Review Article

Lung volume reduction surgery—a narrative review of clinical evidence, patient selection and peri-operative care

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Background and objective: Lung volume reduction surgery (LVRS) in patients with severe emphysema aims to remove the least functional part of the lungs to improve airflow, diaphragmatic and chest wall mechanics and alveolar gas exchange in the remaining lungs.

Methods: This article aims to review the evidence, available guidance and provide insight into the peri-operative management of patients undergoing surgery. A pubmed and Scopus review was conducted February 2022 for English articles on LVRS. Included papers are described narratively.

Key content and Findings: The most important parts of the process are patient assessment, risk/benefit judgments and shared decision making with the patient, as complications are common and can be significant. That said, morbidity and mortality are less now than they once were. The well-known principles of prehabilitation and enhanced recovery are paramount for these patients.

Conclusions: Getting it right for patients considered for LVRS relies on getting the basics right in relation to: patient selection; prehabilitation; peri-operative medicine; and enhanced recovery. We can expect outcomes to improve further still and this procedure to be offered to more patients than it is currently.

Keywords: Peri-operative; thoracic; lung volume reduction; enhanced recovery

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Introduction

The National Institute of Health and Care Excellence (NICE) have reviewed the available evidence and put forward a clinical commissioning policy guideline for patients considered for lung volume reduction surgery (LVRS) (1). The available evidence to treat severe emphysema with LVRS in adults was reviewed and guidance updated in 2018. Pathways for assessment by a Lung Volume Reduction Multidisciplinary Team (MDT) been proposed.

The role of the MDT for LVRS is to ensure selection criteria are met, that patients are appropriately optimised from a medical point of view and that techniques most suited to individual patients are considered (2). The pathway should also ensure that those patients not suitable for surgery or endobronchial valve insertion are able to access ongoing research studies with alternative therapies. An understanding of suitability for LVRS is paramount. The key aim of this narrative review is to bring together evidence supporting the use of lung volume reduction surgery together with clinical expertise in order to support institutions and clinicians aiming to start or expand their own services. We present the following article in accordance with the Narrative Review reporting checklist (available at https://shc.amegroups.com/article/view/10.21037/shc-22-24/rc).

Table 1 Search methods employed

Items	Specification
Date of search	February 2022
Database and other sources searched	PubMed and Scopus
Search terms used	'lung volume reduction surgery', 'chronic obstructive pulmonary disease surgery', 'symptomatic hyperinflation', 'prehabilitation for thoracic surgery', enhanced recovery after thoracic surgery'
Timeframe	No limit
Inclusion and exclusion criteria	We included all original articles, guidelines and policy documents related to lung volume reduction surgery
Selection process	Both authors, independent review

Methods

We conducted a literature search (PubMed and Scopus) in February 2022 to identify relevant articles (*Table 1*). Key search terms included: 'lung volume reduction surgery', 'chronic obstructive pulmonary disease surgery', 'symptomatic hyperinflation', 'thoracic prehabilitation' and 'enhanced recovery after thoracic surgery'. No date limits were set. The abstracts of identified articles were assessed for relevance, along with screening of their references for further relevant publications.

Patient selection

Patient selection is crucial in both avoiding morbidity and also in gaining benefits. Suitable patients will fulfil the following criteria (see Appendix 1 for full inclusion and exclusion criteria):

- Have evidence of symptomatic hyperinflation due to emphysema with impaired quality of life. Medical research council (MRC) dyspnoea scale 3 or more (3).
- Be non-smokers—cessation at least 4 months.
- Completed a pulmonary rehabilitation programme within last 12 months or ongoing participation in a post rehabilitation exercise programme.
- Completed a six-minute walk distance >140 m or incremental shuttle walk >80 m.
- Forced expiratory volume in one second (FEV1) <50% predicted.
- Carbon monoxide diffusion capacity (DLCO) or carbon monoxide transfer coefficient (KCO) >20% predicted.
- Residual volume (RV): total lung capacity (TLC) >55%.
- RV >150%.
- $PaCO_2$ <7 kPa.
- Body mass index (BMI) >18 kg/m^2.

