ORIGINAL ARTICLES

# EVALUATION OF THE QUALITY OF ELECTROCHEMICAL STUDY IN THE DIAGNOSIS OF INFECTION OF PANCREATIC CYSTS

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## Abstract

The formation of pancreatic cysts is a serious complication of acute pancreatitis, chronic pancreatitis and pancreatic injuries. Joulemetry is an integral method for evaluating the electrochemical properties of biological objects. To date, this method has not been used in the study of the electrochemical properties of the contents of pancreatic cysts. The purpose of this study was to evaluate the effectiveness of electrochemical analysis in the detection of infection in the contents of necrotic pancreatic cysts. An electrochemical study of contents of necrotic pancreatic cysts carried out on 106 patients. Group 1 included 84 patients without signs of infection of pancreatic cysts; group 2 included 22 patients with signs of infection of pancreatic cysts. The electrochemical study was conducted as follows: 10 ml of the contents of a pancreatic cyst was injected into a liquid flow sensor of a joule meter, where it was exposed to a electrical current for a short period of time. The resulting data was analyzed using a diagnostic research complex. During the study of the electrochemical properties of the contents of postnecrotic pancreatic cysts by using joulemetry, it was revealed that the current work in patients of group 1 ranged from 0.92 to 18.31 mkJ (on average 5.86±5.02 mkJ), in patients of group 2 – from 19.01 to 26.3 mkJ (on average 22.32±1.92 mkJ). When evaluating the quality of the joulemetric study in determining the early signs of inflammation of the contents of postnecrotic pancreatic cysts, it was proved that the threshold differential diagnostic value of 19.1 mkJ provides 81.8% sensitivity of the proposed method and 80.7% specificity (AUC = 91.3) with a statistically significant difference in current work ($p < 0.001$).

**Keywords:** Postnecrotic pancreatic cysts, pancreatitis, joulemetry, infection, electrochemical properties.

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# ОЦЕНКА КАЧЕСТВА ЭЛЕКТРОХИМИЧЕСКОГО ИССЛЕДОВАНИЯ В ДИАГНОСТИКЕ ИНФИЦИРОВАНИЯ КИСТ ПОДЖЕЛУДОЧНОЙ ЖЕЛЕЗЫ

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## Резюме

Образование кист поджелудочной железы является серьёзным осложнением острого и хронического панкреатита, а также травм поджелудочной железы. Джоульметрия – интегральный метод оценки электрохимических свойств биологических объектов. На сегодняшний день этот метод еще не использовали в изучении электрохимических свойств содержимого кист поджелудочной железы. Целью исследования явилась оценка качества электрохимического исследования в диагностике инфицирования содержимого постнекротических кист поджелудочной железы. Электрохимическое исследование выполнили 106 пациентам с постнекротическими кистами поджелудочной железы. В 1-ю группу вошли 84 пациента без признаков инфицирования кист поджелудочной железы, во 2-ю группу – 22 пациента с признаками инфицирования кист поджелудочной железы. Электрохимическое исследование выполняли следующим образом: содержимое кисты поджелудочной железы забирали в количестве 10 мл и вводили внутрь жидкостного проточного датчика джоульметрического прибора, где за короткий промежуток времени на него действовал ток. Посредством диагностического исследовательского комплекса оценивали полученные результаты. В ходе исследования электрохимических свойств содержимого постнекротических кист поджелудочной железы с помощью джоульметрии было выявлено, что показатель работы тока у больных 1-й группы колебался в пределах от 0,92 до 18,31 мкДж (в среднем 5,86±5,02 мкДж), у пациентов 2-й группы – от 19,01 до 26,3 мкДж (в среднем 22,32±1,92 мкДж). При оценке качества джоульметрического исследования в определении ранних признаков воспаления содержимого постнекротических кист поджелудочной железы доказано, что пороговое дифференциально-диагностическое значение равное 19,1 мкДж обеспечивает чувствительность предложенного метода в 81,8% и специфичность в 80,7% (AUC = 91,3) при статистически значимой разнице показателей работы тока ($p < 0,001$).

**Ключевые слова.** Постнекротические кисты поджелудочной железы, панкреатит, джоульметрия, инфицирование, электрохимические свойства.

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## Introduction

Formation of pancreatic cysts is a serious complication of acute and chronic pancreatitis, as well as pancreatic injuries [1, 2, 3, 4]. Formation of cysts in acute pancreatitis is observed in almost 20% of cases, and this indicator increases 4 times in destructive forms. In chronic pancreatitis, the incidence of pancreatic cysts is between 20% and 40% and in pancreatic injuries, cysts occur in 20-30% of cases [4, 5]. It is worth noting that during the formation of a cyst, quite serious complications can be observed, occurring in almost 40% of cases: bleeding into the cyst cavity, suppuration, perforation, compression of adjacent organs with the corresponding clinical picture.

