Physiotherapy interventions to prevent postoperative pulmonary complications following lung resection. What is the evidence? What is the practice?

Julie C Reeve
Division of Rehabilitation and Occupation Studies, Faculty of Health and Environmental Studies, AUT University, Auckland, New Zealand

ABSTRACT
Following major surgery pulmonary complications are an important cause of postoperative morbidity, contributing to significant increases in length of hospital stay, overall hospital costs and patient discomfort. Physiotherapy aims to prevent and treat pulmonary complications and a number of high quality studies have investigated the efficacy of various physiotherapy interventions in major surgical populations, particularly following cardiac and upper abdominal surgery. To date, however, there have been few studies investigating the effectiveness of physiotherapy interventions in patients undergoing lung surgery via thoracotomy. This paper reviews the limited evidence investigating physiotherapy interventions aimed at preventing postoperative pulmonary complications following lung resection, considers current physiotherapy management for this patient group and makes recommendations for future practice and research. **Reeve J (2008): Physiotherapy interventions to prevent postoperative pulmonary complications following lung resection. What is the evidence? What is the practice? New Zealand Journal of Physiotherapy 36(3): 118-130**
Key words: Postoperative pulmonary complications, lung resection, physiotherapy.

INTRODUCTION

Postoperative pulmonary complications (PPCs) following surgery were first described by Pasteur in 1908 and remain an important cause of postoperative morbidity, contributing to significant increases in patient discomfort, length of hospital stay (LOS), use of resources and overall hospital costs (Brooks-Brunn 1995). PPCs have been defined as a pulmonary abnormality that produces identifiable disease or dysfunction that is clinically significant and adversely affects the clinical course (O'Donohue 1992). Over the past two decades widespread developments in postoperative pain management, together with advances in surgical and anaesthetic techniques, have led to reductions in complications following major surgery and faster discharge from hospital. Nonetheless PPCs remain an important cause of postoperative morbidity and mortality (Lawrence et al 1995, Smetana et al 2006).

Strategies to reduce the incidence of PPCs include screening for and modification of risk factors, optimising preoperative status, patient education, intraoperative management and postoperative pulmonary care. Physiotherapy has been advocated as an important component in the prevention and amelioration of PPCs following surgery and has been regularly utilised in both pre and postoperative care since the 1960s despite evidence for its effectiveness being limited.

Recently, the increasing emphasis on cost effective provision of healthcare and the focus on evidence-based practice has challenged physiotherapists to re-evaluate and justify their traditional practices. In the cardiac and upper abdominal surgical populations, a number of high quality studies and systematic reviews have investigated the efficacy of various physiotherapy interventions, enabling physiotherapists to reappraise their traditional treatment programmes and institute changes in practice (de Charmoy and Eales 1997, Jenkins et al 1990, Mackay et al 2005, Olsen et al 1997, Pasquina et al 2006, Pasquina et al 2003, Stiller et al 1994). These changes include an increasing focus on early mobilisation protocols and a reducing emphasis on prophylactic respiratory care for prevention of PPC.

To date however, there have been few studies investigating the effectiveness of physiotherapy interventions in patients undergoing lung resection and thus there is limited evidence on which to base treatment recommendations. This paper reviews the pathogenesis of PPCs together with the differing criteria used for their diagnosis including how this impacts upon their reported incidence following thoracic surgery. The currently available evidence investigating physiotherapy interventions following lung resection is also reviewed and recommendations are made for clinical practice and further research.

The pathogenesis of postoperative pulmonary complications

Following major surgery of the thorax or upper abdomen there is overwhelming evidence of changes in lung function and associated clinical manifestations (Brooks-Brunn 1995, Craig 1981). The changes in lung function occurring may be both procedure or patient-related and occur intra and/or postoperatively (Brooks-Brunn 1995). Many of these changes are expected following surgery, and are transient and self-limiting (Ford et al 1983, O'Donohue 1985). These changes include a characteristic reduction in lung volumes which is primarily restrictive in nature, a reduction in functional residual capacity predisposing to atelectasis, a slowing of mucociliary clearance, and abnormalities in gaseous exchange (Bourne and Jenkins 1992, Braun et al 1978, Marini 1984, Taggart et al 1993, Tulla et al 1995). Loss of the sigh mechanism, impaired surfactant production and diaphragmatic dysfunction may also occur (Dureuil et al 1987, Ford et al 1983). Furthermore, the potential impact of factors unique to lung surgery such as removal of lung tissue, lung deflation, single lung ventilation and direct handling (of both the lung and diaphragm) during surgery is not fully determined. Pulmonary complications following lung resection may also be associated with the presence of chest drains, integrity of lung tissue remaining following resection and limitations imposed by enforced immobility. Moreover, the surgery may predispose the patient to additional complications unique to thoracic surgery including persistent air leaks, pulmonary insufficiency from lung tissue resection and bronchopleural fistula. Postoperative atelectasis may be further accelerated by high concentrations of inspired oxygen given to prevent or manage associated arterial hypoxaemia (Burger and Macklem 1968, Marini 1984).

All these factors predispose to further reductions in lung volumes, small airway closure, development of gradual and progressive atelectasis and ventilation/perfusion mismatch which may render the patient susceptible to the development of pulmonary infection, pneumonia, hypoxaemia and respiratory failure (Bourne and Jenkins 1992). Patients following thoracic surgery have been demonstrated to have up to a 55% decrease in vital capacity following lobectomy and a 34% decrease in functional residual capacity, which is comparable to reductions in lung volumes in other types of major surgery (Bastin et al 1997, Denehy et al 2001, Gosselink et al 2000, Jenkins et al 1989).

