EMJ EUROPEAN MEDICAL JOURNAL

RESPIRATORY

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Repositive Pressure Therapies Used in the Treatment of Postoperative Respiratory Failure – Evidence for Use and Future Directions

POSITIVE PRESSURE THERAPIES USED IN THE TREATMENT OF POSTOPERATIVE RESPIRATORY FAILURE – EVIDENCE FOR USE AND FUTURE DIRECTIONS

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Disclosure: AJG has received speaker fees, honoraria, and travel expenses from Armstrong Medical UK Ltd.
Support: The publication of this article was funded by Armstrong Medical UK Ltd. The views and opinions expressed are those of the authors and not necessarily of Armstrong Medical UK Ltd.
Received: 25.09.15 **Accepted:** 20.10.15
Citation: EMJ Respir. 2015;3[2]:107-113.

ABSTRACT

Postoperative respiratory failure (RF) is a common problem following all types of major surgery, and which has significant implications for morbidity, mortality, and cost to healthcare systems. Although postoperative RF is usually multifactorial in origin, the development of atelectasis perioperatively is a significant contributory factor. A number of different techniques and devices that apply positive pressure to patients' airways, in an attempt to prevent development of atelectasis and RF following surgery, have been studied in this patient group. Non-invasive ventilation (NIV) is considered the gold standard management for prevention and treatment of postoperative RF and is supported by the greatest body of evidence. However, the delivery of NIV requires provision of a critical care bed, has significant economic implications, and is associated with patient compliance issues. Other techniques, such as high-flow oxygen delivered by high-flow nasal cannulae (HFNC), show some promise and are supported by evidence for benefit in related areas, but currently lack supportive evidence in postoperative patients. Positive pressure physiotherapy techniques, such as positive expiratory pressure therapy, offer an inexpensive and accessible alternative to patients, but also currently lack supporting evidence of benefit with regard to clinical endpoints. Future research in the challenging area of postoperative RF should address the potential alternatives to NIV, including the precise role of HFNC, therapies that may be utilised outside of critical care areas, and combinations of existing therapies.

Keywords: Pulmonary atelectasis, postoperative complications, non-invasive ventilation, high-flow nasal cannulae (HFNC), positive expiratory pressure therapy.

BACKGROUND

Postoperative hypoxia is a well-recognised complication of major surgery that may have a detrimental impact on patient outcomes.[1] Postoperative hypoxia due to the intraoperative development of atelectasis may initially be mild, but it frequently progresses to become established respiratory failure (RF),[2,3] which has significant associated morbidity and mortality.[3] Whilst the impact of any intervention on overall mortality in elective surgical populations is often difficult to quantify due to a low baseline risk, the potential to reduce other adverse healthcare-related events has significant implications for improvement of patient outcomes and economic factors.[1]

Established RF is a common reason for invasive ventilation of surgical patients, with up to 20% of all ventilated intensive care unit (ICU) patients being ventilated due to postoperative RF.[4]

Postoperative RF may occur following a wide range of major surgical procedures,[5] including cardiac,[6] thoracic,[7] vascular,[8] and abdominal operations.[9] It is estimated that as many as 40% of patients will develop respiratory problems following abdominal surgery.[10] As such, the management of complications and RF following major surgery is an area of great interest and research focus.

The pathogenesis of postoperative RF is multifactorial in origin with the development and progression of atelectasis, which may begin intraoperatively and be compounded by a multitude of perioperative factors such as patient discomfort, immobility, and fluid shifts, recognised as being pivotal in the development of established postoperative RF.[11] Approaches to postoperative RF management should always include an appropriate analgaesia regime – often multimodal in delivery to allow patient mobilisation and engagement with therapy whilst ensuring maximal patient comfort – as well as specific interventions to prevent and reverse atelectasis.

A number of positive pressure techniques, which may attenuate the process of atelectasis progression and subsequent development of postoperative RF, have been studied in surgical populations. These include the use of non-invasive ventilation (NIV) and high-flow nasal cannulae (HFNC) to deliver humidified, high-flow oxygen to patients, as well as physiotherapy techniques such as the positive expiratory pressure (PEP) valve device.

This review aims to discuss the evidence supporting the use of these positive pressure interventions and discuss potential future avenues for research and practice in this commonly encountered area.

