

**Title:**

Improving Lung Function in Severe Heterogenous Emphysema with the Spiration® Valve System (EMPROVE): A Multicenter, Open-Label, Randomized, Controlled Trial

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**Running Title:** RCT of the Spiration® Valve System in Emphysema

**Impact:** The results of this multicenter, open-label, randomized, controlled trial highlights the effectiveness of the Spiration Valve System which along with the Zephyr valve, adds to the growing body of evidence for the use of one-way valves in the treatment of severe emphysema.

**Author Contributions:** G. Criner was involved in manuscript writing and as the corresponding author was provided full access to the data and had final responsibility for the decision to submit this original research for publication. All other coauthors were involved in data collection as principal investigators at their respective sites, and as reviewers of the manuscript. A medical writer was employed to rewrite sections that needed to be shortened to comply with the journal word limits and editorial assistance in ensuring that all journal requirements were met.

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**At a Glance Commentary:** While no medical therapy provides relief from the progressive disability of severe emphysema, improved lung function and survival has been seen with lung volume reduction surgery (LVRS). However, eligibility for LVRS is contingent upon the patient's overall health status and pattern of emphysema and is only offered at a limited number of centers. Thus, there is substantial need for less invasive treatment options for severe emphysema.

The Spiration® Valve System (SVS) consists of a one-way valve that blocks inspired airflow to distal portions of the lung affected by disease. Treatment of severe heterogeneous emphysema with the SVS in medically optimized participants achieved significant improvements in FEV<sub>1</sub>, hyperinflation, TLV, dyspnea, and QoL measures compared with optimal medical management alone. SVS offers clinically relevant benefits to severely ill patients with emphysema.

The current study refined objective methods for using quantitative computed tomography as a tool to assess target lobe emphysema characteristics and determine eligibility for bronchoscopic lung volume reduction therapy.

**Supplement:** This article has an online data supplement, which is accessible from this issue's table of contents online at [www.atsjournals.org](http://www.atsjournals.org).

## Abstract

**Rationale:** Less invasive, non-surgical approaches are needed to treat severe emphysema.

**Objective:** Evaluate the effectiveness and safety of the Spiration® Valve System versus optimal medical management.

**Methods:** In this multicenter, open-label, randomized, controlled trial, subjects aged  $\geq 40$  years with severe, heterogeneous emphysema were randomized 2:1 to Spiration Valve System with medical management (treatment) or medical management alone (control).

**Measurements:** The primary efficacy outcome was the difference in mean forced expiratory volume in 1 second ( $FEV_1$ ) from baseline to 6 months. Secondary effectiveness outcomes included: difference in  $FEV_1$  responder rates, target lobe volume reduction, hyperinflation, health status, dyspnea, and exercise capacity. The primary safety outcome was the incidence of composite thoracic serious adverse events. All analyses were conducted by determining the 95% Bayesian credible intervals (BCI) for the difference between treatment and control arms.

**Main Results:** Between October 2013 and May 2017, 172 participants (53.5% male, mean age 67.4) were randomized to treatment (n=113) or control (n=59). Mean  $FEV_1$  showed statistically significant improvements between the treatment and control groups - between-group difference at 6 and 12 months, respectively of 0.101 liters (95% BCI: 0.060, 0.141) and 0.099 liters (95% BCI: 0.048, 0.151). At 6 months, the treatment group had statistically significant improvements in all secondary endpoints except 6 minute walk distance. Composite thoracic serious adverse event incidence through 6

months was greater in the treatment group (31.0% vs 11.9%), primarily due to a 12.4% incidence of serious pneumothorax.

**Conclusions:** In patients with severe heterogeneous emphysema, the Spiration Valve System shows significant improvement in multiple efficacy outcomes, with an acceptable safety profile.

**Trial Registration:** ClinicalTrials.gov, NCT01812447,  
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## Introduction

Chronic obstructive pulmonary disease (COPD) affects an estimated 16 million US residents,<sup>1</sup> and is the fourth leading cause of death in the US.<sup>2</sup> Emphysema alone affects 4.7 million US residents and is associated with progressive physical activity limitations, dyspnea, and reduced quality of life (QoL).<sup>3,4</sup>

Pharmacologic COPD treatments have limited benefit.<sup>5</sup> Inhaled therapies reduce annual decline in forced expiratory volume in 1 second (FEV<sub>1</sub>) more than placebo; however, observed declines have not been clinically relevant. Other guideline-recommended treatments include pulmonary rehabilitation (PR) and continuous oxygen therapy,<sup>6</sup> but no medical therapy provides relief from the progressive disability of severe emphysema.<sup>5</sup>

The National Emphysema Treatment Trial showed that lung volume reduction surgery (LVRS) improved survival compared with medical treatment in participants with upper-lobe emphysema and low exercise capacity, and also improved health status, dyspnea, exercise capacity, and lung function.<sup>7</sup> While effective, most qualifying individuals (80%) are ineligible for LVRS, primarily due to the potential morbidity associated with surgery and the pattern of emphysema and severity of lung function.<sup>8,9</sup> Thus, there is a substantial need for less invasive treatment options for severe emphysema.

The Spiration Valve System (SVS, formerly known as the Intrabronchial Valve, or IBV) consists of a one-way valve that blocks inspired airflow using a flexible umbrella design.



This allows for bronchoscopic placement in selected airway regions, and limits airflow to distal portions of the lung affected by emphysema. The SVS has been evaluated in prior clinical studies using a bi-lateral, partial occlusion treatment methodology,<sup>10,11</sup> which proved ineffective. However, Eberhardt et al<sup>12</sup> along with other subsequent studies<sup>13,14</sup> showed that uni-lobar total occlusion may provide similar physiologic and clinical benefits to LVRS, including reduced hyperinflation, leading to improved lung function and clinical status, in a minimally invasive and potentially reversible manner.<sup>15</sup>

Previous studies using endobronchial valves to treat hyperinflated emphysematous patients have reported that absence of collateral ventilation is pivotal in achieving lobar atelectasis, the overall treatment goal of this therapy.<sup>13,16,17</sup> Collateral ventilation can be assessed using a balloon tipped catheter placed bronchoscopically to measure flow and pressure distally in the targeted lobe.<sup>18</sup> Alternatively, structural integrity of the fissure(s) adjacent to the targeted lobe can be assessed by quantitative high-resolution computed tomography (HRCT), which also acts as a marker for collateral ventilation and aids in patient and lobe selection.<sup>19</sup> The EMPROVE trial represents the largest multicenter study using HRCT analysis of fissure integrity for patient selection and targeted lobar treatment.

The results of the current research have been published in the form of two abstracts presented at the American Thoracic Society<sup>18</sup> and the European Respiratory Society<sup>21</sup> meetings in 2018.

## Methods

The EMPROVE study was a prospective, open-label, randomized, controlled, multicenter trial to assess the safety and efficacy of the SVS procedure in participants with severe heterogeneous emphysema.

### *Participant population*

Up to 220 participants were to be randomized from 41 investigational sites (Appendix 2), with the potential for the study to be stopped early for success or futility. Institutional Review Boards at each site approved the study, and all participants provided written informed consent (Appendix 1). Eligible participants were  $\geq 40$  years old, met American Thoracic Society/European Respiratory Society Guidelines criteria for management of stable COPD, and were able to perform a 6-minute walk test (6MWT)  $\geq 140$ m. Disease severity was assessed by HRCT. Participants were required to have  $\geq 40\%$  emphysema destruction in the target lobe (assessed at  $-920$  Hounsfield Units) and a  $\geq 10\%$  disease emphysema severity difference with the ipsilateral lobe. The target and ipsilateral lobes were required to be separated by an intact fissure, estimated visually to be  $\geq 90\%$  complete with no segmental vessels crossing between adjacent lobes (as assessed by the CT corelab; MedQIA, Los Angeles, CA). Eligible participants had severe dyspnea (Modified Medical Research Council scale [mMRC]  $\geq 2$ ); severe obstructive disease  $FEV_1 \leq 45\%$  of predicted, after bronchodilators; and hyperinflation defined as total lung capacity (TLC)  $\geq 100\%$  and residual volume (RV)  $\geq 150\%$  of predicted. Participants

agreed to attend required follow-up visits and maintain consistent nutrition and exercise habits during the study period (Appendix 3).

All subjects who had not completed a pulmonary rehabilitation (PR) program in the prior 2 years were screened to determine if they should complete a PR program before entering the trial (Appendix 4). Baseline testing included pulmonary function, CT and quality of life assessments (Appendix 5). Randomization occurred within the electronic data capture system at a pre-procedure visit (2:1 randomization to treatment or control group). Patients in both the treatment and control groups received optimal medical management throughout the study; the treatment group additionally received bronchoscopic SVS placement.

### *Procedure*

The SVS valve is designed for placement in selected regions of bronchial airways using a flexible bronchoscope, deployment catheter, and accompanying loader. The valve has a flexible umbrella that blocks inspired airflow to distal portions of lungs affected by disease, while allowing air and mucus to clear proximally from treated airways. Valves are removable using a flexible bronchoscope and forceps, if necessary. The valve comprises a frame made of a super-elastic, biocompatible alloy (Nitinol) and a polyurethane membrane (Figure 1). The membrane is held against the airway mucosa by 6 flexible struts, which expand and contract with airway movement during breathing. The valve is secured in position with 5 anchors and tips that gently penetrate the airway wall to a controlled depth.

An airway sizing system and calibrated balloon was used to determine the appropriate valve width size (5mm, 6mm, 7mm, and 9mm [the 9mm valve was introduced after initial 29 subjects had been randomized in the study]) to treat target lobe airways ranging from 4.75 to 8.75mm. The treatment algorithm called for the complete occlusion of one lobe; this was achieved by using one or more SVS valves to occlude all segments, i.e., lobar, segmental, and/or sub-segmental airways. HRCT imaging and, if necessary, lung perfusion was used to select treatment lobes. Either upper or lower lobes could be targeted for treatment; the right middle lobe was not treated in this study. When two lobes both met criteria for emphysema and heterogeneity, the lobe with the lowest perfusion was treated. To limit subsequent adverse events, physicians were asked to follow a checklist to limit procedure duration. Treated patients remained in the hospital for at least 1 day. The total duration of post procedural hospitalization was at the discretion of the local investigator and within the norms of clinical practice at the local center.