The incidence and diagnosis of PPCs

The spectrum of PPCs after major surgery includes those considered amenable to physiotherapy interventions namely: atelectasis, sputum retention, respiratory infection (including bronchitis and pneumonia), respiratory failure and exacerbation of underlying chronic lung disease; and those which are not amenable to physiotherapy, such as pleural effusion, pulmonary embolus, pneumothorax and pulmonary oedema. However, differentiation between the types of PPCs in the thoracic surgical literature is not always explicit and therefore analysis of the effect of physiotherapy (or other) interventions on PPCs is not always easy to interpret. For example, three studies, where all patients received clearly specified prophylactic physiotherapy following thoracic surgery, found widely differing incidences of PPCs ; however, each used a different method of diagnosing PPCs (Bonde et al 2002, Gosselink et al 2000, Issa et al 1991). Gosselink et al (2000), reported a "PPC" incidence of only 8% in patients having lung resection, Issa et al (1991) found a 36% incidence of "postoperative pneumonia" and Bonde et al (2002) reported rates of postoperative "sputum retention" of 30%. The diagnostic methods used in these studies and others are shown in Table 1.

Many studies report the occurrence of PPCs which include those not usually considered amenable to physiotherapy. Stephan et al (2000) conducted a retrospective review of 266 patients following lung resection and found 25% of patients experienced PPCs, such as prolonged air leaks, pneumothorax and adult respiratory distress syndrome. In addition it would appear that the amount of lung tissue resected may have little influence on the incidence of PPCs. Algar et al (2003) found the overall rate of PPC to be 14% in patients undergoing pneumonectomy, where Jones et al (2003) reviewed patients following segmentectomy and found similar rates of atelectasis (16%) and pneumonia (14%) as those studies examining resection of larger portions of lung tissue (Jones et al 2003).

The wide variability in the reported incidence of PPCs following thoracic surgery demonstrates the lack of consensus regarding what exactly constitutes a clinically significant PPC. The delineation in the literature of what constitutes a pulmonary *abnormality* rather than a pulmonary *complication* is often unclear with little agreement as to what differentiates a clinically significant PPC from a self-limiting, transient dysfunction (O'Donohue 1992).

To date no validated tool exists to define PPCs and thus the criteria used for diagnosis differs between studies (see Table 1). In addition, there is variability in both the measurement of individual criteria that contribute to PPC diagnosis (such as differing measures of oxygenation) plus variability in the way criteria are combined to create a diagnosis (Wynne 2004). Diagnosis of a PPC commonly relies on a number of different criteria which collectively form the diagnostic tool. Criteria may include radiological, bacteriological, clinical signs, patient symptoms or combinations of these (Pasquina et al 2006). Criteria often include measures of oxygenation (such as PaO2 or SpO2), fever, white cell count, and presence of pulmonary infection (e.g. abnormal sputum production and positive sputum microbiology). Additional diagnostic findings such as changes in chest radiograph or changes in auscultation findings are also frequently used. Despite the marked variability in the method of diagnosing PPCs, the incidence of PPCs is often used as an outcome measure to assess the

Table 1. PPC definitions in studies investigating physiotherapy interventions following pulmonary resection.

Authors	PPC definition
Bonde et al., 2002	Sputum retention diagnosed by: "inability to cough significant bronchial secretions into oropharynx" characterised by: ▪ Respiratory distress with rapid, shallow bubbly respirations ▪ Loose large airways rales on auscultation verified by physiotherapist and physician Chest infection diagnosed by: ▪ WCC > 11×10^9 ▪ Consolidation or infiltrate on CXR (against a defined score) ▪ Pyrexia > 38.5^0 ▪ Purulent sputum
Gosselink et al., 2000	PPC diagnosed when 3 criteria fulfilled: ▪ Presence of abnormal CXR (≥ 3 against a defined score) ▪ Elevated temperature > 38^0 with no focus outside lungs ▪ Increased infectious variables (WCC > 12×10^3) or positive signs on sputum microbiology
Ingwerson et al., 1993	PPC assessed by: ▪ FVC ▪ PaO_2 ▪ CXR
Issa et al., 1991	PPC diagnosed when 3 criteria fulfilled: ▪ Fever exceeding 38.5^0 and leucocytosis ▪ Presence of new infiltrate on CXR ▪ Increase in sputum production with large number of granulocytes & single bacterial species on Gram stain.

Sekine et al., 2005	PPC diagnosed by:
	▪ Protracted supplemental O_2 (> 7 days) with O_2 ≤93% at rest or ≥ 90% on exercise
	▪ Bacterial pneumonia confirmed by
	    o CXR infiltrates
	    o Fever exceeding 37.5^0
	    o WCC > 10×10^3
	▪ Interstitial pneumonia confirmed by:
	    o Increased dyspnoea on exercise
	    o Deteriorating ABG's
	    o Diffuse interstitial abnormalities

Varela et al., 2006	PPC diagnosed by either: ▪ Nosocomial pneumonia (according to previously published criteria *) or ▪ Atelectasis confirmed by CXR
Vilaplana et al., 1990 ¥	Alterations to: ▪ CXR ▪ Auscultation ▪ Spirometry ▪ D (A – a) O_2

Key :*(American Thoracic Society 1996), ¥ In Spanish, abstract only in English, ABG – Arterial blood gas, CXR – chest radiograph, D(A-a) O_2 – Alveolar arterial oxygen difference, FVC – Forced vital capacity, PaO_2 – partial pressure of oxygen in arterial blood, PPC - postoperative pulmonary complication, WCC – white cell count.

effectiveness of different postoperative interventions following thoracic surgery.

