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Biomedical Technological Features of Measuring Intraabdominal Pressure in Complications of Diverticulitis

Sergij Malinovskyj

Dnipro State Medical University

Ruslan Duka

Dnipro State Medical University

Iryna Polulyah-Chornovol

Dnipro State Medical University

Volodymyr Sulyma

Dnipro State Medical University

Abstract: Biomedical technologies are used to effectively monitor the condition of patients with acute diverticulitis by measuring intra-abdominal pressure (IAP). Our own data presented in our study indicate the high diagnostic value of IAP monitoring technology as a screening method to prevent the development of complications in the early postoperative period. 114 patients with acute diverticulitis were under observation. Patients were divided into two groups. Group I – 56 patients with laparoscopic surgical intervention technology, laparoscopic-assisted technology or using percutaneous drainage with ultrasound navigation technology. Group II – 58 patients with primary surgical intervention during laparotomy. According to our study, the total proportion of patients with complications prevailed in group II – 20 (34.5%) over 6 (10.1%) in group I ($p=0.005$). Whereas, the use of different surgical methods did not affect the mortality rate in general: 6 (10.3%) in group II and 2 (3.6%) in group I ($p=0.2$). IAP measurements were performed in patients of groups I and II before surgery and daily in the postoperative period until the urinary catheter was removed. The exception was patients with percutaneous drainage of a purulent focus, in whom a urinary catheter was not installed. According to the consensus of the World Society of the Abdominal Compartment Syndrome (WSACS), normal values of intra-abdominal pressure for a healthy adult are 5–7 mm Hg, while value above 12 mm Hg are considered a sign of intra-abdominal hypertension, which is classified into four stages: stage I: 12–15 mm Hg, stage II: 16–20 mm Hg art., III degree: 21–25 mm Hg. art., IV degree: >25 mm Hg. Art. The purpose of the article is to study, based on biomedical engineering and technological capabilities, the dependence of intra-abdominal pressure on the prevalence of the inflammatory process and to identify the influence of the surgical treatment method on intra-abdominal pressure and to determine the prognostic value of intra-abdominal pressure in the diagnosis of the development of abdominal complications in order to prevent their development, reduce mortality and improve treatment outcomes.

Keywords: Diverticulitis, Intra-abdominal pressure, Measurements

Introduction

Acute destructive diverticulitis is a very dangerous complication of diverticular disease of the colon, which is often accompanied by the development of purulent peritonitis. In 15-30% of patients, complications after surgery for acute diverticulitis require repeated surgical intervention. Insufficiency of the colon anastomosis

increases the risk of mortality, the duration of the patient's stay in the hospital and requires significant efforts for correction. Postoperative mortality remains high and ranges from 7% to 25% (Ali, 2018; Popowicz et al., 2025).

Diverticulitis is the inflammation or infection of small, weakened pouches (diverticula) in the colon wall, commonly causing sudden, severe lower-left abdominal pain, fever, nausea, and changes in bowel habits. It is treated with bowel rest, antibiotics, and sometimes surgery, with risks linked to low-fiber diets, age, obesity, and smoking. Timely diagnosis of complications after surgical interventions for acute destructive diverticulitis plays a key role in reducing complications, mortality and improving treatment outcomes.

Diverticulitis occurs when pouches (diverticula) in the colon wall become inflamed or infected, often due to fecal matter getting trapped. Unfortunately, the main obstacle to early diagnosis of purulent-septic complications is the masking, or late manifestations of clinical symptoms. Measurement of intra-abdominal pressure is a recognized method of monitoring the condition of patients, which allows objectively assessing the degree of intra-abdominal hypertension and timely detecting the development of purulent-septic complications. This is one of the most promising methods for solving the problems of early diagnosis of purulent-septic complications (Pemberton, 2023).