A tactical approach to the treatment of patients in this category includes identifying early signs of infection of the contents of the pancreatic cyst and the presence of a connection between the cyst and the duct system of the pancreas [4, 5, 6]. However, the currently existing methods for diagnosing infection of postnecrotic pancreatic cysts have a number of disadvantages: a long period of time before obtaining the result (up to 3-5 days for bacteriological examination), low information content, limitations in use due to contraindications, etc.

It has been proven that under the influence of various factors of the external and internal environment of the body, such as changes in temperature, volume, concentration of electrolytes, the appearance of signs of suppuration or blood elements, etc., the electrical properties of any biological objects change [7]. At the same time, when using microcurrents of 10-100 μA, there are no changes in the physico-chemical processes of the object under study. Joulemetry is an integral method based on the assessment of the values of the current work expended by an external source of electrical energy at the time when the state of the object under study changes.

The advantages of joulemetry include: simplicity of implementation of the method, low time costs, wide application (for all types of biological tissues), high sensitivity of the method, which allows to increase the number of necessary informative features.

It should be noted that it is the timely and accurate diagnosis of early signs of inflammation of of the contents of postnecrotic pancreatic cysts that allows to correctly select the necessary method of surgical treatment and determine the tactical approach as a whole [5, 6].

The aim of the study was to assess the quality of electrochemical study in the diagnosis of infection of the contents of postnecrotic pancreatic cysts.

## Materials and methods

To determine early signs of inflammation of the contents of postnecrotic pancreatic cysts, a method of express diagnostics based on a joulemetric study was developed and introduced into clinical practice (Patent of the Russian Federation for Invention No. 2684424 dated 04/09/2019).

The study was conducted at the Medical Institute of the Federal State Budgetary Educational Institution of Higher Education "Penza State University" and the surgical departments of the State Budgetary Healthcare Institution "Penza Regional Clinical Hospital named after N.N. Burdenko".

For the period from 2016 to 2023 inclusive, 106 patients with postnecrotic pancreatic cysts were treated in the surgical departments of the State Budgetary Healthcare Institution "Penza Regional Clinical Hospital named after N.N. Burdenko".

Depending on the presence of signs of inflammation, the patients were divided into two groups. Group 1 included 84 (79.2%) patients with pancreatic cysts without signs of inflammation, and Group 2 included 22 (20.8%) patients with pancreatic cysts and signs of inflammation. This division was based on clinical and laboratory data and instrumental research data (ultrasound, CT, MRI).

Scientists from Penza State University have developed a joulemetry method and a device for diagnosing the state of biological objects (Patent of the Russian Federation No. 2033606 dated 20/04/95), and received permission from the Ministry of Health of the Russian Federation (minutes of the meeting of the commission on new medical equipment No. 10 dated 18/11/93) for use in clinical practice (Gerashchenko S.I., Nikolsky V.I., Volchikhin V.I., 1993). The Divo joulemeter and IPC 2000 software were developed by the staff of the Medical Devices and Equipment Department of the Penza State University.

Electrochemical (another name is joulemetric) study of the contents of postnecrotic pancreatic cysts was performed as follows: 10 ml of the contents of the patient's pancreatic cyst, obtained by puncture or external drainage under ultrasound control, were taken; these contents were then introduced into the liquid flow sensor of the Divo joulemetric device (Penza); a current of 0.1 mA was passed through the liquid flow sensor of the joulemetric device for less than 8 s. The results were evaluated using a diagnostic research complex (Fig. 1), which included a joulemetric device, a liquid flow sensor, and a computer program for information analysis (IPC 2000).

The IPC 2000 program was used to evaluate the obtained dependencies, which were curves with certain values of potential change over time. Based on the obtained dependencies, the work for each current value was calculated, and graphs were constructed that allowed to analyze the activity of the inflammatory process of pancreatic cysts.

Statistical analysis was performed on an IBM-PC compatible computer using the licensed program BioStat 2010 5.8.3.0 and IBM SPSS Statistics for Windows, Version 25.0. ROC analysis (receiver operating characteristic) was performed to assess the quality of the model of the proposed method for express diagnostics of pancreatic cyst infection based on joulemetry.