The economic impact of PPCs following thoracotomy

PPCs are known to significantly increase intensive care bed days, hospital length of stay and overall health care costs (Gardner and Palasti 1990, Taylor et al 1990, Varela et al 2005, Zehr et al 1998). Stephan et al (2000) reported a significant difference in median LOS on the surgical wards of 10 days (IQR 8.7-13) for patients without PPC, 11 days (IQR 9-17) for those with a PPC and 14 days (IQR 8.5-29) for those requiring admission into ITU with a PPC. Our recent New Zealand audit found the median LOS of seven days for patients making an uncomplicated recovery following thoracic surgery compared to 10 days for those who developed a PPC (Reeve et al 2007b).

Varela et al (2006), compared the LOS and cost effectiveness of a historical control group (n=520), where ward nurses ambulated and instituted incentive spirometry, with a group receiving prophylactic physiotherapy (n=119). Significant differences in LOS between the physiotherapy group (median 5.73 days, range 3–22) and the control group (median 8.33 days, range 3–40) were found. Authors reported a total of 151.75 hospital days following lobectomy to be "saved" by physiotherapy and a total saving of €48,447.81 (approximately €407.12 per treated patient) attributed directly to the physiotherapy programme. Despite the study being neither blinded nor randomised the authors suggest their study was the first to determine the efficacy of physiotherapy interventions in this patient group; however the physiotherapy group had an increased number of patients undergoing video assisted thoracoscopic surgery (VATS) which may have confounded the results.

Hospital costs for lung resection were also reported by Zehr et al (1998) where the institution of a standardised clinical care pathway for major thoracic surgery resulted in a significantly reduced hospital costs and length of stay. Physical therapy charges accounted for 35% of these reductions. However, whilst authors have considered cost savings with physiotherapy interventions no author has, to date, balanced this against the cost of providing the physiotherapy. Given these potential costs, demonstrating the efficacy of physiotherapy interventions and their associated costs would clearly seem appropriate.

Physiotherapy interventions following pulmonary surgery

With the plethora of physiotherapy research in other major surgical populations it is surprising that the efficacy of physiotherapy interventions has remained relatively under-studied in patients undergoing lung resection. Identified as being at equally high or even higher risk of developing PPCs than patients undergoing other types of major surgery, physiotherapy interventions with these patients have been strongly advocated despite little supporting evidence (Kempainen and Benditt 2001, Reilly 1995). To date there have been no randomised trials investigating the efficacy of physiotherapy using a no treatment group and there are only limited data comparing different physiotherapy interventions following lung resection. Given that the usual natural history of PPCs is one of spontaneous improvement as lung volumes improve (O'Donohue 1992), and the steadily accumulating body of evidence that prophylactic postoperative physiotherapy beyond early mobilisation may be unnecessary in some patient groups, randomised controlled trials in this area are essential to determine the efficacy of physiotherapy interventions.

i. Preoperative physiotherapy

Preoperative education

Preoperative education has long been considered a routine and important aspect of care (Brooks-Brunn 1995). The importance of preoperative education on postoperative recovery and pulmonary function is acknowledged in both nursing and medical literature (Grady et al 1988, Hathaway 1986, Hodgkinson et al 2000) however, little data are available providing objective benefits of preoperative physiotherapy interventions. Only one pilot study (available in abstract form only) has evaluated the effect of preoperative physiotherapy education in patients undergoing pulmonary resection (O'Callaghan 2002). This small study (n = 19) compared a control group (receiving nursing assessment and instruction) to a group which received nursing and standardised preoperative physiotherapy assessment. It was unclear what assessment comprised and no criteria for definition of PPC were included. O'Callaghan found no significant differences between groups in incidence of postoperative complications, postoperative LOS patient satisfaction and self-efficacy scores. This study considered an area of physiotherapy practice which has significant resource implications and whose efficacy remains unclear. Despite this limited evidence, our recently completed survey (Reeve et al 2007a), investigating the practice of physiotherapists working in thoracic surgical units in Australia and New Zealand, established that 76% of respondents reported providing preoperative physiotherapy education and/or treatment sessions for some or all patients.

Preoperative pulmonary rehabilitation

Preoperative pulmonary rehabilitation has been demonstrated to significantly improve exercise capacity, dyspnoea and health related quality of life for patients awaiting lung volume reduction surgery and lung transplantation (Bartels et al 2006, Ries et al 2005, Takaoka 2005). Our survey (Reeve et al 2007a) reported that whilst few physiotherapy centres (24%) carried out preoperative pulmonary rehabilitation, those that did used this to improve postoperative outcome for patients undergoing lung transplantation and lung volume reduction surgery rather than for those undergoing lung resection for lung carcinoma. However, recently the value of pulmonary rehabilitation prior to lung resection has come under closer scrutiny. The short period between diagnosis and surgery has often been regarded as an inadequate period of time to sufficiently impact upon exercise capacity and thus be unlikely to reduce pre/post operative risk. Nonetheless, four recent small studies have considered the value of preoperative pulmonary rehabilitation in this population and found changes worthy of further investigation (see Table 2).

