International Journal of Orthopaedic and Trauma Nursing 58 (2025) 101193

Contents lists available at ScienceDirect

International Journal of Orthopaedic and Trauma Nursing

journal homepage: www.elsevier.com/locate/ijotn

Review article

Inspiratory muscle training: A theoretical framework for its selected application in orthopaedic enhancing recovery pathways

Francesco V. Ferraro [a], Rania Edris [b], Thomas W. Wainwright [c,d,e,*]

[a] School of Sports and Exercise Science, College of Science and Engineering, University of Derby, Derby, United Kingdom
[b] School of Science, College of Science and Engineering, University of Derby, Derby, United Kingdom
[c] Orthopaedic Research Institute, Bournemouth University, Bournemouth, United Kingdom
[d] Physiotherapy Department, University Hospitals Dorset NHS Foundation Trust, Bournemouth, United Kingdom
[e] Rehabilitation Department, Lanzhou University, Lanzhou, China

ARTICLE INFO

Keywords:
Respiratory muscle training
Pulmonary rehabilitation
Prehabilitation
Rehabilitation
Orthopaedic

ABSTRACT

This paper explores a theoretical framework for integrating Inspiratory Muscle Training (IMT) into enhanced recovery pathways, emphasising its potential role in mitigating respiratory decline, reducing hospital stays, and improving functional mobility for selected patients. IMT has shown benefits in high-risk surgical populations, including those with chronic respiratory conditions, obesity, obstructive sleep apnea, and frailty. Standardised screening protocols involving respiratory muscle function tests are recommended to identify suitable candidates, with structured IMT programs ideally commencing 6–8 weeks before surgery. Implementing IMT within an enhanced recovery pathway may enhance the ability for early mobilisation, improve oxygenation, and support the functional recovery of patients. While IMT has demonstrated efficacy in various surgical populations, its specific benefits to orthopaedic patients require further consideration and investigation. Indeed, future research should focus on optimising IMT protocols and assessing patient outcomes in the short-term (e.g. length of stay and complications), and the medium-term (e.g. return to activities of daily living). By incorporating IMT into prehabilitation and rehabilitation protocols, we propose that healthcare systems may be able to improve surgical outcomes and patients' well-being while reducing postoperative complications and healthcare burden for at-risk patients.

1. Introduction

Respiratory Muscle Training (RMT) encompasses a range of interventions designed to strengthen the muscles involved in breathing. Originally developed for athletes and healthy individuals to enhance respiratory function and performance (Sapienza et al., 2011; Kowalski et al., 2022), RMT has since expanded into clinical applications, particularly in populations with compromised respiratory function. Based on the targeted muscle groups, RMT can be categorised into Expiratory Muscle Training (EMT), which focuses on the Rectus and Transversus Abdominis, External and Internal Obliques (Laciuga et al., 2014), Inspiratory Muscle Training (IMT) when focuses on the Diaphragm and External intercostal (Rodrigues and McConnell, 2024), or a combination of both (HajGhanbari et al., 2013).

Among these, IMT has gained increasing attention over the past three decades due to its feasibility, low cost (e.g. devices often range from £30–£150 depending on features), and adaptability across different patient populations. Advances in IMT technology have evolved from simple analogic devices to digital and app-based solutions that offer real-time feedback and personalised progression (Stavrou et al., 2021). IMT interventions generally fall into three main modalities: **normocapnic hyperpnea**, which involves near-maximal ventilation for a sustained period (Hill et al., 2010); **flow resistive loading**, where resistance is manipulated through variable-diameter orifices (Mickleborough et al., 2010); and **pressure threshold loading**, which utilises a valve mechanism to generate a set inspiratory resistance (Silva et al., 2013). Of these, **pressure threshold loading has demonstrated the most consistent benefits across a range of conditions** and remains the most widely applied method in both research and clinical practice (McConnell and Romer, 2004; Romer and McConnell, 2003; Paiva et al., 2015).

Within the context of **enhanced recovery pathways**, the potential

* Corresponding author. Orthopaedic Research Institute, Bournemouth University, Bournemouth, United Kingdom.
E-mail address: twainwright@bournemouth.ac.uk (T.W. Wainwright).

https://doi.org/10.1016/j.ijotn.2025.101193
Received 11 March 2025; Received in revised form 6 May 2025; Accepted 19 May 2025
Available online 22 May 2025

role of IMT in orthopaedic patients remains largely unexplored. While most patients undergoing orthopaedic surgery may not require targeted respiratory training, certain **at-risk populations**, such as those with pre-existing respiratory impairments, obesity, frailty, or prolonged immobilisation, may benefit from structured IMT interventions before and after surgery. As enhanced recovery pathways continue to evolve towards more **personalised recovery pathways**, it is worth considering whether IMT could serve as an additional optimisation tool for selected at-risk patients.

This article explores the **theoretical framework for IMT in orthopaedic enhanced recovery pathways**, examining its potential benefits, relevant patient populations, optimal timing (preoperative vs. postoperative), and proposed implementation strategies. Additionally, we discuss existing research gaps and highlight future directions for integrating IMT into clinical practice.

2. Discussion

2.1. Patients potentially at-risk of impaired respiratory function and complications

2.1.1. Chronic Obstructive Pulmonary Disease

Patients with Chronic Obstructive Pulmonary Disease (COPD) experience breathing difficulties and obstruction due to airflow inflammatory responses, increased mucus production and emphysematous destruction of the gas-exchanging surface of the lung (Hogg and Timens, 2009). This condition is more common in males and smokers, with a reported incidence rate of September 8, 1000 person-year (Terzikhan et al., 2016). In orthopaedic surgery, it has been reported that patients with COPD undergoing revision of total knee arthroplasty (TKA) have a higher incidence of postoperative complications compared to non-COPD patients (Gu et al., 2018). Other authors have highlighted that COPD patients undergoing TKA have a higher in-hospital mortality rate (0.1 %) compared to non-COPD patients (0.03 %) and that they also tend to experience longer hospital stays and increased treatment costs (Albagly et al., 2024; Shin et al., 2023). Several studies have shown that IMT has a benefit in COPD populations. Gosselink demonstrated that IMT significantly improved respiratory muscle strength and endurance, resulting in reductions of dyspnoea and improvement in functional exercise capacity and quality of life (Gosselink et al., 2011). Similar results were reported by Figueiredo and Beaumont, who demonstrated improvements in inspiratory muscle strength, functional capacity, and pulmonary function but with no agreement on significant changes in dyspnea and quality of life (Figueiredo et al., 2020; Beaumont et al., 2018).

