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Implementation of Inspiratory Muscle Training (IMT) with Threshold Loading During Early Post-CABG Rehabilitation: An Evidence-Based Case Report

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Abstract:

➢ ***Background:***

Coronary Artery Bypass Grafting (CABG) via median sternotomy often results in a 27–62% decline in inspiratory muscle strength. While standard physiotherapy focuses on mobilization, early-phase Inspiratory Muscle Training (IMT) is critical to prevent post-operative pulmonary complications (POPC) and restore the dynamic strength index (S-index). This study explores an evidence-based approach to early resistive loading in a high-risk cardiac patient.

➢ ***Objective:***

To evaluate the safety and clinical efficacy of low-intensity Threshold-IMT on pain, thoracic expansion, and functional mobility in the immediate post-operative phase.

➢ ***Case Description:***

A 64-year-old male with CAD-3VD and Left Main disease underwent a 4-vessel CABG. On POD 2, the patient presented in the ICCU with restrictive lung patterns, an NRS pain score of 7/10 (movement), restrictive thoracic expansion (0.8 cm), and an ICUMS mobility score of 10 (bed-bound).

➢ ***Intervention:***

A 1-week program (5 sessions) was implemented using a "Protected Loading" framework:

- **Threshold-IMT: Performed at 30% of estimated PI_{max} using a mechanical threshold device. The protocol consisted of 30 breaths, twice daily.**
- **Controlled Pacing: Manual and verbal cues were utilized to ensure a slow, diaphragmatic inspiratory "ramp," optimizing lung recruitment while maintaining hemodynamic stability.**
- **Airway Clearance: ACBT and huffing were performed with sternal splinting.**
- **Gradual Mobilization: Progression from side-lying to independent ambulation.**

➢ ***Results:***

Post-treatment (T5), the NRS movement pain dropped to 0/10, and thoracic expansion increased to 2.8 cm. Functional ability improved significantly to an ICUMS score of 10 (independent walking). Hemodynamic parameters (SpO_2, HR, BP) remained stable throughout all loading cycles, and no pulmonary complications were reported.

➢ ***Conclusion:***

Early implementation of Threshold-IMT at 30% intensity is a safe and effective catalyst for pulmonary recovery post-CABG. This evidence-based approach successfully restores thoracic expansion and functional mobility, preventing the typical respiratory decline associated with major cardiac surgery.

Keywords: *CABG, Inspiratory Muscle Training, Threshold Loading, Early Mobilization.*

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I. INTRODUCTION

Coronary Artery Bypass Grafting (CABG) remains the gold-standard surgical intervention for patients with complex multivessel coronary artery disease and left main involvement. Despite advances in surgical technique and perioperative care, CABG performed through median sternotomy continues to impose significant physiological stress on the cardiopulmonary system. The immediate postoperative period is commonly associated with a marked decline in pulmonary function, characterized by reductions in functional residual capacity (FRC), vital capacity, and inspiratory muscle strength, with studies reporting a 27–62% decrease in maximal inspiratory pressure (PImax) following surgery.

The pathophysiology of post-CABG respiratory dysfunction is multifactorial. Sternotomy alters chest wall compliance, cardiopulmonary bypass contributes to inflammatory pulmonary changes, and phrenic nerve cooling during surgery can induce diaphragmatic paresis. In addition, postoperative pain, fear of movement, and sternal instability promote shallow, rapid breathing patterns with increased reliance on accessory muscles rather than diaphragmatic excursion. This restrictive ventilatory pattern predisposes patients to basal atelectasis, impaired secretion clearance, ventilation–perfusion mismatch, and ultimately the development of Post-Operative Pulmonary Complications (POPC), which remain a major contributor to prolonged hospital stay, increased healthcare costs, and postoperative morbidity and mortality.

Conventional postoperative physiotherapy programs after CABG emphasize early mobilization, incentive spirometry, and airway clearance techniques. While these approaches improve lung volumes and secretion management, they often fail to directly address the loss of inspiratory muscle force-generating capacity. The inspiratory pump—primarily the diaphragm and external intercostals—requires targeted loading to restore neuromuscular efficiency following surgical inhibition. Inspiratory Muscle Training (IMT) using a threshold loading device provides a pressure-dependent resistance that must be overcome before airflow occurs, ensuring consistent diaphragmatic activation independent of breathing flow rate. This mechanical advantage makes threshold IMT superior to flow-dependent devices in stimulating true muscle recruitment.