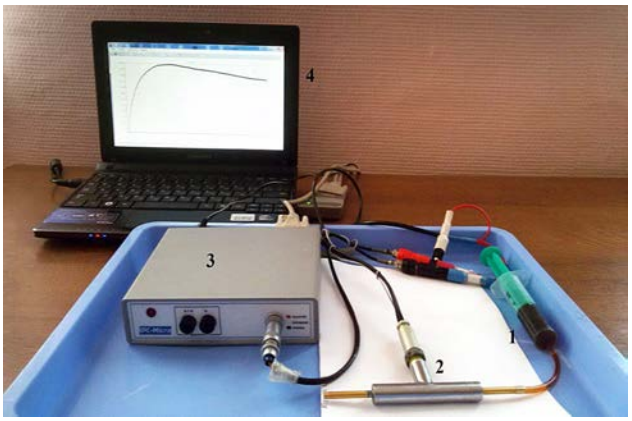


**Рис. 1.** Диагностический исследовательский комплекс: 1 – шприц для нагнетания содержимого кисты; 2 – жидкостной проточный датчик; 3 – джоульметрический прибор; 4 –компьютер с установленной программой IPC 2000.
**Fig. 1.** Diagnostic research complex: 1 – a syringe for pumping cyst contents; 2 – a liquid flow sensor; 3 – a joule meter; 4 – a computer with the IPC 2000 program installed.

## Results and Discussion

To form two groups of patients with a preliminary assessment of infection or absence of infection of pancreatic cysts, criteria were defined based on clinical, laboratory and instrumental data.

The following criteria of clinical, laboratory and instrumental research methods were considered as signs of inflammation of postnecrotic pancreatic cysts:

- increased body temperature;
- the presence of peritoneal symptoms;
- leukocytosis with a shift in the leukocyte formula to the left;
- according to ultrasound: heterogeneous cyst contents (finely dispersed hyperechoic suspension with the presence of partitions), uneven thickening of the cyst wall, signs of infiltration of the parapancreatic tissue;
- according to SCT: heterogeneous structure with hypodense inclusions (density of contents from +20 to +30 HU units), edema and stringiness of the parapancreatic tissue;
- according to MRI: a formation with an increased MR signal on $T_2$-weighted images and an increased MR signal on $T_1$-weighted images, the parapancreatic tissue is heterogeneous with signs of edema.

Postnecrotic pancreatic cysts without signs of inflammation had the following clinical, laboratory and instrumental features:

- no constant hyperthermia was observed;
- no peritoneal symptoms;
- no signs of inflammation in the clinical blood test;
- according to ultrasound: homogeneous anechoic contents of the cyst cavity or heterogeneous contents with a parietal component, smooth clear contour of the formation, no signs of infiltration of the parapancreatic tissue;
- according to SCT: homogeneous structure of the cyst (density of the contents from +5 to +18 HU), no signs of infiltration of the parapancreatic tissue;
- according to MRI: a formation with an increased MR signal on $T_2$-weighted images and a decreased MR signal on $T_1$-weighted images, without edema of the parapancreatic tissue.

During the study of the electrochemical properties of the contents of postnecrotic pancreatic cysts using joulemetry, it was revealed that the current work index (Table 1) in patients of the 1st Group was in the range from 0.92 to 18.31 μJ (on average 5.86±5.02 μJ), in patients of the 2nd Group – from 19.01 to 26.3 μJ (on average 22.32±1.92 μJ).

**Таблица 1**
**Работа тока у больных с признаками воспаления кист поджелудочной железы и без признаков воспаления кист поджелудочной железы**

**Table 1**
**Electric current work in patients with signs of inflammation of pancreatic cysts and without signs of inflammation of pancreatic cysts**

| Исследуемые группы пациентов<br>The studied groups of patients | Количество пациентов, n=106<br>Number of patients, n=106 | | Работа тока, мкДж<br>Electric current work, μJ | Среднее значение<br>The average value |
|---|---|---|---|---|
| | Абс. | % | | |
| 1 группа – больные без признаков воспаления кист поджелудочной железы<br>1 group – patients without signs of inflammation of pancreatic cysts | 84 | 79,2 | от 0,92 до 18,31 | 5,86±5,02 |
| 2 группа – больные с признаками воспаления кист поджелудочной железы<br>2 group – patients with signs of inflammation of pancreatic cysts | 22 | 20,8 | от 19,01 до 26,3 | 22,32±1,92 |
| Итого<br>Total | 106 | 100 | - | - |
| Достоверность<br>Reliability | - | | - | < 0,001 |

Consequently, statistically significant data on infection of postnecrotic pancreatic cysts were obtained ($p < 0.001$): in patients of the 1st group without signs of inflammation of the contents of the pancreatic cysts, a low current work rate was diagnosed (on average 5.86±5.02 μJ), whereas in patients of the 2nd group with signs of inflammation of the contents of the pancreatic cysts, a high current work rate was detected (on average 22.32±1.92 μJ).