### *Outcome measures*

Follow-up and outcome assessments were scheduled for 2 weeks, 1, 3, and 6 months, and annually through 2 or 5 years for the control and treatment groups, respectively. The primary effectiveness endpoint was mean change in FEV<sub>1</sub> post-bronchodilator from baseline to 6 months between treatment and control groups; 12-month results are also reported. Secondary effectiveness endpoints were: FEV<sub>1</sub> difference between responders, defined as a  $\geq 15\%$  improvement; target lobe volume (TLV) reduction, only

assessed in the SVS treatment group, measured by quantitative computed tomography (QCT); hyperinflation, measured by the ratio of residual volume to total lung capacity (RV/TLC); health status and QoL, measured by St. George's Respiratory Questionnaire (SGRQ); dyspnea, measured by mMRC; and exercise capacity, measured by 6MWT. HRCT, plethysmography, and exercise assessments only occurred between baseline and 6 months; therefore, TLV, hyperinflation, and 6MWT data were not assessed at 12 months.

The primary safety endpoint was the incidence of pre-specified composite thoracic serious adverse events (SAEs, Appendix 6) through 6 months; secondary safety endpoints were the rate of each category of thoracic SAE and thoracic SAE rate per patient-year.

### *Statistical analysis*

Analyses of SVS effectiveness and durability were conducted at 6 and 12 months, respectively. Utilizing a Bayesian adaptive design,<sup>22,23</sup> two interim analyses of sample size adequacy were conducted when 100 and 160 participants were enrolled, at which the predictive probability of eventual success was calculated. Based on these, enrollment could be stopped early for futility or probable eventual success, while follow-up continued until the last subject reached 6 months. The maximum possible sample size was 220 (Appendix 7). Subjects with missing data were included in the analysis via Bayesian multiple imputation. The primary effectiveness objective (superiority of SVS based on FEV<sub>1</sub> change from baseline to 6 months) was considered statistically

significant if the posterior probability (PP) exceeded 0.982, a pre-specified threshold value chosen to control type I error rate (under simulation)  $\leq 0.025$ .

Primary and secondary safety analyses were conducted by determining the 95% Bayesian credible intervals (BCI) for the difference and ratio of composite SAE probabilities, as well as each individual thoracic SAE category, in the treatment and control groups (Appendix 8). Secondary effectiveness endpoints were computed as the difference between treatment and control groups at 6 and 12 months compared to baseline. Statistical analysis was conducted in the R statistical language (version 3.4.0; R Foundation for Statistical Computing, Vienna, Austria).

## Results

The trial was conducted from October 8, 2013 to May 3, 2017 at 41 clinical sites (Appendix 1) with 172 participants ultimately randomized to treatment (n=113, 65.7%) and control (n=59, 34.3%) groups at 31 clinical sites (Figure 2). Enrollment was stopped when the predictive probability of success with the existing cohort was  $>0.999$ . By 6 months in the treatment group, 6 subjects had died and 107 had an evaluable visit. By 12 months, 96 subjects had evaluable visits. In the control group (n=59), 8 participants withdrew and 1 died, leaving 50 evaluable subjects at 6 months. By 12 months, 43 subjects had an evaluable visit.

Treatment and control group participants had similar baseline characteristics.

Demographic data, use of pulmonary medications and supplemental oxygen, medical history, lung function, arterial blood gas results, exercise tolerance, SGRQ, mMRC dyspnea scores, and HRCT characteristics were all comparable (Table 1; Appendix 9: Table S2). The only demographic difference was sex; the control group had approximately 15% more males.

Mean procedure duration, defined as the time between bronchoscope insertion and removal, was 24.3 minutes (range, 9 to 73 minutes). The mean and median duration of hospitalization was 3.83 days and 1 day, respectively (Appendix 10: Table S3). Target lobes, defined by pre-procedural imaging, were primarily on the left side (82.3%) with 58.4% being the left upper lobe (Appendix 10: Table S4). QCT was used for target lobe selection in 97.4% of cases. In the remaining 3 cases where two potential target lobes were identified by QCT, perfusion scan results were used, and final determination of the target lobe was by the CT corelab. A total of 476 valves were placed in 113 treatment group participants (mean number per participant,  $3.83 \pm 1.48$ ) (Appendix 10: Table S5).

### *Efficacy outcomes*

The SVS treatment group had significant FEV<sub>1</sub> improvements (Figure 3). At 6 months, the treatment group improved by 0.099 liters on average from baseline (95% BCI: 0.069, 0.128), whereas the control group changed by -0.002 liters (95% BCI: -0.030, 0.026), for a between-group difference of 0.101 liters (95% BCI: 0.060, 0.141). At 12 months, the treatment group improved by 0.067 liters on average (95% BCI: 0.031,

0.103), while the control group decreased by -0.032 liters (95% BCI: -0.069, 0.005), for a between-group difference of 0.099 liters (95% BCI: 0.048, 0.151). (Appendix 11: Table S6).

Secondary effectiveness outcomes were also improved in the SVS treated group. At 6 and 12 months, the between-group difference in FEV<sub>1</sub> responder rates (improvement  $\geq 15\%$ ) was estimated at 25.7% (95% BCI: 12.5%, 37.5%; 0.9998 PP) and 30.4% (95% BCI: 16.8%, 42.5%; 0.9999 PP), respectively, in favor of SVS (Table 3; Appendix 11: Table S7-S9).

At 6 months, treatment group participants had a significant reduction in TLV as measured by QCT (-0.974 L [95% BCI: -1.119, -0.829]), with a 1.0000 PP for mean change  $< 0$  (Table 2; Appendix 11: Table S10). Using a 350 ml reduction in TLV as a threshold, 75% of the SVS treated group achieved a clinically meaningful improvement, with 40% of the entire treatment cohort achieving complete atelectasis of the target lobe.

The SVS treatment group also had significantly greater mean RV/TLC improvement. The between-group difference at 6 months was -0.039 (95% BCI: -0.058, -0.020; 1.0000 PP) in favor of SVS (Table 2; Appendix 11: Table S11a).

There was significantly greater mean improvement in SGRQ (health status) for SVS treatment vs control groups at 6 months, with a between-group difference of -13.0



points (95% BCI: -17.4, -8.5; 1.0000 PP). Results at 12 months were -9.5 points (95% BCI: -14.4, -4.7; 1.0000 PP) (Table 2; Appendix 11: Table S12).

Dyspnea, as measured by mMRC, was significantly improved with SVS treatment, with a between-group difference of -0.6 (95% BCI: -0.9, -0.3; 1.0000 PP) at 6 months and -0.9 (95% BCI: -1.2, -0.6; 1.0000 PP) at 12 months (Table 2; Appendix 11: Table S13).

While not a secondary endpoint of the study, the COPD assessment test (CAT) scores were improved by 4.3 points at 6-months and 5.3 points at 12-months in the treatment group compared to the control group and were statistically significant at both time points (Appendix 11: Table S16).

Change in exercise capacity, measured by 6MWT was not statistically significant at 6 months, with a between-group difference of 6.9 meters (95% BCI: -14.2, 28.2; 0.7438 PP) (Table 2; Appendix 11: Table S14).

Table 3 provides responder rates for all secondary efficacy outcomes.

### *Safety outcomes*

#### Short-term (0-6 months)

At 6 months, the incidence of composite thoracic SAEs was 31.0% in the treatment group and 11.9% in the control group for a statistically significant between-groups difference of 19.1% (95% BCI: 5.9 – 29.7). The higher treatment group incidence was

primarily due to a 12.4% (95% BCI: 4.6 – 18.6) increased incidence of serious pneumothorax (Appendix 12: Table S17-S18), which was statistically significant. Over this time, 32 monitored events of pneumothorax were reported, with 18 protocol-defined (Appendix 6) serious incidents in 16 (14.2%) of 113 treatment group participants, and 14 non-serious pneumothorax events in 13 (11.5%) treatment group participants. The majority (66%) of these pneumothorax events occurred within 3 days of the procedure, within the average hospital stay duration (Appendix 12: Figure S1). Of the 16 subjects with serious pneumothorax events, 11 (69%) had  $\geq 1$  valve removed per the defined pneumothorax management protocol (Appendix 5). Five (5) of these subjects had valves re-implanted upon cessation of the pneumothorax and this subset showed a TLV reduction of -834.0 ml compared to the only -19.2 ml in those that did not have valves replaced. There were no other statistically significant between-group differences in thoracic SAEs by category.

There were six (5.3%) deaths in the treatment group and one (1.7%) death in the control group (Appendix 12: Table S19). This difference between groups was not statistically significant. Only one death (occurring at Day 95 post-SVS procedure) was adjudicated by the study clinical events committee as possibly related to the device due to pneumothorax in the contralateral untreated lobe, which did not resolve before death (Table S20).

There were no statistically significant between-group differences for non-thoracic SAEs, with 11.5% and 3.4% non-thoracic SAEs in the treatment and control groups,

respectively (Appendix 12: Table S19).

#### Long-term (6-12 months)

Between 6 and 12 months, the incidence of composite thoracic SAEs was 21.4% in the treatment group vs 10.6% in the control group (Appendix 12: Table S17), with a between-groups difference of 10.7% (95% BCI: -3.0 – 21.2), which was not statistically significant. There were no statistically significant between-group differences in thoracic SAEs by category. There were 3 non-serious events of pneumothorax in 2 of 113 (1.7%) treatment subjects and no additional serious pneumothorax events (Appendix 12: Figure S1). Three SAEs were adjudicated as device-related (1 case of infection, 1 of pneumonia, and 1 death). There were 4 (3.9%) deaths in the treatment group (one of which was device related) and 3 (6.4%) in the control group (Appendix 12: Table S17 and Table S19, Death details in Table S21). There were no unanticipated device-related SAEs or migration, erosion, or expectoration reported through 12-month follow-up.

There were no statistically significant between-group differences for non-thoracic SAEs, with rates of 12.6% and 12.8% in the treatment and control groups, respectively (Appendix 12: Table S19).