2.1.2. Obesity

Obesity is a condition known to be associated with osteoarthritis and poor metabolic health status (Horan, 2006). In 2021, the Health Survey for England (HSE) reported that 25 % of men and 26 % of women were classified as obese (Digital, 2021). This condition is common in knee arthroplasty, where a recent figure showed 63 % of patients were classified as obese, with a mean Body Mass Index (BMI) of 37.5 kg/m^2, with potentially higher length of stay and mortality risks (Hennrikus et al., 2021; Carender et al., 2022). Obesity can affect the respiratory system and may lead to decreased lung volumes and compliance, causing a higher risk of pulmonary complications, such as hypoventilation and atelectasis (Carron et al., 2020). A recent systematic review and meta-analysis showed that IMT improved physical capacity measured with 6 min walk test and inspiratory muscle strength obtained with maximal inspiratory pressure but had no effects on lung function, BMI and metabolic parameters in obese populations (Caicedo-Trujillo et al., 2023). Similar results were also reported in other metabolic conditions where IMT has excellent results in improving physical capacity and inspiratory muscle strength (Sheraz et al., 2024) with significant increases in inspiratory muscle strength with obese women undergoing open bariatric surgery (Barbalho-Moulim et al., 2011). However, there is an evident gap in research concerning IMT application in obese population undergoing orthopaedic surgery but based on other applications of IMT in other clinical areas, it is possible to conceive that IMT might diminish the length of stay and reduce mortality in the obese population undergoing arthroplasty.

2.1.3. Obstructive sleep apnea (OSA)

Another common condition in elective orthopaedic surgery is Obstructive Sleep Apnea (OSA). A study by Finkel et al. screened 2877 elective surgery patients and found that 23.7 % were at high risk for OSA, with 81 % of these cases previously undiagnosed (Porhomayon et al., 2011). Additionally, it has been shown that OSA is frequently undiagnosed in surgical populations, and its presence is associated with increased perioperative complications (Adesanya et al., 2010). For this condition, several reviews reported the effects of IMT. In particular, de Sousa et al. discussed how IMT in association with cardiac rehabilitation exercises reduces apnea-hypopnea index and improves inspiratory muscle strength, sleepiness and sleep quality compared with cardiac rehabilitation alone (Silva de Sousa et al., 2024). Similarly, Dar et al. and Torres Castro et al. reported that IMT alone significantly improves inspiratory muscle strength, sleep quality, daytime sleepiness and lung function in OSA. However, there is still debate on the effects of IMT on lung function (i.e., Forced Vital Capacity and Forced Expiratory Volume in 1 s) (Torres-Castro et al., 2022; Dar et al., 2022). Although there is no research on the uses of IMT in OSA orthopaedic patients, it is possible that incorporating IMT into the preoperative regimen may be advantageous. Indeed, strengthening respiratory muscles could potentially reduce perioperative respiratory complications and enhance postoperative recovery.

2.1.4. Older patients

Apart from the existing complications mentioned above, it is possible to highlight orthopaedic patients who, without existing complications, can be considered at high risk of respiratory complications, and IMT might be used to mitigate the risks. According to the WHO, in 2020, the number of people aged 60 years and older outnumber children younger than 5 years, and the proportion of the world's population over 60 will nearly double in the next 20 years (WorldHealthOrganization, 2024). According to NHS England, between April 2018 and March 2019, 93.8 % of 81,130 hip replacements were in patients 50^+ years old, with 51.9 % over 70. The highest incidence was in ages 75–79 (323.1 per 100,000 females, 551.9 per 100,000 males). For 93,911 knee replacements, 97.4 % were in patients 50^+ years old, with 51.8 % over 70. The peak occurrence was in ages 75–79 (883.4 per 100,000 females, 760.4 per 100,000 males) (Digital, 2019). A condition that might affect the outcomes of the operation and that is associated with physiological age changes is senile emphysema.

This condition is characterised by the enlargement of airspaces without significant destruction of alveolar walls and decreased elastic recoil (Dyer, 2012). Although not directly pathological, the condition can affect people's physical capacity and even lead to COPD (Janssens et al., 1999). In the past decade, many studies have highlighted the benefit of IMT in older adults, particularly in people over 75, where the improvements in respiratory muscle strength, mobility and balance seem to be highly significant than in adults between 65 and 75 years old (Ferraro et al., 2021). Recently, a systematic review showed how IMT significantly positively affects balance and overall mobility in healthy and frailer older adults (Sheraz et al., 2023), indicating that the intervention is feasible also for frailer populations. Similarly, patients with poor baseline will benefit from IMT intervention, particularly in mobility and respiratory muscle strength. This is likely due to the adaptive training principle, as it has been shown in healthy athletes as well as ill conditions (HajGhanbari et al., 2013; Vorona et al., 2018).

2.1.5. Smoking and vaping

Smoking is known to reduce lung function and can lead to comorbidities during major operations (Alsanad et al., 2025). Similar vaping has been associated with increased airway resistance, breathing difficulties, and transient inflammation (Honeycutt et al., 2022) and it can potentially lead to healing complications affecting the physiological cardiovascular responses (Warner et al., 2020). The WHO reported that smokers are more likely to experience postoperative issues such as impaired heart and lung function, infections, and delayed or impaired wound healing (Organization, 2020). Smokers undergoing knee arthroplasty had a higher incidence of lower respiratory tract infections (4.2 %) compared to non-smokers (2.7 %). Additionally, smokers exhibited increased usage of pain medications post-surgery and higher mortality rates within one year (Pandit et al., 2018). Similarly, research on total hip arthroplasty patients revealed that smokers had an elevated risk of complications such as lower respiratory tract infections, myocardial infarction, and cerebrovascular events compared to non-smokers and ex-smokers. Notably, ex-smokers demonstrated reduced risks, highlighting the benefits of smoking cessation prior to surgery (Matharu et al., 2019). While these studies provide valuable insights, specific research focusing on the effects of IMT in smokers or ex-smokers with reduced lung function is limited. Given the established benefits of IMT in improving respiratory muscle strength and lung function in other populations, it is plausible that smokers or ex-smokers with compromised pulmonary function may also benefit from such training (McConnell, 2013). However, further targeted research is necessary to confirm the efficacy and optimal protocols of IMT in this specific group.

