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ORIGINAL ARTICLE

# Visible negative pressure wound therapy for open abdominal management: A single-center retrospective study

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**Abstract**

**Aim:** This study aimed to compare open abdominal management (OAM) between visible negative pressure wound therapy (NPWT) and commercial NPWT to determine whether NPWT can detect intestinal ischemia in its early stages without causing complications or worsening prognosis, and to determine whether the actual visualization results in early detection.

**Methods:** Patients were divided into two groups: those who underwent OAM with visible NPWT (A: 32 patients) and those who underwent OAM with commercial NPWT (B: 12 patients). We compared background factors, disease severity, vital signs, blood test values, and 28-day outcomes between the two groups. We also checked the records to determine how many visualized cases were detected early and operated on. We then examined the weaknesses of this method.

**Results:** No differences were observed in the background factors or disease severity between the two groups. The duration of the open abdomen and intensive care unit stay were significantly shorter for group A than for group B. The groups showed no significant differences in lactate levels, 28-day outcomes, complications during OAM, or other factors. After a review of the medical records, ischemic progression was detected early, and surgery could be performed in seven cases in the visible NPWT group. The progression of ischemia was confirmed at the time of the second-look operation in two cases in the ascending colon.

**Conclusion:** The visualization device allowed us to gain insights into the intra-abdominal cavity and determine the appropriate time for closing the abdomen without worsening the prognosis.

**KEYWORDS**
acute abdomen, damage control surgery, negative pressure wound therapy, open abdominal management, temporary abdominal closure

## INTRODUCTION

Open abdominal procedures were first described for the management of peritonitis by McCosh in 1897.[1] However, the technique initially experienced a decline in popularity and later gained prominence as open abdominal management (OAM)[2] in trauma damage control surgery. Open abdominal management was introduced to prevent abdominal compartment syndrome and enable easier access for treating bleeding and contamination. Historically, the management of open abdomen posed challenges, leading to the development of innovations such as the towel clip procedure and Bogota bag.[3] Despite these advancements, issues related to contamination control and moisture management persisted. In the 1990s, the use of vacuum pack closure (VPC) started gaining acceptance as a technique for managing

open abdomen procedures. In the late 2000s, VPC products tailored for open abdomen procedures were introduced, and the procedure became simpler. Since 2010, VPC has become widely accepted in Japan as a temporary abdominal closure technique for OAM. However, the intra-abdominal cavity was not visible in this technique because a contact layer had to be laid down to prevent enteroatmospheric fistula[4] and the use of foam for negative-pressure suction. Therefore, when OAM was associated with elevated lactate levels or anemia, the intra-abdominal condition could not be checked except by reopening the abdomen. We believe that if the intra-abdominal cavity could be immediately observed during VPC, bleeding and intestinal ischemia would be detected at an early stage, thus saving lives in the process. Therefore, we added a visualization device to a commercial negative pressure wound therapy (NPWT) kit for the abdomen and called this technique "visible NPWT" (Figure 1). The visible NPWT procedure is outlined in Figure 2.

The present study aimed to compare OAM with visible NPWT and OAM with commercial NPWT to show that OAM with visible NPWT can detect problems, such as intestinal ischemia, at an early stage and does not cause complications or worsen the prognosis. We also show that the actual visualization results in early detection.

## MATERIALS AND METHODS

### Patients

Figure 3 shows the flow diagram of patient selection for the study. Between April 2012 and March 2022, we performed OAM on 139 patients. Patients with trauma were excluded, and those who presented with intestinal ischemia were examined. Therefore, this study included 44 patients diagnosed with intestinal ischemia.