## **Discussion**

The EMPROVE trial evaluated the safety and efficacy of the Spiration® Valve System compared to optimal medical management in patients with severe heterogeneous emphysema. While prior SVS trials using bilateral, partial occlusion of the target lobe

did not show consistent improvement<sup>10,11</sup>, the results of the EMPROVE trial, with single-lobe, total lobar occlusion, shows marked benefits. At 6 months, the primary outcome and a majority of secondary outcome measures were improved in the SVS-treatment group compared to the control group. There was a significant between-group increase in mean FEV<sub>1</sub> from baseline (0.101 liters) and a 25.7% between-group difference in FEV<sub>1</sub> responder rates (defined as improvement of  $\geq 15\%$ ). These results persisted at 12 months. The SVS-treatment group also saw significant reductions in TLV, hyperinflation, and dyspnea. Improved health status and QoL was observed as an 8.1-point mean reduction in the SGRQ, which exceeds the 4-point minimum score change defined as clinically relevant.<sup>24</sup> These efficacy results are very comparable to other randomized clinical trials using one-way valves in a unilateral lobar treatment paradigm.<sup>13,14,16,25</sup>

Although the SVS-treatment group performed better on the 6MWT than the control group (between-group difference: 6.9 meters), this difference was not statistically significant. In contrast, patients who underwent endobronchial valve treatment in the recent LIBERATE trial performed significantly better on 6MWT than control. This improvement is not surprising, as LIBERATE patients were required to maintain a supervised PR program throughout study follow-up,<sup>25</sup> and PR has been shown to improve exercise capacity in patients with COPD.<sup>26</sup> The EMPROVE study was designed with the understanding that only ~40% of COPD patients actually adhere to a PR program due to problems with access and prohibitive cost.<sup>27</sup> As such, EMPROVE subjects were required to have been in a PR program in the 2 years prior to study enrollment (Appendix 4), but were not mandated to maintain a supervised PR program

throughout the study follow-up with only 34.5% and 32.7% of EMPROVE treatment and control subjects, respectively, maintaining a PR regimen through the 12-month follow-up. Thus, the difference between the two trials highlights the importance of additional exercise training by way of pulmonary rehabilitation in translating improved lung function into enhanced exercise performance.

Mean procedure time in EMPROVE (24 minutes) was also shorter than that observed in the LIBERATE trial (34 minutes).<sup>25</sup> This is relevant because shorter procedure times have been associated with fewer procedure-related complications.<sup>11</sup> In the EMPROVE study, post-SVS treatment risks were generally minor and tended to diminish over time. The primary safety outcome, incidence of composite thoracic SAE, was greater in the treatment than control group (31.0% and 11.9%, respectively). However, pneumothorax was the only individual SAE with significantly higher treatment group incidence, similar to comparable studies.<sup>13,25</sup> Early-onset pneumothorax in the treatment group likely resulted from lung conformation changes due to acute reduction in lung volume by valve therapy, triggering rapid ipsilateral non-targeted lobe expansion, a recognized indicator of successful target lobe occlusion.<sup>28</sup> There was no statistically significant difference in mortality between the study groups at any time point. The 5.3% mortality rate in the treatment group is similar to the 3.1% - 5.0% documented in other randomized valve trials,<sup>11,25,29</sup> and lower than the 7.9% - 12% documented in randomized LVRS trials.<sup>7</sup> There were no unanticipated device-related SAEs.

The results of the EMPROVE trial also demonstrate that using HRCT analysis for fissure integrity  $\geq 90\%$  is a useful method to select patients for lack of collateral ventilation that are most likely to achieve targeted lobe atelectasis and improved clinical outcomes. The procedural time for SVS performance was less than other trials using physiological assessment for collateral ventilation and avoids added procedural costs.<sup>32,33</sup> Moreover, in a broader clinical context, HRCT quantitative assessment of fissure integrity may be easier to implement.

### **Strengths and Limitations**

Strengths of the EMPROVE trial include its use of an adaptive sample size, thus shortening overall enrollment time, and planned long-term follow-up: 5 and 2 years for the treatment and control groups, respectively. A key study limitation was the lack of TLV and hyperinflation assessments at 12 months, which would have provided mechanistic data to support improvements in functional and QoL parameters. Additionally, the EMPROVE study, and other recent multicenter, randomized controlled trials, did not blind either subjects or assessors.<sup>16,25,34</sup> While this may introduce bias to the QoL assessments and the 6MWT, it is unlikely that measures such as lung function, TLV, and hyperinflation would be affected by this approach.

### **Conclusion**

Treatment of severe heterogeneous emphysema with the SVS in medically optimized participants selected for fissure integrity  $\geq 90\%$  by quantitative HRCT achieved significant improvements in FEV<sub>1</sub>, hyperinflation, TLV, dyspnea, and QoL measures

compared with optimal medical management alone. The SVS offers clinically relevant benefits for severely ill patients with emphysema and while there are risks with the therapy they are primarily manageable and tend to diminish over time.

The results of the EMPROVE Trial and other randomized trials of valve therapy have led to the inclusion of endobronchial valve therapy as an important component of the clinical therapy recommendations for the underserved patient population with severe emphysema.<sup>35,36</sup>

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Additional contributions: Safety oversight of the Study was provided by a Data and Safety Monitoring Board comprising: John Beamis, MD (Chair), Greg Campbell, PhD (Statistician), Frank Detterbeck, MD, Barry Make, MD and Jonathon Truwit, MD. The Clinical Events Committee (CEC) adjudicated adverse events and comprised: Matthew Brenner, MD (Chair), Richard Helmers, MD, Eric Vallières, MD, Roger Yusen, MD. The study Medical Monitors were Robert Kruklitis, MD and Daniel Nader, MD.



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## Figure Legends

**Figure 1:** Spiration Valve. Key components of the Spiration Valve.

**Figure 2:** Study Subject Disposition Flow Chart

**Figure 3:** Change in FEV<sub>1</sub> at 6 and 12 Months

Mean  $\pm$  95% BCI

BCI=Bayesian credible interval; FEV<sub>1</sub>= Forced expiratory volume in 1 second; PP=Posterior Probability; SVS=Spiration Valve System.



## Tables

Table 1: Subject Demographics and Baseline Characteristics

|                                                                                | Treatment Group<br>(N = 113) |                           | Control Group<br>(N = 59) |                           | Difference (T – C)             |
|--------------------------------------------------------------------------------|------------------------------|---------------------------|---------------------------|---------------------------|--------------------------------|
|                                                                                | N                            | Mean ± SD<br>or N (%)     | N                         | Mean ± SD<br>or N (%)     | 95% BCI                        |
| Sex (Male)                                                                     | 113                          | 54 (47.8%)                | 59                        | 38 (64.4%)                | (-30.9%, -0.8%)                |
| Age (Years)                                                                    | 113                          | 66.7 ± 6.6                | 59                        | 68.1 ± 6.4                | (-3.4, 0.7)                    |
| BMI (kg/m <sup>2</sup> )                                                       | 113                          | 25.3 ± 4.3                | 59                        | 24.6 ± 5.2                | (-0.8, 2.3)                    |
| FEV <sub>1</sub> (L)                                                           | 113                          | 0.825 ± 0.264             | 59                        | 0.792 ± 0.260             | (-0.051, 0.116)                |
| FEV <sub>1</sub> (% Predicted, L)                                              | 113                          | 30.8 ± 8.1                | 59                        | 28.5 ± 8.5                | (-0.4, 5.0)                    |
| FVC (L)                                                                        | 113                          | 2.492 ± 0.754             | 59                        | 2.633 ± 0.757             | (-0.384, 0.101)                |
| FVC (% Predicted, L)                                                           | 113                          | 70.2 ± 16.5               | 59                        | 70.5 ± 16.7               | (-5.6, 5.0)                    |
| TLC (L)                                                                        | 113                          | 7.215 ± 1.530             | 59                        | 7.649 ± 1.431             | (-0.904, 0.035)                |
| TLC (%Predicted, L)                                                            | 113                          | 126.5 ± 14.5              | 59                        | 128.2 ± 17.0              | (-6.9, 3.5)                    |
| RV (L)                                                                         | 113                          | 4.573 ± 1.253             | 59                        | 4.848 ± 1.199             | (-0.665, 0.115)                |
| RV (%Predicted, L)                                                             | 113                          | 207.5 ± 45.0              | 59                        | 213.4 ± 49.3              | (-21.3, 9.4)                   |
| RV/TLC Ratio                                                                   | 113                          | 0.632 ± 0.080             | 59                        | 0.632 ± 0.086             | (-0.028, 0.026)                |
| Prescribed O <sub>2</sub> - Proportion<br>- (L/min)                            | 113                          | 51 (45.1%)<br>1.18 ± 1.43 | 59                        | 27 (45.8%)<br>1.16 ± 1.47 | (-15.7, 14.9)<br>(-0.45, 0.49) |
| PO <sub>2</sub> (mmHg)                                                         | 112                          | 67.9 ± 10.2               | 59                        | 68.0 ± 11.6               | (-3.6, 3.5)                    |
| PCO <sub>2</sub> (mmHg)                                                        | 112                          | 40.2 ± 5.7                | 59                        | 40.9 ± 6.0                | (-2.7, 1.1)                    |
| Pulmonary Rehabilitation<br>- Prior to enrollment<br>- During follow-up period | 113                          | 113 (100%)<br>39 (34.5%)  | 59                        | 59 (100%)<br>18 (30.5%)   | (-11.8, 13.4)                  |
| 6MWT (meters)                                                                  | 113                          | 303.5 ± 84.6              | 59                        | 306.9 ± 104.2             | (-34.8, 28.0)                  |
| Dyspnea (mMRC)                                                                 | 113                          | 2.7 ± 0.7                 | 59                        | 2.7 ± 0.6                 | (-0.2, 0.2)                    |
| COPD Assessment Test                                                           | 113                          | 21.8 ± 6.8                | 59                        | 20.0 ± 6.3                | (-0.3, 3.9)                    |
| SGRQ Total                                                                     | 113                          | 57.2 ± 14.8               | 59                        | 54.6 ± 13.6               | (-1.9, 7.1)                    |
| Target Lobe Volume (L)                                                         | 113                          | 1.843 ± 0.602             | 59                        | 1.820 ± 0.456             | (-0.140, 0.187)                |
| Target Lobe                                                                    | 113                          |                           | 59                        |                           |                                |
| Left Lower                                                                     |                              | 27 (23.9%)                |                           | 9 (15.3%)                 | (-4.2%, 19.5%)                 |
| Left Upper                                                                     |                              | 66 (58.4%)                |                           | 37 (62.7%)                | (-17.8%, 12.0%)                |
| Right Lower                                                                    |                              | 7 (6.2%)                  |                           | 7 (11.9%)                 | (-15.9%, 2.8%)                 |
| Right Upper                                                                    |                              | 13 (11.5%)                |                           | 6 (10.2%)                 | (-9.4%, 10.1%)                 |
| Emphysema Severity (%)                                                         | 113                          | 63.6 ± 10.1               | 59                        | 61.6 ± 11.6               | (-1.6, 5.5)                    |
| Emphysema Heterogeneity (%)                                                    | 113                          | 25.3 ± 12.0               | 59                        | 23.3 ± 11.6               | (-1.8, 5.8)                    |

\* Heterogeneity calculated as the difference in emphysema severity between the target and ipsilateral lobe; 6MWT = 6-minute walk test; BCI = Bayesian credible interval; BMI = body mass index; C = control; COPD = chronic obstructive pulmonary disease; FEV<sub>1</sub> = forced expiratory volume in 1 second; FVC = forced vital capacity; mMRC = Modified Medical Research Council; O<sub>2</sub> = oxygen; PCO<sub>2</sub> = partial pressure of carbon dioxide; PO<sub>2</sub> = partial pressure of oxygen; RV = residual volume; SD = standard deviation; SGRQ = St. George's Respiratory Questionnaire; T = treatment; TLC = total lung capacity.

