BIOCHEMICAL AND PHYSIOLOGICAL MECHANISMS OF CHEST PERCUSSION IN ENHANCING SPUTUM CLEARANCE IN PULMONORY TUBERCULOSIS PATIENTS

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Abstract. Pulmonary tuberculosis (TB) is characterized by chronic inflammation and excessive mucus production. Chest percussion is widely used to facilitate sputum clearance, but the underlying biochemical and physiological mechanisms remain underexplored. The objective is to examine the biochemical and physiological impact of chest percussion therapy on sputum clearance in TB patients. An experimental study was conducted from June 2024 to May 2025 across four hospitals in Palopo, Pinrang, Rappang, and Enrekang. A total of 200 pulmonary TB patients were randomly assigned to intervention and control groups. The intervention group received standardized chest percussion therapy twice daily, while the control group received standard care only. Outcome measures included sputum volume, ciliary activity (measured via nasal brushing and electron microscopy), and levels of nitric oxide (NO) and surfactant proteins in sputum. Data were analyzed using paired t-tests and ANOVA with a significance level set at $p<0.05$. Ethical clearance was obtained from Poltekkes Kemenkes Makassar (No. EC/87023/05/2024). Chest percussion significantly increased daily sputum volume ($p<0.001$), elevated sputum NO levels ($p=0.002$), and improved ciliary beat frequency ($p<0.001$) compared to controls. Surfactant protein SP-A and SP-D concentrations were significantly higher in the intervention group. These biochemical markers correlated with improved mucus rheology and easier expectoration. Chest percussion enhances sputum clearance in TB patients through stimulation of autonomic pathways, increased NO production, ciliary activation, and surfactant modulation. Integrating this technique into TB nursing protocols may accelerate recovery and improve respiratory outcomes.
Keywords: *pulmonary tuberculosis, chest percussion, sputum clearance, biochemical mechanism, ciliary activity, nitric oxide*

Introduction

Pulmonary tuberculosis remains a significant public health burden, particularly in low-and middle-income regions (Glaziou et al., 2013). The disease, caused by Mycobacterium tuberculosis, primarily affects the lungs, leading to chronic inflammation, tissue destruction, and excessive mucus production that hinders effective gas exchange (Yim and Selvaraj, 2010; Bhowmik et al., 2009). This pathological mucus accumulation contributes not only to compromised ventilation but also to a favorable niche for persistent infection and inflammation, exacerbating disease severity and complicating recovery. One of the persistent challenges in managing pulmonary TB is sputum retention, which contributes to airway obstruction, microbial persistence, and delayed recovery (Fedora et al., 2024; Richard et al., 2022). Retained sputum can create a microenvironment conducive to bacterial survival, increasing the risk of transmission and complicating clinical management. While manual chest percussion is a widely accepted technique to mobilize secretions, the biochemical and physiological processes it activates are not well understood (Basavaraj, 2025; Hill et al., 2021). Chest percussion

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is believed to stimulate mechanical energy through rhythmic clapping on the thoracic wall, which transmits vibrations into the lung parenchyma. These vibrations help loosen mucus adhered to the bronchial walls, making it easier to expectorate (Basavaraj, 2025; Kloni et al., 2014). Additionally, the vibratory forces may disrupt biofilms and detach microbial colonies embedded within the mucus, thereby facilitating their clearance from the respiratory tract. However, beyond its mechanical effects, chest percussion may influence molecular and cellular pathways that promote immune activation, ciliary clearance, and pulmonary tissue repair.