Recent literature has highlighted the importance of dynamic inspiratory strength, represented by the Strength Index (S-Index), as a sensitive marker of diaphragmatic contractile performance. Rather than focusing purely on hypertrophy, low-intensity IMT (approximately 30% of PImax) promotes neuromuscular re-education of the diaphragm, improves rib cage kinematics, and facilitates more efficient breathing patterns in the early postoperative period. However, clinicians often hesitate to apply resistive loading soon after sternotomy due to concerns about pain, hemodynamic instability, graft integrity, and sternal dehiscence.

Emerging evidence suggests that when applied within a controlled framework, early IMT is both safe and beneficial in high-risk cardiac patients. Yet, its integration into routine immediate post-CABG rehabilitation remains inconsistent. There is limited clinical reporting on the feasibility of early-phase, protected threshold loading combined with standard physiotherapy during the critical window of postoperative recovery.

Therefore, this case report aims to explore the safety and clinical efficacy of early low-intensity Threshold-IMT initiated on Post-Operative Day 2, within a structured “Protected Loading” rehabilitation framework. The focus is to evaluate its effects on pain, thoracic expansion, oxygenation, and functional mobility while maintaining hemodynamic stability in a patient following multi-vessel CABG.

- *Background: Post-CABG Respiratory Dysfunction*

Coronary Artery Bypass Grafting (CABG) is the standard surgical intervention for complex multivessel coronary artery disease[1]. However, performing this procedure via median sternotomy imposes significant physiological stress, often leading to a 27–62% decline in maximal inspiratory pressure (PImax) and inspiratory muscle strength.

- *Pathophysiology of Respiratory Decline*

The decline in pulmonary function following CABG is multifactorial:

- Surgical Impact: Sternotomy alters chest wall compliance and disrupts normal kinematics and proprioception.
- Diaphragmatic Impairment: Cardiopulmonary bypass (CPB) can lead to inflammatory changes, while cooling the phrenic nerve during surgery may induce transient diaphragmatic paresis.
- Restrictive Breathing Patterns: Postoperative pain and fear of movement promote shallow, rapid breathing with an increased reliance on accessory muscles rather than the diaphragm.
- Post-Operative Pulmonary Complications (POPC): These restrictive patterns predispose patients to basal atelectasis, impaired secretion clearance, and ventilation–perfusion mismatch.

- *The Role of Inspiratory Muscle Training (IMT)*

Conventional physiotherapy focuses on early mobilization and incentive spirometry, but these often fail to directly address the loss of inspiratory muscle force-generating capacity.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26jun1598

- Threshold IMT: Unlike flow-dependent devices, mechanical threshold devices provide pressure-dependent resistance that ensures consistent diaphragmatic activation regardless of flow rate.
- Neuromuscular Re-education: Low-intensity IMT (approximately 30% of PImax aims to restore neuromuscular efficiency and improve rib cage kinematics rather than focusing solely on muscle hypertrophy.
- Clinical Gap: While preoperative IMT is known to reduce POPC, there is limited clinical reporting on the safety and efficacy of early-phase (starting POD 2) threshold loading in high-risk cardiac patients.

II. LITERATURE REVIEW

➢ *Pathophysiology of Post-CABG Respiratory Dysfunction*

Coronary Artery Bypass Grafting (CABG), particularly when performed via median sternotomy, profoundly alters the mechanics of the respiratory system due to surgical trauma, cardiopulmonary bypass (CPB), and perioperative pain. Multiple investigations have established that CABG induces a restrictive ventilatory defect, manifested by reduced lung volumes and diminished respiratory muscle strength. Functional residual capacity (FRC), vital capacity (VC), and maximal inspiratory pressure (PImax) may decline by 27–62% within the first postoperative days, contributing to compromised pulmonary mechanics and gas exchange inefficiency. This phenomenon has been attributed to the combined effects of diaphragmatic dysfunction, intercostal muscle inhibition, and pain-limited chest wall excursion.

Sternal incision and retraction disrupt normal chest wall kinematics and proprioception. Moreover, cooling the phrenic nerve during CPB is known to cause transient diaphragmatic paresis, further exacerbating inspiratory muscle impairment. Pain-induced splinting and shallow breathing patterns not only reduce lung expansion but also shift ventilation toward rapid, accessory muscle-dependent respiration, significantly increasing the risk of basal atelectasis and mucociliary dysfunction. The resulting ventilation–perfusion mismatch, impaired oxygenation, and secretion retention are key contributors to postoperative pulmonary complications (POPC), which remain a leading cause of prolonged hospital stay and increased mortality after cardiac surgery.