**Table 2: Secondary Effectiveness Outcomes**

| <b>Outcome Measure described as change from baseline</b> | <b>Treatment Group Mean <math>\pm</math> SD (N)</b> | <b>Control Group Mean <math>\pm</math> SD (N)</b> | <b>Difference between groups (95% BCI)</b> | <b>Posterior probability of superiority</b> |
|----------------------------------------------------------|-----------------------------------------------------|---------------------------------------------------|--------------------------------------------|---------------------------------------------|
| <b>TLV 6 months</b>                                      | -0.974 $\pm$ 0.74 (102)                             | NA                                                | -0.974 (-1.12, -0.83)*                     | 1.0000                                      |
| <b>RV 6 months</b>                                       | -0.402 $\pm$ 0.85 (105)                             | -0.042 $\pm$ 0.58 (50)                            | -0.361 (-0.59, -0.13)                      | 0.9990                                      |
| <b>RV/TLC 6 months</b>                                   | -0.035 $\pm$ 0.08 (105)                             | 0.005 $\pm$ 0.04 (50)                             | -0.039 (-0.06, -0.02)                      | 1.0000                                      |
| <b>SGRQ 6 months</b>                                     | -8.1 $\pm$ 17.1 (105)                               | 4.8 $\pm$ 10.6 (50)                               | -13.0 (-17.4, -8.5)                        | 1.0000                                      |
| <b>12 months</b>                                         | -5.8 $\pm$ 16.8 (95)                                | 3.7 $\pm$ 10.9 (41)                               | -9.5 (-14.4, -4.7)                         | 1.0000                                      |
| <b>mMRC 6 months</b>                                     | -0.6 $\pm$ 1.0 (107)                                | -0.0 $\pm$ 0.6 (50)                               | -0.6 (-0.9, -0.3)                          | 1.0000                                      |
| <b>12 months</b>                                         | -0.6 $\pm$ 1.1 (94)                                 | 0.2 $\pm$ 0.6 (41)                                | -0.9 (-1.2, -0.6)                          | 1.0000                                      |
| <b>6MWT 6 months</b>                                     | -4.4 $\pm$ 76.7 (102)                               | -11.3 $\pm$ 51.4 (48)                             | 6.9 (-14.2, 28.2)                          | 0.7438                                      |

\* Compared to Baseline; 6MWT = 6-minute walk test; BCI = Bayesian credible interval; FEV<sub>1</sub> = forced expiratory volume in 1 second (L); mMRC = modified Medical Research Council (points); RV = residual volume (L); SD=standard deviation; SGRQ = St. George's Respiratory Questionnaire (points); TLC = total lung capacity; TLV = target lobe volume (L).

Pre-specified hierarchy of testing: TLV, Hyperinflation (RV/TLC), SGRQ, Dyspnea (mMRC), 6MWT, all at 6 months.

Table 3: Responder Rates for all Effectiveness Outcomes

| Outcome Measure<br>Responder Rates        | Treatment Group<br>n/N (%) | Control Group<br>n/N (%) |
|-------------------------------------------|----------------------------|--------------------------|
| <b>FEV<sub>1</sub> (≥15% improvement)</b> |                            |                          |
| 6 months                                  | 39/106 (36.8%)             | 5/50 (10.0%)             |
| 12 months                                 | 32/86 (37.2%)              | 2/39 (5.1%)              |
| <b>TLV (≥ 350ml reduction)</b>            |                            |                          |
| 6 months                                  | 76/102 (74.5%)             | NA                       |
| <b>RV (≥ 310ml reduction)</b>             |                            |                          |
| 6 months                                  | 53/105 (50.5%)             | 16/50 (32.0%)            |
| <b>SGRQ (≥ 4 point reduction)</b>         |                            |                          |
| 6 months                                  | 57/105 (54.3%)             | 9/50 (18.0%)             |
| 12 months                                 | 48/95 (50.5%)              | 9/41 (22.0%)             |
| <b>mMRC (≥ 1 point reduction)</b>         |                            |                          |
| 6 months                                  | 57/107 (53.3%)             | 9/50 (18.0%)             |
| 12 months                                 | 46/94 (48.9%)              | 3/41 (7.3%)              |
| <b>6MWT (≥ 25m improvement)</b>           |                            |                          |
| 6 months                                  | 33/102 (32.4%)             | 11/48 (22.9%)            |

6MWT = 6-minute walk test; FEV<sub>1</sub> = forced expiratory volume in 1 second; RV = residual volume; SGRQ = St. George's Respiratory Questionnaire;

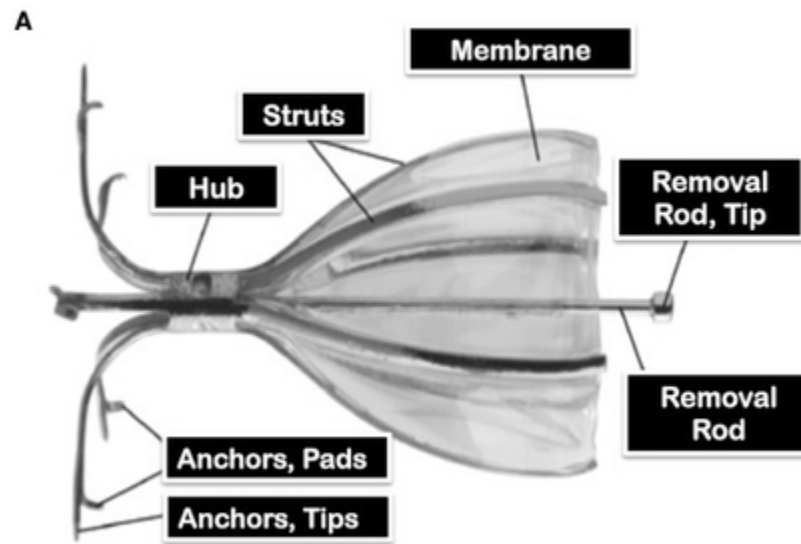


Figure 1: Spiration Valve. Key components of the Spiration Valve.

36x24mm (300 x 300 DPI)

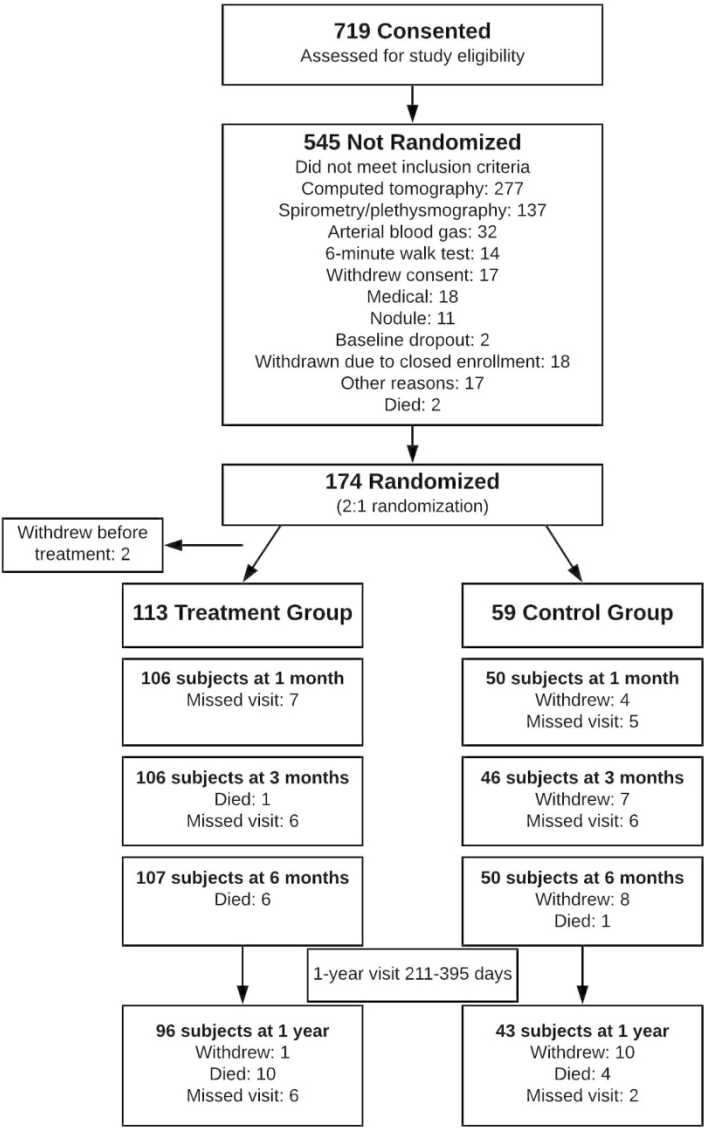


Figure 2: Study Subject Disposition Flow Chart

123x190mm (300 x 300 DPI)

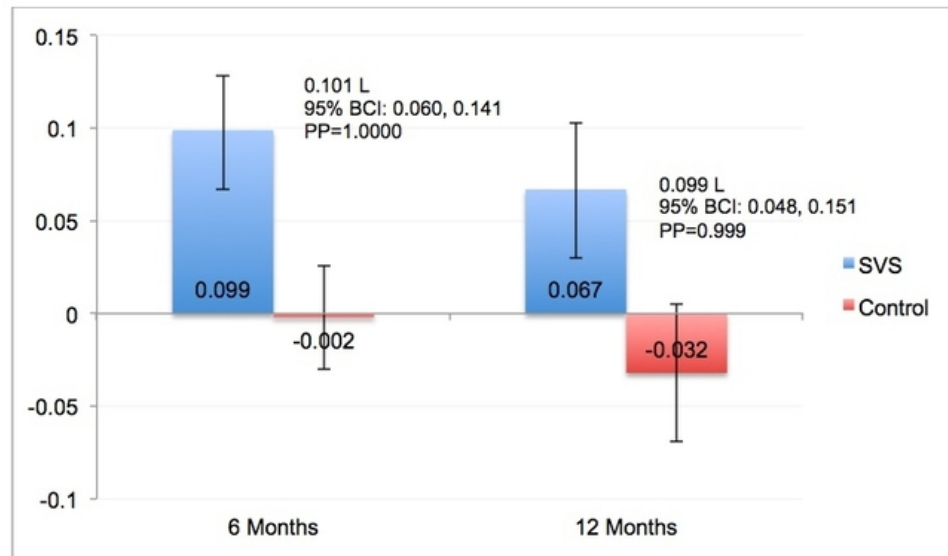


Figure 3: Change in FEV1 at 6 and 12 Months

Mean  $\pm$  95% BCI

BCI=Bayesian credible interval; FEV1= Forced expiratory volume in 1 second; PP=Posterior Probability; SVS=Spiration Valve System.