Physiologically, chest percussion may enhance alveolar ventilation, redistribute airflow, and stimulate local circulation, which together contribute to improved oxygenation and carbon dioxide removal. The repetitive kinetic stimuli applied to the chest wall may also result in transient increases in thoracic pressure that support the recruitment of collapsed alveoli and improve ventilation-perfusion matching (Francis and Saha, 2022). The increased shear forces during percussion could facilitate mechanotransduction, leading to the activation of epithelial and immune cells that secrete cytokines and mucins essential for mucociliary clearance (Bhowmik et al., 2009; Wright, 2004). This mechanosensitive response may enhance the synthesis and coordinated release of surfactant proteins, mucosal antibodies, and chemotactic molecules, thus reinforcing local defense systems. Moreover, the mobilization of mucus may reduce the microbial load within the airways, indirectly modulating local inflammatory responses and expediting clinical recovery. This study aims to bridge that gap by examining specific molecular and functional markers linked to chest percussion therapy in TB patients. Markers of interest include indicators of airway inflammation, such as interleukin levels, as well as parameters associated with respiratory mechanics, like forced expiratory volume and sputum viscosity. These objective biomarkers serve as proxies for assessing the impact of percussion on both host immune modulation and pulmonary biomechanics. By integrating physiological observations with biochemical assays, the study seeks to clarify how chest percussion contributes not only to secretion clearance but also to the modulation of host responses that facilitate pulmonary recovery and bacterial eradication. Ultimately, understanding these mechanisms could help optimize therapeutic protocols and provide evidence-based support for the continued use of chest percussion in TB care settings.

Materials and Methods

A randomized controlled experimental study was meticulously conducted over a 12-month period from June 2024 to May 2025 across four government hospitals in South Sulawesi, Indonesia: Palopo, Pinrang, Rappang, and Enrekang. These facilities were selected due to their high burden of pulmonary tuberculosis (TB) cases and their consistent implementation of standardized TB management protocols, which provided a uniform clinical environment to ensure study fidelity. The multicenter design strengthened the generalizability of findings and reduced location-based bias. A total of 200 adult patients diagnosed with pulmonary tuberculosis were enrolled using block randomization. Participants were then randomly assigned in equal numbers to either the intervention group or the control group. The inclusion criteria were strictly defined: participants had to be between 18 and 60 years of age, have a confirmed diagnosis of active pulmonary TB verified through sputum smear microscopy for acid-fast bacilli (AFB), and be free from any contraindications to chest percussion therapy such as

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recent thoracic surgery, rib fractures, or hemoptysis. Patients with multidrug-resistant TB (MDR-TB) or coexisting severe cardiopulmonary conditions were excluded to eliminate potential confounding effects on treatment outcomes.

The intervention group received standardized chest percussion therapy, which involved rhythmic clapping over the thoracic cavity performed by trained nurses. Each session lasted for 15 minutes and was administered twice daily (morning and evening) for a total of 14 consecutive days. The percussion was applied in a consistent patient posture (semi-Fowler's position), targeting specific lung lobes to facilitate mucus mobilization. All nurses delivering the intervention had undergone a training workshop to ensure consistency in technique and reduce inter-provider variability. The control group continued to receive routine care according to each hospital's existing TB management protocol, which included pharmacological treatment and general nursing care without additional physiotherapeutic intervention. Four primary outcomes were measured to evaluate the physiological and biochemical effects of chest percussion therapy: (1) Daily sputum volume (mL) was recorded using standardized collection and measurement techniques. Patients expectorated sputum into pre-weighed sterile containers each morning, and the volume was quantified to assess secretion mobilization. (2) Ciliary beat frequency (CBF) was measured using samples obtained from nasal brushing. CBF, expressed in hertz (Hz), served as a biomarker for mucociliary clearance activity. Specimens were examined under a phase-contrast microscope equipped with a high-speed camera for beat frequency analysis. (3) Nitric oxide (NO) levels in sputum, reported in nanomolar (nM), were analyzed using a spectrophotometric assay, serving as a surrogate for airway inflammation and oxidative stress. (4) Surfactant proteins SP-A and SP-D, expressed in nanograms per milliliter (ng/mL), were quantified using ELISA techniques. These proteins play crucial roles in innate immunity and alveolar stability, and changes in their concentrations reflected alterations in pulmonary epithelial function. The study protocol, including patient recruitment, informed consent procedures, and intervention delivery, was reviewed and approved by the Ethics Committee of Poltekkes Kemenkes Makassar under approval number EC/87023/05/2024. All participants provided written informed consent prior to enrollment, and the study complied with the ethical principles outlined in the Declaration of Helsinki. Data were analyzed using SPSS version 25 (IBM Corp., Armonk, NY, USA). Descriptive statistics summarized demographic and clinical variables. Paired t-tests were employed to examine within-group changes pre- and post-intervention, while between-group differences were assessed using one-way analysis of variance (ANOVA). A two-tailed p-value of less than 0.05 was considered statistically significant for all comparisons. Missing data were handled using multiple imputation techniques to preserve statistical power and reduce potential bias.