➢ *Conventional Physiotherapy in Post-CABG Care*

Standard postoperative physiotherapy protocols emphasize early mobilization, deep breathing exercises, incentive spirometry, and airway clearance techniques. Early ambulation has consistently been shown to enhance lung volumes and reduce the incidence of POPC, while incentive spirometry aims to increase inspiratory volumes and promote alveolar recruitment. Techniques such as the Active Cycle of Breathing Technique (ACBT) and manual chest physiotherapy are widely utilized to assist secretion clearance.

Although these interventions support general pulmonary rehabilitation, their impact on respiratory muscle strength — particularly the inspiratory musculature — appears limited. Incentive spirometry and flow-dependent devices primarily focus on inhaled volume achievement rather than on the force generation required for effective diaphragmatic recruitment. Consequently, there is a gap in addressing the neuromuscular impairment that directly results from surgical insult and postoperative inhibition of the primary inspiratory muscles.

➢ *Inspiratory Muscle Training: Mechanisms and Devices*

Inspiratory Muscle Training (IMT) involves the application of targeted resistive or threshold loading to the inspiratory muscles, most notably the diaphragm and external intercostals, with the intent of enhancing strength, endurance, and neuromuscular activation. Mechanical threshold devices, unlike flow-dependent systems, impose a pre-set pressure load that must be generated before airflow begins, thereby ensuring consistent effort levels regardless of inspiratory flow rates. Such devices promote true muscle conditioning through load-specific recruitment, making them especially suitable for postoperative respiratory rehabilitation.

A substantial body of evidence supports the role of IMT in improving inspiratory strength and functional outcomes in various clinical populations, including chronic obstructive pulmonary disease (COPD) and heart failure. In the context of cardiac surgery, preoperative IMT has been repeatedly shown to reduce the incidence of POPC and shorten hospital stays. Cochrane reviews and randomized controlled trials have demonstrated that prehabilitation with inspiratory loading significantly improves PImax, reduces atelectasis, and enhances postoperative pulmonary function when compared with conventional care.

➢ *Dynamic Strength and the S-Index*

Emerging respiratory research highlights the importance of dynamic biomarkers of muscle performance such as the Strength Index (S-Index), which reflects the contractile capacity and neuromuscular activation profile of the diaphragm during real breathing tasks. Unlike static measures alone, the S-Index captures functional strength and is increasingly recognized as a predictor of successful extubation and discharge readiness, particularly in critically ill patients.

Low-intensity inspiratory loading — typically prescribed at ≈30% of PImax — does not solely aim for hypertrophy but functions as a neuromuscular re-education stimulus. Through repetitive activation against a controlled resistance, the diaphragm adapts both in recruitment patterns and coordination with accessory muscles, promoting improved chest wall mechanics and breathing efficiency without excessive intrathoracic stress.

➢ *Safety and Timing of Early IMT Post-Surgery*

Despite the theoretical and demonstrated benefits of IMT, clinicians often hesitate to initiate resistive loading soon after major cardiac surgery due to concerns regarding sternal stability, hemodynamic fluctuations, graft integrity, and pain exacerbation. Traditional protocols have therefore deferred IMT until later in the postoperative course, missing a critical

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window where respiratory deconditioning progresses most rapidly.

However, recent pilot studies and clinical observations suggest that carefully prescribed and monitored IMT can be safely introduced in the early postoperative period, provided that loading intensity is appropriately moderated and integrated within a structured rehabilitation framework. Preliminary data indicate that early low-intensity IMT does not compromise hemodynamic stability or sternal healing and may, in fact, accelerate the recovery of lung volumes and inspiratory muscle performance.

➢ *Gaps in Current Evidence*

Although several studies have explored IMT in the preoperative and later postoperative phases of cardiac surgery, there is a paucity of evidence regarding early implementation of threshold IMT initiated within the first postoperative days — especially in high-risk patients with multivessel disease and significant comorbidities. Moreover, the interplay between threshold loading, thoracic expansion, pain modulation, and functional mobility remains inadequately characterized in the existing literature.

III. CASE DESCRIPTION

➢ *Patient Information*

The patient was a 64-year-old male diagnosed with advanced Coronary Artery Disease (CAD), presenting with progressive exertional dyspnoea and angina classified as New York Heart Association (NYHA) Class III. Coronary angiography revealed triple-vessel disease (CAD-3VD) with significant involvement of the left main coronary artery. Owing to the severity of stenosis and clinical symptomatology, the patient was scheduled for elective four-vessel Coronary Artery Bypass Grafting (CABG).

The patient's medical history included Type II Diabetes Mellitus and Systemic Hypertension, both of which were pharmacologically controlled. There was no prior history of chronic pulmonary disease, smoking, neuromuscular disorders, or previous thoracic surgery. Preoperatively, the patient was independent in activities of daily living and ambulated without assistive devices. Baseline oxygen saturation on room air was 97%, and auscultatory examination demonstrated normal vesicular breath sounds bilaterally.