56x32mm (300 x 300 DPI)

## Online Data Supplement

**Title:** Improving Lung Function in Severe Heterogenous Emphysema with the Spiration® Valve System (EMPROVE): A Multicenter, Open-Label, Randomized, Controlled Trial

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**Trial Registration:** [www.clinicaltrials.gov](http://www.clinicaltrials.gov) Identifier NCT01812447.

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**EMPROVE ONLINE DATA SUPPLEMENT APPENDICES**

|                                                                                                          |           |
|----------------------------------------------------------------------------------------------------------|-----------|
| <i>Appendix 1. Informed Consent and Medical Management Evaluation .....</i>                              | <i>3</i>  |
| <i>Appendix 2. Clinical Sites and Study Investigators.....</i>                                           | <i>5</i>  |
| <i>Appendix 3. Detailed Inclusion and Exclusion Criteria .....</i>                                       | <i>7</i>  |
| <i>Appendix 4. Concomitant Medications .....</i>                                                         | <i>8</i>  |
| <i>Appendix 5. Study Design and Methods.....</i>                                                         | <i>9</i>  |
| <i>Appendix 6. Individual Serious Adverse Events (SAEs) Included in the Thoracic SAE Composite .....</i> | <i>12</i> |
| <i>Appendix 7. Sample Size Rationale .....</i>                                                           | <i>13</i> |
| <i>Appendix 8. Statistical Analysis Methods .....</i>                                                    | <i>14</i> |
| <i>Appendix 9. Additional Baseline Characteristics .....</i>                                             | <i>16</i> |
| <i>Appendix 10. Procedure Details .....</i>                                                              | <i>17</i> |
| <i>Appendix 11. Additional Results: Primary and Secondary Efficacy Assessments .....</i>                 | <i>18</i> |
| <i>Appendix 12. Additional Results: Safety Assessments .....</i>                                         | <i>26</i> |



**Appendix 1. Informed Consent and Medical Management Evaluation**

Subjects were required to sign the informed consent prior to screen testing, the run-in period, baseline testing, and enrollment. This study and the informed consent form and all appropriate amendments were reviewed by a qualified Institutional Review Board (IRB). A list of all IRBs and their initial approval date is provided below:

1. University of Cincinnati Hospital (06/05/13)
2. University of Texas Southwestern Medical Center (06/12/13)
3. University of Utah Health Sciences (07/18/13)
4. Kaiser Permanente Riverside Medical Center (06/18/13)
5. Sarasota Memorial Hospital (07/11/13)
6. University of Chicago Medical Center (07/30/13)
7. University of Tennessee Medical Center (06/18/13)
8. Virginia Commonwealth University (08/01/13)
9. Beth Israel Deaconess Medical Center (8/20/13)
10. Carolinas Medical Center (8/21/13)
11. Florida Hospital (07/02/13)
12. University of Maryland Hospital (09/30/13)
13. Medical College of Wisconsin (09/25/13)
14. University of Pennsylvania (11/15/13)
15. Piedmont Hospital (11/05/13)
16. Michael E. DeBakey VA Medical Center (09/04/13)
17. University of California Medical Center at Los Angeles (07/02/13)
18. University of Washington Medical Center (12/16/13)
19. Lahey Hospital & Medical Center (09/11/13)
20. Penn State Milton S. Hershey Medical Center (10/07/13)
21. Mayo Clinic, Jacksonville (09/12/13)
22. Kaiser Permanente Northwest (01/15/14)

23. University of California San Diego Medical Center (10/24/13)
24. Louisiana State University Hospital (03/10/14)
25. The Cooper Health System (02/12/14)
26. Sparks Regional Medical Center (02/14/14)
27. University of Vermont Medical Center (07/01/14)
28. Tampa General Hospital (05/12/14)
29. Northwestern Memorial Hospital (10/23/14)
30. University of Minnesota Medical Center (09/01/14)
31. Detroit Clinical Research Center (10/28/15)
32. Laval Hospital (09/15/15)
33. Vancouver General Hospital (UBC) (12/09/15)
34. Weill Cornell Medicine (Cornell New York Presbyterian Hospital) (08/08/16)
35. California Pacific Medical Center (06/05/15)
36. University of Calgary (10/01/15)
37. The Ottawa Hospital (09/18/15)
38. Vanderbilt University Medical Center (11/09/15)
39. Miami VA Healthcare System (12/11/15)
40. Temple University Hospital (07/14/16)
41. University of Pittsburgh Medical Center (12/29/16)

**Appendix 2. Clinical Sites and Study Investigators****Table S1. Study Investigators and Enrollment by Clinical Site**

| <b>Pivotal Clinical Site</b>                              | <b>Site ID</b> | <b>Subjects Randomized</b> | <b>Principal Investigator</b>     |
|-----------------------------------------------------------|----------------|----------------------------|-----------------------------------|
| University of Cincinnati Hospital                         | 01             | 7                          | Sadia Benzaquen                   |
| University of Texas Southwestern Medical Center at Dallas | 02             | 6                          | Muhammed Abu-Hijleh               |
| University of Utah Health Sciences                        | 03             | 3                          | Chakravarthy Reddy                |
| Kaiser Permanente Riverside Medical Center                | 04             | 3                          | Gregory Marrujo                   |
| Sarasota Memorial Hospital                                | 05             | 14                         | Kirk Voelker                      |
| University of Chicago                                     | 06             | 9                          | Kyle Hogarth                      |
| University of Tennessee Medical Center                    | 07             | 6                          | Paul Branca                       |
| Virginia Commonwealth University                          | 08             | 2                          | Ray Shepherd                      |
| Beth Israel Deaconess Medical Center                      | 09             | 7                          | Adnan Majid                       |
| Carolinas Medical Center                                  | 10             | 7                          | Michael Zgoda                     |
| Florida Hospital Orlando*                                 | 11             | 0                          | Jorge Guerrero                    |
| University of Maryland                                    | 12             | 5                          | Ashutosh Sachdeva                 |
| Medical College of Wisconsin                              | 13             | 3                          | David Johnstone<br>Mario Gaspari  |
| University of Pennsylvania*                               | 14             | 0                          | Andrew Haas                       |
| Piedmont Hospital                                         | 15             | 2                          | Amy Case                          |
| Michael DeBakey VA Medical Center                         | 16             | 7                          | Donald Lazarus<br>Roberto Casal   |
| University of California Medical Center at Los Angeles*   | 17             | 0                          | Christopher Cooper                |
| University of Washington Medical Center*                  | 18             | 0                          | Douglas Wood                      |
| Lahey Hospital & Medical Center                           | 19             | 4                          | Carla Lamb                        |
| Penn State Milton S. Hershey Medical Center               | 20             | 4                          | Michael Reed                      |
| Mayo Clinic, Jacksonville                                 | 21             | 5                          | Jorge Maella                      |
| Kaiser Permanente Northwest                               | 22             | 2                          | Richard Mularski                  |
| University of California Medical Center at San Diego      | 23             | 2                          | Samir Makani                      |
| Louisiana State University Hospital                       | 24             | 6                          | Robert Holladay<br>Adam Wellikoff |
| The Cooper Health System*                                 | 25             | 4                          | Wissam Abouzgheib                 |
| Sparks Regional Medical Center                            | 26             | 3                          | Arturo Meade                      |
| University of Vermont Medical Center                      | 27             | 5                          | Matt Kinsey                       |
| Tampa General Hospital                                    | 28             | 6                          | Karel Calero<br>Mark Rumbak       |
| Northwestern Memorial Hospital                            | 29             | 5                          | Ravi Kalhan                       |
| University of Minnesota*                                  | 30             | 0                          | Erhan Dincer                      |
| Beaumont Botsford Hospital                                | 31             | 3                          | Phillip Kaplan                    |
| Laval University, Quebec                                  | 32             | 16                         | Simon Martel<br>Antoine Delage    |
| Vancouver General Hospital*                               | 33             | 0                          | Jeremy Road                       |
| Cornell NYPH*                                             | 34             | 0                          | Eugene Shostak                    |
| California Pacific Medical Center                         | 35             | 1                          | Benson Chen                       |
| University of Calgary                                     | 36             | 3                          | Christopher Hergott               |
| The Ottawa Hospital*                                      | 37             | 0                          | Kayvan Amjadi                     |
| Vanderbilt University Medical Center                      | 38             | 0                          | Otis Rickman                      |

|                                          |    |            |               |
|------------------------------------------|----|------------|---------------|
| Miami VA Healthcare System               | 39 | 1          | Gregory Holt  |
| Temple University Hospital               | 40 | 21         | Gerard Criner |
| University of Pittsburgh Medical Center* | 41 | 0          | Frank Sciurba |
| <b>Total</b>                             |    | <b>172</b> |               |

\*Site Closed

### **Appendix 3. Detailed Inclusion and Exclusion Criteria**

#### **Additional Inclusion Criteria**

- Subject has abstained from cigarette smoking for 4 months and is willing to abstain throughout the study
- Investigator has confirmed that medical management is within standard of care and subject has been stable and without a COPD exacerbation for  $\geq 6$  weeks
- Subject provides informed consent and is willing and able to participate in a controlled study and return for all study examinations
- Subjects with  $\alpha$ -1 antitrypsin deficiency must have confirmatory blood test