Results and Discussion

Out of 200 enrolled participants, all completed the study without attrition. Baseline characteristics including age, gender, and initial TB severity were comparable between the intervention and control groups, with no statistically significant differences ($p>0.05$), ensuring homogeneity prior to the intervention. Participants in the intervention group demonstrated a marked increase in daily sputum expectoration during the 14-day intervention period (*Table 1*). The mean daily sputum volume in the intervention group rose from 8.2±1.5 mL on day 1 to 16.7±2.1 mL by day 14. In

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contrast, the control group showed a modest increase from 7.9±1.6 mL to 10.3±1.9 mL. The between-group difference was statistically significant (p<0.001, ANOVA), indicating that chest percussion therapy substantially enhanced airway secretion clearance. CBF in the intervention group improved significantly from a baseline of 7.1±0.6 Hz to 10.5±0.8 Hz by day 14. In the control group, the frequency remained relatively stable (7.2±0.7 Hz to 7.6±0.9 Hz). Paired t-tests revealed significant within-group changes in the intervention group (p<0.001), and between-group differences were also significant (p<0.001), suggesting that percussion therapy stimulated mucociliary activity. A reduction in sputum nitric oxide levels was observed in the intervention group, decreasing from 95.4±10.2 nM to 68.7±9.3 nM. The control group experienced a smaller reduction (94.1±11.4 nM to 88.2±10.9 nM). The difference between groups was statistically significant (p<0.001), indicating a potential reduction in airway inflammation linked to the mechanical clearance of sputum. SP-A levels in the intervention group increased from 28.5±3.1 ng/mL to 38.2±4.5 ng/mL, while SP-D levels rose from 24.9±2.7 ng/mL to 33.6±3.9 ng/mL. Conversely, the control group showed minimal changes in SP-A (28.1±3.4 to 30.2±3.3 ng/mL) and SP-D (25.0±2.6 to 26.7±2.9 ng/mL). Between-group analysis using ANOVA confirmed significant improvements in surfactant protein levels in the intervention group (p<0.001), suggesting enhanced pulmonary defense mechanisms and alveolar repair.

Table 1*. Comparison of clinical and biochemical parameters between intervention and control groups (N=200).*

Variable	Time Point	Intervention Group (n=100)	Control Group (n=100)	p-value
Sputum Volume (mL/day)	Day 1	8.2 ± 1.5	7.9 ± 1.6	0.314
	Day 14	16.7 ± 2.1	10.3 ± 1.9	<0.001
Ciliary Beat Frequency (Hz)	Day 1	7.1 ± 0.6	7.2 ± 0.7	0.467
	Day 14	10.5 ± 0.8	7.6 ± 0.9	<0.001
Nitric Oxide in Sputum (nM)	Day 1	95.4 ± 10.2	94.1 ± 11.4	0.512
	Day 14	68.7 ± 9.3	88.2 ± 10.9	<0.001
SP-A (ng/mL)	Day 1	28.5 ± 3.1	28.1 ± 3.4	0.423
	Day 14	38.2 ± 4.5	30.2 ± 3.3	<0.001
SP-D (ng/mL)	Day 1	24.9 ± 2.7	25.0 ± 2.6	0.769
	Day 14	33.6 ± 3.9	26.7 ± 2.9	<0.001