2.1.6. Patients undergoing major orthopaedic surgeries

Although the application of IMT has not been explored in elective and trauma orthopaedic surgeries, it is possible to speculate on its benefits for at-risk patients undergoing major orthopaedic surgery based on data from other surgical specialties. Katsura et al. completed a Cochrane review to assess the effectiveness of preoperative IMT on postoperative pulmonary complications in adults undergoing cardiac or major surgery, and they reported that preoperative IMT reduces post-operative atelectasis, pneumonia and length of hospital stay (Katsura et al., 2015). The benefit of these abdominal and thoracic procedures is interesting, given the previously shown effect of IMT on spinal conditions several studies have reported how IMT can diminish low back pain and improve mobility in healthy and abdominal pathological conditions (Borujeni and Yalfani, 2019; Ahmadnezhad et al., 2020). These results suggest that IMT may be a useful adjunct for patients at-risk undergoing procedures such as major spine surgery, where multi-level fusion procedures are completed for degenerative spine conditions.

Another aspect that has been well explored is the positive association between improvement in inspiratory muscle strength and improvement in dynamic balance (e.g., walking). This is important, given the known increased fall risk in the early recovery stages after TJA or surgery for fractured neck of femur. Recent studies have shown how older populations (65^{+}) and care-home dwellers reported significant improvement in dynamic balance measured with the mini-BEST test following 8 consecutive weeks of IMT (Ferraro et al., 2019, 2020). Similar improvements have been noticed in older diabetes population (SHERAZ et al., 2024a, SHERAZ et al., 2024b), where an IMT intervention has improved an initial lack of balance. More recently, IMT has been associated with other forms of balance training, such as Tai Chi, where improvements in balance were also associated with higher improvements in overall mobility (Ferraro et al., 2025). Hence, it is possible to conceive that integrating IMT in major orthopaedic surgery and TJA as a pre and post rehabilitation intervention may help to increase balance and mobility for certain groups of patients, leading to better post-operative outcomes.

2.1.7. Pre and post rehabilitation

The previous sections discuss the proposed applications of IMT for different types of orthopaedic patients and surgery where the risk of delayed respiratory recovery or complication may be present. In each condition, IMT has been proposed to enhance respiratory function, mobility, balance, and length of stay outcomes. However, it is yet to be confirmed whether at-risk patients should be identified and treated before, after, or at both time points in their intra-operative pathway. This will vary on whether the operation is elective or following trauma, but for elective patients, it is important to calculate the patient's risks for complications or delayed recovery at multiple timepoints and then implement the best treatments (such as IMT for respiratory recovery and complications) for resolving that risk (Briguglio and Wainwright, 2022).

Pre-rehabilitation is becoming extremely common in non-traumatic surgery as a multidisciplinary approach aimed at enhancing a patient's functional capacity and reducing postoperative complications before medical interventions (Fleurent-Grégoire et al., 2024). Two pilot studies, one with major abdominal surgery patients and the other with patients undergoing esophagectomy, showed that preoperative IMT improved postoperative respiratory muscle function (Kulkarni et al., 2010; Dettling et al., 2013). Similar results were also reported by other authors with potential benefits in diminishing pneumonia and atelectasis and increasing mobility post-operatively (Karanfil and Møller, 2018; Guinan et al., 2019). Regarding postoperative IMT application, Azambuja et al., in a recent systematic review, reported that rehabilitative IMT increases maximal inspiratory pressure, 6 min walk test, maximum oxygen consumption and quality of life in patients with heart failure (Azambuja et al., 2020). Similar results were noticed in a more recent review where rehabilitative IMT with adult patients undergoing cardiac surgeries improved PeakVO_2, 6 min walking test, maximal inspiratory pressure, quality of life, postoperative pulmonary complications and spirometry outcomes (Starko et al., 2024). It is possible to deduce that IMT can be used as a pre- and post-operative intervention in orthopaedic surgery, Fig. 1; however, future research should investigate the impact of the intervention on rehabilitative outcomes.

3. Theoretical framework

Given the applications of IMT and clinical results across different contexts discussed, we may summarise that IMT can be associated with four main clinical benefits: i) improvement in respiratory muscle strength and function – due to the conditioning effect of the intervention itself, which focuses on inspiratory muscle strength exercises; ii) improvement in quality of life, due to patients feeling better (measured via QoL dedicated questionnaires (Yekta et al., 2019)) and more active post-intervention; iii) improvement in functional mobility (e.g., 6 min walking tests); iv) improvement in dynamic balance (e.g., mini-BEST). Refer to Fig. 2.

It is possible to highlight three main theories to explain these results. First, the diaphragm plays a dual role in respiration and core stabilisation by modulating intra-abdominal pressure (IAP), which is essential for postural control and balance. Hence, stronger inspiratory muscles contribute to better IAP control, resulting in high core management and better mobility (Hodges and Gandevia, 2000; Papalia et al., 2020). A second theory is that IMT provides patients with less perceived exertion, and as a consequence, it enhances gait endurance and walking performance (e.g., 6 min walking test) (Fabero-Garrido et al., 2022; Shoemaker et al., 2009). A third and final theory is that IMT produces a positive effect on the metaboreflex, which results in increased endurance-based activities (McConnell and Romer, 2004; Illi et al., 2012). An agreement has not been reached regarding the mechanisms that link improvement in inspiratory muscle strength with mobility and balance outcomes hence, it is possible to conclude that a combination of all these elements plays a role as mobility and balance are considered multimodal tasks that require holistic approaches (Pollock et al., 2000).

4. Specific benefits of IMT in orthopaedics

TJA are among the most common elective orthopaedic procedures,

Fig. 1. An older patient uses an Inspiratory Muscle Training device to train their inspiratory muscle strength.

aiming to restore physiological function in patients with advanced osteoarthritis or joint degeneration (Seidlitz and Kip, 2018). Despite the widely recognised success of TJA, post-arthroplasty recovery for some patients continues to be sub-optimal, particularly in terms of reduced functional mobility, increased risk of falls, and social isolation, which may prolong rehabilitation and delays the return to daily activities (Changjun et al., 2023; Chen et al., 2019; Choi et al., 2022).

Studies have shown that a notable percentage of patients continue to experience long-term discomfort following TKA (Edwards et al., 2022), which can affect health-related quality of life, leading to functional limitations, depression, anxiety, and sleep problems (Wylde et al., 2018). While THA is generally associated with improved mobility, it similarly presents significant postoperative mobility challenges that impact recovery and overall patient well-being (Luo et al., 2024). These limitations affect patients' independence and increase fall risk, which prolongs rehabilitation, particularly in older adults or those with pre-existing comorbidities (Olsen et al., 2024; Cole et al., 2022; Edwards et al., 2022; Seidlitz and Kip, 2018).