Jones et al (2007) conducted a prospective observational feasibility study with 20 patients undergoing lung resection for lung cancer to examine the effects of preoperative pulmonary rehabilitation (Jones et al 2007). Significant improvements were shown in VO_{2peak} and 6-minute walk distance (6MWD) (see table 2) between baseline and surgery. However, the mean time from diagnosis to surgery was 67 +/- 27 days, considerably greater than that often seen where many patients may have as little as one or two weeks from diagnosis to surgery. Thirty five percent of the patients had postoperative complications including two postoperative deaths. At postsurgical follow-up (mean 51 days, +/- 27 days) VO_{2peak} and 6MWD returned to baseline (pre pulmonary rehabilitation levels) rather than decreasing below baseline despite lung resection. Other studies have shown reductions of between 12–20% in VO_{2peak} following lung resection without

Table 2. Studies investigating preoperative exercise rehabilitation in thoracic surgery.

Authors	Study design	Patients	Outcome measures	Main results
Jones et al (2007)	Prospective observational study All subjects underwent preop PR programme: ▪ 5 x weekly preop ▪ Cycle ergometry training to 60 – 65% VO_{2peak} Measured at : ▪ Baseline ▪ Presurgery ▪ Postsurgery Intention to treat analysis Last observation carried forward for those lost to follow up	25 preop patients with suspected NSCLC. entered into exs programme 20 proceeded to surgery 7 lost to follow up	VO_{2peak} mL/kg^{-1}/min^{-1} 6MWD PFT ▪ FEV1 ▪ FVC ▪ TLC ▪ RV Exs adherence	Baseline – presurgery (n = 20) ▪ VO_{2peak} (mean increase) • 2.4 mL/kg^{-1}/min^{-1} (95% CI 1.0 to 3.8) ▪ 6MWD (mean increase) • 40 metres (95%CI 16 to 64) ▪ PFTs • No changes ▪ Exs adherence • 72% • Sessions 33 (SD 12) *No significant difference in PFTs* *Significant difference in 6MWD and VO_{2peak}* Baseline – post surgery (n = 13) ▪ VO_{2peak} • 0.1 mL/kg^{-1}/min^{-1} (95% CI 2.0 to 2.1) ▪ 6MWD • 0 metres (95% CI -59 to 60) ▪ PFTs (litres) • FEV1 -0.4 (95% CI -0.2 to -0.6) • FVC -0.5 (95% CI -0.1 to -0.8) • TLC – 0.6 (95% CI -0.3 to -1.4) *No significant difference in 6MWD and $VO_{2peak,}$* *Significant reduction in all PFTs except RV*
Bobbio et al., (2008)	Prospective observational study All subjects underwent outpatient preop PR programme: ▪ 1.5 hours per day, 5 days per week, 4 weeks ▪ Bronchodilators, DBE & coughing, IS, cycle ergometry, muscle stretching, free weights. Measured at: ▪ Pre PR ▪ Post PR	12 COPD patients with NSCLC. undergoing lung resection VO_{2peak} of > 15 mL/kg^{-1}/min^{-1}	C-PET (including VO_{2peak}) PFTs LOS	VO_{2peak} (mean increase) • 2.8 mL/kg^{-1}/min^{-1} (SD 1.9) PFTs • No changes LOS • Median 17.5 (+/-14.8) days *Significant difference in all C-PET measures including $VO_{2peak,}$* *No significant difference in PFT's*

Cesario et al., (2007)	Prospective observational pilot study All subjects underwent inpatient preop PR programme: ▪ 3 hours per day, 5 days per week, 4 weeks ▪ Clearly described incremental cycle ergometry, breathing retraining, PLB, FES, education sessions Measured at : ▪ Pre PR ▪ Post PR	8 patients denied lung surgery on basis of poor PFTs	PFTs 6MWD PaO_2	FVC (L) ▪ Mean +0.44, SEM 0.12 FEV1 (L) ▪ Mean +0.12 SEM 0.06 6MWD (m) ▪ Mean +79.0 SEM 30.4 PaO_2 (mmHg) ▪ Mean +7.2 SEM 3.8 *Significant difference in FVC and 6 MWD* *No significant difference in FEV1*
Sekine et al., (2005)	Cross sectional study with historical controls. Preop exs programme: ▪ Treatment group daily for 2 weeks. DBE & coughing, IS, 30 min exs, walking >5,000 steps ▪ Control group IS delivered daily for 2 weeks by nurses. CPT if necessary by nurses. Post op programme: ▪ Treatment group ambulation, bronchodilation and "chest squeezing" ▪ Control group – not clarified	82 COPD (FEV1/FVC≤70%) patients undergoing lung resection ▪ 22 Treatment group ▪ 60 Control group	PPC LOS PFT PaO_2	LOS (mean days) ▪ Control 29.0 SD 9.0 ▪ Treatment 21.0 SD 6.8, *Significant difference in LOS* PPC *No significant difference in pneumonia, prolonged O_2 supplement, extended ventilation, tracheotomy rate* PFT *No significance difference in FEV1, FVC, FEV1/FVC* $Pa0_2$ *No significance difference in PaO_2*

KEY: C-PET – cardiopulmonary exercise test, CPT – chest physiotherapy, DBE – deep breathing exercises, exs – exercise, FEV1 forced expiratory volume in 1 second, FES – functional electrical stimulation, FVC – forced vital capacity, IS – incentive spirometry, LOS – length of stay, NSCLC – non small cell lung carcinoma, PaO_2 –partial pressure of oxygen in arterial blood, PFTs – pulmonary function tests, PLB – pursed lip breathing, PPC – postoperative pulmonary complication, PR – pulmonary rehabilitation, Pre op – preoperative, RV – residual volume, VO_{2peak} - ,peak oxygen consumption, 6MWD – 6 minute walk distance,

Table 3. Studies investigating physiotherapy respiratory interventions following thoracic surgery.