Fig. 2 and 3 present the measured electrochemical parameters in graphical form, which indicated the presence or absence of signs of inflammation of the contents of postnecrotic pancreatic cysts.

Fig. 2 shows that the saturation point is reached at a time of 3.8 s, the potential value at this point is 4200 mV, whereas in Fig. 3 the saturation point is reached at a time of 0.9 s, the potential value at this point is 2850 mV. Thus, for the electrochemical reaction in patients with infected pancreatic cysts, a higher voltage, amount of time and, as a result, more current work is required to reach the saturation point than in patients with pancreatic cysts without signs of inflammation, which is confirmed by the above data.

All the obtained results of the electrochemical study of the contents of pancreatic cysts were confirmed by bacteriological examination: in 22 patients with signs of inflammation of pancreatic cysts and a high current work rate (on average 22.32±1.92 μJ), growth of microorganisms was observed, in 84 patients without signs of inflammation of pancreatic cysts and a low current work rate (on average 5.86±5.02 μJ), there was no growth of microflora.

The quality of the model of the proposed method for express diagnostics of infection of postnecrotic pancreatic cysts using joulemetry was analyzed. For this purpose, ROC curves were evaluated (Fig. 4).

The presented graph clearly demonstrates that the numerical indicator of the area under the curve (AUC = 91.3) tends to 1.0, which characterizes the excellent quality of the model of the proposed method based on joulemetry.

Fig. 5 shows a graph of the dependence of signs of infection of postnecrotic cysts of the pancreas on the indicators of the current work obtained by joulemetry.

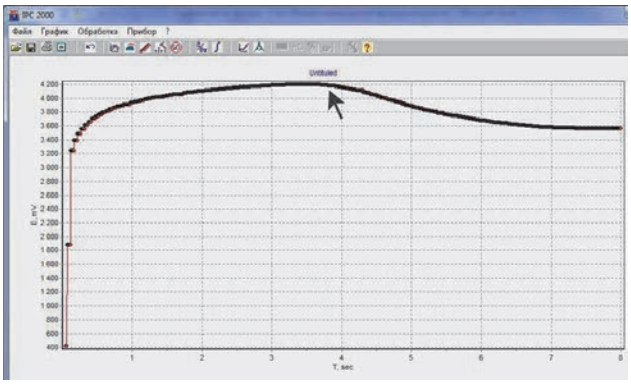

**Рис. 2.** Характерная кривая для кисты с признаками воспаления; стрелкой указана точка насыщения.
**Fig. 2.** A typical curve for a cyst with signs of inflammation, with the arrow indicating the saturation point.

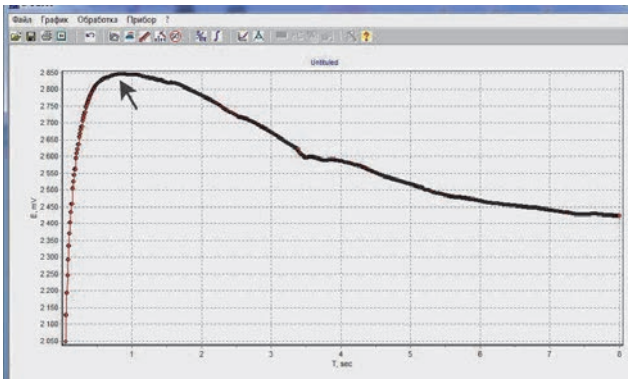

**Рис. 3.** Характерная кривая для кисты без признаками воспаления; стрелкой указана точка насыщения.
**Fig. 3.** A typical curve for a cyst without signs of inflammation, with the arrow indicating the saturation point.

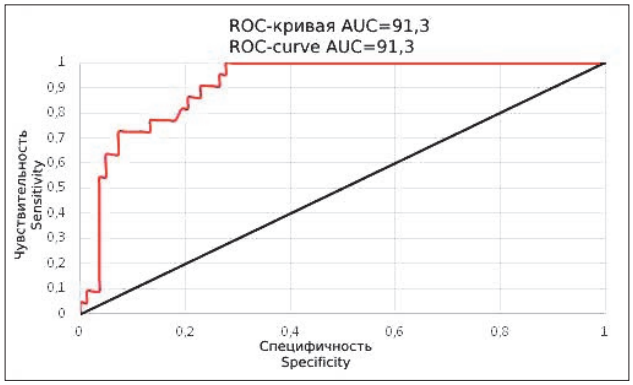


**Рис. 4.** ROC-кривая исследования работы тока у больных с постнекротическими кистами поджелудочной железы при определении их инфицирования на основе джоульметрии. На графике красным цветом показана ROC-кривая, черным – положительная диагональ.
**Fig. 4.** The ROC curve of the study of the electrical current in patients with postnecrotic pancreatic cysts in determining their infection based on joulemetry. The graph shows the ROC-curve in red, and the positive diagonal in black.