Postoperative pulmonary complications (PPCs), as a consequence of anaesthesia, prolonged immobility, and pain-related respiratory restriction (Karcz and Papadakos, 2013) have reduced since the introduction of enhanced recovery pathways but remain a preventable complication of surgery. When they occur, PPCs, such as atelectasis and pneumonia, significantly impact patient outcomes, leading to increased hospital stays, healthcare costs, and higher postoperative morbidity (Fernandez-Bustamante et al., 2017). Specific patient populations, including older adults and individuals with pre-existing respiratory conditions such as COPD, obesity, and OSA, are particularly vulnerable to these complications, and as such, they could potentially benefit from targeted interventions to optimise respiratory function and accelerate recovery (Caicedo-Trujillo et al., 2023; Torres-Castro et al., 2022; Krause-Sorio et al., 2021).

IMT can be a promising intervention to enhance recovery in orthopaedic surgery through its ability to strengthen respiratory muscles, improve lung function pre- and postoperatively, and enhance functional mobility. Evidence suggests that IMT can reduce the length of hospital stay, lower the incidence of PPCs, and contribute to improved post-surgical outcomes (Kendall et al., 2018; Ge et al., 2018). Additionally, preoperative IMT has demonstrated effectiveness in enhancing respiratory endurance and strength, thus reducing postoperative respiratory decline (Katsura et al., 2015). Furthermore, IMT has been shown to be particularly beneficial in reducing PPCs in surgical populations, with notable improvements in inspiratory strength, oxygenation, and functional exercise capacity (Silva de Sousa et al., 2024). In order to realise these benefits, a structured IMT program should ideally commence four to six-eight weeks before surgery (Fig. 2), employing threshold-loading devices to optimise inspiratory muscle strength and reduce post-operative complications (Paiva et al., 2015). Whilst postoperatively, IMT should be integrated into rehabilitation protocols to support respiratory recovery, facilitate early mobilisation, balance and counteract respiratory muscle weakness.

5. Challenges in implementing IMT in ERAS pathways

Despite the promising benefits of IMT, there are significant limitations to its implementation in orthopaedic enhanced recovery pathways. One major challenge is the lack of standardised IMT protocols. The literature shows considerable heterogeneity in IMT regimen design training intensities ranging roughly from 30 % to 80 % of a patient's maximal inspiratory pressure (MIP), frequencies from once daily to several times per week, and program durations from a few weeks up to 3–6 months in different studies (Katsura et al., 2015; Starko et al., 2024). Such variability in intensity, duration and patient selection criteria reflects an absence of consensus on the optimal IMT protocol for surgical patients. This lack of homogeneity makes it difficult to establish best-practice guidelines, as outcomes are hard to compare across studies. However, based on previous literature and expected outcomes, a preliminary recommended protocol is reported in Table 1.

Workflow integration into the perioperative pathway is also challenging, as the prehabilitation window may be too short for patients to complete a meaningful IMT course (see Table 2). Adding IMT sessions requires coordination across multidisciplinary teams. Studies report organisational barriers such as scheduling constraints and poor integration into the patient pathway. Perioperative staff also need training in IMT techniques and devices, which is not routinely part of orthopaedic ERAS protocols. Without dedicated training and buy-in from clinicians, IMT can be inconsistently delivered (Briguglio and Wainwright, 2022).

Patient adherence to IMT regimens is a well-recognised issue. Even when an IMT program is offered, keeping patients engaged and compliant throughout the pre- and postoperative period is difficult as patients who might be skeptical about the benefits of IMT or do not feel an immediate need for it are less likely to commit to the training (Azambuja et al., 2020). Finally, implementing a new prehabilitation intervention requires institutional support in terms of funding, personnel, and infrastructure (Davis et al., 2022). Even though an IMT

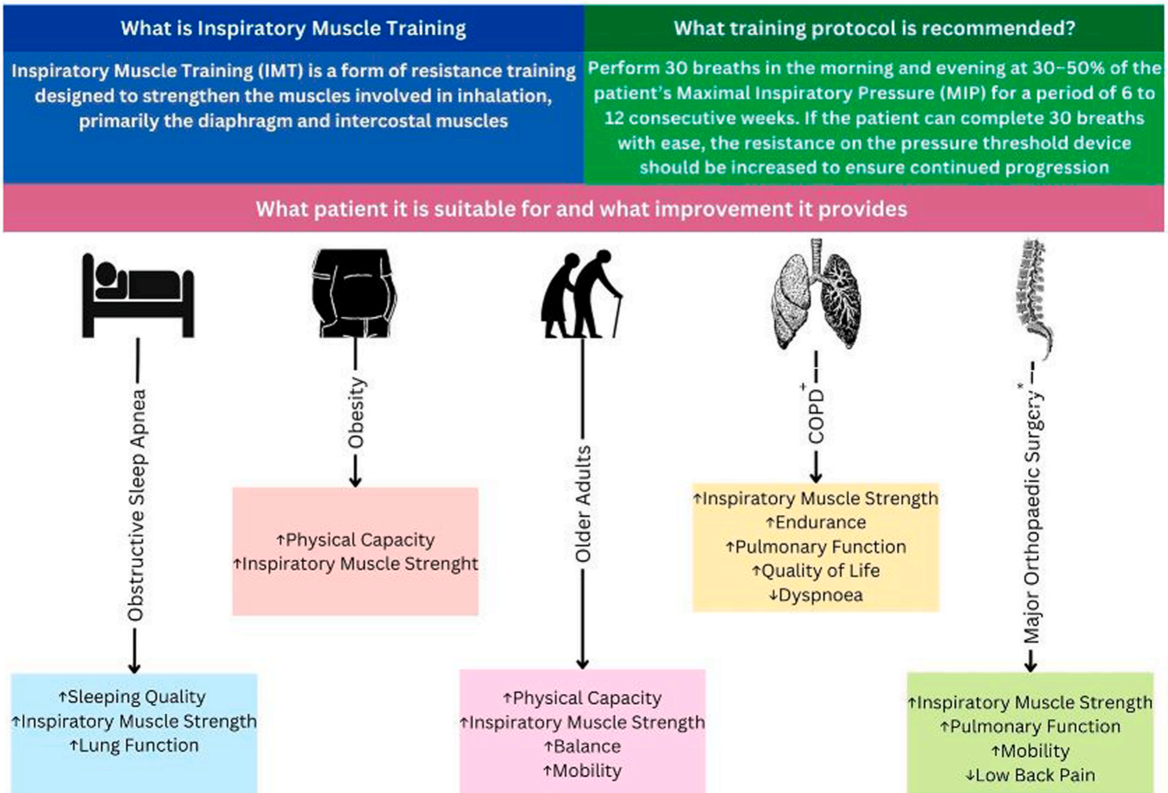

Fig. 2. Infographic summarising the definition of Inspiratory Muscle Training, the recommended training protocol and the conditions discussed in the manuscript. +COPD = Chronic Obstructive Pulmonary Disease, *Including multi-level spinal and prolonged procedures.