POSTOPERATIVE NON-INVASIVE VENTILATION

In recent years there has been considerable interest in the use of NIV, which encompasses both continuous positive airway pressure (CPAP) and non-invasive positive pressure ventilation (NPPV) support, to prevent and treat RF following major surgery.[12-14] It has been demonstrated that NIV use in selected patient groups may reduce the incidence of postoperative hypoxia, respiratory failure, rates of reintubation, incidence of pneumonia, ICU and hospital length of stay, and potentially mortality.[15-17]

While NIV usage remains a popular and very attractive option for high-risk surgical patients, there are a number of factors that may act to limit its use and potential benefits. As NIV must be delivered via a tight-fitting mask or helmet, problems with interface fit, leakage, and patient discomfort are frequently encountered.[18] Patient non-compliance with therapy, particularly due to poor mask fit, leaks, and patient intolerance, is a common problem that may reduce the benefits of treatment.[19] In addition, due to the high level of monitoring required during treatment and the level of nursing input that is required for patients receiving NIV, it is usually delivered to patients in a critical care environment.[20] Therefore, the question of treating with NIV can become a balance of the costs incurred through equipment, disposables, staffing, and critical care bed provision against the potential savings made by preventing complications and reducing length of stay.

HIGH-FLOW NASAL OXYGEN

High-flow nasal oxygen, which is humidified high-flow oxygen delivered via nasal cannulae, is an emerging therapy for critical care and surgical patients. Conventional methods of oxygen delivery to patients are limited by maximum flow delivery rates of 15 L/min to patients whose maximum inspiratory flow rates may be as high as 120 L/min. This can result in the fraction of inspired oxygen (FiO_2) delivered being inconsistent.[21] HFNC allow delivery of air–oxygen mixtures at inspiratory flow rates of up to 60 L/min, which reduces the amount of ambient air entrainment and allows a more reliable and predictable FiO_2 delivery to patients.[22]

Whilst some debate exists regarding the precise mechanism of action of HFNC, it has been demonstrated to be a safe and effective means of providing respiratory support to patients at risk of or suffering from respiratory failure. It is thought that HFNC therapy derives its beneficial clinical effects from a number of favourable physiological mechanisms, including pharyngeal dead-space 'washout', alveolar recruitment, and reduced airflow resistance, which all promote enhanced respiratory parameters and gas exchange.[23-25] There is also evidence to suggest that the higher flow rates delivered via HFNC generate a variable degree of positive end-expiratory pressure (PEEP), which is quoted as being between 3–7 cm $H_2 0$ depending on a number of different patient factors.[26,27] The mechanism of delivery also allows warming and humidification of inspired gases, which may improve function of the mucociliary system and better clearance of secretions.[28,29]

HFNC have been used with positive clinical effects in paediatric populations for some time.[30] While the evidence base for their use in adult patients is evolving, it is currently less compelling. However, there is emerging evidence that HFNC may be a useful alternative therapy to conventional oxygen therapy or NIV in a number of different clinical situations, where there is actual or pending respiratory failure.[31,32]

Patient comfort and tolerance of therapy with HFNC may be better than in several methods of conventional oxygen or NIV delivery,[33] and, as an intervention, it has the potential to be provided outside of Level 2 and 3 critical care facilities.[34] Therefore, HFNC may potentially provide a viable alternative to NIV use in surgical populations, offer cost savings, and provide patient benefits.

Physiotherapy Techniques

A number of different physiotherapy techniques are widely used in clinical practice to potentially reduce the incidence of respiratory complications in the postoperative period.[35] Physiotherapy techniques are widely utilised and form part of recommendations for the care of postoperative patients both inside and outside of critical care areas due to perceived patient benefits, ease of access, and availability.[36] They are generally well tolerated by patients and improvements in endpoints such as oxygen saturations, chest X-ray (CXR) appearances, and exercise tolerance are frequently observed. However, there is a relative lack of supporting evidence for the clinical benefit of physiotherapy when applied routinely in postoperative groups, or in those with established complications.[37]

Major surgery leads to loss of lung volume and patient immobility in the perioperative period, which in turn predisposes patients to the development of clinically significant atelectasis, secretion retention, chest infections, and possible RF. Postoperative physiotherapy aims to improve lung volume, aid secretion clearance, and improve mobility and levels of physical activity. A variety of different techniques are employed according to clinical need and patient ability, including early assisted mobilisation, exercise, thoracic expansion exercises, incentive spirometry, and airway clearance techniques, in order to attenuate this process and reduce the incidence of respiratory complications.[38]