The surgical procedure was performed via median sternotomy under cardiopulmonary bypass (CPB). Four grafts were successfully placed without intraoperative complications. The patient was extubated within the expected postoperative timeframe and transferred to the Intensive Cardiac Care Unit (ICCU) for monitoring and early rehabilitation.

➢ *Clinical Findings (Post-Operative Day 2)*

On Post-Operative Day 2 (POD-2), the patient was referred for physiotherapy assessment in the ICCU. Hemodynamic stability was confirmed before examination. Despite stable vital signs, the patient demonstrated clinical features consistent with early postoperative respiratory dysfunction.

Pain assessment using the Numeric Rating Scale (NRS) indicated a score of 7/10 during movement and coughing, localized primarily to the sternotomy region. This resulted in protective posturing and inhibited thoracic excursion.

Thoracic expansion measured at the xiphoid level was markedly restricted at 0.8 cm, reflecting reduced rib cage mobility. Respiratory rate was elevated at 24 breaths per minute, and the breathing pattern was predominantly apical with minimal diaphragmatic contribution.

Auscultation revealed reduced air entry at the bilateral lung bases accompanied by fine end-inspiratory crepitations, suggesting developing basal atelectasis. Peripheral oxygen saturation on room air was recorded at 93%.

Cardiovascular examination showed a heart rate of 86 beats per minute and blood pressure of 128/78 mmHg. Continuous cardiac monitoring did not reveal any arrhythmias or ischemic changes during assessment.

➢ *Functional Assessment*

Functional mobility was evaluated using the Intensive Care Unit Mobility Scale (ICUMS). The patient scored 10, indicating that he was bed-bound and required assistance for rolling, sitting, and positional changes. The reduced mobility was primarily influenced by postoperative pain, respiratory discomfort, fear of movement, and reduced endurance.

The patient exhibited difficulty in performing effective coughing due to sternal pain, increasing the risk of secretion retention and pulmonary complications.

➢ *Clinical Problem List*

Based on the comprehensive assessment, the following impairments were identified:

- Reduced inspiratory muscle performance with shallow breathing pattern.
- Severely restricted thoracic expansion.
- High movement-related sternal pain.
- Impaired airway clearance capacity.
- Decreased functional mobility and endurance.
- Increased risk for postoperative pulmonary complications (POPC).

➢ *Clinical Reasoning and Eligibility for IMT*

Given the presence of a restrictive ventilatory pattern, pain-limited respiration, and reduced mobility, early restoration of diaphragmatic function was prioritized. Conventional breathing exercises alone were considered insufficient to restore inspiratory muscle force-generating capacity. Therefore, initiation of a low-intensity Threshold Inspiratory Muscle Training (IMT) program was clinically justified.

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Prior to implementation, the patient was screened for contraindications to IMT, including hemodynamic instability, uncontrolled arrhythmias, excessive oxygen requirement, active air leaks, or neurological compromise. None were present. After explaining the rehabilitation protocol and obtaining informed consent, the patient was enrolled in the early postoperative Protected Loading IMT program beginning on POD-2.

The intervention aimed to enhance diaphragmatic recruitment, improve thoracic mobility, reduce pain-related respiratory inhibition, and facilitate early functional recovery while maintaining sternal integrity and physiological safety.

- *Intervention*

The rehabilitation program was initiated on Post-Operative Day 2 (POD-2) and continued for five consecutive days until POD-7. The intervention was structured around a "Protected Loading" framework, integrating early Threshold Inspiratory Muscle Training (IMT) with pain control strategies, airway clearance, and progressive mobilization. All sessions were conducted under continuous physiological monitoring to ensure patient safety and sternal protection.

- *Threshold Inspiratory Muscle Training Protocol*

Inspiratory muscle training was performed using a mechanical threshold loading device that imposed a pressure-dependent resistance to inspiration. The initial training load was set at approximately 30% of the patient's estimated maximal inspiratory pressure (PImax), in accordance with evidence-based recommendations for early-phase respiratory muscle conditioning.

The patient was positioned in a high Fowler's position (60–70° head elevation) to optimize diaphragmatic excursion and minimize sternal strain. Each IMT session consisted of 30 inspiratory efforts per session, performed twice daily.