Table 1
– Examples of Inspiratory Muscle Training protocol to be used in orthopaedic surgery.

Phase	Setting	Frequency	Intensity	Progression	Supervision
Pre-operative Phase 2–4 weeks before surgery	Home	1–2x/day, 15 min	50 % of the measured MIP	Increasing resistance when patients can achieve more than 30 breaths	Weekly physio check-in
Days 1–5 post-op	Hospital/ Home	1- 2x/day, 15 min	30 % of pre-op MIP	Increasing resistance when patients can achieve more than 30 breaths	Physiotherapist supervised whilst in hospital.
Days 6–14 post-discharge	Home	2x/day, 15 min	40–50 % of updated MIP	Increasing resistance when patients can achieve more than 30 breaths	Patient logs, effort and symptoms; weekly remote check-ins
Weeks 3–ongoing	Home	2x/day, 15 min	60–70 % of MIP	Aim to reach maximum resistance within eight consecutive weeks of training	None needed

A protocol of Inspiratory Muscle Training for orthopaedic surgery has not been developed yet; however, it is possible to create a protocol based on previous findings. Modified from Ferraro et al. (2025); McConnell (2013). MIP = Maximal Inspiratory Pressure; min = minutes.
As an example - The above Inspiratory Muscle Training protocol could be applied to the surgical pathway for the below patient.
Patient profile: Mrs X is a 74-year-old female scheduled for an elective total hip replacement (THR) due to severe osteoarthritis. Her medical history includes well-controlled COPD (GOLD Stage II), obesity (BMI 36), and reduced mobility due to her hip joint pain. Pulmonary function tests reveal a XX (low-normal for age and sex). She is an ex-smoker and lives independently but reports struggling with prolonged exertion and stair-climbing.
Preoperative Screening and MDT Planning: Following her pre-operative assessment, Mrs X is identified as potentially at risk of postoperative pulmonary complications (PPCs) and impaired cardio-respiratory capacity. The preoperative team (which may include physiotherapist, nurse specialist, and respiratory therapist) recommend an Inspiratory Muscle Training (IMT) program integrated into her enhanced recovery pathway.

device for an individual patient is relatively inexpensive, running a program at scale entails costs for equipment procurement, staff training, and potentially extending preoperative services. A qualitative study of a multimodal prehabilitation program noted that staff shortages and lack of organisational capacity were major barriers to prehabilitation implementation (Fuchs et al., 2024). Indeed, inconsistent availability of IMT across institutions reflects these systemic issues, highlighting the need for greater investment and structural support.

6. Conclusive summary of clinical recommendations

To optimise surgical outcomes and reduce postoperative complications, we propose that IMT could be systematically integrated into enhanced recovery pathways for at-risk patients through a screening process (e.g. respiratory muscle function tests such as maximal inspiratory pressure) and tailored intervention protocols (such as four to six-eight weeks of training). We propose that by IMT may be a useful adjunct to enhanced recovery pathways in order to help promote early mobilisation, reduce pulmonary complications, and improve overall balance, mobility and quality of life for patients with impaired

Table 2
– Comparison between Inspiratory Muscle Training's known benefits and its expected benefits in the orthopaedic surgery population.

IMT Known Benefits	IMT Expected Benefits in the Orthopaedic surgery population
• Improves respiratory muscle strength and function • Enhances lung function and oxygenation • Reduces postoperative pulmonary complications (e.g., atelectasis, pneumonia) • Improves functional mobility (e.g., 6-min walk test) • Enhances balance and reduces fall risk • Reduces perceived exertion and improves exercise tolerance • Improves quality of life and reduces fatigue • Supports recovery in high-risk populations (e.g., COPD, obesity, OSA) • Reduces hospital length of stay and healthcare burden • Can be integrated into prehabilitation and rehabilitation programs	• Enhances post-arthroplasty recovery by improving respiratory endurance • Reduces postoperative pulmonary complications in TKA and THA patients • Facilitates early mobilisation and rehabilitation effectiveness • Improves functional mobility, potentially accelerating return to daily activities • Reduces fall risk, particularly in older adults undergoing joint replacement • May alleviate postoperative fatigue and improve patient-reported outcomes • Supports patients with pre-existing respiratory conditions, improving surgical outcomes • Reduces hospital stay duration by enhancing recovery efficiency • May mitigate the impact of prolonged immobilisation on respiratory function • Contributes to a holistic recovery approach by addressing both physical and respiratory health

respiratory function. A multidisciplinary approach involving surgeons, anaesthetists, nurses, and respiratory therapists is essential for successful integration. Future research should focus on refining IMT protocols, assessing long-term benefits, and validating its role in orthopaedic surgical pathways. In conclusion, IMT may be a useful intervention to add to orthopaedic enhanced recovery pathways, given its proven evidence base in other areas, low cost, and potential to help accelerate recovery and reduce complications for those patients at a higher risk of respiratory-related complications.