#### **Exclusion Criteria**

- Severe gas exchange abnormality in either  $\text{PCO}_2$  or  $\text{PO}_2$ 
  - $\text{PCO}_2 > 5$  mm Hg or
  - $\text{PO}_2 < 45$  mm Hg on room air
- Co-existing major medical disease, alcoholism, or drug abuse potential that:
  - Will limit evaluation, participation, or follow-up during 6-month study period
  - Includes neurological or musculoskeletal conditions that may interfere with testing
- $\text{BMI} < 15 \text{ kg/m}^2$
- Hospitalization for COPD exacerbation or respiratory infections in the 3 months prior to baseline testing
- Bronchitis with sputum production  $> 4$  tablespoons or 60 ml per day
- Active asthma component to disease or requires more than 15 mg of prednisone daily
- Presence of giant bulla ( $> 1/3$  volume in either lung)
- Severe pulmonary hypertension based on clinical evaluation
- Prior lung volume reduction surgery or major lung procedures (lobectomy or greater)

- Lung nodule anticipated to require evaluation or intervention during 6-month study period
- Demonstrated unwillingness or inability to complete screening or baseline data collection procedures
- Diffuse emphysema pattern
- Classified as American Society of Anesthesiologists Class >P4 (assessing fitness for surgery), including presence of co-morbidity that could significantly increase risk of a bronchoscopy procedure
- Participated in a study of an investigational drug or device within the 30 days prior to participation in this study or currently participating in another clinical study

#### **Appendix 4. Concomitant Medications**

- Medication could include 3 types of inhaled bronchodilators in common clinical use:
  - Short-acting  $\beta$ -agonists
  - Long-acting  $\beta$ -agonists
  - Long-acting anti-cholinergic drugs
- Inhaled corticosteroids could be discontinued or continued during the study period
  - Inhaled steroids could not be added during the study period
  - Oral corticosteroids (eg, prednisone) were minimized prior to run-in period
  - Patients were not eligible for enrollment if using >15 mg prednisone or equivalent per day
  - Patients able to successfully taper steroid dose could be considered for enrollment
- Oral methylxanthines (ie, theophylline) and other approved respiratory medications could be discontinued or continued during study period, but could not be added to participant's medical regimen during study period.

**Supplemental Oxygen, COPD Exacerbations, and Pulmonary Rehab**

- Supplemental oxygen, if prescribed, was to remain stable during study period. Any changes to prescribed oxygen were explained and documented in participant's clinical records.
- COPD exacerbations were treated by each participant's physician. Intermittent oral and intravenous glucocorticoids were allowed for COPD exacerbations.
- All participants were assessed to determine if they should complete a pulmonary rehabilitation (PR) program prior to participating. Those who completed a PR program in 2 years prior to consent were not required to participate in another. If they had not completed a PR program in the last 2 years, the study investigator determined if the patient was likely to clinically benefit from a PR program. If no, patients were not required to complete a PR program; if yes, patients were required to complete a certified outpatient or supervised home-based PR program.

## **Appendix 5. Study Design and Methods**

Participants considered eligible after screening tests were evaluated for stable medical management, which was required before starting the 6-week run-in period. Participants were deemed stable based on ACP/ACCP/ATS/ERS Guidelines for Management of Stable COPD.<sup>1</sup> The evaluation included details on COPD medications, oxygen use, and pulmonary rehabilitation. Any changes required to achieve participant stability had to be made before the start of the 6-week run-in period. Participants were expected to maintain stable medical management during the 6-month primary endpoint period and not elect any additional interventions to treat their emphysema.

### **Run-in and Baseline Testing**

A 6-week run-in period was required to allow a subject to achieve treatment stability and observe that a COPD exacerbation has not occurred prior to baseline testing. The run-in was repeated if patients experienced a COPD exacerbation, or if significant medical management changes were required during the initial 6 weeks.

Baseline testing followed the 6-week run-in period and consisted of patient history and physical examination and evaluation of pulmonary function and morphology, including the following:

- Office evaluation
  - Age, sex, height, weight, BMI, ethnicity, race
  - General physical examination
  - Detailed pulmonary examination with record of pulmonary medications
  - Vital signs
  - Pulmonary examination with review of pulmonary medications and notation of any changes and why
  - SpO<sub>2</sub> and O<sub>2</sub> level if O<sub>2</sub> prescribed
- Clinical laboratory tests



- Routine blood tests
- Urine or serum cotinine test
- $\alpha$ 1-Antitrypsin level with confirmatory blood test, and phenotyping, if indicated
- Female participants of childbearing potential: serum human chorionic gonadotropin pregnancy test within 7 days of procedure
- Physiologic testing
  - 6MWT with prescribed oxygen, if any
  - Pulmonary function tests (PFT) including
    - Spirometry post-bronchodilator (eg albuterol MDI 2 puffs)
    - Lung volume by plethysmography (TLC)
- Imaging studies
  - High resolution computed tomography (HRCT) scan for assessing high heterogeneity and inter-lobar fissures
  - Proportion of lobar lung parenchyma destroyed by emphysema was established by HRCT
  - HRCT to determine lobe volumes including target lobe volume
- Questionnaires
  - Medical Research Council, Modified (mMRC) Questionnaire (administered by a trained interviewer or an investigator)
  - St. George's Respiratory Questionnaire (SGRQ)
  - COPD Assessment Test (CAT)
  - SF-36 Health Survey (SF-36)
  - Quality of Well Being Questionnaire – Utility Scale (QWB)

## Management of Pneumothorax

Pneumothorax after valve placement can be an effect of the desired treatment response that is associated with complete lobe treatment and atelectasis. The management of pneumothorax is

an integral part of valve treatment. The origin of pneumothoraces is thought to be from the rupture of stretched, diseased tissue adjacent to the volume-reduced lobe.

The EMPROVE study used the following management guidelines for pneumothorax events. However, clinical management of pneumothorax varied depending on clinical circumstances, so exceptions to these guidelines were expected.

- A small and minimally symptomatic pneumothorax was to be observed or aspirated.
- A large or symptomatic pneumothorax was to require tube thoracostomy drainage for lung expansion.
- If there was a persistent air leak after 3 days of tube drainage, 1 valve was to be removed from the treated lobe to allow expansion of the lobe (if the left upper-lobe was the treatment lobe, the removal would be from a lingular segment). For those patients whose persistent air leak then resolved within 4 days of valve removal, discharge would occur with replacement of the 1 valve scheduled in 6 weeks. During the valve replacement procedure, if previously placed valves were observed to be sub-optimally placed, the investigator may remove and replace any sub-optimally placed valves.
- If the leak did not resolve within 4 days of valve removal, the remaining valves were to be removed. These subjects were to be followed for any AEs until the event subsided, or in case of permanent impairment, until the event stabilized and the overall clinical outcome had been ascertained, at which time the subject was to be withdrawn from the study.
  - This event was to be considered an SAE, belonging to the category of "Pneumothorax requiring surgical intervention or prolonged air leak >7 days defined as the time from chest tube insertion to the time the air leak is not present."

## **Appendix 6. Individual Serious Adverse Events (SAEs) Included in the Thoracic SAE Composite**

- Acute asthma or bronchospasm requiring admission to an intensive or critical care unit
- Acute exacerbation of COPD that is acute onset, life threatening, and requires hospitalization
- Airway injury from valve placement, valve migration, or airway stenosis from a valve, requiring surgical intervention
- Death from the procedure or device
- Massive hemoptysis (estimated over 300 ml in 24 hours and requiring transfusion, surgery, or arterial embolization) attributed to the procedure or device
- Pneumonia in the valve-treated lobe that requires hospitalization, IV antibiotics, and valve removal
- Pneumonia NOT in the valve-treated lobe that is life-threatening, acute onset, and requires hospitalization and IV antibiotics
- Pneumothorax requiring surgical intervention or prolonged air leak > 7 days defined as the time from chest tube insertion to the time the air leak is not present
- Respiratory failure that requires mechanical ventilatory support for > 24 hours
- Tension pneumothorax that is life-threatening, acute onset, and requires hospitalization and treatment

## **Appendix 7. Sample Size Rationale**

This study was designed to adaptively determine the appropriate sample size via a Bayesian adaptive design.<sup>2,3</sup> Though the pre-specified analysis used Bayesian methods, the choice of maximum sample size was guided by the usual considerations for a t-test with one-sided  $\alpha = 0.025$ : using conservative assumptions (difference in means = 100mL, sd = 200mL in each group, 2:1 allocation ratio), a sample size of 165 (110 treatment, 55 control) subjects is required to achieve 85% power. Allowing for missing data and a modest sample size increase to compensate for power loss caused by interim analyses, a maximum of N=220 subjects was chosen. Interim analyses at N=100 and N=160 enrollments were planned, at which the trial could stop enrolling for futility (based on a low predictive probability of success) or eventual success (based on a high predictive probability of success). In this adaptive design, the sole analysis to determine success occurs 6 months after enrollment stop (thus avoiding enrollment over-runs during the last 6 months of follow-up). Randomization followed a 2:1 (Treatment:Control) allocation ratio and was stratified by site, using a blocked randomization scheme with blocks of randomly varying sizes.

Bayesian statistical modeling was used to predict 6-month FEV<sub>1</sub> change-from-baseline measures from the change-from-baseline measures at 1 month and 3 months. For those with outcomes at all time points, a linear regression of 6-month FEV<sub>1</sub> outcome on the earlier FEV<sub>1</sub> measures (1-month and 3-month) was used to establish posterior distributions for the regression coefficients, from which 6-month FEV<sub>1</sub> observations were predicted for those who were missing only the 6-month measure. Similar regression models were used to predict 6-month outcomes for those with baseline and 1-month data, baseline and 3-month data, and only baseline data. Imputing 6-month values multiple times and combining each set of imputed values with the observed 6-month data, a set of posterior probabilities of superiority was obtained. The proportion of posterior probabilities exceeding the pre-specified threshold of

0.982 determined the predictive probability of eventual success on which stopping decisions were based..

### **Appendix 8. Statistical Analysis Methods**

The primary effectiveness objective was to establish that the Spiration Valve System is superior to control as assessed by change from baseline in FEV<sub>1</sub>. The hypothesis of interest is

$$H: \mu_t > \mu_c,$$

where  $\mu_t$  and  $\mu_c$ , represent the mean FEV<sub>1</sub> change from baseline for the Treatment and Control Groups, respectively. The Spiration Valve System will be declared to be superior to control if it can be established that the posterior probability  $\Pr(H \mid \text{data}) > \Psi$ , where  $\Psi$  is a pre-specified threshold value that is chosen to achieve a type I error rate (under simulation) of at most 0.025. The value  $\Psi$  specified for this trial is  $\Psi = 0.982$ , noticeably greater than a value of 0.975 that might be expected in a design without interim analyses.

