Clinical Investigations

Respiration

Respiration 2017;93:236–246
DOI: 10.1159/000455878

Received: November 11, 2016
Accepted after revision: January 5, 2017
Published online: February 1, 2017

Feasibility and Safety of a Transthoracic Pneumostoma Airway Bypass in Severe Emphysema Patients

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For editorial comment see p. 232

Keywords
Pulmonary emphysema · Hyperinflation · Lung volume reduction

Abstract
Background: Emphysema is characterised by airflow obstruction, hyperinflation, and resultant dyspnoea. It is worth investigating whether decompression improves lung mechanics and enhances quality of life (QoL). ***Objectives:*** The purpose of this study was to describe the feasibility and safety of creating a transthoracic pneumostoma to enable lung reduction. ***Methods:*** A transthoracic 10-mm diameter Portaero Access Tube (Portaero™, Cupertino, CA, USA) was implanted via a third intercostal space incision in 15 severe emphysema patients [mean age 63 years, forced expiratory volume in 1 s 54% predicted, diffusing capacity for carbon monoxide 31% predicted, residual volume 246% predicted, Six-Minute Walk Test 296 m]. Four weeks later, an 8-mm Portaero Disposable Tube (3–8 cm in length) was substituted and changed daily thereafter. The targeted primary endpoints were a ≥12% increase in forced expiratory volume in 1 s and a decrease of ≥4 points in Saint George's Respiratory Questionnaire score at 6 months. ***Results:*** Sixteen procedures were performed on 15 patients, complicated by 1 intercostal haemorrhage, 1 pneumothorax, and universal mild surgical emphysema. Early patency issues were common, but often responded to external endoscopic debridement or argon plasma laser. Three-month patency was achieved in 9 of 15 patients, and 6 of these had long-term patency (mean of 4 years). Patency was associated with potentially useful long-term improvements or stability in spirometry, residual volume, and QoL. However, the primary endpoints were not met at 6 months. ***Conclusion:*** The creation and maintenance of a transthoracic pneumostoma appears feasible and safe in patients with severe emphysema. Further studies refining patient selection (perhaps via chest computed tomography collateral ventilation and fissure assessments), techniques, and tube materials are suggested.

Introduction

Emphysema is characterised by irreversible destruction of the lung parenchyma, resulting in loss of elastic recoil and lack of radial support of the airways during exhalation. In turn, this leads to air trapping and progressive lung hyperinflation. The clinical consequences include dyspnoea, exercise limitation, impaired quality of life (QoL), and restricted survival [1].

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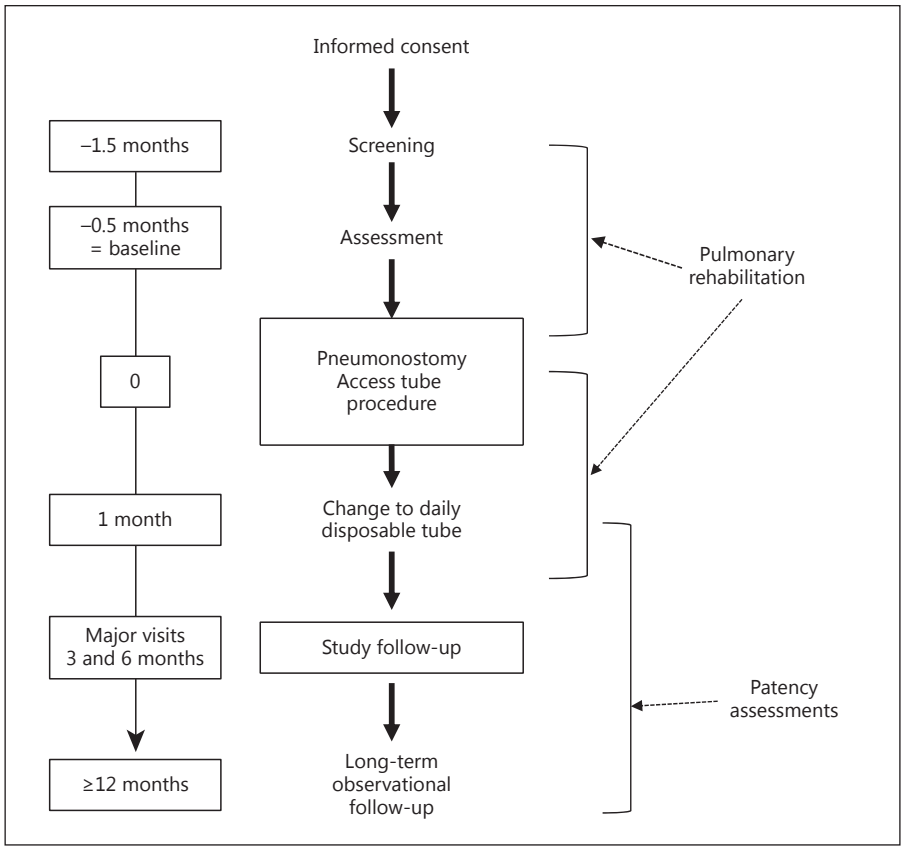

Fig. 1. Schema outlining the study design.