CRediT authorship contribution statement

Francesco V. Ferraro: Writing – review & editing, Writing – original draft, Visualization, Conceptualization. **Rania Edris:** Writing – review & editing, Writing – original draft. **Thomas W. Wainwright:** Writing – review & editing, Writing – original draft, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Guest Editor for VSI - Enhanced Recovery Pathways in Orthopaedic and Trauma Care (TWW) If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Adesanya, A.O., Lee, W., Greilich, N.B., Joshi, G.P., 2010. Perioperative management of obstructive sleep apnea. Chest (Am. Coll. Chest Physicians) 138, 1489–1498.
Ahmadnezhad, L., Yalfani, A., Borujeni, B.G., 2020. Inspiratory muscle training in rehabilitation of low back pain: a randomized controlled trial. J. Sport Rehabil. 29, 1151–1158.
Albagly, A., Kobo, O., Yonai, Y., Berkovich, Y., Steinfeld, Y., 2024. COPD patient's outcomes following total knee arthroplasty—an analysis of the national inpatients sampling (2016–2020). J. Clin. Med. 13, 5578.
Alsanad, M., Aljanoubi, M., Alenezi, F.K., Farley, A., Naidu, B., Yeung, J., 2025. Preoperative smoking cessation interventions: a systematic review and meta-analysis. Perioper. Med. 14, 5.
Azambuja, A.D.C.M., DE Oliveira, L.Z., Sbruzzi, G., 2020. Inspiratory muscle training in patients with heart failure: what is new? Systematic review and meta-analysis. Phys. Ther. 100, 2099–2109.
Barbalho-Moulim, M.C., Miguel, G.P.S., Forti, E.M.P., Do Amaral Campos, F., Costa, D., 2011. Effects of preoperative inspiratory muscle training in obese women undergoing open bariatric surgery: respiratory muscle strength, lung volumes, and diaphragmatic excursion. Clinics (São Paulo) 66, 1721–1727.
Beaumont, M., Forget, P., Couturaud, F., Reychler, G., 2018. Effects of inspiratory muscle training in COPD patients: a systematic review and meta-analysis. The clinical respiratory journal 12, 2178–2188.
Borujeni, B.G., Yalfani, A., 2019. Reduction of postural sway in athletes with chronic low back pain through eight weeks of inspiratory muscle training: a randomized controlled trial. Clin. BioMech. 69, 215–220.
Briguglio, M., Wainwright, T.W., 2022. Nutritional and physical prehabilitation in elective orthopedic surgery: rationale and proposal for implementation. Therapeut. Clin. Risk Manag. 21–30.
Caicedo-Trujillo, S., Torres-Castro, R., Vasconcello-Castillo, L., Solis-Navarro, L., Sanchez-Ramirez, D., Núñez-Cortés, R., Vera-Uribe, R., Muñoz-Muñoz, I., Barros-Poblete, M., Romero, J.E., 2023. Inspiratory muscle training in patients with obesity: a systematic review and meta-analysis. Front. Med. 10, 1284689.
Carender, C.N., Glass, N.A., Demik, D.E., Elkins, J.M., Brown, T.S., Bedard, N.A., 2022. Projected prevalence of obesity in primary total knee arthroplasty: how big will the problem get? J. Arthroplast. 37, 1289–1295.
Carron, M., Safaee Fakhr, B., Ieppariello, G., Foletto, M., 2020. Perioperative care of the obese patient. Journal of British Surgery 107, e39–e55.
Changjun, C., Jingkun, L., Yun, Y., Yingguang, W., Yanjun, R., Debo, Z., Kaining, Z., Pengde, K., 2023. Enhanced recovery after total joint arthroplasty (TJA): a contemporary systematic review of clinical outcomes and usage of key elements. Orthop. Surg. 15, 1228–1240.
Chen, S.K., Voaklander, D., Perry, D., Jones, C.A., 2019. Falls and fear of falling in older adults with total joint arthroplasty: a scoping review. BMC Muscoskelet. Disord. 20, 1–8.
Choi, Y.S., Kim, T.W., Chang, M.J., Kang, S.-B., Chang, C.B., 2022. Enhanced recovery after surgery for major orthopedic surgery: a narrative review. Knee surgery & related research 34, 8.
Cole, S., Kolovos, S., Soni, A., Delmestri, A., Sanchez-Santos, M.T., Judge, A., Arden, N. K., Beswick, A.D., Wylde, V., Gooberman-Hill, R., 2022. Progression of chronic pain and associated health-related quality of life and healthcare resource use over 5 years after total knee replacement: evidence from a cohort study. BMJ Open 12, e058044.
Dar, J.A., Mujaddadi, A., Moiz, J.A., 2022. Effects of inspiratory muscle training in patients with obstructive sleep apnoea syndrome: a systematic review and meta-analysis. Sleep Science 15, 480–489.
Davis, J.F., van Rooijen, S.J., Grimmett, C., West, M.A., Campbell, A.M., Awasthi, R., Slooter, G.D., Grocott, M.P., Carli, F., Jack, S., 2022. From theory to practice: an international approach to establishing prehabilitation programmes. Current Anesthesiology Reports 12, 129–137.
Dettling, D.S., van der Schaaf, M., Blom, R.L., Nollet, F., Busch, O.R., van Berge Henegouwen, M.I., 2013. Feasibility and effectiveness of pre-operative inspiratory muscle training in patients undergoing oesophagectomy: a pilot study. Physiother. Res. Int. 18, 16–26.
Digital, N., 2021. Health Survey for England 2021: overweight and obesity. https://digital.nhs.uk/data-and-information/publications/statistical/health-survey-for-england/2021/part-2-overweight-and-obesity.
Digital, N.H.S., 2019. Patient-Reported Outcome Measures (PROMs): Finalised Hip & Knee Replacements (April 2018 - March 2019). NHS Digital.
Dyer, C., 2012. The interaction of ageing and lung disease. Chron. Respir. Dis. 9, 63–67.
Edwards, R.R., Campbell, C., Schreiber, K.L., Meints, S., Lazaridou, A., Martel, M.O., Cornelius, M., Xu, X., Jamison, R.N., Katz, J.N., 2022. Multimodal prediction of pain and functional outcomes 6 months following total knee replacement: a prospective cohort study. BMC Muscoskelet. Disord. 23, 302.
Fabero-Garrido, R., Del Corral, T., Angulo-Díaz-Parreño, S., Plaza-Manzano, G., Martín-Casas, P., Cleland, J.A., Fernandez-DE-Las-Penas, C., López-DE-Uralde-Villanueva, I., 2022. Respiratory muscle training improves exercise tolerance and respiratory muscle function/structure post-stroke at short term: a systematic review and meta-analysis. Annals of Physical and Rehabilitation Medicine 65, 101596.
Fernandez-Bustamante, A., Frendl, G., Sprung, J., Kor, D.J., Subramaniam, B., Ruiz, R. M., Lee, J.-W., Henderson, W.G., Moss, A., Mehdiratta, N., 2017. Postoperative pulmonary complications, early mortality, and hospital stay following noncardiothoracic surgery: a multicenter study by the perioperative research network investigators. JAMA Surg. 152, 157–166.
Ferraro, F.V., Gavin, J.P., Wainwright, T., Mcconnell, A., 2019. The effects of 8 weeks of inspiratory muscle training on the balance of healthy older adults: a randomized, double-blind, placebo-controlled study. Physiological reports 7, e14076.
Ferraro, F.V., Gavin, J.P., Wainwright, T.W., Mcconnell, A.K., 2020. Comparison of balance changes after inspiratory muscle or Otago exercise training. PLoS One 15, e0227379.
Ferraro, F.V., Gavin, J.P., Wainwright, T.W., Mcconnell, A.K., 2021. Association between inspiratory muscle function and balance ability in older people: a pooled data analysis before and after inspiratory muscle training. J. Aging Phys. Activ 30, 421–433.
Ferraro, F.V., Zhou, Y., Roldan, A., Edris, R., 2025. Multimodal respiratory muscle training and Tai Chi intervention with healthy older adults: a double-blind randomised placebo control trial. J. Bodyw. Mov. 42, 527–534.
Figueiredo, R.I., Azambuja, A.M., Cureau, F.V., Sbruzzi, G., 2020. Inspiratory muscle training in COPD. Respir. Care 65, 1189–1201.
Fleurent-Grégoire, C., Burgess, N., Mcisaac, D.I., Chevalier, S., Fiore, J.R.J.F., Carli, F., Levett, D., Moore, J., Grocott, M.P., Copeland, R., 2024. Towards a common definition of surgical prehabilitation: a scoping review of randomised trials. British journal of anaesthesia.
Fuchs, T.I., Pfab, C., Kiselev, J., Schaller, S.J., Spies, C., Rombey, T., 2024. Barriers and facilitators to the implementation of prehabilitation for elderly frail patients prior to

