	18.9±4.49	25.5±6.57	31.7±4.33	41.9±9.16	47.0±18.1
$IVP_{Muscle\ contraction}$	27.9±9.16	39.1±14.9	46.1±13.4	53.0±15.1	59.9±22.7
p-value	0.012	0.012	0.012	0.025	0.018
BMI>25 (n=8)					
$IVP_{End\text{-}expiration}$	23.4±5.81	33.1±10.2	44.2±22.2	51.0±21.5	49.5±13.9
$IVP_{Muscle\ contraction}$	26.7±6.35	39.0±9.91	49.0±19.2	57.0±20.9	54.2±15.0
p-value	0.025	0.018	0.091	0.018	0.043

Data are presented as mean ± standard deviation. Pressures are expressed in mmHg. *BMI: Body mass index, IVP: Intravaginal pressure.*

VI. Reproducibility against the gold standard method

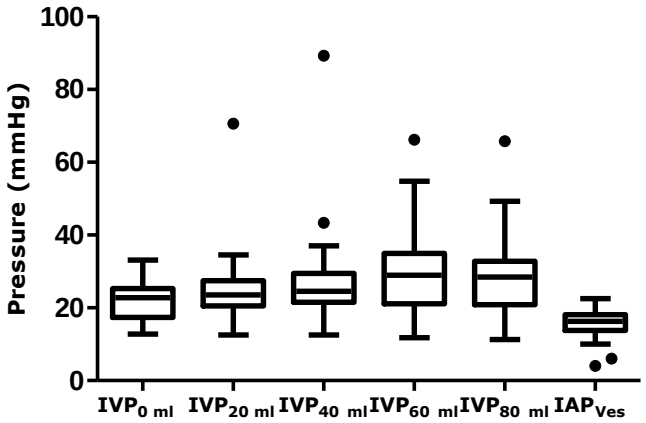

Figure 3: Detection of outliers.
The figure shows outliers for a woman undergoing CS at $IVP_{40\ ml}$ (43.4 mmHg) and $IVP_{80\ ml}$ (65.8 mmHg). In addition, IVP measured at 20 ml (70.6 mmHg), 40 ml (89.3 mmHg), 60 ml (66.2 mmHg) and vesical pressure (4 mmHg) did not lie between the lower and upper pressure limits for a woman at the abdominal surgery division. Finally, a small outlier at IAP_{Ves} (6 mmHg) was detected although the patient needed not to be removed from the dataset. The lower and upper pressure limits were $IVP_{0\ ml}$: 6.61-36.1 mmHg, $IVP_{20\ ml}$: 11.6-36.6 mmHg, $IVP_{40\ ml}$:10.4-40.8 mmHg, $IVP_{60\ ml}$: 6.75-48.9 mmHg, $IVP_{80\ ml}$: 4.4-49.5 mmHg, IAP_{Ves}: 8-108 mmHg. *CS: Caesarean section, IVP: Intravaginal pressure, IAP_{Ves}: Intra-vesical pressure.*