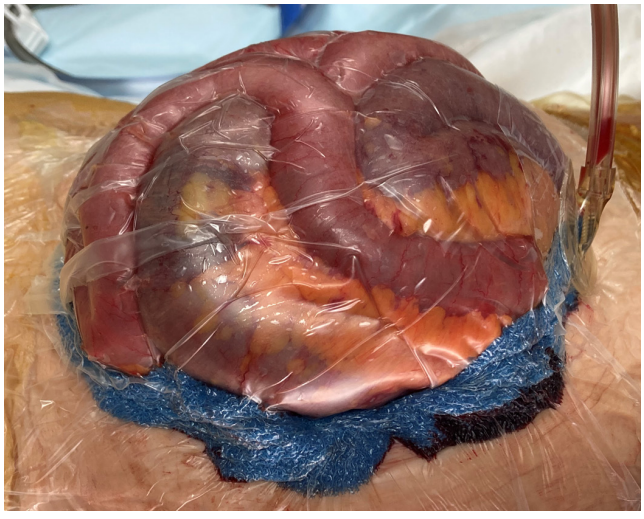

**FIGURE 1** Approach to visualize the intra-abdominal cavity during open abdominal management. Our technique is referred to as "visible negative pressure wound therapy".

We excluded cases of death within 7 days because we thought that the poor condition of the underlying disease that was the basis for hospitalization was very likely to be irreversible in the first place.

The criteria for reopening the abdomen, if not confirmed by commercial NPWT, were two consecutive elevations of lactate and unstable hemodynamics.

### Setting of the study

Our innovations for the visualization of NPWT in the abdomen were based on the VAC system (KCI USA) and the AbThera OA Negative Pressure Therapy System (KCI USA).

For visualization, the sponge-structured foam in the kit was shaped in the form of a ring and placed along the edge of the open abdominal wound. All other procedures were carried out in accordance with the manufacturer's instructions.

Because all cases were handled by one team, there was no bias in the decision to perform OAM, the choice of equipment to use, or the method of OAM.

### Study design

Patients were divided into two groups: the OAM group that underwent visible NPWT (group A: 32 patients) and the OAM group that was managed with the commercial product (group B: 12 patients). Patient background factors, the severity of illness, vital signs at the time of admission to the intensive care unit (ICU), blood laboratory test results, duration of laparotomy, duration of ICU stay, 28-day outcome, and complications (infection, bleeding, and progression of ischemia) were retrospectively compared between the groups.

Among the visible NPWT group, cases that could be detected and operated on at an early stage of ischemia, that is, when the bowel color begins to change from pale to dark purple, were extracted from the records. Conversely, we evaluated the characteristics of cases in which necrosis was identified during the second-look operation.

### Study outcomes and statistical analysis

Continuous variables were expressed as means and standard deviations and were compared using ANOVA. Categorical data were expressed as proportions and compared using the $\chi^2$-test. JMP Pro 16.0.0 (SAS Institute Inc.) was used for statistical analysis. The significance level was set at $p < 0.05$.

## RESULTS

The results of the comparison between the two groups are presented in Table 1. The two groups did not show significant

