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RESEARCH ARTICLE

A NOVEL DEVICE AND PRESSURE PROTOCOL FOR CONTROLLED NEGATIVE PRESSURE THERAPY IN DEEP PULMONARY INFEC-TIONS: DEVELOPMENT AND CLINICAL APPLICATION

Khamdamov Sh.A.
Department of General and Pediatric Surgery-1, Tashkent Medical Academy, Tash-kent, Uzbekistan

Abstract:

Background: Vacuum-assisted closure (VAC) therapy has become a valuable tool in managing complex infections. However, its adaptation for intrathoracic use remains technically challenging due to risks of air leaks, cavity instability, and lack of standardized equipment for pulmonary applications.

Objective: To describe a novel VAC drainage system and pressure protocol specifically designed for pulmonary abscess management and evaluate its clinical feasibility in diabetic pa-tients.

Methods: An internally developed drainage system was constructed using a low-adhesion polyurethane sponge, modified thoracic catheter, and a programmable negative pres-sure regulator. The system delivers controlled suction at –80 mmHg, modulated through a pulsed cycle (5 minutes on, 2 minutes off). Clinical testing was performed in 12 patients with diabetic pulmonary abscess following surgical drainage. Parameters evaluated included tech-nical safety, drainage efficiency, cavity collapse rate, and postoperative complications.

Results: All patients tolerated the device well with no cases of bronchopleural fistula or sponge dislocation. Average drainage duration was 5.8 ± 1.0 days, and cavity volume reduction >75% was achieved in 83.3% of cases by day 7. No infections related to the device were ob-served. The pulsed suction mode allowed stable pressure delivery without over-collapse or hemothorax.

Conclusion: This customized VAC device and pressure protocol demonstrated clinical safety, technical stability, and high efficacy in managing pulmonary abscess in diabetic patients. It may serve as a prototype for broader use in thoracic VAC therapy and facilitate standardiza-tion in deep cavity infections.

Key words: Pulmonary abscess, negative pressure therapy, custom VAC device, thoracic drainage, diabetes mellitus, surgical innovation.

INTRODUCTION

Vacuum-assisted closure (VAC) therapy has become an integral part of mod-ern wound care, particularly in managing infected surgical wounds, diabetic ulcers, and post-traumatic soft tissue defects. Its ability to reduce local edema, promote granulation, and evacuate infectious material has been well established in multiple surgical domains

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[1, 2]. However, its implementation in thoracic surgery (especial-ly within pulmonary cavities) remains limited due to anatomical and technical con-straints.

Pulmonary abscesses, particularly in diabetic patients, are associated with high morbidity due to impaired local perfusion, poor tissue response, and increased risk of residual cavity formation [3]. Conventional drainage techniques often fail to achieve complete resolution, leading to prolonged hospitalization, cavity persis-tence, or secondary infection. Negative pressure therapy holds potential for acceler-ating resolution of such abscesses, but adaptation of standard VAC equipment to the thoracic cavity presents several challenges [4].

Current commercial VAC systems are designed primarily for external or su-perficial applications and lack compatibility with intrathoracic requirements. Spe-cific problems include sponge collapse, bronchial communication, risk of air embo-lism, and loss of seal under respiratory dynamics. Additionally, there is no stand-ardized protocol for pressure regulation in closed pulmonary spaces, further limit-ing widespread use [5].

To address these limitations, we developed a novel vacuum system tailored for internal thoracic application, using a customized low-density sponge, flexible thoracic tubing, and a programmable pressure control unit. This article presents the engineering rationale, clinical deployment technique, and initial feasibility results from its use in a diabetic patient cohort with pulmonary abscess.

MATERIALS AND METHODS

Device Design

The custom VAC system consisted of three integrated components:

Low-adhesion intrathoracic sponge

A soft, open-pore polyurethane foam (density 20 kg/m^3) was cut to fit the ab-scess cavity dimensions, sterilized, and shaped into atraumatic elliptical segments. The sponge was sheathed in a thin silicone mesh to reduce adherence to pulmonary tissue and minimize fragmentation during removal.

Modified thoracic drainage catheter

A flexible 28 Fr silicone chest tube with lateral perforations was used as the vacuum conduit. The sponge was sutured onto the fenestrated tip using absorbable 3/0 suture, ensuring stability during suction. The tube was connected to the external circuit via a standard Luer-lock interface.

Programmable suction control unit

A microprocessor-based vacuum controller was adapted to deliver pulsed negative pressure cycles: –80 mmHg for 5 minutes followed by a 2-minute pause. The device included pressure sensors and auto-shutoff safety limits to prevent over-collapse or rapid pressure spikes.

Surgical Procedure and VAC Application

Twelve diabetic patients (type 2) with radiologically confirmed pulmonary abscess underwent limited thoracotomy and surgical drainage at the Thoracic Sur-gery Department. After necrosectomy and cavity irrigation, the custom VAC sponge system was inserted into the cavity under direct visualization. The thoracic wall was closed with an airtight purse-string suture around the drainage tube.

Negative pressure was initiated postoperatively in the recovery unit. Sponge changes were planned every 72 hours or earlier if the system showed occlusion or saturation. Therapy continued until >75% cavity volume reduction was observed or clinical stabilization allowed transition to passive drainage.