elective surgery: a qualitative study with healthcare professionals. BMC Health Serv. Res. 24, 536.
Ge, X., Wang, W., Hou, L., Yang, K., Fa, X., 2018. Inspiratory muscle training is associated with decreased postoperative pulmonary complications: evidence from randomized trials. J. Thorac. Cardiovasc. Surg. 156, 1290–1300 e5.
Gosselink, R., DE Vos, J., van Den Heuvel, S., Segers, J., Decramer, M., Kwakkel, G., 2011. Impact of inspiratory muscle training in patients with COPD: what is the evidence? Eur. Respir. J. 37, 416–425.
Gu, A., Wei, C., Maybee, C.M., Sobrio, S.A., Abdel, M.P., Sculco, P.K., 2018. The impact of chronic obstructive pulmonary disease on postoperative outcomes in patients undergoing revision total knee arthroplasty. J. Arthroplast. 33, 2956–2960.
Guinan, E., Forde, C., O'Neill, L., Gannon, J., Doyle, S., Valkenet, K., Trappenburg, J., van Hillegersberg, R., Ravi, N., Hussey, J., 2019. Effect of preoperative inspiratory muscle training on physical functioning following esophagectomy. Dis. Esophagus 32, doy091.
Hajghanbari, B., Yamabayashi, C., Buna, T.R., Coelho, J.D., Freedman, K.D., Morton, T. A., Palmer, S.A., Toy, M.A., Walsh, C., Sheel, A.W., 2013. Effects of respiratory muscle training on performance in athletes: a systematic review with meta-analyses. J. Strength Condit Res. 27, 1643–1663.
Hennrikus, M., Hennrikus, W.P., Lehman, E., Skolka, M., Hennrikus, E., 2021. The obesity paradox and orthopedic surgery. Medicine 100, e26936.
Hill, K., Cecins, N.M., Eastwood, P.R., Jenkins, S.C., 2010. Inspiratory muscle training for patients with chronic obstructive pulmonary disease: a practical guide for clinicians. Arch. Phys. Med. Rehabil. 91, 1466–1470.
Hodges, P.W., Gandevia, S.C., 2000. Activation of the human diaphragm during a repetitive postural task. J. Physiol. 522, 165–175.
Hogg, J.C., Timens, W., 2009. The pathology of chronic obstructive pulmonary disease. Annu. Rev. Pathol. 4, 435–459.
Honeycutt, L., Huerne, K., Miller, A., Wennberg, E., Filion, K.B., Grad, R., Gershon, A.S., Ells, C., Gore, G., Benedetti, A., 2022. A systematic review of the effects of e-cigarette use on lung function. NPJ primary care respiratory medicine 32, 45.
Horan, F., 2006. Obesity and joint replacement. The Journal of Bone & Joint Surgery British 88, 1269–1271.
Illi, S.K., Held, U., Frank, I., Spengler, C.M., 2012. Effect of respiratory muscle training on exercise performance in healthy individuals: a systematic review and meta-analysis. Sports Med. 42, 707–724.
Janssens, J.-P., Pache, J.-C., Nicod, L., 1999. Physiological changes in respiratory function associated with ageing. Eur. Respir. J. 13, 197–205.
Karanfil, E.T., Møller, A.M., 2018. Preoperative inspiratory muscle training prevents pulmonary complications after cardiac surgery–a systematic review. Dan Med J 65, A5450.
Karcz, M., Papadakos, P.J., 2013. Respiratory complications in the postanesthesia care unit: a review of pathophysiological mechanisms. Can. J. Respir. Ther.: CJRT= Revue canadienne de la therapie respiratoire: RCTR 49, 21.
Katsura, M., Kuriyama, A., Takeshima, T., Fukuhara, S., Furukawa, T.A., 2015. Preoperative inspiratory muscle training for postoperative pulmonary complications in adults undergoing cardiac and major abdominal surgery. Cochrane Database Syst. Rev.
Kendall, F., Oliveira, J., Peleteiro, B., Pinho, P., Bastos, P.T., 2018. Inspiratory muscle training is effective to reduce postoperative pulmonary complications and length of hospital stay: a systematic review and meta-analysis. Disabil. Rehabil. 40, 864–882.
Kowalski, T., Granda, D., Klusiewicz, A., 2022. Practical application of respiratory muscle training in endurance sports. Strength Condit. J. 10, 1519.
Krause-Sorio, B., An, E., Aguila, A.P., Martinez, F., Aysola, R.S., Macey, P.M., 2021. Inspiratory muscle training for obstructive sleep apnea: protocol development and feasibility of home practice by sedentary adults. Front. Physiol. 12, 737493.
Kulkarni, S., Fletcher, E., Mcconnell, A., Poskitt, K., Whyman, M., 2010. Pre-operative inspiratory muscle training preserves postoperative inspiratory muscle strength following major abdominal surgery–a randomised pilot study. Ann. R. Coll. Surg. Engl. 92, 700–705.
Laciuga, H., Rosenbek, J.C., Davenport, P.W., Sapienza, C.M., 2014. Functional outcomes associated with expiratory muscle strength training: narrative review. J. Rehabil. Res. Dev. 51.
Luo, D., Fan, Z., Yin, W., 2024. Chronic post-surgical pain after total knee arthroplasty: a narrative review. Perioper. Med. 13, 108.
Matharu, G., Mouchti, S., Twigg, S., Delmestri, A., Murray, D., Judge, A., Pandit, H., 2019. The effect of smoking on outcomes following primary total HIP arthroplasty: a POPULATION-BASED cohort study of 60 812 patients. Orthopaedic proceedings. Bone Joint Lett. 13, 13.
Mcconnell, A., 2013. Respiratory Muscle Training: Theory and Practice. Elsevier Health Sciences.
Mcconnell, A., Romer, L., 2004. Respiratory muscle training in healthy humans: resolving the controversy. Int. J. Sports Med. 25, 284–293.
Mickleborough, T., Nichols, T., Lindley, M., Chatham, K., Ionescu, A., 2010. Inspiratory flow resistive loading improves respiratory muscle function and endurance capacity in recreational runners. Scand. J. Med. Sci. Sports 20, 458–468.