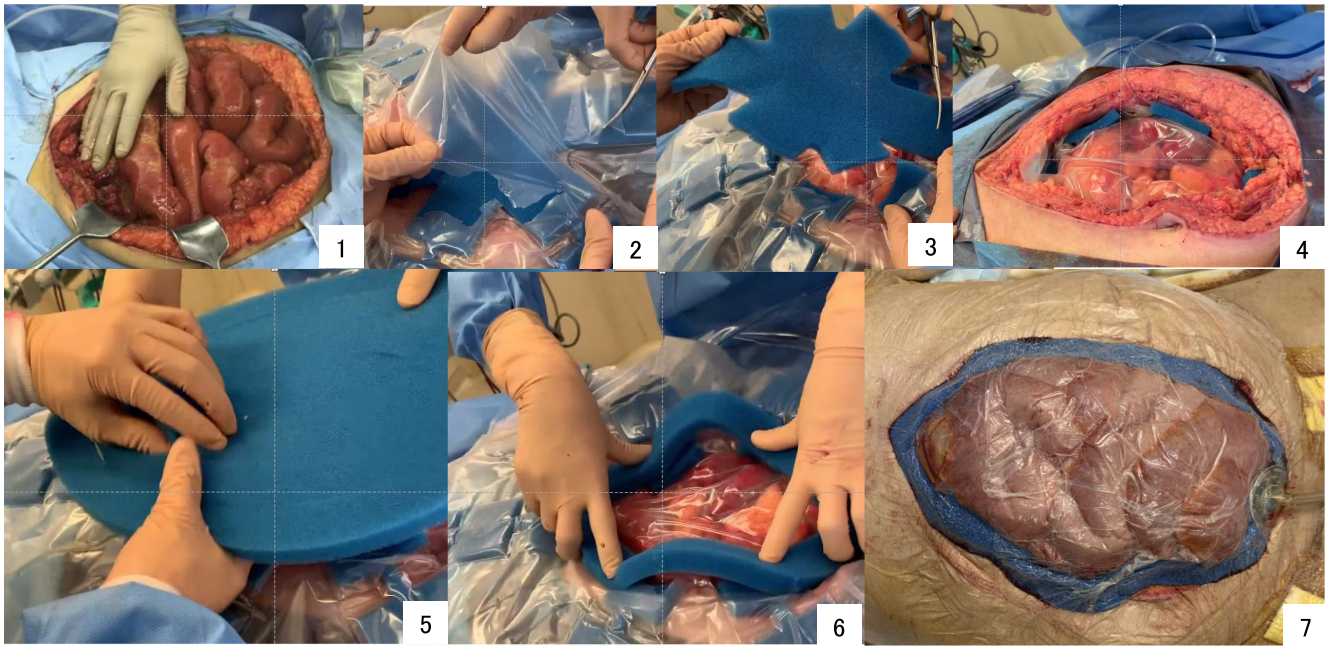


**FIGURE 2** Visible negative pressure wound therapy (NPWT) procedure. (1) Clean the abdominal cavity and perform temporary abdominal closure with visible NPWT. (2) Remove the film from the front in the center of the protective layer. (3) Remove the center of the blue foam in the protective layer and leave only the legs. (4) Insert the protective layer into the abdominal cavity such that the central remaining portion of the film cut out of the protective layer reaches the open wound. The leg portion of the foam is placed radially along the abdominal wall toward the bottom of the abdominal cavity. (5) Cut out the center of the blue foam. (6) Place the foam along the edge of the wound. (7) Cover the entire wound with film and initiate negative pressure to complete.

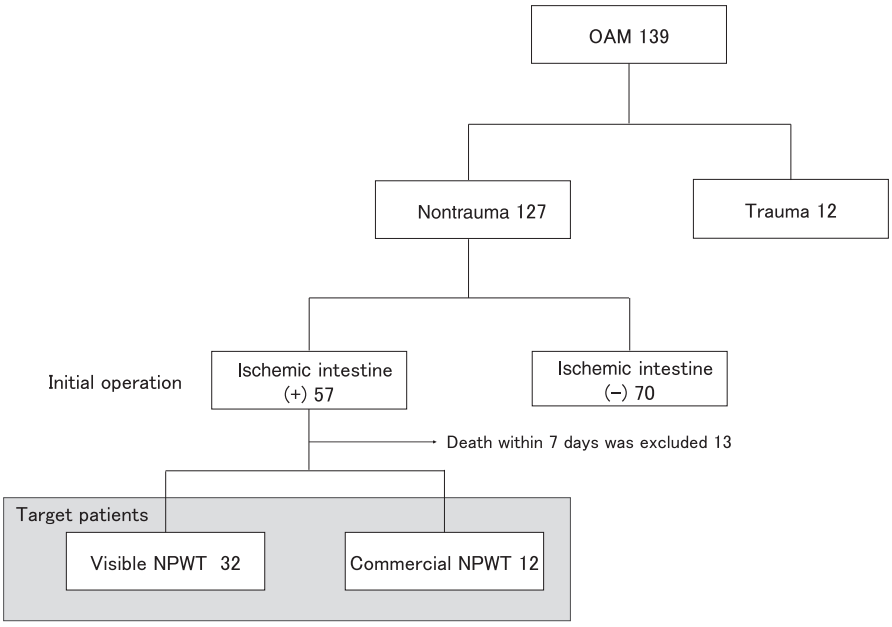


**FIGURE 3** Flow diagram of patient selection. NPWT, negative pressure wound therapy; OAM, open abdominal management.

differences in age, sex distribution, the Sequential Organ Failure Assessment (SOFA) score, Acute Physiology and Chronic Health Evaluation (APACHE) II score, or the predicted mortality rate.