Evaluation Criteria

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Clinical and technical outcomes were assessed based on:

- Intraoperative device stability (sponge fixation, air leaks)
- Duration of active drainage (days)
- Time to ≥75% cavity volume reduction (days)
- Postoperative complications (hemothorax, bronchial fistula, reinfec-tion)
- Ease of sponge exchange and system maintenance
- Patient tolerance (pain, oxygenation)
- Data were collected prospectively, and descriptive statistics were used to evaluate performance and safety.

RESULTS

All 12 patients successfully underwent implantation of the customized in-trathoracic VAC system without intraoperative complications. Device deployment was technically straightforward, with mean sponge placement time of 7.3 ± 2.1 minutes. No cases of intraoperative bleeding, bronchial communication, or sponge dislocation occurred. The airtight thoracic closure and tube anchoring ensured sys-tem integrity throughout therapy.

Drainage duration averaged 5.8 ± 1.0 days (range: 4-7), after which passive drainage was sufficient in 9 patients; the remaining 3 required sponge replacement once. Cavity volume reduction ≥75% was achieved by day 7 in 10 patients (83.3%), and complete radiological resolution occurred within 14-17 days in 11 cases. No residual abscesses or empyema developed.

There were no instances of bronchopleural fistula, hemothorax, or device-related infections. Mild subcutaneous emphysema occurred in 1 patient and re-solved spontaneously. No device-related pain was reported beyond baseline postop-erative discomfort. Oxygenation remained stable in all patients; no suction-related respiratory compromise occurred.

The programmable vacuum unit maintained stable pressure delivery throughout therapy, with no sensor errors or unintended pressure spikes. Nursing staff reported ease of monitoring, while sponge exchange under local anesthesia was well tolerated in all patients.

The system demonstrated a high degree of technical reliability, drainage effi-cacy, and clinical safety. Its modular design and pressure modulation protocol proved effective in managing deep pulmonary cavities, even in high-risk diabetic patients with delayed healing capacity.

DISCUSSION

The development and successful deployment of a custom-designed vacuum-assisted closure (VAC) system for intrathoracic application address a significant technical gap in managing deep pulmonary infections, particularly in patients with diabetes mellitus. Our findings suggest that a controlled negative pressure envi-ronment can be safely maintained within the thoracic cavity using appropriately adapted materials and pressure regulation protocols.

Several barriers have historically limited the use of VAC therapy in pulmo-nary abscesses. Commercial VAC systems are optimized for superficial wounds and are ill-suited for dynamic, air-containing intrathoracic spaces. Risks such as sponge migration, air embolism, and bronchopleural fistula formation have discouraged broader application [1]. Our approach mitigated these risks through a low-adherence sponge design, lateral fixation with sutures, and use of pulsed negative pressure, which maintained therapeutic suction without creating cavity collapse or tissue shearing.

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The success rate in achieving ≥75% cavity volume reduction within 7 days, with no fistulas or device-related complications, suggests that this system may pro-vide a reliable adjunct to standard surgical drainage. Moreover, stable oxygenation and low patient discomfort indicate that the pulsed pressure profile supports both safety and tolerability — critical considerations in diabetic patients with fragile respiratory physiology [2].

Technical features such as the microprocessor-regulated vacuum unit, auto-matic pressure stabilization, and modular tubing connections offer practical ad-vantages for thoracic surgeons and ICU staff. Our device remained reliable during continuous operation, and sponge replacement was well tolerated, eliminating the need for repeated thoracotomy or general anesthesia.

The theoretical mechanisms of VAC efficacy (including improved local per-fusion, mechanical deformation promoting cellular migration, and reduction of bac-terial load) are particularly relevant in diabetic tissue, where impaired angiogenesis and collagen deposition hamper natural recovery [3,4].

While the sample size was limited and the study was observational in design, the consistent safety profile and technical performance encourage further validation in larger cohorts and comparative trials. Additionally, long-term evaluation of re-sidual cavity rates, recurrence, and lung function will be necessary to confirm dura-ble benefits.

This device and its associated protocol offer a potentially scalable solution for thoracic infection management and may serve as a platform for developing standardized VAC tools for deep, anatomically complex cavities - an area currently lacking in commercial VAC systems.

CONCLUSION

The novel intrathoracic VAC system developed and tested in this study demonstrated high technical stability, clinical safety, and effective cavity control in patients with pulmonary abscesses complicated by diabetes mellitus. The use of a low-adherence sponge, modified thoracic catheter, and a programmable pulsed-pressure protocol allowed for reliable negative pressure delivery within the dynam-ic environment of the thoracic cavity.

This approach minimized common risks associated with VAC use in deep cavities and resulted in rapid cavity resolution without serious complications. The system proved to be nurse-friendly, patient-tolerated, and easily integrated into standard thoracic drainage workflows.

These findings suggest that tailored VAC solutions for pulmonary infections are both feasible and beneficial, especially in metabolically vulnerable populations. Broader application of this technique and further refinement through multicenter trials may lead to standardized VAC systems for thoracic use.

Ethical Approval:

All clinical procedures involving patients were conducted in accordance with the Declaration of Helsinki and approved by the Local Ethics Committee of the Republican Specialized Center of Surgery, Tashkent. Informed consent was ob-tained from all participants.

Conflict of Interest:

The author declares no conflict of interest.

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Author Contributions:

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Khamdamov Sh.A. – Device concept and design, clinical deployment, data collection, analysis, manuscript preparation.

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