Authors	Study design	Patients	Outcome measures	Results - PPC Incidence	Main Results - Other
Bonde et al., 2002	Partially blinded RCT. Subjects randomised to: ▪ Control group - standard care including postop CPT ▪ MT group - standard care including postop CPT plus MT	102 high risk subjects following lung resection using strict inclusion criteria	Sputum retention Chest infection Physiotherapy visits SRRLTI SRD	Sputum retention 32% (n = 16) ▪ Control 28.8% (n =15) ▪ MT 2.0% (n = 1) Chest infection 67.0% (n = 34) ▪ Control 38.5% (n = 20) ▪ MT 28.0% (n = 14) *Significant difference between groups in incidence of postop sputum retention (p< 0.005)* *No significant difference between groups in incidence of chest infection.*	Physio visits/day ▪ Control 1.88 SD 0.93 ▪ MT 1.73 SD 0.72 SRRLTI ▪ Control 13.5% (n = 7) ▪ MT 2% (n = 1) SRD ▪ Control 5.8% (n = 3) ▪ MT 0% (n = 0) *No significant difference between groups in physiotherapy visits or SRD* *Borderline significance in SRRLTI (p=0.006)*
Chatham et al, 1993	Cross over design. On each of four postop days subjects underwent in randomised order: ▪ PT only (P) ▪ Flutter only (F) ▪ PT & flutter (PF) ▪ PT & Shamflutter (PSF)	24 patients undergoing thoracotomy: ▪ 20 lung resection ▪ 3 pleural surgery ▪ 1 gastric surgery	VC 24 hour sputum collection	Not measured	VC (L) ▪ P 1.51 ▪ F 1.39 ▪ PF 1.52 ▪ PSF 1.49 Sp Vol (mean mls) ▪ P 14.0 ▪ F 10.3 ▪ PF 14.4 ▪ SFP 15.4 *No significant difference between any of 4 treatment options*
Gosselink et al ., 2000	Partially blinded RCT. Subjects randomised to: ▪ Control group - postop CPTonly ▪ Treatment group- postop CPT with IS	67 thoracic surgery patients: ▪ 40 lung resection ▪ 27 oesophageal resection	PPC LOS FEV_1 recovery	PPC rate 12.0% (n = 8) ▪ Control 12.5% (4/35) ▪ Treatment 11.5% (4/32) PPC rate by surgery type ▪ Lung 8.0% (n = 3) ▪ Oesoph 19.0% (n =5) *No significant difference between groups*	LOS (days) ▪ Control 15 SD 7 ▪ Treatment 14 SD 8 FEV_1 recovery ▪ Control 88% SD 44% ▪ Treatment 73% SD 17% *No significant difference between groups*
Ingwerson et al., 1993	Partially blinded RCT Subjects randomised to CPT with one of the following: ▪ CPAP ▪ PEP ▪ IR-PEP	160 patients: ▪ 60 cardiac surgery ▪ 59 pulmonary resection ▪ 41 exploratory thoracotomy	FVC PaO_2 CXR Patient preference	FVC (Day 4 postop) ▪ Mean decrease 52.6% PaO_2 (Day 4 postop) ▪ Mean value 86.1% of preop CXR ▪ No diff in incidence of atelectasis *No significant difference between groups*	PEP mask favoured by patients

Issa et al., 1991	Unblinded RCT. Subjects randomised to: ▪ Treatment - postop CPT with MT ▪ Control - postop CPT only	30 patients following lung resection	PPC CPT requirement	PPC rate 36% (n = 11) ▪ Treatment 13% (n = 2) ▪ Control 60% (n = 9) *Significant difference between groups (p < 0.03)*	CPT No of sessions (Mean): ▪ Treatment 7 ▪ Control 8 ▪ Range 6 – 11 Total time (Mean) ▪ Treatment 92 mins ▪ Control 112 mins ▪ Range 55 – 235 mins *No significant difference between groups*
Varela et al., 2006	Cross sectional study with historical controls	639 subjects undergoing lung resection between 1994 – 2004 (open and thoracoscopic): ▪ 520 control group ▪ 119 physiotherapy group	Pneumonia Atelectasis LOS ppoFEV$_1$	Pneumonia 14.2% (n = 54) ▪ Control 9.2% (n = 48) ▪ Physio 5.0% (n = 6) Atelectasis 9.4% (n = 42) ▪ Control 7.7% (n = 40) ▪ Physio 1.7% (n = 2) *Significant decrease in atelectasis rates between groups (O.R. 0.20; 95% CI: 0.05 – 0.86)* *No significant difference in pneumonia rate between groups (O.R. 0.52; 95% CI: 0.22-1.25)*	LOS ▪ Control 8.33 (3 - 40) days ▪ Physio 5.73 (2 - 22) days ppoFEV$_1$ ▪ Control 69.14% (SD 16.97) ▪ Physio 68.8% (SD 15.72) *Significant difference in LOS between groups (p = <0.001)* *No significant diff in ppoFEV$_1$ between groups*
Vilaplana et al., 1990 ¥	RCT (blinding unclear) Subjects randomised to: ▪ Treatment – IS with CPT ▪ Control – CPT only	37 subjects undergoing thoracic surgery: ▪ 21 lung resection ▪ 16 oesophageal resection	PPC LOS	Radiological alterations ▪ Treatment 38.8% (n=7) ▪ Control 31.5% (n=6) Auscultation alterations ▪ Treatment 55.5% (n=10) ▪ Control 63.0% (n=12) *No significant differences between groups*	LOS (days) ▪ Treatment 23.8 (SD 11) ▪ Control 30.5 (SD 16) *No significant differences between groups*

