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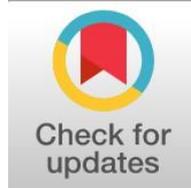
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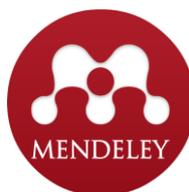
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Prevention of Postoperative Purulent-Inflammatory Complications Using Photodynamic Therapy in Strangulated Hernias

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Abstract

General Background: Postoperative infectious complications remain a major challenge in abdominal surgery, particularly in cases of strangulated abdominal hernias where microbial contamination of the surgical field frequently occurs. **Specific Background:** Photodynamic therapy using photosensitizers and light activation has been proposed as an antimicrobial approach, while methylene blue represents an accessible and low-cost photosensitizer that can be activated by LED irradiation. **Knowledge Gap:** Despite its potential advantages, the clinical and microbiological role of methylene-blue-mediated photodynamic therapy in preventing postoperative purulent-inflammatory complications in strangulated hernia surgery has not been sufficiently investigated. **Aims:** This study aimed to evaluate the microbiological characteristics of hernial sac infections and assess the preventive potential of intraoperative photodynamic therapy using methylene blue and LED irradiation. **Results:** A comparative clinical study of 225 patients showed that hernial sac infections were predominantly polymicrobial, with *Escherichia coli* (46%), *Staphylococcus aureus* (28%), and *Staphylococcus epidermidis* (6%) being the most common pathogens. Combined photodynamic treatment reduced microbial contamination from 10^4 CFU/ml to 10^2 CFU/ml and lowered postoperative complications from 16.3% in the control group to 6.3% in the treated group, while also shortening hospital stay from 10.0 ± 0.67 days to 7.3 ± 0.77 days. **Novelty:** The study demonstrates the clinical and microbiological benefits of intraoperative photodynamic sanitation using methylene blue and LED light in strangulated hernia surgery. **Implications:** The findings support the use of accessible photodynamic techniques as a practical strategy for reducing postoperative purulent-inflammatory complications

and improving surgical outcomes.

Highlights:

- Significant Decrease in Bacterial Contamination After Intraoperative Photodynamic Sanitation
- Lower Frequency of Postoperative Purulent-Inflammatory Events in Treated Patients
- Shorter Hospitalization Period Following Methylene-Blue–Based Photodynamic Treatment

Keywords: Photodynamic Therapy, Strangulated Hernia, Methylene Blue, Surgical Site Infection, Postoperative Complications.

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Introduction

Postoperative infectious complications remain one of the most serious problems in abdominal surgery [14]. Surgical site infections significantly worsen treatment outcomes, increase the duration of hospitalization, and may lead to systemic septic complications [12, 15].

The risk of infection is particularly high in patients with strangulated abdominal hernias. Strangulation of abdominal organs is often accompanied by intestinal obstruction, ischemic damage, and necrosis of the affected tissues. These pathological processes create favorable conditions for microbial contamination of the hernial sac and its contents [2, 5, 10, 15]. During surgical intervention, opening of the hernial sac and evacuation of infected exudate inevitably result in contamination of the operative field.

Persistence of infected fluid in the abdominal cavity or surgical wound may subsequently lead to wound suppuration, abscess formation, or generalized infection. A significant proportion of hernia recurrences following surgical repair is associated with postoperative infectious complications. Published evidence suggests that infections may be responsible for as many as 70% of recurrent cases [9, 15].

Consequently, the development of reliable intraoperative methods designed to reduce bacterial contamination of operative wounds represents an important objective in modern hernia surgery [1, 7].

Among the emerging approaches, photodynamic therapy (PDT) has recently been explored as a potentially effective antimicrobial technique [3, 6, 8, 13]. The therapeutic effect of PDT is based on photochemical reactions occurring after activation of a photosensitizing agent by light of a specific wavelength. The interaction between the activated photosensitizer and molecular oxygen leads to the formation of reactive oxygen species, which have pronounced cytotoxic and bactericidal effects [3, 6, 8].

Various photosensitizers have been proposed for photodynamic therapy. However, many commonly used agents are expensive and not widely available in clinical practice in several countries [4].

In addition, some PDT protocols require laser equipment that is not accessible in many surgical hospitals [8, 11].

Methylene blue represents a promising alternative photosensitizer due to several advantages:

- wide availability and low cost;
- strong absorption in the visible light spectrum;
- effective activation by LED radiation with a wavelength close to 640 nm;
- previously demonstrated antimicrobial properties in inflammatory diseases [4, 6].