The patient was instructed to generate sufficient inspiratory pressure to open the valve of the threshold device, followed by a slow, controlled exhalation. Emphasis was placed on diaphragmatic recruitment rather than accessory muscle dominance. Verbal and tactile cues were provided to facilitate a gradual inspiratory "ramp," ensuring controlled lung inflation while avoiding rapid, forceful gasping that could increase intrathoracic pressure.

Rest intervals were allowed as needed to prevent fatigue, and perceived exertion was monitored throughout the session.

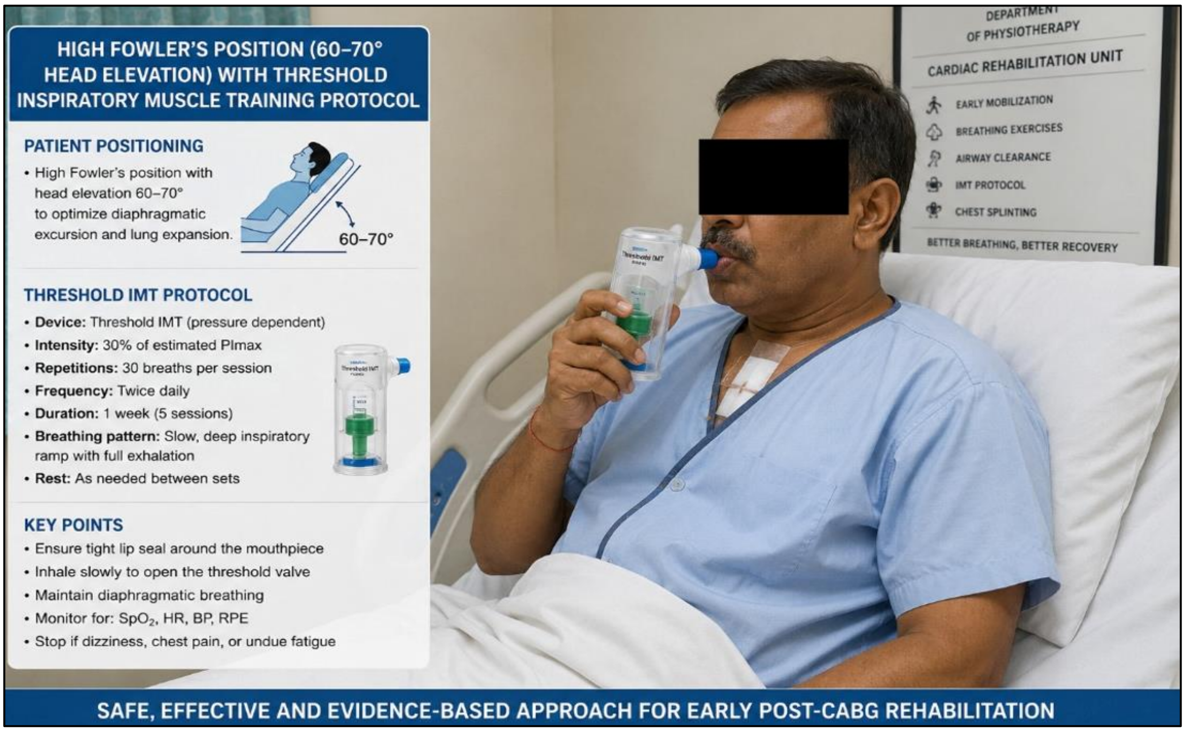

Fig 1 Threshold Inspiratory Muscle Training in high Fowler's Position.

- *Controlled Pacing and Positioning Strategies*

To minimize postoperative discomfort and reduce risk to sternal integrity, controlled breathing pacing was integrated into all respiratory exercises. The patient was educated on synchronizing inspiration with diaphragmatic descent and rib cage expansion while maintaining neutral spinal alignment.

Manual facilitation techniques, including gentle rib cage guidance, were applied to encourage lateral costal expansion. Excessive shoulder elevation and upper chest breathing were actively discouraged. The therapist provided continuous feedback to optimize breathing efficiency and minimize compensatory patterns.

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Sternal precautions were reinforced throughout therapy, including avoidance of excessive trunk rotation, pushing, or pulling during respiratory manoeuvres.

Fig 2 Controlled Pacing, Optimal Positioning, and Manual Facilitation Enhance Breathing Efficiency and Protect Sternal Integrity.

➢ *Airway Clearance Techniques*

Airway clearance was facilitated using the Active Cycle of Breathing Technique (ACBT), incorporating breathing control, thoracic expansion exercises, and forced expiratory techniques (huffing).

The patient was trained in sternal splinting, using a pillow placed against the sternotomy site during coughing and huffing to provide external support and pain modulation. This strategy enabled more effective secretion clearance without excessive discomfort or fear of movement.