Surgical removal of the most affected emphysematous segments has been shown to relieve hyperinflation and improve QoL. However, this type of surgery has also been associated with significant morbidity and mortality [2–5]. Bronchoscopic lung volume reduction (LVR) techniques have subsequently evolved in an attempt to emulate the surgical success while minimising these risks [6–8]. In considering the clinical results of these bronchoscopic approaches, it has become apparent that the emphysematous lung has important parenchymal non-airway pathways of collateral ventilation [4, 9]. The extent of intra- and interlobar collateral ventilation is variable between lobes and sides of an individual patient as well as across different emphysema patterns. However, collateral ventilation is particularly common in severe widespread emphysema (often referred to as homogeneous emphysema), typically where interlobar fissures are poorly developed and parenchymal destruction is widespread [9].

Although this collateral ventilation mitigates the positive effects of LVR techniques which rely on lobar isolation (e.g., 1-way endobronchial valves aiming to create targeted LVR in particularly affected emphysematous areas, often referred to as heterogeneous emphysema) [6, 7, 10], it has been hypothesised that in the presence of collateral ventilation, creation of an exit passage which bypasses the airways could potentially usefully improve air trapping and hyperinflation [11, 12]. Such a passage could therefore theoretically be efficacious in either homogeneous or heterogeneous disease.

The creation of an intrapulmonary airway bypass by placing up to ten 3-mm segmental airway stents into the adjacent lung parenchyma showed early promise, but a sizeable trial ultimately showed that within 3 months, the passages were irreversibly overgrown with fibrosis tissue and the initial positive clinical benefits were lost [12]. An alternate approach, creating an extrapulmonary airway bypass with a single approximately 8-mm tube placed into the lung parenchyma through the chest wall, has also shown feasibility in a small pilot study of severe emphysema patients [13]. In this study, an endotracheal tube was initially used, but was subsequently replaced by a prototype pneumonostomy device (Portaero™, Cupertino, CA, USA), with superior retention and tolerability.

Table 1. Study inclusion and exclusion criteria

Inclusion criteria
Age ≥45 years
Smoking history ≥20 pack-years
FEV_1/FVC post bronchodilator <70%
FEV_1 post bronchodilator >20% and <45%
Hyperinflation as defined by TLC >100% and RV >150% predicted
DLCO >20% predicted
PaO_2 ≥45 mm Hg and $PaCO_2$ <60 mm Hg
≥12 sessions of pulmonary rehabilitation within 12 months
HRCT findings of >50% destructive emphysema in targeted lobes [9]
Non-smoking ≥3 months and throughout the study
Exclusion criteria
Six-minute walk distance <140 m after pulmonary rehabilitation
Clinically significant daily sputum production or bronchiectasis
≥3 exacerbations requiring hospital admission ≤12 months
Use of non-invasive ventilation with the exception of sleep apnoea treatment
Body mass index <17 or >31
Blood pressure >200/110 mm Hg
History of stroke ≤12 months
Severe pulmonary hypertension (RVSP ≥49 mm Hg on echocardiogram or >45 mm Hg on right heart catheter)
History of chest infection <30 days
History of myocardial infarction <6 months, left ventricle ejection fraction <45%
High bleeding risk
Known α-1 antitrypsin deficiency
Prior ipsilateral lung volume reduction surgery, lobectomy, or pleural surgery
Presence of giant bullae that occupy more than one-third of the lung volume
Known lung cancer or pulmonary nodule which requires investigation
Current treatment with high-dose corticosteroids (defined as >10 mg/day prednisolone for >30 days within 2 months)

DLCO, diffusing capacity for carbon monoxide; FEV_1, forced expiratory volume in 1 s; FVC, forced vital capacity; HRCT, high-resolution computed tomography; RV, residual volume; RVSP, right ventricular systolic pressure; TLC, total lung capacity.

The current study aims to describe (1) the feasibility and safety of creating and maintaining a transthoracic Portaero pneumostoma and (2) the efficacy of this concept at 3 months, 6 months, 12 months, and beyond, as assessed by spirometry, lung volume, exercise testing, and QoL.

Methods

This prospective, non-randomised Ethics Committee-approved study was undertaken between June 2009 and January 2012 at the Alfred Hospital (Australian New Zealand Clinical Trials Registry 12610000190000). The current report represents a single-centre portion of a larger multicentre study that was never completed, collated or abstracted due to financial issues affecting the sponsoring company. The study outline is summarised in Figure 1. The patient group represented a severe emphysema population referred initially for consideration of surgical/bronchoscopic lung reduction or transplantation. All interested participants provided written informed consent and subsequently underwent an initial screening to determine preliminary eligibility. The inclusion and exclusion criteria are summarised in Table 1.

Assessment at baseline included spirometry, lung volume, Six-Minute Walk Test, arterial blood gases, cycle ergometry, chest radiograph, chest high-resolution computed tomography (HRCT), and QoL questionnaires (Saint George's Respiratory Questionnaire [SGRQ] and modified Medical Research Council Dyspnea Scale). Spirometry, body plethysmography, and Six-Minute Walk Test were performed according to the guidelines of the American Thoracic Society [14].

Potentially eligible patients were required to have attended a minimum of 12 sessions of supervised pulmonary rehabilitation over a period of at least 6 weeks, or to have completed a program within the past 12 months. Surgery was performed within 2 weeks of baseline assessment.