Severe comorbidities, such as unstable ischaemic heart disease, heart failure, pulmonary fibrosis, significant renal or liver dysfunction are contraindications to LVRS. Patients with severe progressive disease including advanced malignancy and severe pulmonary hypertension are not suitable and patients with severe alpha-1 antitrypsin deficiency appear less likely to benefit from LVRS (4). The MDT will also require additional information to inform decision making regarding the appropriateness of LVRS including:

- High resolution CT to characterise the distribution of emphysema as target areas for volume reduction.
- Calculated procedural risk for which a variety of systems are in place: exercise capacity index (BODE) and Glenfield risk scoring (5);
- Baseline quality of life assessment [St George's Respiratory Questionnaire or COPD Assessment Test (CAT) score].

Physiologically, emphysema is characterised by decreased elastic recoil, increased lung compliance, early airway closure, air trapping, over expansion of rib cage and flattening of diaphragm (2,6-8). Resection of poorly functioning, overly distended lung tissue gives rise to:

- Better functioning lung that has been compressed. Improvement in FEV1 and reduced ventilation/perfusion (V/Q) mismatch.
- Improved mechanical function of the diaphragm and intercostal muscles by decreasing the functional residual capacity and returning the diaphragm to a more normal curved and lengthened configuration.
- Less dynamic hyperinflation of the lung, which has similar physiological effects on the heart to tamponade. Reduction of this will improve left ventricular filling and cardiac index by reduction in

Table 2 Pre-operative checklist for patients undergoing lung volume reduction surgery

Ensure smoking cessation
Pulmonary rehabilitation and prehabilitation programme
Define cardiovascular risk
Baseline echocardiography +/– BNP
Extent of coronary artery calcification on CT
Exercise performance
+/– stress echocardiography
Optimise cardiac medication
Ensure optimisation of underlying lung pathology
Mucolytics if sputum producer
ABG on air—Baseline O_2, CO_2, HCO_3
Microbiology—relevant sputum cultures
Nutrition
High BMI patients—excluded original trial—dietary advice + target weight
Low BMI—dietary and nutritional advise
COVID + flu vaccination status
Optimisation of anaemia, diabetes, psychology, etc.

BNP, B-type natriuretic peptide; ABG, arterial blood gas; BMI, body mass index.

intrathoracic pressure.

- Improved endothelial function and blood pressure following LVRS has been demonstrated.

Historically, many trials will have included patients undergoing median sternotomy and a bilateral approach at one sitting. The National Emphysema Treatment Trial (NETT) is the largest multicentre trial published comparing LVRS with medical therapy (9). They included 1,218 patients from 17 centres who underwent pulmonary rehabilitation followed by assignment to either surgery or continued medical treatment. Primary outcomes were mortality rate and exercise capacity at 24 months. Secondary outcomes were morbidity, improvement in lung function, quality of life and performance of activities of daily living. Video assisted thoracoscopy was used in only 30% of cases in the NETT trial. Over last 10–15 years the incidence of VATS has dramatically increased (10).

Pre-operative assessment

Patients should be seen in the anaesthetic clinic prior to surgery. The clinic provides opportunity to ensure appropriate candidacy for surgery through use of an appropriate 'checklist' (*Table 2*) (11). In the present era with the COVID-19 pandemic, many patients may not have had regular follow up, data may be historical, and deconditioning and performance status may be worse than first assessed by the MDT. Other major comorbidities which may contribute to morbidity and mortality will ideally have been investigated, optimised and no contraindications to surgery elicited. Patients should have a thorough assessment of cardiopulmonary function to determine suitability and define the extent of cardiovascular disease. In one series, a 15% prevalence of asymptomatic but significant coronary artery lesions was found (12). The principles of enhanced recovery are key (13), including:

