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The role of indirect calorimetry in nutritional and metabolic therapy of pancreatogenic sepsis: a prospective controlled comparative study

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Abstract

INTRODUCTION: Destructive forms of acute pancreatitis are accompanied by a pronounced systemic inflammatory response and rapid development of pancreatogenic sepsis. This condition induces the development of hypermetabolism-hypercatabolism syndrome, characterized by increased energy expenditure and profound disturbances in protein metabolism. As a result, a critical nutrient deficiency is formed, aggravating organ dysfunction and increasing mortality. In this regard, optimization of nutritional support taking into account individual metabolic needs is a key aspect of intensive care for this category of patients. **OBJECTIVE:** To evaluate the effectiveness of targeted nutritional support based on indirect calorimetry in comparison with standard nutritional therapy in patients with pancreatogenic sepsis. **MATERIALS AND METHODS**: A single-center retrospective-prospective study was conducted involving 140 patients with infected pancreatic necrosis complicated by sepsis, divided into two groups: Group 1 (n = 71) — standard nutritional support, Group 2 (n = 69) — targeted nutritional support using indirect calorimetry. Instrumental, anthropometric, laboratory parameters, the dynamics of the severity of nutritional deficiency, as well as patient survival were assessed over 28 days. **RESULTS:** In Group 2, the energy requirement was 22.6–37.8 kcal/kg/day, protein intake was 1.0–1.8 g/kg/day, carbohydrate intake was 1.5–4.9 g/kg/day, and lipid intake was 1.1–1.8 g/kg/day. The total protein level (p < 0.05), absolute lymphocyte count (p < 0.05), and BMI (p < 0.05) were higher in the group receiving targeted nutritional support. The incidence of severe nutritional deficiency and 28-day mortality were significantly lower in the study Group 2. **CONCLUSIONS:** Personalized nutritional support based on the use of indirect calorimetry

НУТРИТИВНАЯ ПОДДЕРЖКА

Роль непрямой калориметрии в нутритивно-метаболической терапии панкреатогенного сепсиса: проспективное контролируемое сравнительное исследование

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Реферат

АКТУАЛЬНОСТЬ: Деструктивные формы острого панкреатита сопровождаются выраженным системным воспалительным ответом и быстрым развитием панкреатогенного сепсиса. Данное состояние индуцирует развитие синдрома гиперметаболизма-гиперкатаболизма, характеризующегося повышенным энергетическим расходом и глубокими нарушениями белкового обмена. Вследствие этого формируется критический дефицит нутриентов, усугубляющий органную дисфункцию и увеличивающий летальность. В связи с этим оптимизация нутритивной поддержки с учетом индивидуальных метаболических потребностей представляет собой ключевой аспект интенсивной терапии данной категории пациентов. **ЦЕЛЬ ИССЛЕДОВАНИЯ:** Оценить эффективность таргетной нутритивной поддержки, основанной на применении непрямой калориметрии, в сравнении со стандартной нутритивной терапией у пациентов с панкреатогенным сепсисом. **МАТЕРИАЛЫ И МЕТОДЫ:** Проведено одноцентровое ретроспективно-проспективное исследование с участием 140 пациентов с инфицированным панкреонекрозом, осложненным сепсисом, разделенных на 2 группы: 1-я (n = 71) — стандартная нутритивная поддержка, 2-я (n = 69) — таргетная нутритивная поддержка с использованием непрямой калориметрии. В течение 28 дней оценивались инструментальные, антропометрические, лабораторные показатели, динамика тяжести нутритивной недостаточности, а также выживаемость пациентов. **РЕЗУЛЬТАТЫ:** Во 2-й группе потребность в энергии составила 22,6–37,8 ккал/кг/сут, потребление белка — 1,0–1,8 г/кг/сут, потребление углеводов — 1,5–4,9 г/кг/сут, потребление липидов — 1,1–1,8 г/кг/сут. Уровень общего promotes adequate correction of metabolic disorders, improving clinical outcomes, and should be included in recommendations for intensive care of acute pancreatitis.

белка ($p < 0,05$), абсолютное число лимфоцитов ($p < 0,05$) и индекс массы тела ($p < 0,05$) были выше в группе, пациенты которой получали таргетную нутритивную поддержку. Частота развития тяжелой нутритивной недостаточности и уровень 28-дневной летальности были значимо ниже во 2-й исследуемой группе. **ВЫВОДЫ:** Персонализированная нутритивная поддержка на основе применения непрямой калориметрии способствует адекватной коррекции метаболических нарушений, улучшая клинические исходы, и должна быть включена в рекомендации по интенсивной терапии острого панкреатита.