The exact location for placement of the pneumostoma was determined by the surgeon based on the examination of the anatomical features of the patient's chest wall; an insertion site adjacent to an area of severely affected lung (but clear of significant vessels) was chosen, as judged by HRCT. The second to third intercostal

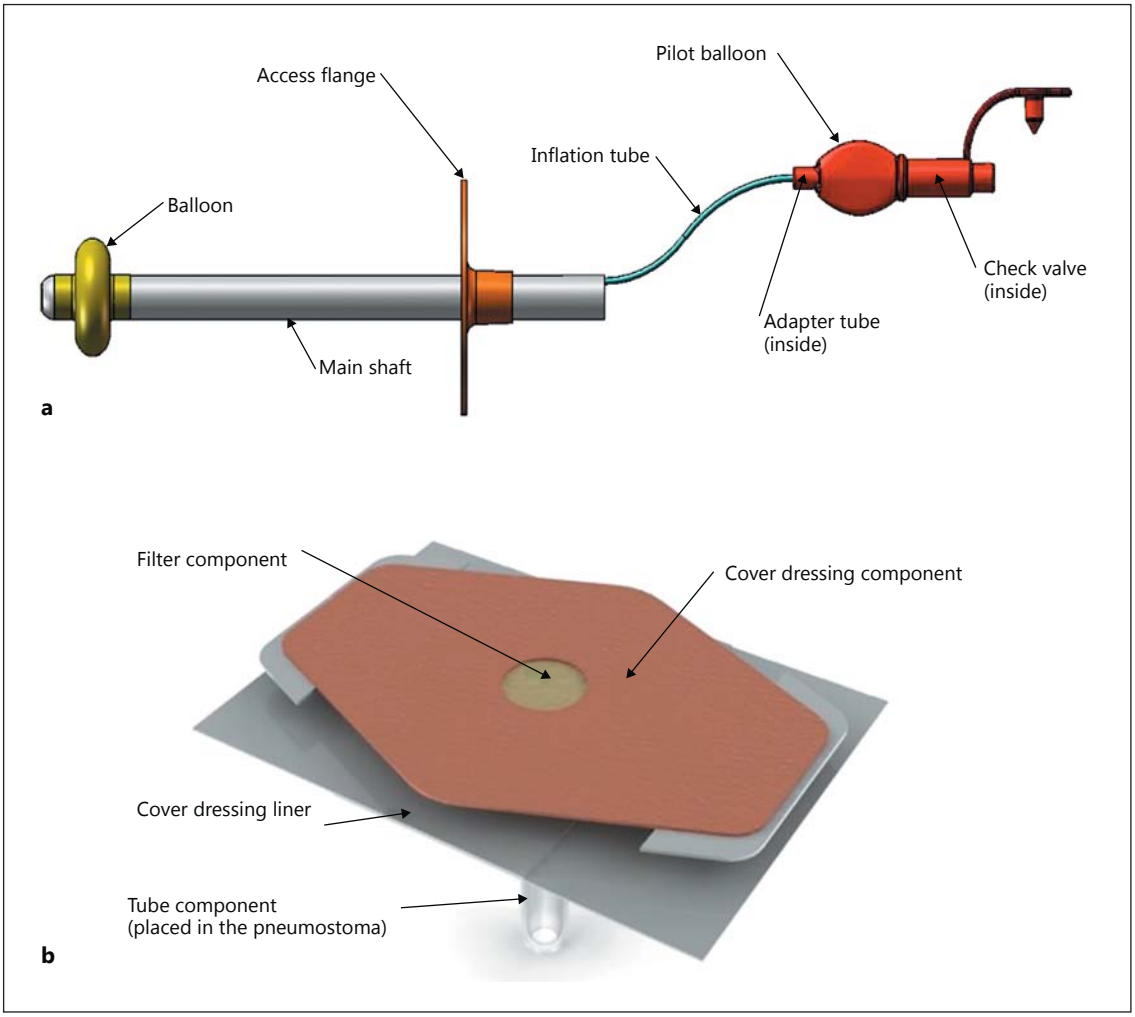

Fig. 2. a Prototype access tube featuring a distal balloon and a proximal flange that hold the tube in position within the lung and the chest wall. **b** Daily disposable access tube featuring variable lengths within the lung and chest wall and an adhesive backing that holds the tube to the skin.

spaces in the midclavicular line were typically targeted. Under general anesthesia, with an endotracheal tube in situ, a mini-thoracotomy was performed. An intercostal catheter (underwater seal connected) was placed adjacently and, for the first 4 patients, a localised abrasive pleurodesis was performed in anticipation of postoperative air leak issues. Dacron pledget-reinforced purse-string stitches were inserted through both the parietal and visceral pleura, followed by an incision of the lung via scalpel/diathermy, and gentle insertion of the initial 10-mm Portaero Access Tube into the lung parenchyma. To lock the tube in place and avoid air leak, a distal 10-ml anchoring contrast-filled balloon (Fig. 2a; prototype access tube, first 9 cases)/distal anchoring flange released (second-generation access tube, subsequent 7 cases) and the purse-string sutures were pulled tight around the tube with the wound closed in layers. A further circular flange was slipped over the tube and sutured to the tube. Venting of air through the pneumostoma and absence of parastomal air leak were confirmed. The access tube was finally connected to an Atrium Pneumostat drainage system (Atrium Medical Corp., Hudson, NH, USA).