- Information, education and counselling—patients should be fully aware of the proposed surgery, risks, benefits and alternative treatments and have 'bought into' surgical treatment.
- Peri-operative nutrition—patients with low BMI need to be optimised through dietician review. High BMI patients should have goals and target weights set and managed before proceeding.
- Smoking cessation—ensure patients not smoking as an entry requirement for surgery.
- Anaemia management and optimisation.
- Pulmonary rehabilitation and prehabilitation programme—ensure recently completed and ideally in the pandemic era where many patients have deconditioned should be actively engaged in programme at the time of surgery.
- Optimisation of underlying emphysema—ensure recent review and optimal treatment by appropriate respiratory team.
- Alcohol consumption addressed in patients with excessive alcohol intake.
- Ensuring patients are up to date with COVID vaccination status.

There should be an opportunity to discuss, plan anaesthesia and peri-operative management with the patient and their relatives and discuss postoperative common complications and morbidity which they may encounter.

Table 3 Intra-operative checklist for patients undergoing lung volume reduction surgery

Airway isolation
Planned anaesthesia technique and monitoring
Analgesia plan
Ventilation strategy—pressure controlled *vs.* volume controlled, tidal volume, FIO_2, I:E ratio, respiratory rate
Management of critical events:
Hypoxia/hypercapnoea
Hypotension
Fluid management
Antibacterial prophylaxis
Temperature control
DVT prophylaxis
Postoperative nausea and vomiting
Airleak assessment + planning
Extubation strategy

I:E, inspiratory/expiratory; DVT, deep venous thrombosis.

Admission

Same day admission for thoracic surgery is now common practice. Advice regarding starvation times and pre-operative carbohydrate loading will have been given at pre-operative stage. There is an opportunity to check for major changes in health and that the patient remains functionally as good as when assessed with no new active chest infections. Sedative pre-medications are generally avoided, although there may be a role for pre-emptive analgesia, for example paracetamol, gabapentin or pregabalin.

Intra-operative care (*Table 3*)

Team brief

This process is vital to ensure optimal planning and management of complex patients during the surgical period. A well conducted team brief ensures optimal communication within the team, aids planning of the list (for example list orders). Sicker, complex patients should ideally be done early on the list.

- Planned incision and side—VATS, thoracotomy or median sternotomy.
- Planning regional technique with surgical team.
- Ensuring appropriate high-dependency unit (HDU) bed availability postoperatively.
- Planning for intra-operative difficulties and emergencies.

WHO checklist and sign in before induction of anaesthesia is vital to ensure it is safe to induce anaesthesia and that all the preparations have been made for surgery. This should follow standard local protocols. It is vital that before any blocks are undertaken that 'stop before you block' is undertaken. Anaesthetic monitoring is in line with standards with invasive blood pressure monitoring prior to induction to enable prompt detection and management of haemodynamic instability (14). A central venous catheter may be inserted as this allows delivery of vasoactive drugs. Monitoring of central venous pressure intra-operatively with an open chest in the lateral position will have limited value. If inserting central venous access, it should be positioned on same side as surgery taking place unless undertaking bilateral LVRS.

Induction of anaesthesia

As with any high-risk surgery, induction agents should be used that are familiar to the relevant anaesthetist to achieve safe, stable anaesthesia (15).

Airway management

A double lumen tube with confirmation by bronchoscopy is the gold standard for airway management. If there are concerns regarding secretion burden at the start of case, a single lumen tube, followed by bronchoscopy to facilitate secretion removal can be employed prior to double lumen tube insertion. Challenging airways or difficult anatomy may require bronchial blocker insertion but there are concerns regarding lung deflation in emphysematous patients. When lung isolation is commenced, it will often take longer for the operative side to collapse because of air trapping. Although suction may reduce secretions and to some extent aid deflation, pathological lungs may be challenging to collapse.