Flat or diffuse prior distributions are specified for all secondary effectiveness analyses. For any hypothesis test, a posterior probability greater than 97.5% for the specified hypothesis will be considered to constitute evidence in favor of the hypothesis, in the same sense that a frequentist analysis would reject a null hypothesis when  $p < 0.025$  and call it “statistically significant.”

Secondary effectiveness measures are formally tested in the following pre-specified hierarchy, using a posterior probability threshold of 0.975 to determine significance and continuation of testing:

- Target lobe volume (baseline to 6 months)
- Hyperinflation (baseline to 6 months)

- SGRQ (baseline to 6 months)
- Dyspnea (baseline to 6 months)
- 6MWT (baseline to 6 months)
- FEV<sub>1</sub> Responders (proportions who achieve  $\geq 15\%$  improvement from baseline to 6 months)

For the primary safety objective, the statistical analyses will consist of presenting 95% Bayesian credible intervals for the difference and ratio of the probability of the composite SAE in the treatment and control groups. Independent beta (1,1) prior distributions will be used for the probability of an event in the treatment and control groups ( $\pi_T$  and  $\pi_C$ ). The 95% Bayesian credible intervals will be presented for the difference in the probabilities,  $\pi_T - \pi_C$ , and for the ratio of these probabilities,  $\pi_T / \pi_C$ . The 95% Bayesian credible intervals will be those ranging from the 2.5th to the 97.5th percentiles.

For the secondary safety objective, the rate of each individual thoracic serious adverse event will be analyzed. Calculations for each event will count subjects only once if they have more than one occurrence of each serious adverse event. The statistical analyses will consist of presenting 95% Bayesian credible intervals for the probabilities of each SAE. Independent beta (1,1) prior distributions will be used for the probability of an event in the treatment and control groups ( $\pi_T$  and  $\pi_C$ ). The 95% Bayesian credible intervals will be presented for  $\pi_T$  and  $\pi_C$  as well as for the difference  $\pi_T - \pi_C$  and the ratio  $\pi_T / \pi_C$ .

**Appendix 9. Additional Baseline Characteristics****Table S2. Pulmonary Medications and Use of Supplemental Oxygen**

| <b>Baseline Medication</b>                                                                     | <b>Treatment<br/>% (n/N)</b> | <b>Control<br/>% (n/N)</b> |
|------------------------------------------------------------------------------------------------|------------------------------|----------------------------|
| <b>Monotherapy</b>                                                                             | 7.1% (8/113)                 | 6.8% (4/59)                |
| <b>Combination therapy</b>                                                                     | 92.9% (105/113)              | 93.2% (55/59)              |
| <b>Bronchodilator</b>                                                                          | 100% (113/113)               | 100% (59/59)               |
| <b>Steroid</b>                                                                                 | 81.4% (92/113)               | 84.7% (50/59)              |
| <b>Long-acting beta-agonist<br/>bronchodilator and<br/>inhaled corticosteroid</b>              | 76.1% (86/113)               | 79.7% (47/59)              |
| <b>Methylxanthines</b>                                                                         | 5.3% (6/113)                 | 11.9% (7/59)               |
| <b>Short acting beta agonist<br/>bronchodilator and short<br/>acting muscarinic antagonist</b> | 7.1% (8/113)                 | 6.8% (4/59)                |
| <b>Short acting muscarinic<br/>antagonist</b>                                                  | 7.1% (8/113)                 | 6.8% (4/59)                |
| <b>Long acting muscarinic<br/>antagonist</b>                                                   | 0.9% (1/113)                 | 0.0% (0/59)                |
| <b>PDE-4 inhibitor</b>                                                                         | 12.4% (14/113)               | 1.7% (1/59)                |
| <b>Mucolytic</b>                                                                               | 1.8% (2/113)                 | 0.0% (0/59)                |
| <b>Leukotriene receptor<br/>antagonist</b>                                                     | 4.4% (5/113)                 | 8.5% (5/59)                |
| <b>Supplemental Oxygen</b>                                                                     | 45.1% (51/113)               | 45.8% (27/59)              |

**Appendix 10. Procedure Details****Table S3. Procedure Times and Hospital Stay by Group**

|                             | <b>N</b> | <b>Mean</b> | <b>Standard deviation</b> | <b>Max</b> | <b>Min</b> | <b>Median</b> |
|-----------------------------|----------|-------------|---------------------------|------------|------------|---------------|
| <b>Procedure time (min)</b> | 113      | 24.26       | 11.43                     | 73         | 9          | 22            |
| <b>Hospital stay (days)</b> | 113      | 3.81        | 10.12                     | 95*        | 1          | 1             |

\* 1 Patient not discharged, died at 95 days.

**Table S4. Target Lobe Treated**

| <b>Target lobe</b>      | <b>Number of subjects (N=113)</b> | <b>Percent</b> |
|-------------------------|-----------------------------------|----------------|
| <b>Left upper lobe</b>  | 66                                | 58.4%          |
| <b>Left lower lobe</b>  | 27                                | 23.9%          |
| <b>Right upper lobe</b> | 13                                | 11.5%          |
| <b>Right lower lobe</b> | 7                                 | 6.2%           |

**Table S5. Valves Used and Placed During Initial Procedure**

| <b>Category</b>                         | <b>Count</b> | <b>Number of subjects</b> |
|-----------------------------------------|--------------|---------------------------|
| <b>Total valves used</b>                | 536          | 113                       |
| <b>Total valves used but not placed</b> | 60           | 12                        |
| <b>Total valves placed</b>              | 476          | 113                       |



## Appendix 11. Additional Results: Primary and Secondary Efficacy Assessments

The pre-specified analysis included Bayesian multiple imputation for missing data, however, completers only analysis (without Bayesian imputation) is also included,

**Table S6: FEV<sub>1</sub> - Means and Change from Baseline through 12 Months**

| FEV <sub>1</sub> (L)    | Treatment Group                                                          | Control Group                                                              | Difference (T–C)        |                                                    |
|-------------------------|--------------------------------------------------------------------------|----------------------------------------------------------------------------|-------------------------|----------------------------------------------------|
|                         | Mean ± SD (N)<br>[min, median, max]                                      | Mean ± SD (N)<br>[min, median, max]                                        | Estimate*,<br>(95% BCI) | Posterior<br>Probability of<br>( $\mu_T > \mu_C$ ) |
| <b>Baseline</b>         | 0.825 ± 0.264 (113)<br>[0.410, 0.790, 1.460]                             | 0.792 ± 0.260 (59)<br>[0.370, 0.760, 1.530]                                |                         |                                                    |
| <b>1 Mo</b>             | 0.974 ± 0.324 (102)<br>[0.350, 0.920, 1.990]                             | 0.808 ± 0.221 (50)<br>[0.440, 0.790, 1.460]                                |                         |                                                    |
| <b>3 Mo</b>             | 0.940 ± 0.315 (105)<br>[0.350, 0.900, 2.020]                             | 0.820 ± 0.239 (45)<br>[0.400, 0.820, 1.320]                                |                         |                                                    |
| <b>6 Mo</b>             | 0.937 ± 0.296 (106)<br>[0.340, 0.905, 1.820]                             | 0.811 ± 0.274 (50)<br>[0.440, 0.750, 1.700]                                |                         |                                                    |
| <b>12 Mo</b>            | 0.920 ± 0.301 (86)<br>[0.330, 0.860, 1.760]                              | 0.790 ± 0.257 (39)<br>[0.410, 0.770, 1.460]                                |                         |                                                    |
| <b>1 Mo – Baseline</b>  | 0.145 ± 0.173 (102)<br>[-0.190, 0.105, 0.750]                            | -0.000 ± 0.101 (50)<br>[-0.260, -0.005, 0.240]                             |                         |                                                    |
| <b>3 Mo – Baseline</b>  | 0.121 ± 0.172 (105)<br>[-0.330, 0.110, 0.680]                            | -0.003 ± 0.102 (45)<br>[-0.340, 0.000, 0.180]                              |                         |                                                    |
| <b>6 Mo – Baseline</b>  | 0.099 ± 0.154 (106)<br>[-0.260, 0.080, 0.530]<br>95% BCI: (0.069, 0.128) | -0.002 ± 0.098 (50)<br>[-0.240, -0.010, 0.210]<br>95% BCI: (-0.030, 0.026) |                         |                                                    |
|                         | Completers Only – Without Predictions                                    |                                                                            | 0.101<br>(0.060, 0.141) | 1.0000                                             |
|                         | With Predictions for Missing Values                                      |                                                                            | 0.097<br>(0.057, 0.138) | 1.0000                                             |
| <b>12 Mo - Baseline</b> | 0.067 ± 0.167 (86)<br>[-0.280, 0.060, 0.600]<br>95% BCI: (0.031, 0.103)  | -0.032 ± 0.114 (39)<br>[-0.300, -0.030, 0.390]<br>95% BCI: (-0.069, 0.005) |                         |                                                    |
|                         | Completers Only – Without Predictions                                    |                                                                            | 0.099<br>(0.048, 0.151) | 0.9999                                             |
|                         | With Predictions for Missing Values                                      |                                                                            | 0.088<br>(0.037, 0.137) | 0.9997                                             |

BCI = Bayesian credible interval; C = control; Mo = month; N = total of number of patients randomized/enrolled/treated; SD = standard deviation; T = treatment; FEV<sub>1</sub> = forced expiratory volume in 1 second.

\*Posterior median

**Table S7: FEV<sub>1</sub> Responders (Defined as ≥15% Improvement)**

| FEV <sub>1</sub><br>Responder<br>Rate (≥15%<br>Improvement) | Treatment Group                       | Control Group | Difference (T–C)        |                                                                   |
|-------------------------------------------------------------|---------------------------------------|---------------|-------------------------|-------------------------------------------------------------------|
|                                                             | n/N (%)                               | n/N (%)       | Estimate*,<br>(95% BCI) | Posterior<br>Probability of<br>(p <sub>T</sub> > p <sub>C</sub> ) |
| <b>1 Mo</b>                                                 | 47/102 (46.1%)                        | 6/50 (12.0%)  |                         |                                                                   |
| <b>3 Mo</b>                                                 | 50/105 (47.6%)                        | 4/45 (8.9%)   |                         |                                                                   |
| <b>6 Mo</b>                                                 | 39/106 (36.8%)                        | 5/50 (10.0%)  |                         |                                                                   |
|                                                             | Completers Only – Without Predictions |               | 25.7%<br>(12.5, 37.5)   | 0.9998                                                            |
|                                                             | With Predictions for Missing Values   |               | 23.4%<br>(10.7, 35.8)   | 0.9998                                                            |
|                                                             |                                       |               |                         |                                                                   |
| <b>12 Mo</b>                                                | 32/86 (37.2%)                         | 2/39 (5.1%)   |                         |                                                                   |
|                                                             | Completers Only – Without Predictions |               | 30.4%<br>(16.8, 42.5)   | 0.9999                                                            |
|                                                             | With Predictions for Missing Values   |               | 24.9%<br>(12.0, 37.3)   | 0.9999                                                            |
|                                                             |                                       |               |                         |                                                                   |

BCI = Bayesian credible interval; C = control; FEV<sub>1</sub> = forced expiratory volume in 1 second; Mo = month; N = total of number of patients randomized/enrolled/treated; n = number of patients in the subset at the given time point; T = treatment.