Postoperatively, all patients received 5 days of intravenous and 10 days of oral antibiotics as well as 10 sessions of pulmonary rehabilitation after discharge. As per study protocol, the intraparenchymal pneumostoma tract was given 3–4 weeks after the procedure to heal around the access tube before being exchanged for the 8-mm Portaero Disposable Tube (Fig. 2b). The choice of 3- to 8-cm tube length was based on patient chest wall thickness. Patients received detailed oral and written instructions on their responsibilities regarding stomal care, tube placement, removal, and disposal. Disposable tubes were expected to be exchanged by the patient every second day (or more frequently as necessary should there be an accumulation of secretions).

Follow-up visits were scheduled at 0.5, 1, 2, 3, 4, 5, and 6 months, with 6-monthly contact thereafter. An experienced study nurse provided backup telephone support and triage. During these

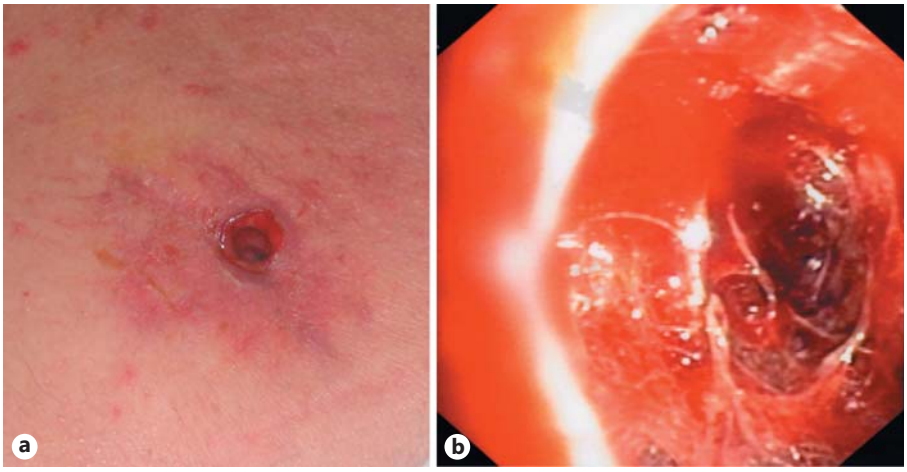

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Fig. 3. a A typical stomal opening 6 months post procedure. **b** Endoscopic view of the lung parenchyma through the stoma.

visits, patients were reviewed in regard to possible adverse effects as well as an assessment of stomal patency. The patient's description of noise or flow, the ability to note bubbles over the stoma when saline was dripped upon it, and the visualisation of actual lung parenchyma at the time of endoscopic pneumonostomy examination (see below) were all noted (Fig. 3). Evaluation of airflow via a CO_2 detector or pneumotachography (even with the addition of nasal continuous positive airway pressure of 5 cm H_2O) proved unhelpful and was abandoned.

Endoscopic evaluation of the pneumostoma was undertaken as part of the 2- and 3-monthly assessments or at any point if there were concerns about stomal patency. A 4.9-mm Olympus 15C (Olympus, Tokyo, Japan) fibreoptic bronchoscope was inserted under topical 1% lignocaine anesthesia into the stoma either directly or via the daily access tube. In the event of poor patency, combinations of gentle endoscopic pressure and stomal toilet via suction or 15C bronchoscopy biopsy forceps (Olympus) were used to remodel the passage or remove new ingrowing fibrous tissue. As clinically indicated, an argon plasma coagulator (System 7550; Conmed, Sydney, Australia) was used endoscopically through the stoma for particularly troublesome stenosis or granulation tissue.

At 3 and 6 months, detailed physiological and QoL assessments were performed. Spirometry and body plethysmography results at 12 and 18 months (and beyond if available) were also analysed. The focus of this pilot study was on collecting the outcomes of patients with a functioning stoma.

Reflecting contemporaneous and prior LVR studies [2–8], the prospectively defined primary efficacy endpoints would be met if the forced expiratory volume in 1 s increased by ≥12% or if the SGRQ score decreased by ≥4 points at 6 months.

The degree of HRCT alveolar destruction in the target lobe was assessed using visual scoring and defined as the percent lobar volume of low-attenuation emphysematous change [9]. Fissure integrity was assessed by reviewing coronal, sagittal, and axial slices of the baseline HRCT on the side of the pneumostoma. The major fissure on the left and horizontal fissure on the right were evaluated. Fissures were classified as complete if their entire length could be identified and followed through consecutive slices.

The study results are reported using simple descriptive statistics. Means and standard deviations are quoted unless otherwise noted. With very small numbers, *p* values are not quoted.

Results

Sixteen procedures were performed on 15 patients between June 2009 and January 2012. Baseline demographic, pulmonary, and functional characteristics are summarised in Table 2. Figure 4a shows a representative example of a postoperative chest X-ray and Figure 4b a representative example of an HRCT scan.

Perioperative Outcomes

There were no significant perioperative complications in 13 patients. One patient had a significant intercostal arterial haemorrhage and pneumothorax requiring a return to the operating room. One patient had a pneumothorax at 7 days requiring reinsertion of an intercostal catheter. All cases had mild surgical emphysema.