KEYWORDS: pancreatitis, sepsis, indirect calorimetry, nutritional support

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КЛЮЧЕВЫЕ СЛОВА: панкреатит, сепсис, непрямая калориметрия, нутритивная поддержка

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Introduction

The pancreas plays one of the most important roles in maintaining body homeostasis through its involvement in digestion and metabolism due to its exocrine and endocrine functions. Disruption of these functions during the development of severe acute pancreatitis leads to pronounced nutritional deficiency in patients with this condition. The course of infected pancreatic necrosis with sepsis, as with other critical conditions, is accompanied by the development of hypermetabolism-hypercatabolism syndrome, a nonspecific body response to injury characterized by dysregulatory changes in metabolism. The main physiological characteristic of this syndrome is an increase in metabolic rate compared to the basal metabolic rate, leading to increased oxygen consumption with simultaneous hyperproduction of carbon dioxide, development of hypoproteinemia with the formation of a negative nitrogen balance, and other disturbances in the anabolism-catabolism system [1, 2]. A personalized nutritional support protocol for a patient with severe acute pancreatitis should be based on adequately conducted metabolic monitoring. To date, indirect calorimetry is the only most reliable way to measure a patient's energy and plastic needs. It involves assessing the patient's current energy requirement based on the simultaneous measurement of oxygen consumption and carbon dioxide excretion during spontaneous or mechanical ventilation [3]. Furthermore, this method allows not only for calculating the patient's energy requirement in real-time but also for assessing the metabolic pathways of nutrients, which is extremely important when planning and conducting nutritional therapy for patients with severe forms of acute pancreatitis [4].

Objective

To evaluate the effectiveness of targeted nutritional support based on the application of indirect calorimetry compared to standard nutritional therapy in patients with pancreatogenic sepsis.

Materials and methods

The study included all patients who met the inclusion and exclusion criteria, with infected pancreatic necrosis and sepsis, who underwent intensive treatment in the Intensive Care Unit (ICU) of the Septic Center of the Krasnoyarsk Regional Clinical Hospital between 2018 and 2024. A preliminary power calculation was not performed. The total sample size was 140 patients. All were divided into 2 groups, comparable to each other in terms of gender, age, body mass index (BMI), and severity of the initial condition (Table 1). Statistical analysis confirmed the absence of significant differences between the groups in baseline parameters ($p > 0.05$). In Group 1 (retrospective), an analysis of the medical records of 71 patients who received intensive care in the ICU between 2018 and 2020 and received standard nutritional support, which did not use indirect calorimetry to determine the body's energy needs, was conducted. Group 2 (prospective) included 69 patients who received intensive care in the ICU from 2021 to 2024 and targeted nutritional support based on the use of indirect calorimetry.

The metabolic activity of the studied patients was also assessed based on anthropometric and laboratory research methods. Anthropometric methods included measurement of:

- BMI;
- body weight deficit in %.

Laboratory methods included determination of the levels of:

- serum albumin;
- total protein;
- absolute lymphocyte count in peripheral blood.

To assess the severity of the patients' condition, the following scales were used:

- SOFA;
- APACHE II.

The following parameters of the conducted indirect calorimetry were assessed:

- REE (Resting Energy Expenditure), kcal/day;
- Prot/REE (Protein/Resting Energy Expenditure) — protein utilization in metabolism, %;
- CHO/REE (Carbohydrates/Resting Energy Expenditure) — carbohydrate utilization in metabolism, %;
- FAT/REE (Fats/Resting Energy Expenditure) — fat utilization in metabolism, %.