In clinical practice, intra-abdominal pressure measurements are recognized as important prognostic criteria for preventing complications after surgical interventions for acute destructive diverticulitis. The World Society of the Abdominal Compartment Syndrome (WSACS) consensus recommended method for measuring intra-abdominal pressure is an indirect, standardized, and based on pressure transmission through a urinary catheter filled with sterile saline. Studies have shown that this method has high accuracy and correlation with intraoperative direct measurements of intra-abdominal pressure. According to various authors, early monitoring of intra-abdominal pressure allows for timely detection of progressive abdominal hypertension associated with the development of purulent-septic complications. Measurement of intra-abdominal pressure as a screening tool allows for the detection of critical changes long before the appearance of clinical signs. In modern surgery, the practice of routine measurement of intra-abdominal pressure in high-risk patients is widespread, in particular after intestinal resections.

According to the consensus of the World Society of the Abdominal Compartment Syndrome (WSACS), normal values of intra-abdominal pressure for a healthy adult are 5–7 mm Hg, while value above 12 mm Hg are considered a sign of intra-abdominal hypertension, which is classified into four stages: stage I: 12–15 mm Hg, stage II: 16–20 mm Hg art., III degree: 21–25 mm Hg. art., IV degree: >25 mm Hg. art. Chandra et al. (2018), Jacobs et al. (2022), Francesco Tiralongo et al. (2023), note that timely diagnosis of abdominal hypertension syndrome significantly improves the results of treatment of critically ill surgical patients. Our own data presented in our study also indicate the high diagnostic value of intra-abdominal pressure monitoring as a screening tool, allowing for the prompt detection of signs of purulent-septic complications in the early postoperative period.

The purpose of the article is to study, based on biomedical engineering and technological capabilities, the dependence of intra-abdominal pressure on the prevalence of the inflammatory process and to identify the influence of the surgical treatment method on intra-abdominal pressure and to determine the prognostic value of intra-abdominal pressure in the diagnosis of the development of abdominal complications in order to prevent their development, reduce mortality and improve treatment outcomes (Ampatzidou et al., 2018).

Measuring intra-abdominal pressure depending on the prevalence of the inflammatory process and after colorectal interventions, identifying the influence of the surgical treatment method on intra-abdominal pressure, determining the prognostic value of intra-abdominal pressure in the diagnosis of the development of abdominal complications, prevents the development of purulent-septic complications, reduces mortality, improves treatment outcomes, and increases the quality of postoperative monitoring. Researchers aren't sure what causes diverticulosis and diverticulitis. They think certain factors may play a role in causing or increasing the risk for these conditions, including:

- Your genetics. Certain genes may make some people more likely to develop the conditions.
- Lifestyle factors such as:
- Diets low in fiber and high in red meat
- Lack of physical activity
- Taking certain medicines, such as nonsteroidal anti-inflammatory drugs (NSAIDs) and steroids
- Having obesity
- Smoking

Researchers are also looking at other possible factors that may play a role in these conditions. Those factors include bacteria or stool (poop) getting caught in a pouch in your colon and changes in the microbiome in the intestines. Your microbiome is made up of the bacteria and other organisms in your intestines (Naves & D'Ippolito, 2017).

Who is more likely to develop diverticulosis and diverticulitis?

Diverticulosis is common, especially as people age. More than one-third of U.S. adults between the ages of 50 and 59 have diverticulosis. More than two-thirds who are over age 80 have it. Most of those people will not have symptoms or problems. But some of them will develop diverticulitis.

What are the symptoms of diverticulosis and diverticulitis? (Catherine et al., 2023). Diverticulosis usually doesn't cause symptoms. But some people can have chronic symptoms such as:

- Bloating
- Constipation or diarrhea
- Cramping or pain in the lower abdomen (belly)
- Diverticulitis may cause acute symptoms such as:
- Abdominal pain, most often in the lower left side of your abdomen
- Constipation or diarrhea
- Fevers and chills
- Nausea or vomiting

The pain caused by diverticulitis is usually severe and comes on suddenly. Less often, the pain may be mild and worsen over several days. What other problems can diverticulosis and diverticulitis cause?