Three-Month Outcomes

On review at 3 months (Table 3), 9 of 15 patients (16 stomas) had functional pneumonostomies. In 1 case the procedure was repeated after 20 weeks on the contralateral side in a lower rib space because of practical difficulties for the patient and staff inserting the daily disposable tube into the stomal tract, with stomal loss at 8 weeks. In a further 2 cases, the patient was not able to regularly place the daily tube into the true lung parenchymal tract, leading to the creation of a blind false tract and permanent stomal closure at week 8. In another 3 cases, the

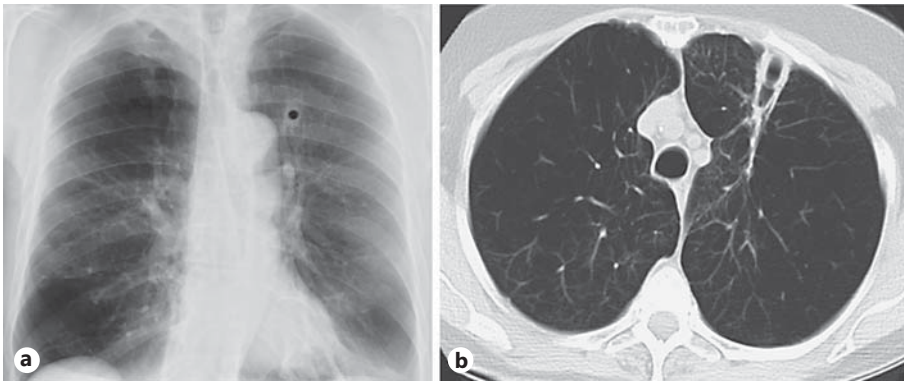

Fig. 4. a Anterior chest X-ray featuring a left upper lobe stoma (appearance of a black hole). **b** Transverse HRCT cut through the upper lung fields demonstrating the daily disposable access tube in situ. A small amount of lung fibrosis surrounds the tube tract.

Table 2. Baseline demographic, pulmonary, and functional characteristics

Age at time of insertion, years	63.1 (6.2)
Male, %	57.5 (8)
FEV_1, L	0.65 (0.14)
FEV_1, % predicted	25.4 (4.3)
FVC, L	2.46 (0.70)
DLCO, %	30.6 (11)
RV, L	4.85 (0.69)
RV, % predicted	245.6 (30.0)
TLC, L	7.4 (1.2)
RV/TLC ratio	0.66 (0.05)
pO_2, mm Hg	69.1 (9)
pCO_2, mm Hg	42.2 (5)
mMRC (0–4)	3.1 (0.9)
SGRQ (0–100)	
Total score	59 (11)
Symptom score	55 (22)
Activity score	83 (16)
Impact score	47 (15)
Endurance cycle ergometry, s	210 (86)
Six-Minute Walk Test, m	296 (94)

Figures are means with standard deviations in parentheses. DLCO, diffusing capacity for carbon monoxide; FEV_1, forced expiratory volume in 1 s; FVC, forced vital capacity; mMRC, modified Medical Research Council Dyspnea Scale; RV, residual volume; SGRQ, Saint George's Respiratory Questionnaire; TLC, total lung capacity.

pneumostoma was initially established, however significant granulation tissue resulted in recurrent occlusion of the tract despite reopening attempts to this point (n = 1, week 10), or the patient was unwilling to undergo reopening because of perception of poor prior efficacy (n = 2, weeks 4 and 10). In 1 case the stoma was never patent and was not suitable for reopening. Fifteen stomal refining/reopening attempts (1–2 attempts per patient) were made in 10 patients. Two minor wound infections required short courses of oral antibiotics. There were no upper or lower respiratory tract infectious complications.

Six-Month Outcomes

On review at 6 months (Table 3), 9 of 15 patients had a functional pneumostoma. One previously patent tract could not be reopened at 15 weeks because of risk of a repeat significant haemorrhage associated with an earlier reopening (this was the only significant stomal haemorrhage seen in the whole study). One previously blocked tract was surgically reopened successfully at 20 weeks. A further 14 stomal refining/reopening attempts (1–3 attempts per patient) were made in 6 patients.

Twelve-Month Outcomes

On review at 12 months (Table 3), 6 of 14 patients had a functional pneumostoma. One functioning stoma patient had died of a rapidly progressive Pancoast tumour since the 6-month review. The other 2 previously patent tracts had closed by the patient's choice based on poor efficacy (43 and 49 weeks). A further 5 stomal refining/reopening attempts (1–2 attempts per patient) had been made in 3 patients.

Long-Term Outcomes

Beyond the study period, the same 6 patients with 12-month patency maintained long-term patency for a current mean of 4 years. Indeed, 2 are still patent at 7 years, 1 patient died at 3 years with a patent stoma following a fall, 1 patient with a patent stoma was successfully transplanted at 3 years because of limited stomal efficacy, while 2 stomas had been allowed to close by the patient's choice (n = 1 at 3 years with patency/reopening concerns,