Table 1. Characteristics of the studied patients

Criteria	Group 1 (*n* = 71)	Group 2 (*n* = 69)
Gender (M/F)	45/26	51/18
Age, years	48 [36; 62]	43 [35; 60]
BMI (Body mass index), kg/m²	27.8 [24.9; 34.9]	29.4 [26.0; 32.6]
APACHE II (Acute Physiology and Chronic Health Evaluation)	15 [12; 18]	14 [10; 17]
SOFA (Sequential Organ Failure Assessment)	3 [2; 5]	3 [2; 5]
SAPS II (Simplified Acute Physiology Score)	24 [17.3; 31.5]	23 [15.0; 30.0]

Table 2. Criteria and degrees of nutritional deficiency

Indicators	Normal	Mild	Moderate	Severe
BMI (18–25 years), kg/m²	23.0–18.5	18.5–17.0	16.9–15.0	< 15.0
BMI (over 25 years), kg/m²	26.0–19.0	19.0–17.5	17.5–15.5	< 15.5
BMI (over 60 years), kg/m²	26–21	21–19	19–17	< 17
Albumin, g/L	> 35	35–30	30–25	< 25
Lymphocytes, ×10⁹/L	1.2	1.2–1.0	1.0–0.8	< 0.8
Transferrin, g/L	> 2.0	2.0–1.8	1.8–2.5	< 1.25
Total protein, g/L	> 60	55–59	54–50	< 50
Body weight deficit, %	< 10	11–10	21–30	> 30

To assess the effectiveness of targeted nutritional support in both study groups, the following were determined:

- the proportion (in %) of patients with a certain severity of nutritional deficiency at different periods of the study according to the table of criteria and degrees of nutritional deficiency (Table 2);
- 28-day mortality and survival analysis.

The study was conducted at the following stages of stay in the ICU: Stage I upon admission (Day 1 in ICU), Stage II — Day 3; Stage III — Day 5; Stage IV — Day 7, Stage V — Day 11, Stage VI — Day 14, Stage VII — Day 21, and Stage VIII — Day 28.

In both study groups, nutritional support was initiated as early as possible (within 24–48 hours of admission) in the absence of contraindications. Early enteral nutrition was preferred; however, if contraindications existed, the studied patients received total parenteral nutrition. For enteral nutrition, standard isocaloric enteral formulas were used, administered to patients via a nasojejunal tube placed distal to the ligament of Treitz. For patients in the study Group 1, energy requirements for planning nutritional support were determined using the Harris—Benedict equation, and daily protein requirements were determined empirically (1.3–1.5 g/kg of actual body weight). Patients in the study Group 2 received nutritional support based on the results of indirect calorimetry.

Inclusion criteria:

- Diagnosis of infected pancreatic necrosis, sepsis;
- Participant age from 18 to 65 years;
- Presence of written patient consent to participate in the study.

The diagnosis of pancreatitis was made based on the presence of at least two of the following signs identified in patients: typical clinical presentation (intense, unrelieved by spasmolytics, girdle pain, uncontrollable vomiting, abdominal distension; history of alcohol consumption, spicy food, or cholelithiasis, etc.); characteristic signs on ultrasound: increased size, decreased echogenicity, blurring of pancreatic contours, presence of free fluid in the abdominal cavity; hyperfermentemia (hyperamylasemia or hyperlipasemia) exceeding the upper limit of normal by three times or more. The diagnosis of sepsis was made based on the presence of an established source of infection and the presence of multiple organ dysfunction (SOFA ≥ 2) in patients [5]. Intensive therapy was conducted according to the clinical guidelines of the Ministry of Health of the Russian Federation for the treatment of acute pancreatitis and sepsis [6].

Exclusion criteria:

- Age younger than 18 and older than 65 years;
- Presence of contraindications to nutritional support (presence of severe uncorrectable hypoxemia (arterial partial pressure of oxygen (PaO_2) < 60 mm Hg with increasing fraction of inspired oxygen (FiO_2) > 70 % or more), hypercapnia (arterial partial pressure of carbon dioxide ($PaCO_2$) > 80 mm Hg), refractory shock);
- History of severe diabetes mellitus accompanied by pre-existing metabolic disorders (accompanied by nephropathies, retinopathies, and peripheral neuropathies, as well as tendencies to significant fluctuations in blood sugar levels throughout the day, tendencies to hypoglycemia and ketoacidosis);
- Presence of severe renal failure, contributing to inadequate assessment of urinary nitrogen losses;
- Presence of malignant neoplasms, contributing to significant urinary nitrogen losses;
- Need for using a high fraction of inspired oxygen (FiO_2> 60 %), affecting the results of indirect calorimetry, during mechanical ventilation (MV);
- Patient refusal to participate in the study.