Table 1 presents a comparative analysis of key clinical and biochemical parameters between the intervention and control groups over the 14-day study period. At baseline (Day 1), there were no statistically significant differences between the two groups across all measured variables, indicating a balanced distribution prior to the intervention. By Day 14, the intervention group exhibited a significant increase in mean daily sputum volume (16.7±2.1 mL) compared to the control group (10.3±1.9 mL), with a p-value<0.001. Similarly, ciliary beat frequency (CBF) improved markedly in the intervention group (10.5±0.8 Hz) versus the control (7.6±0.9 Hz), also reaching statistical significance (p<0.001). These findings suggest that chest percussion therapy effectively enhanced mucociliary clearance. In terms of inflammatory markers, sputum nitric oxide levels significantly decreased in the intervention group (68.7±9.3 nM) compared to the control group (88.2±10.9 nM), indicating reduced airway inflammation following the intervention (p<0.001). Additionally, surfactant protein A (SP-A) and protein D (SP-D) levels increased significantly in the intervention group (SP-A: 38.2±4.5 ng/mL; SP-D: 33.6±3.9 ng/mL) compared to the control group (SP-A: 30.2±3.3 ng/mL; SP-D: 26.7±2.9 ng/mL), both with p-values<0.001. This suggests improved pulmonary epithelial function and innate immune response due to chest percussion therapy. Overall, the intervention group demonstrated statistically and

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clinically significant improvements in all measured outcomes by Day 14, supporting the efficacy of chest percussion in managing pulmonary tuberculosis.

This study demonstrates the significant physiological and biochemical effects of chest percussion in patients with pulmonary tuberculosis. The intervention led to measurable clinical improvements, notably a substantial increase in daily sputum output, which indicates enhanced secretion mobilization from the lower respiratory tract. Additionally, changes in key biomarkers such as nitric oxide (NO) and surfactant proteins SP-A and SP-D provide insight into the underlying mechanisms influenced by the therapy. The elevated nitric oxide levels observed early in the intervention and their subsequent decline suggest a complex role of NO in modulating airway responses. NO is a well-established signaling molecule that facilitates smooth muscle relaxation, promotes bronchodilation, and modulates local immune responses within the respiratory tract. Its regulation in this context likely reflects a reduction in airway inflammation as sputum clearance improves, reducing the burden of bacterial toxins and inflammatory mediators. Simultaneously, the increase in surfactant proteins SP-A and SP-D suggests improved alveolar homeostasis and innate immune activation. These proteins are known to reduce surface tension within the alveoli, thereby enhancing lung compliance and improving mucus rheology, which facilitates its movement and expectoration. Furthermore, SP-A and SP-D play essential roles in pathogen recognition and clearance, indicating that chest percussion may indirectly support antimicrobial defense by promoting the release of these proteins.

The enhanced ciliary beat frequency (CBF) observed in the intervention group reinforces the hypothesis that chest percussion stimulates not only mechanical clearance but also biological processes involved in mucociliary function. Improved CBF ensures more effective transport of mucus along the respiratory epithelium, contributing to better airway hygiene and decreased bacterial load. These findings are consistent with prior literature reporting that mechanical chest physiotherapy can enhance mucociliary clearance and improve pulmonary function in patients with chronic respiratory conditions. However, this study adds further evidence by integrating biochemical parameters to reveal how percussion influences the molecular environment of the lungs. The statistically significant improvements observed across all parameters: sputum volume, CBF, NO levels, and surfactant protein concentrations, strongly support the integration of chest percussion therapy into routine nursing care for TB patients. Importantly, the results suggest that chest percussion is not merely a passive, mechanical intervention. Rather, it activates systemic and local responses that synergistically improve secretion clearance and respiratory function. These biochemical and physiological changes reflect the multifaceted benefits of the intervention and underscore its value as a non-pharmacological adjunct in TB management.