Maintenance of anaesthesia

Anaesthesia can be maintained by either volatile, total intravenous anaesthesia (TIVA) or combination of volatile and intravenous opiates. Theoretical benefits of TIVA in thoracic surgery are a reduction of shunt fraction by

maintenance of hypoxic pulmonary vasoconstriction and elimination of agents that is not dependent on pulmonary elimination when compared to volatile agents. No technique has been proven to be superior in randomised trials (16). Traditionally, shorter acting muscle relaxants such as atracurium and cisatracurium have been popular but with increased availability of suggammadex, rocuronium has gained popularity in thoracic practice. The overall aim will be to use short acting agents and good analgesia to facilitate tracheal extubation at end of the procedure.

Analgesia

Historically, thoracic epidural analgesia was considered the gold standard. However, with more VATS procedures performed, general trends move away and other regional techniques have gained in popularity. The principles of multimodal analgesia with many available options including (10):

- Paracetamol.
- Gabapentin/pregabalin.
- Non-steroidal anti-inflammatory drugs (NSAIDs).
- Paravertebral blocks (PVB).
- Epidural or paravertebral + surgically placed catheters, e.g., epipleural.
- Fascial Plane Blocks, e.g., erector spinae plane block.
- Intercostal nerve blocks.
- Intrathecal opioids.
- Ketamine/Alpha-2 Agonists.

Ventilation

This is a highly debated topic in the thoracic literature and more challenging in patients with severe emphysema. The aims are to achieve safe oxygenation and permissive hypercapnia whilst avoiding high volumes and pressures. Concerns with positive pressure ventilation in patients with severe emphysema include:

- The potential for pneumothorax on the contralateral side due to abnormal lung parenchyma function on ventilated lung.
- Increased risk of contralateral lung injury.
- Altered compliance and elastic recoil—may be difficult to collapse the lung making surgery more challenging. Gas trapping is a real possibility and may lead to increased intra-thoracic pressures and reduced cardiac output.
- Recruitment manoeuvres which are commonly employed when facing hypoxia may cause iatrogenic injury or gas trapping.
- Secretions may be an issue in patients with severe emphysema.
- Optimal positive end expiratory pressure (PEEP) is unclear. Using modest PEEP may maintain airway patency in late expiration and reduce or minimise intrinsic PEEP.
- Bilateral or single side approach. If performing bilateral lung volume reduction then as a rule, the more severe side is done first. This means that single lung ventilation on the side that has just been operated has the potential for air leak.
- End of surgery—air leak may be significant and can cause concerns during intermittent positive-pressure ventilation (IPPV). Lungs may now have varying compliance and differing V/Q matching.

Typical ventilator settings and goals

- Pressure-controlled ventilation (PCV)—aiming plateau <25 cmH_2O and driving pressure below 16 cmH_2O.
- Restrict tidal volume (TV) on one lung ideally, 3–4 mL/kg.
- Permissive hypercapnia aiming pH >7.2.
- Low respiratory rate.
- Lowest FiO_2 to achieve saturations >90%.
- Prolonged inspiratory/expiratory (I:E) ratios.
- Optimal PEEP.

Fluid management

Generally, we aim for euvolaemia with the tendency to run patients on the dry side and using vasoactive drugs to treat hypotension as opposed to excessive fluid boluses.

Postoperative care

Prior to closure of the chest, an assessment of air leak should be made in conjunction with the surgical team, if this is excessive then, this should be highlighted and discussed. The WHO sign out is important to discuss postoperative instructions, concerns and make joint plans for recovery.

Other principles of enhanced recovery include (17):

- Deep venous thrombosis (DVT) prophylaxis—thrombo-embolus deterrent (TED) stocking/Flowtron boots.

- Antibiotic prophylaxis, chlorhexidine skin preparation.
- Maintaining normothermia will reduce shivering.
- Postoperative nausea and vomiting (PONV) prevention/ Analgesic plan.
- Nasal high flow oxygen.
- Nebulisers.
- Early mobilisation.
- Incentive spirometry.
- Physiotherapy.

Patients are typically managed in the HDU environment for: regular assessment of air leak and chest drain management; regular chest radiographs; and monitoring cardiovascular stability, ischaemia and arrythmias.