Statistics. For statistical analysis, the IBM SPSS Statistics 26.0 package (IBM Corporation, USA) was used. The Shapiro—Wilk test (for $n \leq 50$) or Kolmogorov—Smirnov test (for $n \geq 50$) were used to assess the conformity of quantitative variables to the normal distribution law. For descriptive statistics of variables meeting the criteria of the normal distribution law, the mean value with standard deviation (M ± SD) was used. The Student's *t*-test was used for comparing unrelated groups. For descriptive analysis of variables that did not meet the criteria of the normal distribution law, median (Me) and interquartile range (IQR) indicators were used. The Mann—Whitney *U*-test (for quantitative variables), Fisher's exact test (F) and odds ratio (OR) with 95 % confidence interval (95 % CI) (for qualitative variables), and the Wilcoxon test for analyzing the dynamics of related groups were used. One-way analysis of variance — ANOVA (ANalysis Of VAriance) was used to determine the presence or absence of statistically significant changes in quantitative indicators during the patients' stay in the ICU. The Kaplan—Meier method and the Wilcoxon, log-rank, and Tarone—Ware tests were used for survival analysis and determination of 28-day mortality. A statistically significant difference was determined at a *p*-value of less than 0.05 or if the 95 % CI did not include 1.0.

Ethical approval. The study was approved by the Local Ethical Committee of the V.F. Voino-Yasenetsky Krasnoyarsk State Medical University, Ministry of Health of Russia, protocol No. 109/2021 dated 16.11.2021.

Results

Daily Resting Energy Expenditure indicators demonstrated significant intergroup differences. In Group 1, the REE values calculated using the Harris—Benedict equation remained almost unchanged throughout the entire study period ($p > 0.05$). In Group 2, a wider range of REE values was recorded, changing statistically significantly during the study period ($p < 0.05$). Between Day 7 and Day 11, REE significantly decreased relative to the first day in the ARD ($p < 0.05$) (Table 3).

When recalculating REE per actual body weight of Group 2 patients, values in the range of 22.6–37.8 kcal/kg/day were obtained (Table 4).

The daily protein requirement of Group 1 patients was determined empirically — 1.3–1.5 g/kg/day (based on actual body weight) [7]. In Group 2 patients, the minimum daily protein requirement was calculated based on the Prot/REE indicator, determined by indirect calorimetry. This indicator reflected the daily amount of protein intake. The values of the indicator varied from 1.0 g/kg/day to 1.8 g/kg/day ($p < 0.05$). Analysis of the indicator over time revealed characteristic changes: in the first 11 days, the average protein intake was 1.0–1.4 g/kg/day ($p > 0.05$) with a peak by Day 14 ($p < 0.05$) and a subsequent decrease by Day 28 of observation (Table 5).

In the standard nutritional support group (Group 1), carbohydrate and lipid requirements were not calculated. It is known that incorrect dosing of macronutrients in patients with pancreatogenic sepsis is associated with the development of hyperglycemia, difficulty in weaning from MV, and hypertriglyceridemia — a proven predictor of adverse outcome in destructive forms of acute pancreatitis [8].

The use of metabolography (indirect calorimetry) in Group 2 allowed for an objective determination of the minimum daily requirement for basic nutrients based on their utilization indicators. Carbohydrate intake (CHO/REE) was 1.5–4.9 g/kg/day with peak values by Day 21 of observation ($p < 0.01$) (Table 6), while the values of lipid intake (Fat/REE) did not change statistically significantly throughout the entire study period ($p > 0.05$) (Table 7).

To assess the effectiveness of targeted nutritional support, a comparative analysis of the dynamics of laboratory and anthropometric parameters between the groups was conducted. The dynamics of the severity of nutritional deficiency during the patients' stay in the ICU were also assessed. The 28-day mortality in the comparison groups was analyzed as the main efficacy criterion.

Table 3. REE of patients during their stay in the ICU

Groups		Observation day								*p*
		1	3	5	7	11	14	21	28	
Group 1, REE (HB)	(M ± SD)	2320 ± 390	2315 ± 401	2290 ± 401	2292 ± 426	2234 ± 383	2256 ± 456	2172 ± 502	2420 ± 267	*> 0.05*
Group 2, REE (IC)	(M ± SD)	2444 ± 813	2402 ± 683	2679 ± 1149	1946 ± 319*	1738 ± 421*	2437 ± 356	2599 ± 77	2124 ± 431	*< 0.05*
		> 0.05	> 0.05	> 0.05	< 0.01	< 0.05	> 0.05	< 0.05	> 0.05	

* — statistically significant change in the indicator relative to Day 1 in the ICU.