*(American Thoracic Society 1996) ¥ In Spanish, abstract only in English

Key : CI – confidence interval, CPAP – continuous positive airway pressure, CPT – chest physiotherapy, CXR – chest radiograph, D(A-a) O_2 – Alveolar arterial oxygen difference, FVC – forced vital capacity, IR-PEP – inspiratory resistance positive expiratory pressure, IS – Incentive spirometry, LOS – length of stay, mls – millilitres, MT – minitracheostomy, OR odds ratio, PEP – positive expiratory pressure, ppoFEV$_1$ -postoperative FEV$_1$, PPC – postoperative pulmonary complication, PT – physiotherapy, RCT – randomised controlled trial, SD – standard deviation, SRD – Sputum related deaths, SRRLTI- Sputum retention related life threatening incidents, VC – vital capacity, WCC – white cell count, PPCs or improve gas exchange postoperatively (Vilaplana et al 1990).

Vilaplana's findings were further supported by Gosselink et al (2000) where patients undergoing lung or oesophageal surgery were randomised into groups receiving physiotherapy alone or, physiotherapy plus incentive spirometry. Physiotherapy interventions were standardised although compliance with the hourly regimens was not measured. Incidence of PPCs was low (8% following lung resection) and there was no significant difference between treatment and control groups. The study also found a mean reduction in vital capacity and forced expiratory volume in one second of 55% in both groups with no significant differences in the restoration of pulmonary function. Given the low incidence of PPCs the study was not powered sufficiently to detect a significant difference in PPC between groups.

These studies suggest that while incentive spirometry can provide an *assessment* of pulmonary function following lung resection it has no role for routine use in the *restoration* of pulmonary function and prevention of pulmonary complications. This mirrors findings in other surgical groups (Freitas et al 2008, Overend et al 2001).

Minitracheostomy

Minitracheostomy is a percutaneously inserted, small bore tracheal cannula providing continuous access for airway suction. Two clinical trials have evaluated the prophylactic use of minitracheostomy with physiotherapy following lung resection in the prevention of sputum retention. Issa et al (1991) randomly allocated patients into two groups, a treatment group (n=15) who received minitracheostomy postoperatively and a control group (n=15). All patients received preoperative physiotherapy, three times daily postoperative physiotherapy and hourly incentive spirometry. In addition the treatment group received hourly airway suction via the minitracheostomy. Thirty six percent of patients developed pneumonia, with a significantly higher rate ($p<0.03$) in the control group, despite the regular physiotherapy highlighted above. In addition, the physiotherapy techniques used in the study included manual techniques, postural drainage and intermittent positive pressure breathing. These treatment techniques no longer reflect current practice for this patient group where the most common interventions are early ambulation, deep breathing exercises and coughing (Reeve et al 2007a) so results should be interpreted with caution. A similar study investigated whether prophylactic minitracheostomy could prevent sputum retention in a group of 102 high risk patients undergoing lung resection (Bonde et al 2002). Patients were randomised into a control group (n=52) who received at least twice daily physiotherapy for five days or a minitracheostomy group (n=50) that received physiotherapy as per the control group with at least twice daily minitracheostomy aspiration for five days. The primary end point was sputum retention diagnosed by the attending physiotherapist (unblinded) with secondary end points including chest infection and sputum related life threatening events. Whilst the incidence of sputum retention was significantly greater in the control group ($p<0.005$), there were no significant differences in the diagnosis of chest infection between groups potentially indicating that control group patients had increased difficulty in effectively clearing secretions. Once again, overall incidence of PPCs was above that reported in other studies and this is may be due to the higher risk status of the sample studied.

The results from both of these studies indicate that minitracheostomy may be more effective than physiotherapy alone in the prevention of sputum retention in high risk patient groups, yet our survey of Australian and NZ thoracic surgical units found that 74% of respondents reported never using minitracheostomy in their units and the remaining respondents (26%) reported only rarely using them (Reeve et al 2007a). Further research investigating the role of minitracheostomy and physiotherapy in preventing respiratory complications is warranted.

Other adjuncts to physiotherapy

In an early study investigating the efficacy of the flutter device following thoracotomy, 20 patients received, on the first four postoperative days in random order: physiotherapy alone, flutter alone, flutter with physiotherapy and sham flutter with physiotherapy (Chatham et al 1993). Primary outcome measures were vital capacity and 24 hour sputum volume. Authors paid minimal attention to both maturation effects and to determining whether sputum production/retention was a specific problem in this patient group. The authors acknowledged difficulties associated with sputum volume as an outcome measure (such as reliability) and, although the study found no significant treatment differences, the authors highlighted that the study had insufficient power to detect these.