Lung expansion and sputum clearance treatments are active wherever possible, with patient and therapist working together. However, passive techniques such as positioning and manual therapies such as percussion may be required to improve clearance of secretions[39] in less able or immobile patients. Breathing adjuncts such as PEP therapy, where patients generate an expiratory pressure of up to 20 cm H_2O by breathing against a mouthpiece valve device, may also be used postoperatively to increase functional residual capacity and mobilise secretions.[40] This is especially useful in those with dynamic airway collapse, such as smokers, or those with a history of chronic obstructive pulmonary disease (COPD). Figure 1 demonstrates the CXR changes seen before and after therapy with a PEP device following thoracic surgery.

Physiotherapy in the postoperative period is a multimodal specialty, and for the purposes of this review only positive pressure adjuncts will be further considered.

EVIDENCE FOR USE IN CURRENT PRACTICE

Non-Invasive Ventilation

Treatment with NIV is widely accepted to have beneficial effects on intubation rates and mortality in a wide range of patient groups with acute RF.[41-43] CPAP used prophylactically has been demonstrated to reduce rates of reintubation, pneumonia, and other pulmonary complications following abdominal,[16] vascular,[44] and cardiac surgery.[45] NPPV has been demonstrated to have mortality benefits when used in patients with RF following lung resection surgery.[17] Meta-analysis evidence suggests a mortality benefit associated with NIV usage in mixed postoperative populations.[15]

The decision regarding provision of NIV is often influenced by a number of different patient and organisational factors, including type and duration of surgery, patient comorbidities, and availability of Level 2 critical care beds. No definitive, unifying guidance for the postoperative use of NIV exists and it is often used variably according to clinician preference, or accepted local practice. Despite these issues, however, NIV is widely considered to be a vital respiratory support therapy for the effective management of established postoperative RF.[46]

High-Flow Nasal Cannulae

Humidified oxygen delivered by HFNC is a relatively new intervention in adult populations, and in recent years the evidence base for its use in a variety of clinical settings where additional respiratory support is required has grown. HFNC have a number of physiological benefits that confer a potential advantage over the use of conventional oxygen therapy. In a recent clinical trial, it was demonstrated that the use of HFNC provided improved oxygenation and 90-day survival in patients with acute hypoxic RF when compared with treatment with NIV.[32] This is a very important finding as the benefits of NIV in hypoxic RF have been questioned for some time, and the emergence of an alternative and complementary therapy in this area is welcomed. HFNC have also been used to beneficial effect in recently extubated critical care patients. When compared with standard oxygen therapy, it was demonstrated that HFNC reduced extubation failure and reintubation rates.[33] It also aided the prevention of severe desaturations and hypoxia during intubations in critical care units.[47]

Use of HFNC has been studied in postoperative populations with some encouraging results. In a recently published, non-inferiority study, Stéphan and colleagues[31] found that the use of continuous HFNC in patients with hypoxaemia following cardiac surgery is as effective as intermittent NPPV in preventing a need for reintubation. A large, European, multicentre, randomised controlled trial is currently recruiting patients to compare the use of HFNC and standard oxygen therapy in patients with mild hypoxaemia following abdominal surgery. It is hoped that the results of this study will further clarify the role of HFNC in hypoxic postoperative patients and help to guide contemporary practice.

The available evidence supporting the use of HFNC would seem to suggest that they are effective in treating hypoxic RF, which is often the predominant aetiology in postoperative populations. However, studies that specifically address the issue of postoperative RF are currently lacking and the efficacy of HFNC therapy compared with CPAP postoperatively has yet to be studied. Concerns also remain regarding the possibility that the use of HFNC may lead to delayed intubation in patients with worsening RF, as has been seen previously with NIV use.[48] This phenomenon may to lead to an increase in mortality in patients treated with HFNC.[49] While there is encouraging emerging evidence to support the use of HFNC in a variety of settings, further work is required to help define their precise role in the management of postoperative RF, as well as the duration and timing of their use.