HB — Harris—Benedict equation; IC — indirect calorimetry; REE — resting energy expenditure.

Note: Results of one-way analysis of variance (ANOVA) are shown in italics.

Table 4. REE of Group 2 patients

Indicator		Observation day								*p*
		1	3	5	7	11	14	21	28	
REE (IC), kcal/kg/d	(M ± SD)	29.1 ± 8.5	28.8 ± 8.6	30.0 ± 7.7	24.1 ± 4.0	22.6 ± 0.3	38.1 ± 3.7	37.8 ± 4.4	34.7 ± 3.1	*< 0.05*

REE — resting energy expenditure; IC — indirect calorimetry.

Note: Results of one-way analysis of variance (ANOVA) are shown in italics.

Table 5. Daily protein intake in Group 2 patients

Groups		Observation day								*p*
		1	3	5	7	11	14	21	28	
Group 2, g/kg/d	(M ± SD)	1.0 ± 0.6	1.4 ± 1.2	1.1 ± 0.7	1.0 ± 0.7	1.2 ± 0.8	1.8 ± 0.5*	1.8 ± 0.7*	1.3 ± 0.5*	*< 0.05*

* — statistically significant change in the indicator relative to Day 1 in the ICU.

Note: Results of one-way analysis of variance (ANOVA) are shown in italics.

A comparative analysis of protein metabolism indicators revealed a significantly higher level of total protein in patients receiving targeted nutritional support (Group 2) during the first 11 days of stay in the ICU ($p < 0.05$). However, in the subsequent observation period (days 14–28), intergroup differences were not statistically significant ($p > 0.05$) (Table 8).

Analysis of serum albumin dynamics showed a tendency towards higher values in Group 2 compared to the control group. However, intergroup differences were not statistically significant at all stages of observation ($p > 0.05$) (Table 9).

The detected hypoalbuminemia in both study groups is likely due to capillary leak syndrome — a characteristic pathophysiological component of sepsis [9]. This fact significantly limits the diagnostic value of serum albumin as a marker of nutritional deficiency in this category of patients, which can lead to erroneous assessment of their metabolic status.

For the synthesis of immune cells necessary for an adequate response to infection, the absence of a pronounced protein-energy deficiency in the patient's body is required. The absolute lymphocyte count in peripheral blood is used as an auxiliary parameter for assessing the nutritional status of patients.

In patients receiving targeted nutritional support (Group 2), a significant increase in the absolute lymphocyte count was recorded starting from Day 5 of stay in the ICU ($p < 0.05$). This dynamic indicates a positive effect of targeted nutritional therapy on cellular immunity indicators in this group of patients (Table 10).

Analysis of anthropometric indicators revealed significant intergroup differences. In the standard nutritional support group, a progressive loss of body weight with a cor-

Table 6. Daily carbohydrates intake in Group 2 patients

Groups		**Observation day**								***p***
		1	**3**	**5**	**7**	**11**	**14**	**21**	**28**	
Group 2, g/kg/d	(M ± SD)	2.5 ± 1.7	2.6 ± 2.3	3.0 ± 1.6	1.9 ± 0.7	2.4 ± 0.7	1.5 ± 0.8	5.1 ± 0.1*	3.2 ± 1.0	*< 0.01*

* — statistically significant change in the indicator relative to Day 1 of stay in the ICU.

Note: Results of one-way analysis of variance (ANOVA) are shown in italics.

Table 7. Daily fats intake in Group 2 patients

Groups		**Observation day**								***p***
		1	**3**	**5**	**7**	**11**	**14**	**21**	**28**	
Group 2, g/kg/d	(M ± SD)	1.8 ± 1.3	1.6 ± 0.8	1.5 ± 0.9	1.5 ± 0.6	1.1 ± 0.8	2.5 ± 1.5	1.1 ± 0.2	1.1 ± 0.3	*> 0.05*

Note: Results of one-way analysis of variance (ANOVA) are shown in italics.