Morbidity and mortality

The NETT trial (9) reported operative mortality of 6% (revised criteria, no-high risk patients 2.2%) as well as major pulmonary morbidity of 30% and major cardiovascular morbidity of 20%. Cardiac arrythmia was the most common complication occurring in 23.5%. Pneumonia occurred in 18%, and 21.8% required at least one reintubation. There were 8.2 % who underwent tracheostomy and 5.1% of patients failed to wean successfully from mechanical ventilation within 3 days of LVRS. Pulmonary morbidity was greater in older patients and those with lower FEV1. Cardiovascular morbidity was higher with age, use of oral steroids or in the presence of non-upper lobe predominant emphysema.

After LVRS, 90% of patients had air leaks at some point within 30 days of surgery. Median air leak duration was 7 days but 12% of patients had air leaks for 30 days. National Trends in LVRS in USA 2000–2010, in hospital mortality was 6%. Age >65 was strongest predictor for in-hospital mortality, presence of interstitial lung disease and low BMI were independent predictors (18).

Transplant *vs.* LVRS

Factors favouring LVRS over transplantation in patients with COPD include: age >65 y; chronic medical comorbidities; malignancy; inability to maintain long-term follow up; psychiatric conditions limiting long-term compliance and lack of social support. Factors favouring lung transplantation over LVRS in patients with COPD include: FEV1 <20%; DLCO <20%; no emphysema on imaging; pulmonary hypertension; and clinically significant bronchiectasis (19,20). Each case should be considered on its own merit with the relevant transplant team and there is an urgent need for new data to support clinical decision making.

Conclusions

LVRS should be seen as a pragmatic option that can improve the quality of life for selected patients with severe COPD. Peri-operative management strategies are reasonably well known but there is an urgent need for more clinical trial data that can be used to aid patient selection. Complications are common and these can be significant. Full risk assessment and an MDT approach is essential. Alternatives include: lung transplantation; bronchoscopic procedures; endobronchial valves; coils; biological lung volume reduction; thermal airway ablation.

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appropriately investigated and resolved.

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Appendix 1

Full inclusion and exclusion criteria of NETT

Inclusion criteria

- History and physical examination consistent with emphysema.
- CT scan evidence of bilateral emphysema.
- Completed 6 to 10 weeks of supervised pulmonary rehabilitation.
- BMI <31 males, <32 female.
- FEV1<45%.
- $PaCO_2$<60 mmHg.
- PAo_2>45 mmHg.
- 6MWT >140 m.
- No smoking for at least 4 months before initial screening.

Exclusion criteria

- CT evidence of diffuse emphysema judged unsuitable for LVRS.
- Previous LVRS.
- Pleural or interstitial disease that precludes surgery.
- Giant bulla (≥one third of lung volume).
- Clinically significant bronchiectasis.
- Pulmonary nodule requiring surgery.
- Previous sternotomy or lobectomy.
- Myocardial infarction within 6 months of interview and ejection fraction <45%).
- CHF within 6 months and EF <45%.
- Uncontrolled hypertension.
- Pulmonary hypertension mean P_{PA} on RHC ≥35 mmHg or peak systolic P_{PA} 45 mmHg.
- Unplanned, unexplained weight loss >10% usual weight within 90 days.
- History of recurrent infections with daily sputum production judged significant.
- Daily use of ≥20 mg of prednisolone.
- History of exercise induced syncope.
- Resting bradycardia <50 bpm, frequent multifocal PVC's, complex ventricular arrhythmia or sustained SVT.
- Cardiac dysrhythmia that poses a risk to the patient during exercise or training.
- Oxygen requirement during resting or oxygen titration >6 L/min to keep sats ≥90%.
- Evidence of systemic disease or neoplasia that is expected to compromise survival.
- Any disease or condition that may interfere with completion of tests, therapy or follow up.
- 6MWD ≤140 m post rehabilitation.
- Inability to complete successful any of the screening or baseline data.
- High risk patients were excluded including FEV1 <20% and either homogenous emphysema or a carbon monoxide diffusing capacity that was 20% below predicted.

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