Table 3. Clinical outcomes

Case No.	Reopen	Patent at 13 weeks	Reopen	Patent at 26 weeks	Reopen	Patent at 52 weeks	Reopen	Patency maintained, weeks	Closure reason	Patient's status in 2016
1	0	yes	0	yes	0	yes	0	349	still open	alive
2	1	yes	0	yes	0	yes	0	342	still open	alive
3	2	yes	1	yes	0	yes	2	218	patient choice, skin	alive
4	2	yes	2	yes	2	yes	1	158	open at death	trauma death
5	1	yes	0	yes	0	yes	1	136	patient choice, reopenings	pneumonia death
6	0	yes	3	yes	0	yes	0	130	patient choice, efficacy	alive (transplant)
7	2	yes	3	yes	0	no	–	66	patient choice, efficacy	COPD death
8	1	yes	0	yes	0	–	–	39	open at death	cancer death
9	1	yes	2	no	–	–	–	15	patient choice, haemorrhage, risk of reopening	alive (transplant)
10	1	no	3	yes	2	no	0	43	patient choice, reopenings	alive (transplant)
11	0	no	0	–	–	–	–	4	reopening not possible	alive
12	0	no	0	–	–	–	–	0	patient choice, reopenings	alive (transplant)
13	0	no	0	–	–	–	–	8	patient choice, tube issues	COPD death
14	0	no	0	–	–	–	–	8	patient choice, tube issues	cancer death
15	2	no	0	–	–	–	–	4	patient choice, reopenings	alive (transplant)
16	2	no	–	–	–	–	–	8	reopening not possible	alive (transplant)

COPD, chronic obstructive pulmonary disease; Reopen, attempt at stomal reopening/refinement.

Table 4. Physiological outcomes

Variable	Stoma not patent at 13 weeks[1] (n = 7)				Stoma patent at 13 weeks (n = 9)				Stoma patent at 26 weeks (n = 6)					
	baseline	13 wk	26 wk	52 wk	baseline	13 wk	26 wk	52 wk	baseline	13 wk	26 wk	52 wk	78 wk	latest[1]
FEV_1, % predicted	24.1 (5.3)	21.7 (3.2)	22.8 (4.9)	20.0 (2.2)	26.4 (3.3)	28.4 (5.1)	27.1 (6.3)	26.7 (6.3)	26.8 (4.0)	29.3 (5.6)	28.8 (6.5)	28.0 (6.0)	29.8 (9.7)	28.2 (11.4)
FVC, % predicted	76.7 (11.8)	69.7 (12.5)	69.3 (12.7)	63.3 (6.9)	75.8 (19.6)	81.4 (23.6)	78.9 (29.1)	76.5 (24.4)	82.3 (21.2)	86.2 (25.2)	82.7 (29.8)	80.6 (24.8)	84.2 (26.9)	84.0 (24.6)
TLC, % predicted	141 (7.6)	165 (21)	143 (8.6)	146 (8.5)	145 (17)	144 (11.9)	152 (20.6)	148 (17.8)	148 (19)	144 (14.1)	155 (20.4)	148 (17.8)	144 (12.2)	–
RV, % predicted	244 (39)	271 (29)	268 (26)	294 (46)	247 (23.1)	231 (41)	234 (26)	253 (20)	245 (20)	221 (40)	234 (28)	253 (20)	233 (30)	–
RV/TLC ratio	0.66	0.69	0.69	0.73	0.65	0.62	0.63	0.67	0.64	0.60	0.63	0.67	0.69	–
Six-minute walk distance, m	287 (86)	116 (90)	176 (29)	–	304 (105)	311 (117)	323 (112)	–	344 (105)	368 (104)	349 (97)	–	–	–
Work rate	22 (7)	20 (7)	20 (7)	–	27 (10)	27 (10)	30 (8)	–	32 (8)	32 (8)	32 (8)	–	–	–
Cycle endurance, s	188 (48)	104 (29)	60 (50)	–	228 (107)	228 (107)	278 (178)	–	272 (89)	–	306 (178)	–	–	–

Figures are means with standard deviations in parentheses. FEV_1, forced expiratory volume in 1 s; FVC, forced vital capacity; RV, residual volume; TLC, total lung capacity; wk, weeks. [1] Data incomplete past 13 weeks.