The two groups showed no significant differences in vital signs such as the respiratory rate, ratio of arterial partial pressure of oxygen ($PaO_2$) to inspired oxygen concentration ($FiO_2$) (P/F ratio), heart rate, mean arterial pressure, lactic acid, Glasgow Coma Scale score, or body temperature.

The duration of open abdomen and ICU stay were significantly shorter in group A than in group B. The two groups showed no significant differences in 28-day outcomes or complications as a secondary event during OAM.

**TABLE 1** Characteristics of patients who underwent open abdominal management (OAM) with visible negative pressure wound therapy (NPWT) (group A, $n = 32$) and those who underwent OAM with commercial NPWT (group B, $n = 12$).

| | A | B | *P* value |
|---|---|---|---|
| Age (years) | 77.9 ± 1.8 | 76.5 ± 3.0 | 0.65 |
| Sex | | | |
| Male | 12 | 6 | 0.45 |
| Female | 20 | 6 | |
| SOFA score | 8.6 ± 0.7 | 8.6 ± 1.2 | 0.49 |
| APACHE II score | 28 ± 1.5 | 25.8 ± 2.4 | 0.77 |
| Predictive mortality score (%) | 69.9 ± 3.9 | 63.2 ± 6.3 | 0.81 |
| RR (/min) | 32.7 ± 2.5 | 31.4 ± 4.0 | 0.78 |
| P/F ratio | 288.6 ± 21.5 | 254.1 ± 35.1 | 0.79 |
| HR (/min) | 121.5 ± 6.4 | 118.1 ± 10.5 | 0.61 |
| MAP (mmHg) | 70.7 ± 4.0 | 56.3 ± 6.5 | 0.97 |
| Lactate (mmol/L) | 8.0 ± 1.0 | 5.6 ± 1.6 | 0.89 |
| GCS | 8.7 ± 0.8 | 10.8 ± 1.4 | 0.10 |
| BT (°C) | 36.3 ± 0.2 | 36.6 ± 0.4 | 0.21 |
| Bowel resection in the first operation | | | |
| Yes | 26 | 11 | 0.40 |
| No | 6 | 1 | |
| Duration of OAM (days) | 2.7 ± 1.3 | 7.2 ± 2.2 | 0.04 |
| Duration of ICU stay (days) | 9.1 ± 2.2 | 19.3 ± 3.6 | 0.01 |
| Duration of hospital stay (days) | 63.1 ± 11.8 | 82.8 ± 19.3 | 0.19 |
| 28-day outcome | | | |
| Alive | 29 | 11 | 0.91 |
| Dead | 3 | 1 | |
| Complications | | | |
| Yes | 21 | 9 | 0.55 |
| No | 11 | 3 | |

*Abbreviations*: APACHE, Acute Physiology and Chronic Health Evaluation; BT, body temperature; GCS, Glasgow Coma Scale; HR, heart rate; ICU, intensive care unit; MAP, mean arterial pressure; P/F, ratio of arterial partial pressure of oxygen to the inspired oxygen concentration; RR, respiratory rate; SOFA, Sequential Organ Failure Assessment.

In the present study, the bowel was resected in 26 cases in group A and 12 cases in group B.

There were six cases with visible NPWT without resection in the first operation, and one showed ischemia progression. However, none of them were resected. Conversely, in group B, there was one case in which bowel resection was not carried out at the first operation; nine in group A and three in group B were resected after the second operation.

There were no complications due to visualization in the cases in group A.