Some people with diverticulosis and diverticulitis may develop serious health problems (complications). Diverticular bleeding happens when a small blood vessel within the wall of a pouch bursts. The bleeding may be severe and sometimes even life-threatening (Mishchenko et al., 2021). People with diverticulitis can also develop serious problems such as:

- Abscess, a painful, swollen, pus-filled area caused by infection
- Fistula, an abnormal opening or passage between the colon and another part of the body, such as the bladder or vagina
- Intestinal obstruction, a partial or total blockage that keeps food, fluids, air, or stool from moving through your intestines
- Perforation, or a hole, in your colon
- Peritonitis, an infection of the lining of the abdominal cavity.

Diverticulosis is defined by the presence of diverticula due to herniation of mucosa and muscularis mucosa through the muscularis propria at sites of vascular penetration in the colon and is asymptomatic in the vast majority affected. There are global differences of distribution, in Western industrialized societies, the most common site is in the left colon, but in Asia right sided diverticulosis predominates (Chandra et al., 2018; Minordi, 2020; Mali et al., 2019).

Diverticular disease is defined as clinically significant and symptomatic diverticulosis, which may have an absence of macroscopically overt colitis and in true diverticulitis there is macroscopic inflammation of diverticula with related acute or chronic complications. Whilst overall, diverticulitis affects only 4% of those with diverticulosis, in younger patients (aged 40-49 years) this peaks at 11%.

Diverticulosis is one of the most common chronic diseases, yet research in this field on pathogenesis has lagged behind other common conditions such as diabetes mellitus. However, in the last decade there have been major advances in taxonomy that can be used to relate to patients' outcome and treatment in both medicine and surgery. It has been shown there is an association with age, diet, drugs and smoking.

That diverticulosis is a chronic disease is shown by mucosal pathology with subtle chronic inflammation present in those with asymptomatic diverticulosis and inflammation may lead to muscular hypertrophy, enteric nerve remodeling with disordered motility. The diverticulitis quality of life instrument shows that this condition impacts markedly on patients' well-being and prevention and amelioration of complications should be the aim of treatment and further research to attain this goal is needed.

The role of the microbiota in diverticulosis and diverticular disease is underexplored. This systematic review aimed to assess all literature pertaining to the microbiota and metabolome associations in asymptomatic diverticulosis, symptomatic uncomplicated diverticular disease (SUDD), and diverticulitis pathophysiology (Minordi et al., 2020). Butyrate-producing microbial species were decreased in abundance, suggesting a possible contribution to the pathogenesis of diverticular disease. *Comamonas* species was significantly increased in asymptomatic diverticulosis patients who later developed diverticulitis. Metabolome analysis reported significant differences in diverticulosis and SUDD, with upregulated uracil being the most consistent outcome in both. No significant differences were reported in the mycobiome (Jacobs et al., 2022).

Method

As part of the study to assess the results of treatment of acute destructive diverticulitis using minimally invasive and traditional methods of intervention for early diagnosis of the development of purulent-septic complications, IAP measurement was performed intraoperatively and in the postoperative period through a urinary catheter, according to the recommendations of WSACS (World Society of the Abdominal Compartment Syndrome).

The study included 114 patients who were divided into 2 groups depending on the treatment tactics.

I (main) group - 56 patients who were treated with minimally invasive methods of treatment.

II group (comparison) - 58 patients who underwent traditional laparotomic surgery.

The inclusion criteria for the study were: patients with purulent-destructive complications of acute diverticulitis of the colon, who were subject to surgical treatment and gave consent to participate in the study. Patients with uncomplicated diverticular disease, acute uncomplicated diverticulitis, chronic forms of diverticulitis, acute diverticulitis complicated by bleeding, patients who were in an extremely serious and agonal condition (patients with an anesthetic risk assessment of ASA V), as well as patients who did not give consent to participate in the study were excluded from the study.

Surgical interventions were performed by 2 teams of surgeons, who at the beginning of the study had experience in more than 250 cases of surgical interventions on the colon. In the event of the development of purulent-destructive complications, urgent surgical (interventional) treatment was performed. The issue of choosing an open laparotomy or minimally invasive intervention was decided collectively, according to the developed algorithm for choosing the method of surgical intervention, which is based on the assessment of the degree of purulent-destructive process according to the Hinchey classification (Tiralongo et al., 2023). The algorithm for providing care was unified and agreed upon in clinical centers.