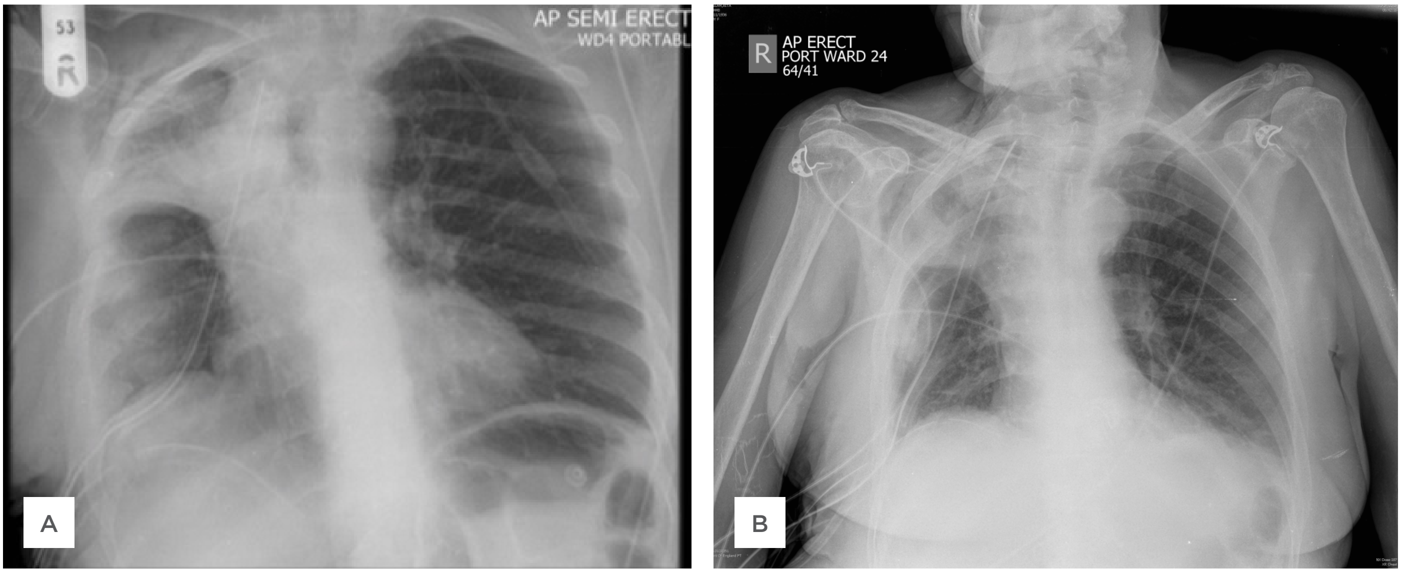

Figure 1: Chest X-ray changes before and after treatment with positive expiratory pressure (PEP) therapy in a patient with respiratory failure following right upper lobectomy surgery. A) Before PEP therapy. B) Increased lung volume and improvement of basal atelectasis after PEP therapy.

Positive Pressure Physiotherapy Techniques

Positive pressure physiotherapy techniques, such as PEP therapy, have been used to support and enhance patient respiratory function in a variety of clinical settings for many years. PEP is established in the physiotherapy treatment of those with bronchiectasis, cystic fibrosis, and COPD. There is little convincing or contemporary evidence available to support the use of PEP postoperatively and, unsurprisingly, its uptake has been more variable in this population.

Early work on breathing techniques in patients following cardiac surgery found that PEP therapy used routinely following coronary artery bypass grafting led to a non-significant tendency towards reduced pulmonary complications compared with standard therapy.[50] The same authors conducted a similar study in a mixed population of cardiac and thoracic patients, but included mask CPAP as a comparative therapy.[51] They found that PEP and mask CPAP have comparable effects on oxygenation, CXR appearances, and measured lung volumes, with participants reporting a greater preference for treatment with PEP therapy. Later work, which compared patients who received PEP therapy with patients who received no physiotherapy following cardiac surgery, found a reduction in atelectasis and improved lung function following PEP therapy.[40]

The evidence base in this area is generally lacking: studies often demonstrate poor methodological quality and conflicting results. Systematic reviews of trials in physiotherapy techniques applied routinely in cardiac,[52] abdominal, and thoracic surgical patients[53] have reported only a small number of trials. These studies often offer scant evidence for the positive benefits of such techniques, and conclude that the role of routine physiotherapy, including PEP, remains unproven. These reviews, however, use data compiled from studies of differing interventions and represent something of a heterogeneous population. Therefore, they draw general conclusions regarding the benefits of many therapy modalities in postoperative patients.