In addition, 12 of the present cases required additional bowel resection. Of these, three were in the commercial NPWT group and nine were in the visible NPWT group. Review of the medical records revealed early ischemic necrosis in seven cases in the visible NPWT group: The progression of ischemia was confirmed at the time of the second-look operation in two cases in the ascending colon. In the commercial NPWT group, three additional resections were all carried out at the time of the second-look operation: two for partial necrosis of the small intestine and one for necrosis of the sigmoid colon.

## DISCUSSION

Open abdominal management has been shown to improve the prognosis of trauma and acute abdomen when indicated.[5] Although trauma requiring damage control surgery is the most common target for OAM, the majority of OAM procedures are now undertaken for patients with unstable vital signs for abdominal disorders worldwide.[6] In fact, OAM for these patients accounts for more than 90% of all cases in our hospital. Open abdominal management facilitates easy access, preventing abdominal compartment syndrome, bleeding, and contamination.[7] However, commercial products used for the temporary abdominal closure technique cannot adequately visualize the intra-abdominal cavity, potentially obscuring the cause of elevated lactate levels during intensive care management; consequently, reoperation might not be possible, or the patient may undergo unnecessary reoperation. The Bogota bag has been considered to facilitate decision-making, avoid unnecessary laparotomies, or allow for reopening of the abdomen when necessary.[8] The Bogota bag is an infusion bag that visualizes the intestinal tract in the abdominal cavity, even without a contact layer. We considered reproducing this idea using a commercial product by removing the central part of the foam, as shown in Figure 4. Figure 5A shows an intestinal tract with suspected ischemia but not necrosis (white circle). In Figure 5B, the intestinal tract showing necrosis is visible (white circles).

As shown in Figure 4, we measured the pressure at the tip of the octopus foot portion using a pigtail catheter during OAM. As the monitors at our hospital could only measure down to −50 mmHg, we performed NPWT at −50 mmHg and found that the pressures at the trackpad and the tip of the foam in the paracolic gutter were both approximately −50 mmHg. We confirmed that the results were consistent with those previously obtained[9] using the commercial procedure, indicating that negative pressure was correctly managed. Table 1 shows that group A tended to have a slightly worse general condition in terms of severity of illness and vital signs compared with group B. Specifically, the P/F ratio and mean arterial pressure appeared more favorable based solely on numerical values. However, according to the evaluation using the APACHE II scale, the general condition in group A was worse than in group B but with no significant difference. Thus, no adverse events were observed as a result of modifying the existing NPWT kit for OAM. In addition, the 28-day outcome and incidence of subsequent events were comparable to those of the standard approach. A shorter period of OAM also allowed early recognition of intestinal necrosis and timely removal of the intestinal tract, which could have resulted in a shorter ICU stay.

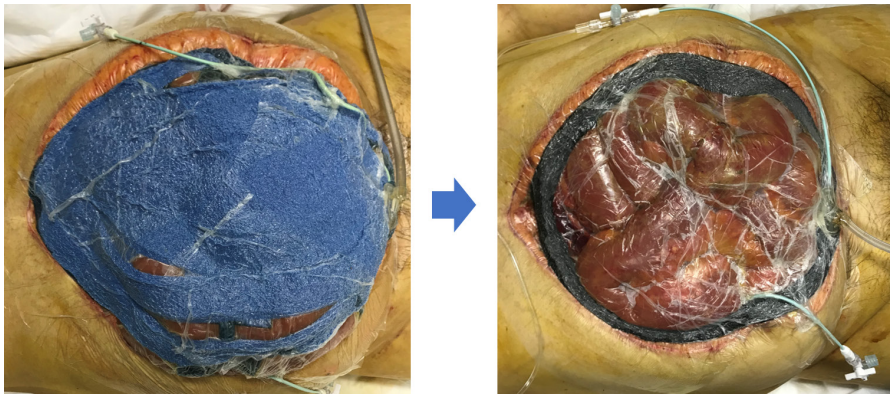

**FIGURE 4** Visualization during open abdominal management by removing the central part of the foam. The central part of the foam was removed, as shown in the figure, leaving the blue foam only at the wound edges. Incidentally, a pigtail catheter was inserted to measure intra-abdominal pressure; however, such a catheter is not inserted in visible negative pressure wound therapy.