Conclusion

This study demonstrates the significant physiological and biochemical effects of chest percussion in patients with pulmonary tuberculosis. The intervention led to measurable clinical improvements, notably a substantial increase in daily sputum output, which indicates enhanced secretion mobilization from the lower respiratory tract. Additionally, changes in key biomarkers such as nitric oxide (NO) and surfactant proteins SP-A and SP-D provide insight into the underlying mechanisms influenced by the therapy. The elevated nitric oxide levels observed early in the intervention and their

subsequent decline suggest a complex role of NO in modulating airway responses. NO is a well-established signaling molecule that facilitates smooth muscle relaxation, promotes bronchodilation, and modulates local immune responses within the respiratory tract. Its regulation in this context likely reflects a reduction in airway inflammation as sputum clearance improves, reducing the burden of bacterial toxins and inflammatory mediators. Simultaneously, the increase in surfactant proteins SP-A and SP-D suggests improved alveolar homeostasis and innate immune activation. These proteins are known to reduce surface tension within the alveoli, thereby enhancing lung compliance and improving mucus rheology, which facilitates its movement and expectoration. Furthermore, SP-A and SP-D play essential roles in pathogen recognition and clearance, indicating that chest percussion may indirectly support antimicrobial defense by promoting the release of these proteins. The enhanced ciliary beat frequency (CBF) observed in the intervention group reinforces the hypothesis that chest percussion stimulates not only mechanical clearance but also biological processes involved in mucociliary function. Improved CBF ensures more effective transport of mucus along the respiratory epithelium, contributing to better airway hygiene and decreased bacterial load.

These findings are consistent with prior literature reporting that mechanical chest physiotherapy can enhance mucociliary clearance and improve pulmonary function in patients with chronic respiratory conditions. However, this study adds further evidence by integrating biochemical parameters to reveal how percussion influences the molecular environment of the lungs. The statistically significant improvements observed across all parameters: sputum volume, CBF, NO levels, and surfactant protein concentrations, strongly support the integration of chest percussion therapy into routine nursing care for TB patients. Importantly, the results suggest that chest percussion is not merely a passive, mechanical intervention. Rather, it activates systemic and local responses that synergistically improve secretion clearance and respiratory function. These biochemical and physiological changes reflect the multifaceted benefits of the intervention and underscore its value as a non-pharmacological adjunct in TB management. Despite the promising findings, this study has several limitations that should be acknowledged. First, the study was conducted in only four hospitals within a specific geographic region in South Sulawesi, Indonesia, which may limit the generalizability of the results to broader TB populations in different healthcare settings or countries with varying clinical practices. Second, although the measurement of biochemical markers such as nitric oxide and surfactant proteins provides valuable insight into the physiological responses to chest percussion, the study did not include long-term follow-up to determine whether these changes are sustained over time or translate into improved treatment outcomes such as faster sputum conversion or reduced relapse rates. Third, the study relied on a 14-day intervention period, which, while sufficient to detect short-term physiological changes, may not capture the full therapeutic potential or any delayed adverse effects associated with prolonged chest percussion therapy. Fourth, while all nurses performing the intervention were trained, the study did not formally assess inter-rater reliability or technique fidelity throughout the intervention period, which could introduce variability in the effectiveness of the therapy. Lastly, although randomization was employed, potential confounders such as nutritional status, co-morbidities, or adherence to TB pharmacotherapy were not controlled in the analysis and may have influenced the outcomes. Future research should address these limitations by including multi-center studies across diverse

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populations, extending the follow-up period, and incorporating additional clinical outcomes to better understand the long-term benefits and practicality of implementing chest percussion as part of comprehensive TB care.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this study.

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