Statistical processing of the research materials was carried out using bio-statistics methods implemented in the STATISTICA v.6.1 software package (Statsoft Inc., USA) (license number AGAR909E415822FA). The selection of parametric and non-parametric methods of statistical analysis was carried out after checking the distribution law of quantitative traits (Shapiro-Wilk criterion). In cases of normal distribution law, parametric statistical characteristics of mean values were used - arithmetic mean (M), standard error of the mean (m), and when comparing unrelated groups - Student's t-test; when the distribution deviated from normal, the median (Me), quartiles (25–75%) and Mann-Whitney test (U) were used.

In order to compare two samples of binary traits, Pearson's 2 criterion or Fisher's exact criterion with the construction of conjugation tables were used. Regression analysis was performed to assess the relationship between indicators. The minimum statistical probability was determined at $p < 0.05$. For statistical processing of qualitative data, they were represented by a binary or categorical attribute.

The age of the patients ranged from 36 to 86 years and averaged 59.25 ± 3.09 years in group I and 62.49 ± 3.24 years in group II. At the same time, the majority of patients belonged to the elderly and senile age. According to the analysis of the studied groups, it can be stated that they did not statistically differ in gender and age (Francis et al., 2019).

In order to study the dependence of intra-abdominal pressure on the prevalence of the inflammatory process and to study the influence of the surgical treatment method on intra-abdominal pressure, its measurement was performed using the Kron method in patients of both groups during hospitalization and in the early

postoperative period. Its significance in the diagnosis of the development of abdominal complications was assessed.

Intra-abdominal pressure was measured in most patients of the main (I) group and the comparison (II) group before surgery and daily in the postoperative period until the urinary catheter was removed. The exception was patients who underwent percutaneous drainage of a purulent focus - they did not have a urinary catheter installed. Intra-abdominal pressure was measured once a day at normal values (5–11 mm Hg) or in the presence of intra-abdominal hypertension of the 1st degree (12–15 mm Hg). At higher pressure values, as well as in the presence of other clinical signs of a complicated course of the postoperative period - the study was performed 2–3 times a day. Analysis of the obtained intra-abdominal pressure data in patients of both groups allowed to distribute patients by the degree of intra-abdominal hypertension depending on the prevalence of destructive changes.

IAP measurements were performed in patients of groups I and II before surgery and daily in the postoperative period until the urinary catheter was removed. The exception was patients with percutaneous drainage of a purulent focus, in whom a urinary catheter was not installed.

According to the consensus of the World Society of the Abdominal Compartment Syndrome (WSACS), normal values of intra-abdominal pressure for a healthy adult are 5–7 mm Hg, while value above 12 mm Hg are considered a sign of intra-abdominal hypertension, which is classified into four stages: stage I: 12–15 mm Hg, stage II: 16–20 mm Hg art., III degree: 21–25 mm Hg. art., IV degree: >25 mm Hg. Art.

Results and Discussion

It was found that in limited purulent-destructive process (group I) the average value of intra-abdominal pressure was 13.3 ± 0.7 mm Hg, and was significantly lower than in patients with unlimited peritonitis (group II) – 18.4 ± 1.0 mm Hg ($p < 0.01$). In group I, this indicator after surgery was 12.9 ± 0.8 mm Hg and was lower than before surgery ($p < 0.01$) (Holovanova et al., 2017). This indicated that the increase in intra-abdominal pressure during the laparoscopic surgery (application of carboperitoneum) did not lead to an increase in intra-abdominal hypertension in the early postoperative period, and the surgery itself contributed to its decrease. It was also found that intra-abdominal pressure in all cases rapidly increased with the development of abdominal postoperative complications from 13.0 ± 0.5 mm Hg. up to 20.3 ± 0.7 mm Hg, which makes postoperative monitoring of intra-abdominal pressure a reliable screening method for diagnosing complications.