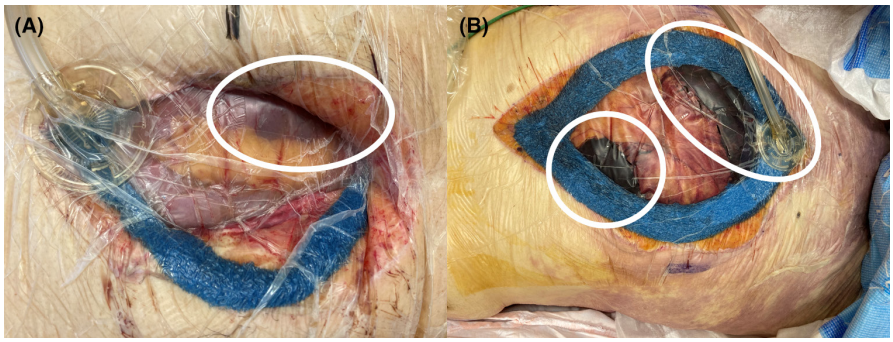


**FIGURE 5** Visibility of ischemia or necrosis by visible negative pressure wound therapy. (A) Intestinal tract with suspected ischemia but not necrosis (white circle). (B) Intestinal tract showing necrosis is visible (white circles).

Furthermore, there was no case where the abdomen could not be closed. The longest time a patient required OAM management during the observation period was 54 days. In this case, the patient in group B died without the abdomen being closed; however, rather than being unable to close the abdomen, it was intentionally opened to control the infected source. Moreover, there were no cases of enteroatmospheric fistula formation because the exposed form was turned inward to avoid issues.

In patients who underwent visible NPWT, 78% (seven of nine) of those who required additional bowel resection were detected at an early stage of ischemia. This fact might indicate that the visible NPWT could contribute sufficiently to clinical practice. Conversely, there are weaknesses. Only the area that can be confirmed by the open wound, which is basically a window, can be confirmed. For this reason, temporary abdominal closure was carried out by adjusting the position so that the dissected ends of the intestine and possible areas of ischemia progression could be confirmed at the window. As shown in the present results, necrosis of invisible organs such as the colon cannot be detected.

This study had some limitations. The results were obtained from a small sample size of participants at a single institution. Moreover, the reasons for performing visible NPWT were unclear because the cases were extracted from medical records. Thus, the selection of cases was arbitrary. The present study results did not allow us to statistically prove the advantage of visibility. However, as shown in the Figure 1, we thought it was clear that visibility is extremely useful because it gives a sense of security to the physician and the medical staff. We will continue to work toward improving the reliability of this technique by adding findings from more cases.

## CONCLUSION

The visualization device allowed us to understand the intra-abdominal cavity and close the abdomen at the appropriate time without worsening the prognosis. Intra-abdominal visualization is an extremely important resource in terms of clear sharing of information when managing patients with OAM as a team. It was also suggested that visible NPWT could contribute to early detection in actual clinical practice. As visualization did not have any negative impact on the patients in this study, we consider it a valuable opportunity to develop and implement such a system.

### ACKNOWLEDGMENTS

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## CONFLICT OF INTEREST STATEMENT

Dr. Jun Oda is Editor-in-Chief of *Acute Medicine and Surgery* and co-author of this article. They were excluded from the peer review process and all editorial decisions related to the acceptance and publication of this article. Peer review was handled independently by the *Acute Medicine and Surgery* editorial office and Dr. Yausyuki Kuwagata as the Editor to minimize bias. The other authors declare no conflict of interests for this article.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## ETHICS STATEMENT

Approval of the research protocol: The protocol for this research project has been approved by a suitably constituted Ethics Committee of the institution, and it conforms to the provisions of the Declaration of Helsinki (Research Ethics Committee of Kansai Rosai Hospital, Approval No. 22D075g).
Informed consent: The requirement for written informed consent was waived.
Registry and the registration no. of the study/trial: N/A.
Animal studies: N/A.

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