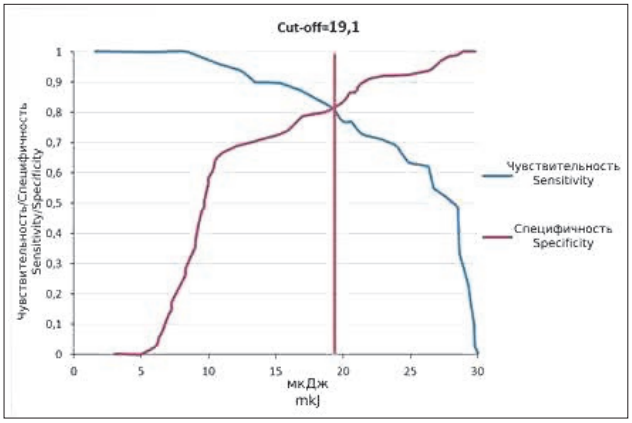


**Рис. 5.** Значение точки отсечения (cut-off) наличия/отсутствия признаков инфицирования содержимого постнекротической кисты ПЖ при джоульметрии.
**Fig. 5.** The value of the cut-off point for the presence/absence of signs of infection of the contents of a postnecrotic pancreatic cyst during joulemetry.

During the study, the cut-off point value for the presence/absence of signs of infection of the contents of a postnecrotic pancreatic cyst was determined: 19.1 μJ (if the current work value is > 19.1 μJ, then the cyst has signs of infection; if the current work value is ≤ 19.1 μJ, then the cyst is not infected).

Table 2 shows a fragment of the ROC-curve coordinate table for the study of current work in patients with postnecrotic pancreatic cysts when determining infection of their contents using the joulemetric method.

Based on the table of coordinates of the ROC curve of the study of the current work in patients with postnecrotic cysts of the pancreas when determining their infection based on joulemetry, the threshold differential diagnostic value was taken to be the current work index equal to 19.1 μJ. This value ensures the sensitivity of the proposed method of express diagnostics of exudate infection in local pancreatogenic peritonitis based on joulemetry equal to 81.8%, and specificity equal to 80.7% (AUC = 91.3).

All the obtained results of the electrochemical study of the contents of pancreatic cysts were confirmed by bacteriological examination: in 22 patients with signs of inflammation of pancreatic cysts and a high current work rate (on average 22.32±1.92 μJ), growth of microorganisms was observed; in 84 patients without signs of inflammation of pancreatic cysts and a low current work rate (on average 5.86±5.02 μJ), growth of microflora was not observed.

**Таблица 2**
**Фрагмент таблицы координат ROC-кривой исследования работы тока у пациентов с постнекротическими кистами ПЖ при определении инфицирования их содержимого**

**Table 2**
**A fragment of the coordinate table of the ROC-curve of the study of elecrical current work in patients with postnecrotic pancreatic cysts in determining infection of their contents**

| Работа тока, мкДж Electric current work, μJ | Чувствительность Sensitivity | Специфичность Specificity |
|---|---|---|
| 10,1 | 0,9789 | 0,6378 |
| 13,42 | 0,9213 | 0,7066 |
| 16,91 | 0,8708 | 0,7853 |
| 19,1 | 0,8182 | 0,8072 |
| 20,14 | 0,7835 | 0,8113 |
| 22,76 | 0,7412 | 0,8810 |
| 23,1 | 0,7244 | 0,9227 |

## Conclusion

During the electrochemical study of the contents of postnecrotic pancreatic cysts, statistically significant data on infection of the cyst contents were obtained ($p < 0.001$). When the current work was from 19.01 to 26.3 μJ (on average 22.32 ± 1.92 μJ), infection of the postnecrotic pancreatic cyst was diagnosed; the current work indicator from 0.92 to 18.31 μJ (on average 5.86 ± 5.02 μJ) indicates the absence of infection.

When assessing the quality of the joulemetric study in determining the early signs of inflammation of the contents of postnecrotic cysts of the pancreas, it was proven that the threshold differential diagnostic value of 19.1 μJ provides the sensitivity of the proposed method at 81.8% and specificity at 80.7% (AUC = 91.3) with a statistically significant difference in the current work indicators ($p < 0.001$).

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