Intra-abdominal pressure measurements were also performed for the purpose of early diagnosis of colonic anastomotic leaks in patients of both groups. The mean values of intra-abdominal pressure in patients of group I (Hinchey I and II) and group II (Hinchey III–IV) clearly reflect a statistically significant increase in intra-abdominal pressure in generalized peritonitis (Hinchey III–IV) (Hinchey et al., 1978). In patients with limited purulent-destructive process (Hinchey I and II), group I, the average value of intra-abdominal pressure was 13.3 ± 0.7 mm Hg, and was significantly lower than in patients of group II with unlimited peritonitis (Hinchey III and IV) – 18.4 ± 1.0 mm Hg (U Mann-Whitney test = 250.0; $p < 0.01$), which was generally quite predictable.

The average value of intra-abdominal pressure at the time of hospitalization in group II was 15.1 ± 1.2 mm Hg. Normal intra-abdominal pressure was detected in 12 (20.7%) patients, intra-abdominal hypertension of stage 1 – in 20 (34.5%), stage 2 – in 21 (36.2%), stage 3 – in 5 (8.6%). In group I, this indicator was 15.0 ± 1.0 mm Hg (normal intra-abdominal pressure in 12 (21.4%) patients, intra-abdominal hypertension stage 1 in 16 (28.6%), stage 2 in 25 (44.6%), stage 3 in 3 (5.4%) and did not differ from the comparison group, which is an additional criterion for the comparability of the groups as a whole (Mann-Whitney U test = 1603; $p > 0.05$) (Lambrichts, 2019). According to our data, patients with intra-abdominal hypertension of stage 3 were only 7.0% in both groups; we did not observe patients with intra-abdominal hypertension of stage 4.

It was very important to determine the influence of the surgical treatment method on the intra-abdominal pressure in the immediate postoperative period and during subsequent treatment. We found that in group II, on the first day after laparotomy, the intra-abdominal pressure was 14.6 ± 0.8 mm Hg and was not statistically different from the preoperative value (Mann-Whitney U test = 1556.0; $p > 0.05$). In group I, this same indicator was 12.9 ± 0.8 mm Hg and was significantly lower than before the operation (Mann-Whitney U test = 973.5; $p < 0.01$), although not very pronounced in absolute figures. In the case of normal values (5–11 mm Hg) or the presence of intra-abdominal hypertension of the first degree (12–15 mm Hg), measurements were performed once a day.

At higher values or clinical signs of complications, the studies were performed 2–3 times a day. The purpose of monitoring intra-abdominal pressure was to determine the dependence of this indicator on the prevalence of purulent-inflammatory process, the influence of surgical tactics and the prognostic value of intra-abdominal pressure regarding the development of complications. The average intra-abdominal pressure at the time of hospitalization in group II was 15.1 ± 1.2 mm Hg (normal intra-abdominal pressure in 20.7% of patients, intra-abdominal hypertension stage 1 in 34.5%, stage 2 in 36.2%, stage 3 in 8.6%). In group I, it was 15.0 ± 1.0 mm Hg (normal intra-abdominal pressure in 21.4%, intra-abdominal hypertension stage 1 in 28.6%, stage 2 in 44.6%, stage 3 in 5.4%). The difference was not statistically significant ($p > 0.05$).

In patients in group I with a limited process (Hinchey I-II), the intra-abdominal pressure was 13.3 ± 0.7 mm Hg. In group II, intra-abdominal pressure on the 1st day after laparotomy was 14.6 ± 0.8 mm Hg (no changes, $p > 0.05$), while after laparoscopic surgery it decreased to 12.9 ± 0.8 mm Hg ($p < 0.01$). It was found that laparoscopy does not contribute to intra-abdominal hypertension in the postoperative period, despite the use of carboperitoneum, unlike laparotomy, which causes persistence of increased intra-abdominal pressure due to greater surgical trauma and intestinal paresis. In patients with anastomotic insufficiency, a sharp increase in intra-abdominal pressure was observed - on average from 13.0 ± 0.5 to 20.3 ± 0.7 mm Hg., which indicates a high sensitivity of this diagnostic criterion.