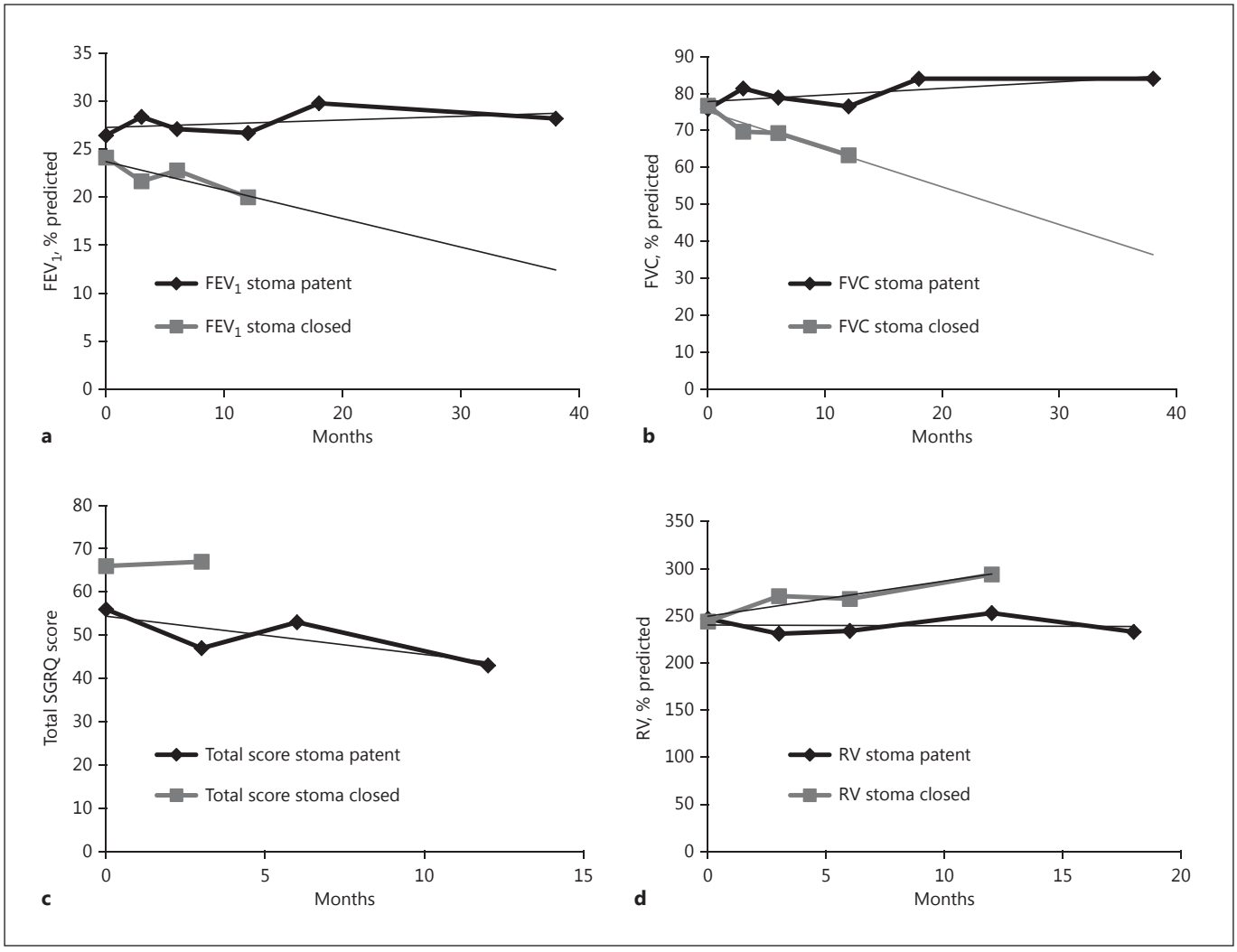

Fig. 5. Physiological and quality of life measures versus time post procedure, split into those with a patent versus those with a closed stoma at the 3-month mark. Lines of best fit are included for ease of comparison: forced expiratory volume in 1 s (FEV_1; % predicted) (**a**), forced vital capacity (FVC; % predicted) (**b**), Saint George's Respiratory Questionnaire (SGRQ) total score (**c**), and residual volume (RV; % predicted) (**d**).

the patient having died of pneumonia, and $n = 1$ at 4 years with recurrent skin irritation and need for intermittent antibiotics, the patient still being alive). A further 4 stomal refining/reopening attempts (1–2 attempts per patient) were made in 3 patients. There were no long-term complications of a patent or closed stoma. In all cases removal of the daily access tube permanently led to rapid stomal closure, without need for further intervention.

Amongst the 9 patients who entered the study and did not have 12-month stomal patency, 4 went on to be successfully transplanted (at 1–3 years), 2 died of airways disease (at 1–4 years), 2 died of cancer (as discussed above and melanoma beyond 12 months), and 1 continues to await a lung transplant. Although not officially recorded for study purposes, it was notable that clinically significant infective airways disease exacerbations and hospitalisations were uncommon in this group.

Efficacy Outcomes

Key spirometric, body plethysmographic, and exercise results are detailed in Table 4, split according to stomal functionality (i.e., patent or closed) at 3 and 12 months (Fig. 5). Table 5 details the SGRQ and modified Medical Research Council Dyspnea Scale scores. Although there

Table 5. Quality of life outcomes

Variable	Stoma not patent at 13 weeks[1] (n = 7)				Stoma patent at 13 weeks (n = 9)			
	baseline	13 wk	26 wk	52 wk	baseline	13 wk	26 wk	52 wk
SGRQ								
Symptom score	55.7	63.0	–	–	54.7	48.3	50.9	45.4
Activity score	97.3	100	–	–	77.1	72.4	74.4	64.2
Impact score	51.7	49.3	–	–	44.3	30.7	40.7	29.6
Total score	66.3	67.3	–	–	56.3	46.7	53.0	43.0
mMRC	3.0	3.3	3.5	–	2.7	1.7	1.9	–

mMRC, modified Medical Research Council Dyspnea Scale; SGRQ, Saint George's Respiratory Questionnaire; wk, weeks. [1] Data incomplete past 13 weeks.

were some promising trends, the prospectively defined primary efficacy endpoints at 6 months were not met.

Explant Lung Histology

The histology of the explanted lungs from the 5 patients subsequently transplanted revealed only relatively minor changes in the area of the pneumonostomy, ranging from just emphysema to a focal 25 × 15 × 20 mm area of non-descript fibrosis. In 2 cases occasional multinucleated giant cells were noted.