Despite these advantages, the potential of methylene blue-mediated photodynamic therapy for the prevention of postoperative complications in strangulated abdominal hernias has not been sufficiently investigated.

Aim of the Study

This study aimed to investigate the preventive potential of intraoperative photodynamic antimicrobial treatment employing methylene blue and LED light exposure in reducing postoperative purulent and inflammatory complications among patients undergoing surgery for strangulated abdominal hernias.

Materials and Methods

The microbiological examination was carried out according to standard bacteriological protocols. Isolation of pure microbial strains was achieved by mechanical streaking on solid nutrient media. Microorganisms were subsequently identified to the genus and species levels using a combination of morphological assessment, staining reactions, culture characteristics, and biochemical tests (Table 1).

Table 1. Microbiological Characteristics of Hernial Sac Exudate in Strangulated Hernia Cases

Microorganism	Detection frequency (%)
<i>Staphylococcus aureus</i>	28
<i>Staphylococcus epidermidis</i>	6
<i>Escherichia coli</i>	46
Other microorganisms	20

Note: The analysis did not reveal any differences in the microbial spectrum of hernial fluid among the comparison groups.

For microbial cultivation, the following nutrient media were employed:

- ✓ 1% carbohydrate broth
- ✓ 1% carbohydrate agar
- ✓ 5% blood agar

The microbial load was calculated by counting colony-forming units on Petri dishes with subsequent correction for dilution factors. The results were expressed as CFU per square centimeter.

Table 2. Effect of photodynamic therapy on microbial contamination

Experimental condition	Microbial count (CFU/ml)
Control (no PDT)	10^4
PDT (0.05% methylene blue + LED irradiation)	10^2

Methylene blue was used as a photosensitizing agent. Stock solutions with concentrations of 1% and 10% were prepared, while working solutions with concentrations ranging from 0.001% to 0.1% were prepared immediately before use.

Photodynamic irradiation was performed using a certified LED device FDU-1 with the following parameters:

- ✓ wavelength of LED radiation: 640 ± 20 nm;
- ✓ power density of irradiation: 200 mW/cm^2 (Figure 1).

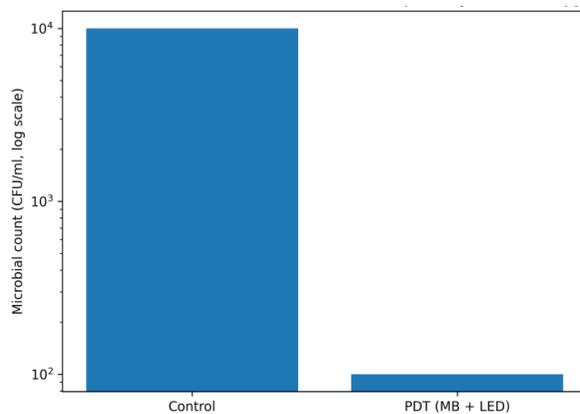


Figure 1. Decrease of microbial contamination after photodynamic therapy using methylene blue and LED irradiation.

A total of 225 patients with strangulated abdominal hernias undergoing treatment in surgical units were included in the clinical investigation. The study population was stratified into two groups.

Main group

The study (main) group comprised 127 patients who received surgical treatment between 2018 and 2020. In these patients, intraoperative photodynamic sanitation of the surgical wound was performed after preliminary photosensitization with 0.05% methylene blue solution followed by LED irradiation.

Radiation parameters were:

- ✓ power density of radiation – 200 mW/cm^2 ;
- ✓ delivered energy density – $25\text{--}35 \text{ J/cm}^2$.

Furthermore, a collagen hemostatic sponge (Hemogubka) was applied intraoperatively to ensure effective hemostasis and lymphatic drainage control and to prevent postoperative seroma development.

Control group

A total of 98 patients treated during the period from 2015 to 2017 formed the control group and underwent conventional surgical management. Wound irrigation in this group was performed using a furacilin solution (1:5000).

Statistical processing of the obtained data included calculation of mean values, standard errors, and confidence intervals. Statistical significance was evaluated using Student's t-test, and differences were considered significant at $p < 0.05$.

Results

In the initial experimental stage, the influence of LED irradiation with a wavelength of 640 ± 20 nm on the microbial flora present in hernial sac fluid was investigated. The duration of irradiation exposure included the following intervals: 1 minute; 3 minutes; 5 minutes; 10 minutes.