Monitoring was carried out from 3 to 14 days. Intra-abdominal pressure in patients with an uncomplicated course decreased by 2–3 days. In cases of increased pressure, additional diagnostics were performed. No case of abdominal hypertension syndrome was detected. Surgical treatment is a complex process with many obvious and hidden factors that affect the course of the postoperative period and, in particular, the indicators of intra-abdominal pressure. However, the presented study data show that minimally invasive laparoscopic treatment due to the need to impose carboperitoneum and iatrogenic increase in intra-abdominal pressure during the operation does not lead to an increase in intra-abdominal hypertension in the early postoperative period, but, on the contrary, reduces it (Leon et al., 2021).

On the first day after laparotomy, intra-abdominal pressure remains elevated approximately to the preoperative level, despite the sanitation of the abdominal cavity. This is probably due to greater surgical trauma, prolonged exposure of the abdominal cavity to air, which inevitably leads to varying degrees of intestinal paresis, edema of visceral organs, and temporary increased exudation. But never, in both study groups, was there a significant increase in intra-abdominal pressure (increasing by a degree) and the development of abdominal hypertension syndrome on the first day after surgery.

Conclusion

The obtained data indicate that laparoscopy is a safe method of intervention from the point of view of intra-abdominal pressure. A decrease in intra-abdominal pressure after surgery can be considered as a prognostically favorable sign. An increase in intra-abdominal pressure correlates with the development of complications, which makes it a valuable predictor. Thus, measuring intra-abdominal pressure depending on the prevalence of the inflammatory process and after colorectal interventions, identifying the influence of the surgical treatment method on intra-abdominal pressure, determining the prognostic value of intra-abdominal pressure in the diagnosis of the development of abdominal complications, prevents the development of purulent-septic complications, reduces mortality, improves treatment outcomes, and increases the quality of postoperative monitoring.

Intra-abdominal pressure monitoring is a highly sensitive method for early diagnosis of complications in the postoperative period in acute destructive diverticulitis, which allows to assess the severity of the disease, the effectiveness of surgical intervention and predict the development of complications. Increased intra-abdominal pressure in patients of group II (with Hinchey III-IV) is a predictor of a complicated course and requires more active monitoring.

There is no convincing evidence of microbial dysbiosis in colonic diverticula to suggest that the microbiota contributes to the pathogenesis of asymptomatic diverticulosis, SUDD, or diverticular disease. Future research investigating microbiota involvement in colonic diverticula should consider an investigation of mucosa-associated microbial changes within the colonic diverticulum itself. A significant increase in intra-abdominal pressure may be an early sign of anastomotic failure and requires immediate intervention. Laparoscopic treatment is accompanied by a smaller increase in intra-abdominal pressure and, accordingly, a better course of the postoperative period.

Recommendations

It is advisable to include routine measurement of intra-abdominal pressure in biomedical engineering and technological protocols for postoperative surveillance in abdominal surgery. Further research is needed to study the dynamics of intra-abdominal pressure in patients with different types of anastomosis and the possibility of using combined biomarkers to increase the accuracy of prediction.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest.

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Author(s) Information

Sergij Malinovskyj

Dnipro State Medical University
Vernadskyj Street, 9, Dnipro, 49000, Ukraine
ORCID iD: <https://orcid.org/0000-0002-5554-836X>

Ruslan Duka

Dnipro State Medical University
Vernadskyj Street, 9, Dnipro, 49000, Ukraine
ORCID iD: <https://orcid.org/0000-0003-3962-8746>

Iryna Polulyah-Chornovol

Dnipro State Medical University
Vernadskyj Street, 9, Dnipro, 49000, Ukraine
ORCID iD: <https://orcid.org/0009-0002-3677-8757>

Volodymyr Sulyma

Dnipro State Medical University
Vernadskyj Street, 9, Dnipro, 49000, Ukraine
ORCID iD: <https://orcid.org/0000-0002-8373-6480>
*Contact e-mail: Volodyasulyma2@gmail.com

*Corresponding author(s) contact email

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