The frequency and intensity of airway clearance were adjusted according to patient tolerance, auscultatory findings, and oxygen saturation levels.

➢ *Progressive Mobilization Program*

Early mobilization was integrated concurrently with respiratory rehabilitation. The mobilization program followed a graded progression designed to restore functional capacity while respecting cardiovascular and sternal safety limits.

- Days 1–2: In-bed active range-of-motion exercises, bed mobility training, and sitting at the edge of the bed with postural correction.
- Days 3–4: Transfer training to a chair, sit-to-stand practice, and marching in place with supervision.
- Days 5–7: Supervised ambulation within the ward environment, gradually progressing toward independent walking.

Throughout mobilization, heart rate, blood pressure, respiratory rate, and oxygen saturation were continuously monitored. Activity was modified or paused if physiological parameters deviated more than ±10% from baseline values.

➢ *Safety Monitoring and Termination Criteria*

To ensure patient safety, predefined termination criteria were established. IMT or mobilization sessions were discontinued if the patient demonstrated:

- Oxygen saturation < 90%
- Heart rate increase > 20 beats per minute from baseline
- Systolic blood pressure change > 20 mmHg
- New-onset arrhythmia
- Excessive dyspnea (Borg scale > 6)
- Dizziness, nausea, or chest discomfort

No adverse events were observed throughout the intervention period. Hemodynamic stability was maintained during all sessions, and no signs of sternal instability or wound complications were reported.

➢ *Therapeutic Rationale*

The Protected Loading framework was designed to deliver sufficient inspiratory resistance to stimulate diaphragmatic neuromuscular recruitment while minimizing mechanical stress on the sternum and cardiovascular system. By combining threshold loading with controlled pacing, airway clearance, and early mobilization, the intervention targeted both pulmonary mechanics and functional recovery simultaneously.

This integrated approach aimed to counteract postoperative respiratory inhibition, improve thoracic mobility, reduce pain-related breathing limitation, and facilitate earlier return to independent mobility.

IV. RESULTS

The patient demonstrated clinically meaningful improvements across respiratory, pain, and functional domains following the five-day Protected Loading rehabilitation program incorporating early Threshold Inspiratory Muscle Training (IMT). All outcome measures were collected at baseline (Post-Operative Day 2) and at completion of the intervention period (Post-Operative Day 7).

➢ *Pain Outcomes*

Movement-related pain at the sternotomy site, measured using the Numeric Rating Scale (NRS), showed a substantial reduction over the intervention period. At baseline, the patient reported an NRS score of 7/10 during coughing and positional transitions. Following completion of the IMT-based rehabilitation program, pain scores decreased to 0/10, enabling the patient to perform breathing exercises, coughing, and functional mobility without protective guarding or fear of movement.

This reduction in pain was accompanied by improved confidence in performing deep breathing and coughing tasks, facilitating more effective pulmonary hygiene.

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26jun1598

➢ *Thoracic Expansion*

Thoracic expansion, measured at the xiphoid level, improved markedly following intervention. Baseline chest excursion of 0.8 cm increased to 2.8 cm by POD-7, representing more than a threefold improvement in rib cage mobility.

This increase indicated enhanced diaphragmatic contribution and improved chest wall mechanics, reflecting recovery from the restrictive ventilatory pattern typically observed following median sternotomy.

➢ *Functional Mobility*

Functional status, evaluated using the Intensive Care Unit Mobility Scale (ICUMS), demonstrated significant progression. At baseline, the patient scored 10, indicating bed-bound status with dependence for positional changes. Following the intervention, the ICUMS score improved to 10 (independent walking), reflecting the patient's ability to ambulate independently within the ward environment without assistance.

The patient progressed from assisted sitting to independent transfers and ambulation, demonstrating improved endurance, balance, and confidence in movement.

➢ *Oxygenation and Hemodynamic Stability*

Peripheral oxygen saturation on room air improved from 93% at baseline to 98% post-intervention, indicating enhanced ventilation-perfusion matching and alveolar recruitment.

Throughout all IMT and mobilization sessions, the patient maintained hemodynamic stability. Heart rate and blood pressure remained within ±10% of baseline values. No episodes of oxygen desaturation, cardiac arrhythmia, dizziness, or excessive dyspnea were observed during therapy sessions.