Ingwerson et al. (1993), in a varied patient group which included thoracic surgical patients, investigated the use of three different positive pressure mask therapies on the resolution of atelectasis and incidence of PPCs. No significant differences were found between differing surgical groups and between the differing mask therapies. Thus, while these masks may be used to supplement conventional physiotherapy, it is not known whether they contribute to improved outcomes. Our survey showed that positive pressure therapies are rarely used by physiotherapists in patients undergoing pulmonary surgery, with a number of physiotherapists considering these positive pressure devices to be contraindicated in this population (Reeve et al 2007a).

preoperative pulmonary rehabilitation (Wang et al 2006). Jones' work has been further corroborated by Cesario et al in a small pilot study (n=8) of patients who undertook preoperative pulmonary rehabilitation after being denied surgery on the basis of their poor pulmonary function (Cesario et al 2007). Significant improvements were gained in 6MWD with preoperative pulmonary rehabilitation. Following the preoperative programme all patients received surgery on the basis of their improvement, mortality was nil and no PPCs were reported (Cesario et al 2007). Despite the small numbers and non randomised nature of these studies, they demonstrate a 'proof of principle' that high intensity exercise prior to lung resection may improve exercise capacity, and therefore allow greater surgical treatment options, for patients undergoing lung resection for lung cancer.

Studies have shown VO_{2peak} to be a strong independent predictor of surgical complication rate (Beckles et al 2003, Benzo et al 2007, Win et al 2006) with a recent meta-analysis demonstrating a mean VO_{2peak} of $15mL/kg^{-1}/min^{-1}$ to be the threshold for increased postoperative risk (Benzo et al 2007). Bobbio et al (2008) investigated the impact of a preoperative pulmonary rehabilitation programme on exercise capacity in 12 patients with chronic obstructive pulmonary disease (COPD) with a VO_{2peak} $<15mL/kg^{-1}/min^{-1}$ presenting for lung resection for lung cancer (Bobbio et al 2008). A significant improvement in mean VO_{2peak} following rehabilitation resulted with 11 patients proceeding to surgery. Whilst mortality was nil, 73% (n=8) of these patients presented with a PPC following surgery and mean LOS was reported as being greater than those reported in other studies.

High risk groups were further investigated by Sekine et al (2005) who studied the impact of a preoperative pulmonary rehabilitation programme on postoperative outcomes in 22 patients with lung cancer and co-existent COPD undergoing lung resection (Sekine et al 2005). Sixty patients having previously undergone surgical resection formed a historical control group. Postoperative LOS was significantly longer in the control group but was extraordinarily high in both groups compared with other studies. Although there was no significant difference in PPCs between groups there was a tendency for fewer PPCs in the pulmonary rehabilitation group despite pulmonary function tests starting and remaining lower in this group (see Table 2).

The feasibility of administering a preoperative pulmonary rehabilitation programme within the short time frame between diagnosis and surgery remains an obstacle to this type of intervention. However, given the reported improvements in VO_{2peak} following preoperative pulmonary rehabilitation, a case could be argued to institute this for those patients presenting with borderline pulmonary function tests in whom surgery has been deemed inappropriate unless improvements in VO_{2peak} can be achieved.

A continuing focus on randomised, controlled studies of preoperative physiotherapy interventions including education and exercise rehabilitation in all patients undergoing lung surgery is required. This should help determine the benefits of these interventions on surgical prognosis, postoperative complication rate, and longer term recovery including quality of life.

ii. Postoperative physiotherapy interventions

To date there have been no prospective randomised controlled trials with a 'no physiotherapy' treatment group following thoracic surgery. As a result, it is not possible to state whether prophylactic respiratory physiotherapy is beneficial. Clarification of the role and efficacy of these interventions is long overdue. All studies that have been undertaken to date have evaluated additional interventions compared with, or in addition to, more traditional physiotherapy interventions such as deep breathing and coughing (see Table 3).

Incentive spirometry

Incentive spirometry is a handheld mechanical device developed to encourage sustained maximal inspirations, encourage re-inflation of lung tissue and thus prevent or resolve atelectasis. Studies following cardiac and upper abdominal surgery have found no evidence of benefit from incentive spirometry in reducing the incidence of PPCs (Freitas et al 2008, Overend et al 2001).

Following thoracic surgery a recent study reviewing the efficacy of incentive spirometry found there is no evidence to suggest incentive spirometry can either replace or augment the work of physiotherapists in patients following thoracic surgery but that incentive spirometry is a relatively good measure of lung function following thoracotomy (Agostini et al 2008). Agostini et al (2008) suggest that incentive spirometry may be useful to assess respiratory recovery in the days after thoracic surgery. These findings supported earlier work in which the use of incentive spirometry as a predictor of lung function following lobectomy was measured (Bastin et al 1997). Bastin found that incentive spirometry volumes correlated well with measured vital capacity and inspiratory reserve volume and also concluded that incentive spirometry was a good marker of lung function after lobectomy.

Incentive spirometry following thoracotomy was first investigated by Vilaplana et al (1990). In a paper which is difficult to interpret as it was published in Spanish only, the main finding was that the addition of incentive spirometry to a physiotherapy regimen in a small group of patients pre and post-thoracotomy (including both oesophageal and pulmonary surgery) did not reduce

Ambulation/mobilisation practices

The effects of early mobilisation on postoperative recovery are being increasingly investigated in other surgical groups (Browning et al 2007, Orfanos et al 1999) but remain under investigated in patients following thoracic surgery. Following upper abdominal surgery significant reductions in LOS have been shown in patients following fast track pathways which include early intense mobilisation, although the amount and intensity of mobilisation undertaken is not always clear and nor is adherence to the programmes or the involvement of physiotherapists (Anderson et al 2003, Basse et al 2002, Delaney et al 2001, Delaney et al 2003, Wind et al 2006).