Table 8. Laboratory dynamics of total protein levels

Groups		**Observation day**							
		1	**3**	**5**	**7**	**11**	**14**	**21**	**28**
Group 1	(M ± SD)	56.9 ± 8.3	53.1 ± 6.5	53.2 ± 7.2	55.0 ± 7.0	56.7 ± 5.8	55.6 ± 6.3	59.4 ± 6.4	55.9 ± 7.6
Group 2	(M ± SD)	63.4 ± 10.5	58.0 ± 7.6	58.5 ± 7.5	61.4 ± 8.5	61.7 ± 10.8	55.9 ± 8.5	56.5 ± 7.1	55.4 ± 6.7
		< 0.01	< 0.01	< 0.01	< 0.01	< 0.05	> 0.05	> 0.05	> 0.05

Table 9. Laboratory dynamics of serum albumin levels

Groups		**Observation day**							
		1	**3**	**5**	**7**	**11**	**14**	**21**	**28**
Group 1	(M ± SD)	24.2 ± 4.8	22.8 ± 4.3	22.1 ± 4.8	22.4 ± 4.7	22.7 ± 4.1	21.2 ± 4.9	22.8 ± 4.9	23.3 ± 7.6
Group 2	(M ± SD)	28.0 ± 8.1	25.6 ± 6.6	24.4 ± 6.5	25.6 ± 7.3	23.2 ± 5.3	21.1 ± 5.3	23.5 ± 2.2	25.1 ± 3.1
		> 0.05	> 0.05	> 0.05	> 0.05	> 0.05	> 0.05	> 0.05	> 0.05

responding decrease in BMI was observed over the 28-day observation period. In patients receiving targeted nutritional support, the initial anthropometric parameters were maintained. The values in Group 2 were significantly higher than those in the control group ($p < 0.05$) (Table 11).

it is worth noting the low value of BMI as a diagnostic marker for assessing the severity of protein-energy deficiency, as critically ill patients may experience significant weight gain, which, in turn, is caused by fluid retention due to endothelial dysfunction during infusion therapy. Assessing the body weight deficit of the studied patients, data showed that in this study there were no patients for whom this anthropometric indicator was characteristic.

In both study groups, throughout the entire observation period, all patients had some degree of nutritional deficiency. Assessment of the effectiveness of targeted nutritional-metabolic therapy revealed a significant reduction in the frequency of severe nutritional deficiency in Group 2: by Day 5 — by 8.3 % ($p < 0.05$), by Day 7 — by 13 % ($p < 0.05$), by Day 11 — by 27.9 % ($p < 0.05$), by Day 21 — by 41.7 % ($p < 0.05$), by Day 28 — by 47.7 % ($p < 0.05$) (Table 12).

A comparative assessment of survival considering the time function was also conducted using the Kaplan—Meier method (Figure 1).

Comparative survival analysis using the Kaplan—Meier method revealed statistically significant differences between the groups ($p < 0.0001$ by Wilcoxon, Tarone—Ware, and log-rank tests). The 28-day mortality rate in the standard therapy group was 50.4 % compared to 27.6 % in the targeted nutritional support group.

Discussion

The study results demonstrate significant differences between the actual metabolic needs of patients with pancreatogenic sepsis and existing clinical guidelines for nutritional support. The obtained data indicate the necessity of an individual approach to calculating energy requirements,

Table 10. Laboratory dynamics of the absolute number of lymphocytes

Groups		Observation day							
		1	3	5	7	11	14	21	28
Group 1	(M ± SD)	1.2 ± 0.6	1.1 ± 0.7	1.1 ± 0.5	1.2 ± 0.6	1.2 ± 1.1	1.1 ± 0.6	1.3 ± 0.7	1.4 ± 0.4
Group 2	(M ± SD)	1.3 ± 0.7	1.1 ± 0.5	1.4 ± 0.6	1.4 ± 0.9	1.5 ± 1.1	1.6 ± 0.5	1.7 ± 0.4	1.7 ± 0.8
		> 0.05	> 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

Table 11. Dynamics of body mass index

Groups		Observation day							
		1	3	5	7	11	14	21	28
Group 1	(M ± SD)	29.0 ± 5.0	29.1 ± 4.9	29.0 ± 5.0	28.7 ± 4.9	28.4 ± 4.7	28.3 ± 4.6	27.8 ± 5.4	27.9 ± 5.3
Group 2	(M ± SD)	29.6 ± 4.9	29.7 ± 4.9	30.5 ± 4.8	30.6 ± 5.9	30.5 ± 6.5	30.7 ± 1.8	30.4 ± 2.3	30.5 ± 1.7
		> 0.05	> 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

Table 12. Assessment of the severity of nutritional deficiency

Groups	Nutritional Deficiency	Observation day							
		1	3	5	7	11	14	21	28
Group 1	Mild, %	7	2.9	1.5	3.7	2.8	0	0	0
	Moderate, %	28.2	22.9	23.5	20.4*	22.2*	25.8	18.2*	0
	Severe, %	64.8	74.3	75*	75.9*	77.8*	74.2	81.8*	100*
Group 2	Mild, %	10.5	8.7	4.2	2.2	4.7	3.3	7.1	10.7
	Moderate, %	34.2	29.2	26.1	34.9*	45.4*	36.6	40.1*	35.0*
	Severe, %	55.3	63.1	67.7*	62.9*	49.9*	60.1	52.8*	52.3*

Note: * — statistically significant change in the indicator relative to the indicators of the other group of studied patients.