There is certainly no strong evidence to suggest that PEP therapy may not be beneficial when applied routinely. Its role may, however, be of more importance physiologically in those postoperative patients with increased sputum production, or to ameliorate sputum retention, especially in patients with dynamic airway collapse or atelectasis.

Further work studying the relative benefits of individual therapies used both prophylactically and therapeutically, such as PEP, is warranted in postoperative populations. Focus on specific interventions that may be effective against volume loss, sputum retention, and postoperative RF is urgently needed, especially amongst high-risk populations such as those undergoing major surgery and with a history of smoking or COPD.

POTENTIAL DIRECTIONS AND RESEARCH QUESTIONS FOR THE POSTOPERATIVE PERIOD

Theatre Recovery or Ward-Based Therapy

It is attractive, in theory, to consider using NIV for a short period in theatre recovery as a preventative measure. However, many of the studies that have utilised postoperative NIV to good clinical effect have used longer treatment periods – often 12 hours or more. It has been suggested from clinical studies that shorter periods of treatment in post-surgery recovery units do not result in lasting demonstrable clinical benefits to patients.[54] Issues relating to staff training, patient safety, and appropriate levels of monitoring also potentially limit the use of NIV outside of dedicated critical care areas.[55]

The potential to use HFNC outside of critical care areas remains an attractive option, and pilot studies in emergency department settings suggest this may be a feasible and potentially safe option.[34] However, evidence to support the use of HFNC on general wards is currently lacking and concerns exist about delayed treatment escalation to invasive ventilation in patients deteriorating on HFNC.[49] Robust trials are needed to address this issue and examine the safe duration of treatment outside of critical care areas before pursuing this option further in clinical practice.

Combination Therapy

The combination of therapies to produce a maximal clinical effect whilst reducing any additional burden upon critical care services is an attractive and intriguing future direction for research in postoperative populations. Delivery of oxygen via HFNC delivers only a low, and quite variable, level of PEEP to patients, and this level of PEEP is thought to be heavily dependent on patient inspiratory flow rates.[56] It is plausible that combining the known beneficial effects of HFNC therapy with PEP devices, which would add a higher and more reliable level of PEEP to patients, may result in additional benefits to patients and would potentially have the additional benefit of being available outside of critical care areas. Again, this is an area that currently lacks supporting evidence, but is a potential future avenue for research interest.

DISCUSSION AND CONCLUSIONS

Postoperative RF remains a significant challenge for healthcare providers. This is especially true when considered in the light of an ageing population, increasing demand for provision of services, and higher incidence of significant comorbidities in patients presenting for surgery. At a time when demand for critical care services in general is increasing, the requirement for emergency care provision may mean that elective surgical procedures face cancellation or delay due to a lack of critical care bed capacity. Therefore, any interventions that may reduce the burden of surgical patients on critical care services are of great importance to contemporary practice.

The use of NIV currently has the greatest body of supporting evidence and therefore remains the gold standard for both prophylaxis and treatment of postoperative RF. However, its use as an intervention in surgical patients is relatively resource-heavy and, due to issues of safety, monitoring, and training, it is largely confined to critical care areas. As a result, there exists a definite niche or 'gap in the market' for alternative therapies and approaches, especially those that can be provided in theatre recovery areas or general surgical wards, and which do not mandate occupancy of a critical care bed.

The delivery of humidified oxygen to patients via HFNC represents a very promising and exciting development in the management of postoperative patients. Further work is required to help define the precise role of HFNC in managing postoperative RF, and also to validate the optimum duration of treatment and safety of use outside of critical care areas. Early studies completed in similar and related areas suggest a potential benefit, especially in patients with hypoxaemia. The findings from studies in postoperative populations are eagerly awaited.

PEP therapy is theoretically attractive as it may help to restore lung volumes and clear secretions, especially in high-risk patient groups, and can be delivered at relatively low cost in general ward settings. The evidence base for PEP techniques in postoperative patients is, however, small and conflicting. There is a paucity of contemporary studies reported in the literature, with few trials supporting or refuting the use of this type of physiotherapy postoperatively, or demonstrating an influence on important clinical endpoints. Nevertheless, positive pressure physiotherapy techniques may still have a role to play in selected patient groups and the precise role of PEP in perioperative respiratory management needs to be clearly established.

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