The use of fast track protocols following lung resection remains in its infancy; however, in a recent randomised controlled pilot study, the first report comparing fast track and conservative treatment regimens in 58 patients following lung resection was undertaken (Muehling et al 2008). A significant reduction in the incidence of PPC in the fast track group (36% versus 7%, $p = 0.009$) was found, however there were no significant differences in overall morbidity (46% versus 26%, $p = 0.172$) or LOS (median 11, range 7 – 34). Whilst the fast track group received earlier ambulation (night of operation v postoperative day one), the impact of this was confounded by other differences between groups in the postoperative protocol including preoperative fasting and analgesia administration. Quantifying mobilisation practices and determining the specific effect of early intense mobilisation practices on patient outcomes, including the incidence of PPC, require further investigation in patients following lung resection.

Other physiotherapy studies

Varela et al (2006), in a study involving 639 patients after lung resection, found that physiotherapy may reduce LOS and the incidence of atelectasis (with a subsequent reduction in hospital costs) but appears to have no influence over the incidence of pneumonia and overall morbidity (Varela et al 2006). In this non-randomised, unblinded cross sectional study a routine intensive postoperative physiotherapy programme was compared with historical controls. Authors found LOS and atelectasis rates to be significantly lower in the physiotherapy group; however, more patients underwent VATS procedures in the physiotherapy group which may bias results. VATS approaches have smaller incisions, less muscle division, less rib spreading and require significantly less pain medication than traditional approaches and thus may require less physiotherapy (Li et al 2003, Li et al 2004b). Our survey reported that the physiotherapy management of patients undergoing VATS surgery was different from that of open thoracotomy in 87% of survey respondents. Respondents consistently suggested faster mobilisation, significantly reduced physiotherapy input (often screening or assessment only) and faster discharge from hospital in patients undergoing VATS (Reeve et al 2007a).

Varela et al (2006) suggest their study to be the first to confirm the effectiveness of physiotherapy within the thoracic surgery population; however, this should be interpreted with caution until evidence from robust clinical trials is available to corroborate or refute these findings

SUMMARY

It is surprising that so little high quality evidence exists to determine best physiotherapy practice for patients following lung surgery, particularly considering the significant resource implications associated with the delivery of physiotherapy for these patients, and the increasing volume of evidence questioning the role of routine physiotherapy after other types of surgery. Professionals accepting responsibility for the delivery of patient care implicitly accept the responsibility of justifying both the efficacy and expense of their interventions (Bond 1996, Chesson et al 1996). Although high level evidence in this patient group is scarce, Reeve et al found that the majority of physiotherapists reported implementing prophylactic respiratory interventions to prevent PPCs for patient undergoing lung resection and this usually consisted of preoperative education and postoperative respiratory interventions with early ambulation (Reeve et al 2007a). Currently, there is insufficient evidence to inform optimal physiotherapy management for patients undergoing lung resection and further randomised controlled trials are urgently required. This will help guide practice in the management of these patients in order to target resources efficiently and appropriately. Given the current lack of high quality evidence, it has been recommended that both pre and postoperative physiotherapy interventions should continue to be provided until further information to guide practice is available (Denehy 2008).

This review has only considered the role of physiotherapy in preventing PPCs ; however, another aspect of physiotherapy, considered beyond the scope of this review, is the provision of postoperative exercise rehabilitation for patients following discharge from hospital to improve exercise capacity and quality of life (Nazarian 2004). In addition, shoulder dysfunction and chronic post-thoracotomy pain have been widely reported after thoracic surgery and although their exact prevalence is not known, they can result in considerable postoperative morbidity (Landreneau et al 1994, Li et al 2004a, Li et al 2004b). Whilst it is not the intention of this paper to consider these problems and associated interventions it is acknowledged that these are areas of practice which cause considerable postoperative morbidity and in which some physiotherapists report implementing interventions to prevent problems associated with surgery and deconditioning (Reeve et al 2007a). Once again, little high quality evidence is available to substantiate these interventions and these areas also require further investigation to help inform practice. Well designed, adequately powered randomised controlled trials are urgently required to enable physiotherapists to target their interventions appropriately for the pre and postoperative management of patients following major thoracic surgery.

Key Points

- Postoperative pulmonary complications are a major cause of morbidity and mortality following thoracic surgery and physiotherapy interventions aim to prevent and remediate these.
- Despite high quality evidence in other major surgical groups, there is limited evidence to guide physiotherapy practice in the management of patients undergoing thoracic surgery.
- The majority of physiotherapists in thoracic surgical units throughout Australia and New Zealand continue to provide routine prophylactic physiotherapy following thoracic surgery.
- Until the efficacy of physiotherapy interventions in this population is clearly established pre and postoperative physiotherapy treatment should continue to be provided.

ACKNOWLEDGEMENTS

The author would like to acknowledge the work of Kathryn MacPherson, Kathy Stiller, Linda Denehy and Leigh Hale in reviewing this study. Their expert advice, support and insightful comments are greatly appreciated.

ADDRESS FOR CORRESPONDENCE

Julie C Reeve, MSc (Physiotherapy), Grad Dip Phys, Senior Lecturer, School of Physiotherapy AUT University, Private Bag 92006, Auckland 1020. Email: Julie.reeve@aut.ac.nz Tel: 09 9219999 ext 7085. Fax: 09 0219620

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