HRCT Tissue Density and Fissure Integrity Scoring

The tissue density of the targeted lobes was >75% destroyed (emphysema score 4 ± 1) in 5 of 9 with stomal patency and 2 of 7 with a closed stoma at 3 months, and in 3 of 6 with long-term patency. The tissue density in the target lobes of the remaining patient population was emphysema score 3. The adjacent major fissure integrity was incomplete in 6 of 9 with stomal patency and in 3 of 7 with a closed stoma at 3 months, and in 5 of 6 with long-term patency. Overall, 5 of 9 patients with incomplete fissures achieved long-term patency, compared to 1 of 7 patients with complete fissures.

Discussion

This study supports the concept of transthoracic decompression of hyperinflated emphysematous lungs. It was feasible and safe to create and maintain a transthoracic pneumostoma. Early patency issues were identified, but patency at 3 months portended long-term patency for the majority of patients. Long-term patency was associated with potentially useful improvements or stability in QoL and respiratory physiology, particularly when contrasted with those where stomal patency was lost by 3 months. Notwithstanding, the prospectively defined primary efficacy endpoints at 6 months were not met.

Several studies previously suggested that decompression had the potential to be an effective therapy for emphysema [11–13], and the present study takes this further via the identification of strategies to maintain patency and the significantly longer period of clinical follow-up. Lausberg et al. [11] previously noted that physiological improvements could be seen with even a functionally patent pinhole, akin to placing a pin in a balloon. The EASE trial extended this concept by successfully placing 3-mm stents through the wall of proximal airways; unfortunately patency and therefore efficacy were lost within weeks [12]. In the current study, with a larger tract, repeated stomal toileting with simple local remodelling of the chest wall and parenchymal tract via a standard fibreoptic bronchoscope proved a practical and efficacious mode of maintaining patency.

Beyond the immediate postoperative period, maintaining patency proved the only significant issue of living with the stoma, as local or parenchymal issues were rare, even in long-term follow-up. Potentially having a patent pneumostoma might provide some protection against acute hyperinflation at the time of exacerbations of airways disease.

The loss of patency represented several issues. The requirement to frequently change the Portaero Disposable Tube proved to be physically, and occasionally psychologically, difficult for some patients. The tubes were made of a relatively stiff plastic, and threading along the length of the stomal tract was not necessarily easy. Its designers envisaged the tube would need regular replacement to

clear secretions, however in practice secretions were not an issue, and potentially the local abrasive effect actually adversely contributed to subsequent local inflammation and scarring. Similarly, parenchymal scarring at the distal end of the disposable tube tract represented localised fibrosis. As revealed by the explanted lung tissue examined at lung transplantation, avascular parenchymal fibrosis was actually subtle and focal, with no apparent role of infection.

Defining patency proved more difficult than expected. This represented the challenge of fitting measuring devices to the stoma, as well as the clinical reality of only low flow rates through the stoma. Ultimately, although unquantifiable, the best assessment tool proved to be the presence of bubbles when saline was instilled gently into the stoma.

Patency at 3 months predicted subsequent long-term patency and clinical utility. Interestingly, although not primarily considered in this study's design, our results suggest that patency may be linked to HRCT-defined lack of fissure integrity and the extent of emphysematous parenchymal destruction. Incomplete fissuring has previously been suggested to correlate with collateral ventilation [9, 15], a desirable feature when the aim is to decompress the whole lung through one pneumostoma. Increased lung destruction may simply represent less parenchymal tissue to physically wrap over the end of the disposable access tube.

Improvement or stability in QoL and physiological measures beyond the first 3 months was only evident in patients with patency and likely represented slow, relatively subtle improvements in dynamic hyperinflation, particularly during exercise and exacerbations. As such, these clinically desirable effects may not be so clearly seen by examining simple spirometric outcomes. As has been described in traditional LVR [2–6], we hypothesise that remodelling of the diaphragm could further contribute longer-term improvements to explain this. Although not ever intended in a pilot study to be powered to be conclusive, the results of those who never achieved or lost patency do represent a limited comparator group. The subtle fibrosis that was left behind after a stoma had closed could not explain the apparently consistent diverging differences noted across the 2 groups over longer-term follow-up.

The lessons learnt from the current study should be applied to reinvigorate clinical trials in this area. A future study of hyperinflated emphysema patients should be undertaken with the aim to percutaneously place a stoma/pneumonostomy that does not need daily tube changes, and uses materials that do not irritate the tract or parenchyma and have enough surface area to minimise the risk of distal obstruction. Consideration of directly measuring collateral ventilation via balloon obstructive techniques [15] or indirectly via HRCT analyses [15, 16] would be relevant to optimise case selection. Techniques should be developed to quantify and promote stomal airflow. Follow-up should be at least 12 months to confirm sustained safety and efficacy. Consideration of a randomised comparator best medical therapy arm will ultimately be necessary if future studies continue to suggest that QoL, exacerbation/hospitalisation rates, and mortality prove to be more clinically relevant (and important) indicators than simple physiological measures. Clinical success could possibly be enhanced by inserting bilateral tubes in suitable patients.

In conclusion, the creation and maintenance of a transthoracic pneumonostomy appears feasible and safe in patients with severe emphysema. Long-term improvements or stability in QoL and physiological variables may be of therapeutic benefit to at least a portion of the highly symptomatic emphysema population. Further studies are now appropriate to improve patient selection and optimise clinical outcomes. As identified in the current study, advances in stomal tract tube design and more sophisticated HRCT and physiological characterisation of collateral ventilation will aid significantly in this regard.

Acknowledgement

The work presented here was partly funded by Portaero.

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