➢ *Safety and Adverse Events*

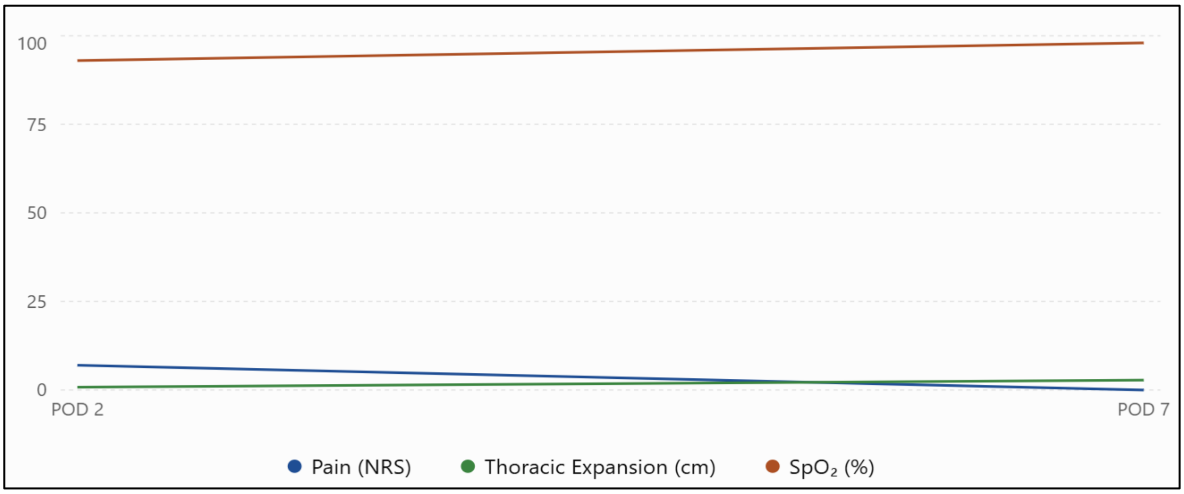
No adverse events related to Threshold-IMT, airway clearance, or mobilization were recorded. There were no signs of sternal instability, wound complications, excessive fatigue, or cardiopulmonary compromise.

The patient tolerated the full dosage of 30 breaths twice daily without interruption, demonstrating good adherence and perceived comfort with the training protocol.

➢ *Summary of Outcome Measures*

Table 1 Clinical Outcomes Following Early Threshold IMT Post-CABG from Post-Operative Day (POD) 2 and POD 7.

Parameter	Pre-Intervention (POD 2)	Post-Intervention (POD 7)
Pain (NRS)	7/10	0/10
Thoracic Expansion	0.8 cm	2.8 cm
ICUMS Score	10 (Bed-bound)	10 (Independent walking)
SpO2 (Room Air)	93%	98%



Graph 1 Clinical Outcomes Following Early Threshold IMT Post-CABG from Post-Operative Day (POD) 2 and POD 7.

➢ *Clinical Interpretation*

The observed improvements suggest that early low-intensity Threshold-IMT integrated with protected mobilization contributes positively to postoperative pulmonary recovery, pain modulation, and functional independence in CABG patients. Restoration of thoracic mobility and oxygenation occurred without compromising cardiovascular stability or sternal safety, supporting the feasibility of early inspiratory loading in the acute post-CABG phase.

V. DISCUSSION

This case report demonstrates that early implementation of low-intensity Threshold Inspiratory Muscle Training (IMT) within a Protected Loading framework can be safely integrated into immediate post-CABG rehabilitation and may significantly enhance pulmonary recovery, pain modulation, and functional mobility. The patient exhibited substantial improvements in thoracic expansion, oxygenation, pain

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reduction, and independence without compromising hemodynamic stability or sternal integrity.

➢ *Restoration of Inspiratory Muscle Function*

Following CABG, patients typically experience a pronounced decline in inspiratory muscle performance due to diaphragmatic inhibition, altered chest wall mechanics, and pain-induced respiratory splinting. In the present case, baseline thoracic expansion was severely restricted, reflecting reduced rib cage excursion and diminished diaphragmatic recruitment. After five days of targeted IMT, chest expansion improved from 0.8 cm to 2.8 cm, indicating restoration of inspiratory pump efficiency.

Threshold loading requires the patient to generate a preset inspiratory pressure before airflow occurs, thereby stimulating deeper motor unit recruitment in the diaphragm compared with flow-dependent devices. This mechanism supports neuromuscular re-education rather than simple volume training. The observed improvement aligns with prior findings suggesting that low-intensity IMT (~30% PImax) enhances dynamic inspiratory strength and rib cage kinematics without excessive intrathoracic pressure.

➢ *Influence on Pain and Breathing Mechanics*

One of the notable findings in this case was the complete resolution of movement-related pain (NRS 7/10 to 0/10). Although pain is often considered a limiting factor for respiratory loading after sternotomy, the current outcome suggests the opposite effect when loading is properly controlled. Improved lung expansion and coordinated diaphragmatic activation may reduce accessory muscle overuse and sternal "tugging," thereby decreasing nociceptive input from the sternotomy site.