During the procedure, the irradiation power density was maintained at 200 mW/cm^2 . The obtained results indicated that LED irradiation applied alone did not produce a pronounced antibacterial effect, even when the exposure duration was increased to 3–5 minutes.

At the second stage of the experiment, the antimicrobial properties of methylene blue solutions with the following concentrations were evaluated:

- ✓ 1%;
- ✓ 0.1%.
- ✓ 0.01%;
- ✓ 0.001% was investigated.

Solutions with concentrations between 0.001% and 0.1% did not demonstrate direct bactericidal activity. However, these concentrations effectively stained microbial cells and facilitated visualization during microscopic examination.

Based on these findings, 0.05% methylene blue was selected as the optimal photosensitizer for further photodynamic experiments.

Subsequent experiments evaluated the combined effect of methylene blue photosensitization and LED irradiation.

A pronounced antimicrobial effect was observed when the following parameters were used:

- ✓ methylene blue concentration – 0.05%;
- ✓ power density – 200 mW/cm^2 ;
- ✓ irradiation time – 3–5 minutes.

Under these conditions, microbial contamination decreased from 10^4 CFU/ml in the control samples to 10^2 CFU/ml after photodynamic treatment, representing a 100-fold reduction in bacterial count.

Clinical Results

Postoperative complications were analyzed in both study groups (Table 3).

Table 3. Postoperative complications in study groups

Complication	Main group (n=127)	%	Control group (n=98)	%
Seroma	4	3.1	7	7.1
Hematoma	2	1.6	1	1.0
Wound suppuration	2	1.6	5	5.1
Infiltrate	0	0	2	2.0
Skin necrosis	0	0	1	1.0
Total complications	8	6.3	16	16.3

In the main group (127 patients), complications occurred in 8 patients (6.3%):

- ✓ seroma – 4 cases (3.1%);
- ✓ hematoma – 2 cases (1.6%);
- ✓ wound suppuration – 2 cases (1.6%).

No cases of wound infiltrate or skin necrosis were observed.

In the control group (98 patients), complications developed in 16 patients (16.3%):

- ✓ seroma – 7 cases (7.1%);
- ✓ hematoma – 1 case (1.0%);
- ✓ wound suppuration – 5 cases (5.1%);
- ✓ infiltrate – 2 cases (2.0%);
- ✓ skin necrosis – 1 case (1.0%) (Figure 2).

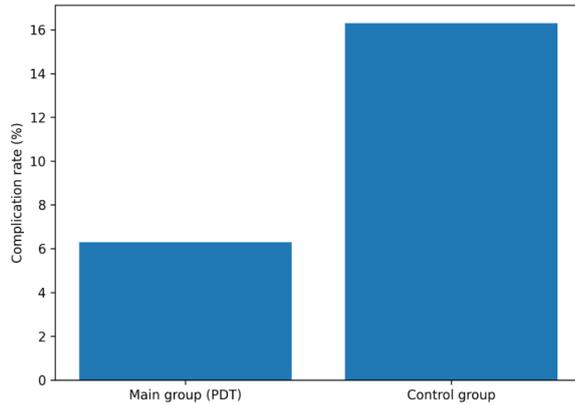


Figure 2. Reduction in the incidence of postoperative purulent-inflammatory complications after intraoperative photodynamic therapy.

Thus, the incidence of postoperative complications in the main group was 2.6 times lower compared with the control group.

Hospital Stay

Implementation of photodynamic therapy also resulted in a reduction in the duration of hospitalization (Table 4).

Table 4. Average duration of hospital stay

Group	Number of patients	Hospital stay (days)
Main group (PDT)	127	7.3 ± 0.77
Control group	98	10.0 ± 0.67

Average hospital stay:

Main group — 7.3 ± 0.77 days;

Control group — 10.0 ± 0.67 days.

Conclusions

1. Hernial fluid in strangulated abdominal hernias contains polymicrobial flora dominated by *Escherichia coli*, *Staphylococcus aureus*, and *Staphylococcus epidermidis*.
2. Separate use of methylene blue or LED irradiation does not produce a significant antimicrobial effect.
3. Photodynamic therapy combining 0.05% methylene blue and LED irradiation (640 nm) demonstrates strong bactericidal activity.
4. Intraoperative photodynamic sanitation reduces postoperative purulent-inflammatory complications from 16.3% to 6.3% and shortens hospital stay.

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