Olsen, U., Sellevold, V.B., Gay, C.L., Aamodt, A., Lerdal, A., Hagen, M., Dihle, A., Lindberg, M.F., 2024. Factors associated with pain and functional impairment five years after total knee arthroplasty: a prospective observational study. BMC Muscoskelet. Disord. 25, 22.
Organization, W.H., 2020. Smoking Greatly Increases Risk of Complications after Surgery. World Health Organization website. November, 9.
Paiva, D.N., Assmann, L.B., Bordin, D.F., Gass, R., Jost, R.T., Bernardo-Filho, M., França, R.A., Cardoso, D.M., 2015. Inspiratory muscle training with threshold or incentive spirometry: which is the most effective? Rev. Port. Pneumol. 21, 76–81.
Pandit, H., Mouchti, S., Matharu, G., Delmestri, A., Murray, D., Judge, A., 2018. The effect of smoking on postoperative complications and PATIENT-REPORTED outcomes following primary knee arthroplasty. Orthopaedic proceedings. Bone Joint Lett. 46, 46.
Papalia, G.F., Papalia, R., Diaz Balzani, L.A., Torre, G., Zampogna, B., Vasta, S., Fossati, C., Alifano, A.M., Denaro, V., 2020. The effects of physical exercise on balance and prevention of falls in older people: a systematic review and meta-analysis. J. Clin. Med. 9, 2595.
Pollock, A.S., Durward, B.R., Rowe, P.J., Paul, J.P., 2000. What is balance? Clin. Rehabil. 14, 402–406.
Porhomayon, J., el-Solh, A., Chhangani, S., Nader, N.D., 2011. The management of surgical patients with obstructive sleep apnea. Lung 189, 359–367.
Rodrigues, G.D., Mcconnell, A.K., 2024. The Misuse of Respiratory Resistive Loading during Aerobic Exercises: Revisiting Mechanisms of "Standalone" Inspiratory Muscle Training. American Physiological Society, Rockville, MD.
Romer, L.M., Mcconnell, A.K., 2003. Specificity and reversibility of inspiratory muscle training. Med. Sci. Sports Exerc. 35, 237–244.
Sapienza, C., Troche, M., Pitts, T., Davenport, P., 2011. Respiratory strength training: concept and intervention outcomes. Seminars in Speech and Language. © Thieme Medical Publishers, pp. 21–30.
Seidlitz, C., Kip, M., 2018. Introduction to the indications and procedures. White Paper on Joint Replacement: Status of Hip and Knee Arthroplasty Care in Germany, pp. 1–14.
Sheraz, S., Ferraro, F.V., Siddiqui, F.A., Tariq, H., Anthony Faghy, M., Malik, A.N., 2023. The effects of inspiratory muscle training on balance and functional mobility: a systematic review. PGM (Postgrad. Med.).
Sheraz, S., Malik, A.N., Ferraro, F.V., Siddiqi, F.A., 2024. Multifactorial inspiratory muscle training and its impact on respiratory and functional parameters of patients with diabetic polyneuropathy—a Randomized Controlled Trial. Physiother. Res. Int. 29, e2127.
Shin, K.-H., Kim, J.-U., Jang, I.-T., Han, S.-B., Kim, S.-B., 2023. Impact of Chronic Obstructive Pulmonary Disease on outcomes after total joint arthroplasty: a Meta-analysis and systematic review. Indian J. Orthop. 57, 211–226.
Shoemaker, M.J., Donker, S., Lapoe, A., 2009. Systematic review: inspiratory muscle training in patients with chronic obstructive pulmonary disease: the state of the evidence. Cardiopulm. Phys. Ther. J. 20, 5–15.
Silva DE Sousa, A., Pereira Da Rocha, A., Brandão Tavares, D.R., Frazão Okazaki, J.É., DE Andrade Santana, M.V., Fernandes Moça Trevisani, V., Pereira Nunes Pinto, A.C., 2024. Respiratory muscle training for obstructive sleep apnea: systematic review and meta-analysis. J. Sleep Res. 33, e13941.
Silva, I.S., Fregonezi, G.A., Dias, F.A., Ribeiro, C.T., Guerra, R.O., Ferreira, G.M., 2013. Inspiratory muscle training for asthma. Cochrane Database Syst. Rev.
Starko, G., Müller, D., Lipka, A., Feiereisen, P., Corbellini, C., Abreu, R.M.D., 2024. Effects of respiratory muscle training pre-and post-cardiac surgery in adults: a scoping review. J. Cardiovasc. Dev. Dis. 11, 351.
Stavrou, V.T., Tourlakopoulos, K.N., Daniil, Z., Gourgoulianis, K.I., 2021. Respiratory muscle strength: new technology for easy assessment. Cureus 13.
Terzikhan, N., Verhamme, K.M., Hofman, A., Stricker, B.H., Brusselle, G.G., Lahousse, L., 2016. Prevalence and incidence of COPD in smokers and non-smokers: the Rotterdam Study. Eur. J. Epidemiol. 31, 785–792.
Torres-Castro, R., Solis-Navarro, L., Puppo, H., Alcaraz-Serrano, V., Vasconcello-Castillo, L., Vilaró, J., Vera-Uribe, R., 2022. Respiratory muscle training in patients with obstructive sleep apnoea: a systematic review and meta-analysis. Clocks & sleep 4, 219–229.
Vorona, S., Sabatini, U., al-Maqbali, S., Bertoni, M., Dres, M., Bissett, B., van Haren, F., Martin, A.D., Urrea, C., Brace, D., 2018. Inspiratory muscle rehabilitation in critically ill adults. A systematic review and meta-analysis. Annals of the American Thoracic Society 15, 735–744.
Warner, D.O., Preston, P., Subramanyam, R., Kathuria, H., Hollingsworth, H., 2020. Smoking or Vaping: Perioperative Management. *UpToDate*. UpToDate Inc, Waltham, MA.
WORLDHEALTHORGANIZATION, 2024. Ageing and health. https://www.who.int/news-room/fact-sheets/detail/ageing-and-health.
Wylde, V., Beswick, A., Bruce, J., Blom, A., Howells, N., Gooberman-Hill, R., 2018. Chronic pain after total knee arthroplasty. EFORT Open Rev. 3, 461–470.
Yekta, A.H.A., Esfahani, M.P., Salehi, S., Hassabi, M., Khosravi, S., Kharabian, S., Sohrabi, M.R., Mafi, A.A., Rezaei, S., 2019. Assessment of the effects of inspiratory muscle training (IMT) and aerobic training on the quality of life of patients with chronic obstructive pulmonary disease. Tanaffos 18, 223.