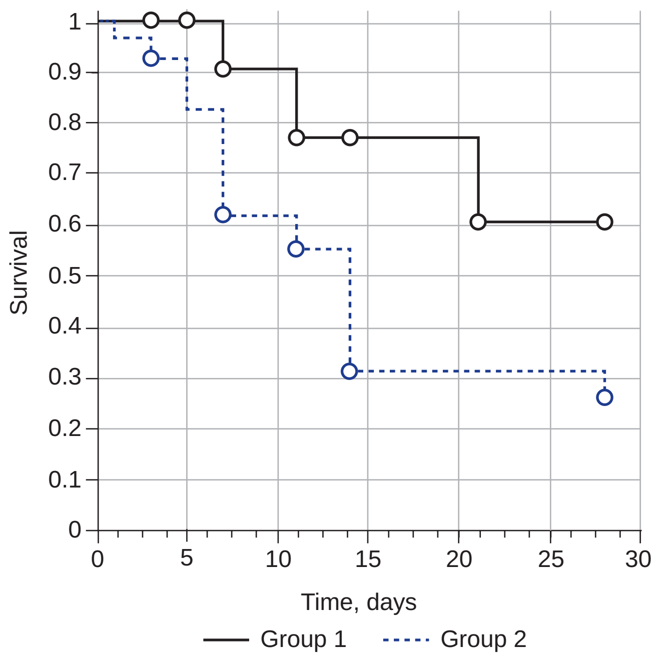

Fig. 1. 28-day mortality

as well as nutrient requirements, using methods of metabolic monitoring.

Analysis of energy requirements revealed an optimal caloric intake in the range of 22.6–37.8 kcal/kg/day, which exceeds the recommended values (25–30 kcal/kg/day) [7, 10]. These differences may be due to the variability of the metabolic response depending on the severity of the septic process, confirming the need for dynamic assessment using indirect calorimetry.

Regarding the protein component, a significant spread of individual needs was established (1.0–1.8 g/kg/day) compared to recommended values of 1.3–1.5 g/kg/day [7, 10]. Metabolographic study also allowed for determining optimal dosages of carbohydrates (1.5–4.9 g/kg) and lipids (1.1–2.5 g/kg). We were unable to find similar studies in patients with infected pancreatic necrosis in the available literature.

The application of targeted nutritional-metabolic therapy was accompanied by a significant increase in the level of total protein ($p < 0.05$) and absolute lymphocyte count ($p < 0.05$), indicating a positive effect on protein metabolism and immune status. We also could not find similar studies in the available literature. The absence of significant differences between the studied groups in albumin level corresponds to the pathophysiological features of sepsis, which is also confirmed by the literature on this topic [11]. The most significant result was the reduction in 28-day mortality from 50.4 % to 27.6 % ($p < 0.0001$), confirming the clinical significance of a personalized approach to nutritional support. The literature contains data on reduced 28-day mortality in critically ill patients receiving personalized nutritional support [12], however, similar data for patients with infected pancreatic necrosis were not found.

The obtained data emphasize the need to revise standard approaches to nutritional support in pancreatogenic sepsis, taking into account individual metabolic characteristics. The development of nutritional support algorithms based on dynamic metabolic monitoring seems a promising direction.

Conclusion

Indirect calorimetry allows for accurate determination of energy and macronutrient needs and optimization of targeted nutritional-metabolic therapy in patients with infected pancreatic necrosis and sepsis. Personalized nutritional support based on metabolographic monitoring promotes adequate correction of metabolic disorders, improving clinical outcomes, and should be included in recommendations for the intensive care of acute pancreatitis.

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Author contribution. All authors according to the ICMJE criteria participated in the development of the concept of the article, obtaining and analyzing factual data, writing and editing the text of the article, checking and approving the text of the article.

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