Furthermore, the integration of controlled pacing and sternal splinting likely enhanced patient confidence during breathing and coughing tasks, reducing fear-avoidance behavior. Improved pain control facilitated deeper breathing and more effective airway clearance, contributing to enhanced pulmonary mechanics and oxygenation.

➢ *Functional Recovery and Early Mobilization*

Functional immobility is a common sequela in early post-CABG patients and contributes to respiratory deconditioning and delayed discharge. The patient in this report progressed from bed-bound status to independent ambulation within five days. This improvement reflects the synergistic effect of combining respiratory muscle training with progressive mobilization.

Improved inspiratory strength and thoracic mobility reduce ventilatory demand during activity, allowing patients to tolerate upright postures and ambulation more efficiently. Early IMT likely lowered the work of breathing, enabling earlier participation in functional tasks and promoting overall rehabilitation progression.

➢ *Safety of Early Threshold Loading*

A persistent concern among clinicians is the potential risk of initiating resistive breathing exercises soon after sternotomy. Excessive intrathoracic pressure could theoretically compromise graft patency or sternal stability. However, the current case supports the feasibility and safety of low-intensity threshold loading when implemented within a Protected Loading framework.

Throughout the intervention, heart rate, blood pressure, and oxygen saturation remained within ±10% of baseline, and no arrhythmias or desaturation episodes occurred. No signs of wound complications or sternal instability were observed. These findings support previous literature suggesting that 30% PImax represents a therapeutic "sweet spot" that stimulates inspiratory muscles while avoiding excessive mechanical stress.

VI. CONCLUSION

This case report demonstrates that early implementation of low-intensity Threshold Inspiratory Muscle Training (IMT) within a Protected Loading framework is a safe and clinically effective strategy during the immediate post-operative phase following Coronary Artery Bypass Grafting (CABG). Initiated as early as Post-Operative Day 2, Threshold-IMT at approximately 30% of estimated maximal inspiratory pressure facilitated meaningful improvements in thoracic expansion, oxygenation, pain reduction, and functional mobility without compromising hemodynamic stability or sternal integrity.

The Integration of controlled Inspiratory loading with airway clearance and progressive mobilization directly addressed the underlying neuromuscular inhibition of the diaphragm that typically occurs after median sternotomy. Rather than relying solely on volume-based breathing exercises, this approach restored inspiratory pump efficiency, enhanced chest wall mechanics, and reduced pain-related respiratory splinting, thereby accelerating functional recovery.

Although limited by its single-case design, the present report provides clinically relevant evidence supporting the feasibility of early threshold loading in high-risk cardiac patients. Incorporating IMT into standard post-CABG rehabilitation protocols may reduce postoperative pulmonary complications, promote earlier independence, and optimize respiratory recovery. Larger controlled trials are warranted to further establish dosing parameters, long-term benefits, and integration strategies for routine cardiac physiotherapy practice.

VII. CLINICAL IMPLICATIONS

This case reinforces the concept that postoperative respiratory rehabilitation should not be limited to volume expansion and mobilization alone. Targeting the inspiratory pump with early threshold loading addresses the underlying neuromuscular deficit that contributes to restrictive breathing patterns after CABG.

Integrating IMT into standard cardiac rehabilitation bundles may enhance pulmonary recovery, reduce pain-

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related respiratory inhibition, accelerate functional independence, and potentially lower the incidence of postoperative pulmonary complications. Early-phase IMT may also improve patient confidence and engagement in rehabilitation.

VIII. LIMITATIONS

As a single-case report, the findings cannot be generalized without caution. The absence of direct measures of PImax or S-index limits quantitative interpretation of inspiratory muscle performance. Additionally, longer-term follow-up was not available to determine whether gains in thoracic expansion and mobility were maintained after discharge.

Future research should include randomized controlled trials examining early threshold IMT in larger CABG populations, incorporating objective respiratory muscle metrics, longer follow-up periods, and comparisons with conventional physiotherapy protocols.

FUTURE DIRECTIONS

Further studies should explore optimal IMT dosing parameters, progression strategies, and integration timing within cardiac surgery pathways. Investigating the impact of early IMT on length of hospital stay, readmission rates, and quality-of-life outcomes would further clarify its clinical value.

- *Conflict of Interest*

The authors declare that there is no conflict of interest regarding the publication of this article. The authors have no financial, personal, or professional relationships that could inappropriately influence or bias the work reported in this paper.

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