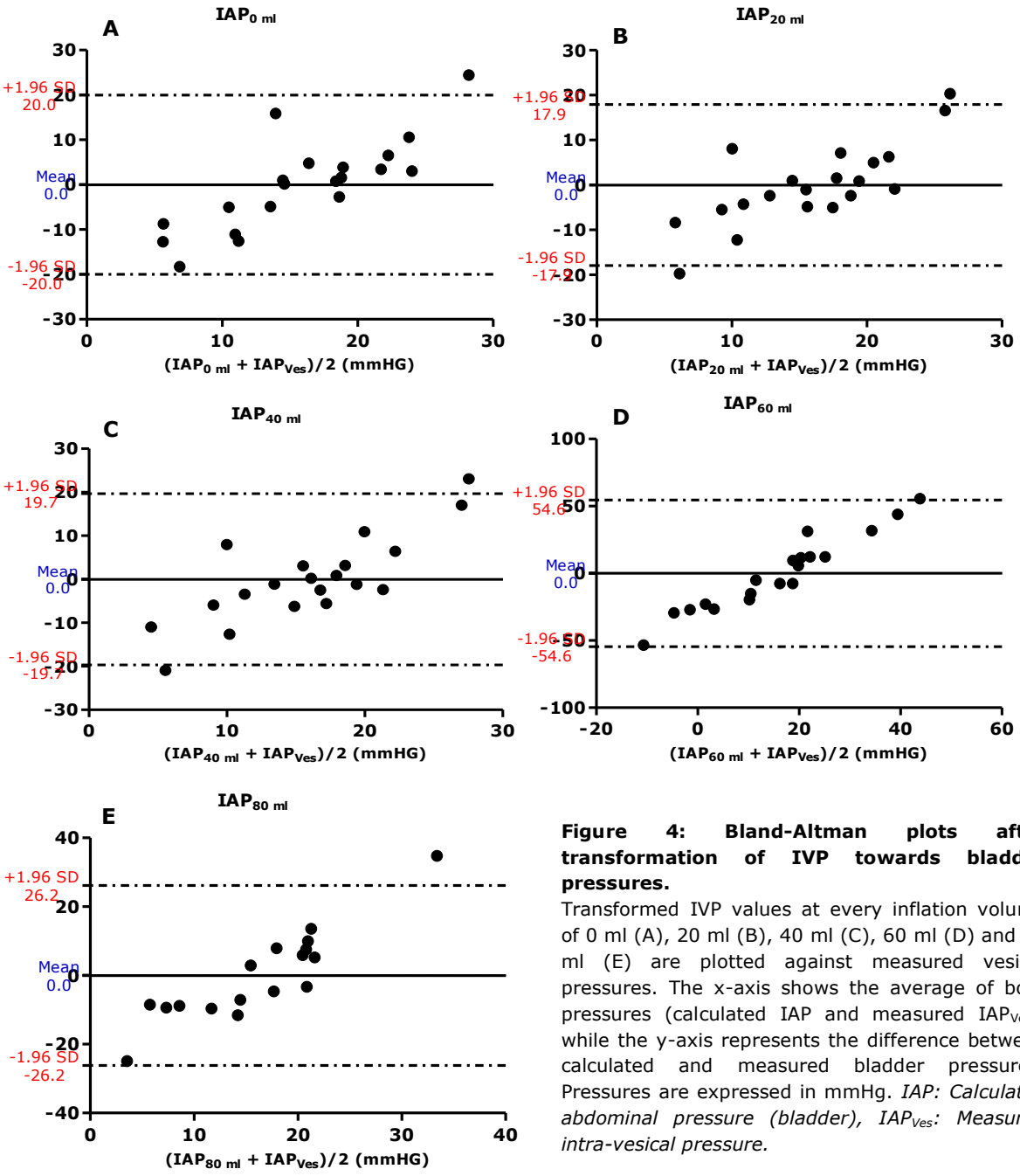

Figure 4: Bland-Altman plots after transformation of IVP towards bladder pressures.
Transformed IVP values at every inflation volume of 0 ml (A), 20 ml (B), 40 ml (C), 60 ml (D) and 80 ml (E) are plotted against measured vesical pressures. The x-axis shows the average of both pressures (calculated IAP and measured IAP_{Ves}), while the y-axis represents the difference between calculated and measured bladder pressures. Pressures are expressed in mmHg. *IAP: Calculated abdominal pressure (bladder), IAP_{Ves}: Measured intra-vesical pressure.*

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Measuring intra-abdominal pressure using an intravaginal pressure tip balloon catheter: a pilot study

Richting: **master in de biomedische wetenschappen-klinische moleculaire wetenschappen**
Jaar: **2016**

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Christiaens, Sigrid

Datum: **7/06/2016**