\*Posterior median

**Table S8. FEV<sub>1</sub> Responders with ≥12% Improvement**

| FEV <sub>1</sub> Responder<br>≥ 12%<br>improvement | Treatment Group                       | Control Group | Difference (T–C)        |                                                                   |
|----------------------------------------------------|---------------------------------------|---------------|-------------------------|-------------------------------------------------------------------|
|                                                    | n/N (%)                               | n/N (%)       | Estimate*,<br>(95% BCI) | Posterior<br>Probability of<br>(p <sub>T</sub> > p <sub>C</sub> ) |
| <b>1 Mo</b>                                        | 50/102 (49.0%)                        | 10/50 (20.0%) |                         |                                                                   |
| <b>3 Mo</b>                                        | 53/105 (50.5%)                        | 7/45 (15.6%)  |                         |                                                                   |
| <b>6 Mo</b>                                        | 46/106 (43.4%)                        | 8/50 (16.0%)  |                         |                                                                   |
|                                                    | Completers Only – Without Predictions |               | 26.4%<br>(11.8, 39.5)   | 0.9997                                                            |
|                                                    | With Predictions for Missing Values   |               | 24.2%<br>(10.3, 37.8)   | 0.9996                                                            |
|                                                    |                                       |               |                         |                                                                   |
| <b>12 Mo</b>                                       | 36/86 (41.9%)                         | 4/39 (10.3%)  |                         |                                                                   |
|                                                    | Completers Only – Without Predictions |               | 30.1%<br>(14.8, 43.4)   | 0.9999                                                            |
|                                                    | With Predictions for Missing Values   |               | 27.2%<br>(13.4, 40.6)   | 0.9999                                                            |
|                                                    |                                       |               |                         |                                                                   |

BCI = Bayesian credible interval; C = control; FEV<sub>1</sub> = forced expiratory volume in 1 second; Mo = month; N = total of number of patients randomized/enrolled/treated; n = number of patients in the subset at the given time point; SD = standard deviation; T = treatment.

\*Posterior median

**Table S9. FEV<sub>1</sub> Responders with  $\geq 20\%$  Improvement**

| FEV <sub>1</sub> Responder<br>$\geq 20\%$<br>improvement | Treatment Group                       | Control Group | Difference (T–C)        |                                                   |
|----------------------------------------------------------|---------------------------------------|---------------|-------------------------|---------------------------------------------------|
|                                                          | n/N (%)                               | n/N (%)       | Estimate*,<br>(95% BCI) | Posterior<br>Probability<br>of<br>( $p_T > p_C$ ) |
| <b>1 Mo</b>                                              | 44/102 (43.1%)                        | 4/50 (8.0%)   |                         |                                                   |
| <b>3 Mo</b>                                              | 40/105 (38.1%)                        | 3/45 (6.7%)   |                         |                                                   |
| <b>6 Mo</b>                                              | 35/106 (33.0%)                        | 2/50 (4.0%)   |                         |                                                   |
|                                                          | Completers Only – Without Predictions |               | 27.7%<br>(16.3, 38.2)   | 1.0000                                            |
|                                                          | With Predictions for Missing Values   |               | 25.5%<br>(14.4, 36.4)   | 1.0000                                            |
| <b>12 Mo</b>                                             | 28/86 (32.6%)                         | 1/39 (2.6%)   |                         |                                                   |
|                                                          | Completers Only – Without Predictions |               | 28.2%<br>(15.9, 39.6)   | 1.0000                                            |
|                                                          | With Predictions for Missing Values   |               | 24.1%<br>(12.6, 35.4)   | 1.0000                                            |

BCI = Bayesian credible interval; C = control; FEV<sub>1</sub> = forced expiratory volume in 1 second; Mo = month; N = total of number of patients randomized/enrolled/treated; n = number of patients in the subset at the given time point; SD = standard deviation; T = treatment.

\*Posterior median

**Table S10. Target Lobe Volume - Means and Change From Baseline Through 6 Months**

| TLV (L)          | Treatment Group                                     | Estimate*,<br>(95% BCI)    | Posterior<br>Probability of<br>( $\mu_T < 0$ ) |
|------------------|-----------------------------------------------------|----------------------------|------------------------------------------------|
|                  | Mean $\pm$ SD (N)<br>[min, median, max]             |                            |                                                |
| <b>BL</b>        | 1.843 $\pm$ 0.602 (113)<br>[0.980, 1.670, 3.831]    |                            |                                                |
| <b>6 Mo</b>      | 0.869 $\pm$ 0.856 (102)<br>[0.000, 0.886, 3.437]    |                            |                                                |
| <b>6 Mo – BL</b> | -0.974 $\pm$ 0.736 (102)<br>[-3.403, -0.974, 0.280] |                            |                                                |
|                  | Completers Only –<br>Without Predictions            | -0.974<br>(-1.119, -0.829) | 1.0000                                         |

BCI = Bayesian credible interval; BL = baseline; C = control; Mo = month; N = total of number of patients randomized/enrolled/treated; SD = standard deviation; T = treatment; TLV = target lobe volume.

\*Posterior median

**Table S11a: Hyperinflation (RV/TLC) - Means and Change From Baseline Through 6 Months**

| Hyperinflation (RV/TLC) | Treatment Group                                                                  | Control Group                                                                | Difference (T-C)           |                                                    |
|-------------------------|----------------------------------------------------------------------------------|------------------------------------------------------------------------------|----------------------------|----------------------------------------------------|
|                         | Mean $\pm$ SD (N)<br>[min, median, max]                                          | Mean $\pm$ SD (N)<br>[min, median, max]                                      | Estimate*,<br>(95% BCI)    | Posterior<br>Probability of<br>( $\mu_T < \mu_C$ ) |
| <b>BL</b>               | 0.632 $\pm$ 0.080 (113)<br>[0.443, 0.636, 0.836]                                 | 0.632 $\pm$ 0.086 (59)<br>[0.453, 0.648, 0.817]                              |                            |                                                    |
| <b>3 Mo</b>             | 0.594 $\pm$ 0.092 (103)<br>[0.367, 0.596, 0.823]                                 | 0.632 $\pm$ 0.081 (45)<br>[0.411, 0.643, 0.762]                              |                            |                                                    |
| <b>6 Mo</b>             | 0.595 $\pm$ 0.099 (105)<br>[0.318, 0.602, 0.826]                                 | 0.628 $\pm$ 0.084 (50)<br>[0.443, 0.633, 0.795]                              |                            |                                                    |
| <b>3 Mo – BL</b>        | -0.036 $\pm$ 0.080 (103)<br>[-0.312, -0.024, 0.123]                              | 0.010 $\pm$ 0.046 (45)<br>[-0.059, 0.008, 0.150]                             |                            |                                                    |
| <b>6 Mo – BL</b>        | -0.035 $\pm$ 0.080 (105)<br>[-0.253, -0.030, 0.136]<br>95% BCI: (-0.050, -0.019) | 0.005 $\pm$ 0.039 (50)<br>[-0.087, 0.005, 0.103]<br>95% BCI: (-0.007, 0.016) |                            |                                                    |
|                         | Completers Only – Without Predictions                                            |                                                                              | -0.039<br>(-0.058, -0.020) | 1.0000                                             |
|                         | With Predictions for Missing Values                                              |                                                                              | -0.039<br>(-0.058, -0.020) | 1.0000                                             |

BCI = Bayesian credible interval; BL = baseline; C = control; Mo = month; N = total of number of patients randomized/enrolled/treated; RV = residual volume; SD = standard deviation; T = treatment; TLC = total lung capacity.

\*Posterior median

**Table S11b: Residual Volume (RV) Means and Change From Baseline Through 6 Months**

| Residual Volume (L)    | Treatment Group                                                                  | Control Group                                                                  | Difference (T-C)           |                                                    |
|------------------------|----------------------------------------------------------------------------------|--------------------------------------------------------------------------------|----------------------------|----------------------------------------------------|
|                        | Mean $\pm$ SD (N)<br>[min, median, max]                                          | Mean $\pm$ SD (N)<br>[min, median, max]                                        | Estimate*,<br>(95% BCI)    | Posterior<br>Probability of<br>( $\mu_T < \mu_C$ ) |
| <b>Baseline</b>        | 4.573 $\pm$ 1.253 (113)<br>[2.740, 4.280, 8.770]                                 | 4.848 $\pm$ 1.199 (59)<br>[2.840, 4.720, 8.600]                                |                            |                                                    |
| <b>3 Mo</b>            | 4.147 $\pm$ 1.302 (103)<br>[2.000, 3.940, 8.310]                                 | 4.898 $\pm$ 1.268 (45)<br>[3.190, 4.660, 8.500]                                |                            |                                                    |
| <b>6 Mo</b>            | 4.191 $\pm$ 1.309 (105)<br>[1.940, 3.980, 8.670]                                 | 4.730 $\pm$ 1.172 (50)<br>[3.160, 4.485, 8.230]                                |                            |                                                    |
| <b>3 Mo – Baseline</b> | -0.410 $\pm$ 0.900 (103)<br>[-5.280, -0.340, 1.500]                              | 0.104 $\pm$ 0.562 (45)<br>[-1.110, 0.140, 2.280]                               |                            |                                                    |
| <b>6 Mo – Baseline</b> | -0.402 $\pm$ 0.849 (105)<br>[-3.360, -0.330, 1.630]<br>95% BCI: (-0.567, -0.238) | -0.042 $\pm$ 0.583 (50)<br>[-1.190, -0.035, 1.340]<br>95% BCI: (-0.208, 0.124) |                            |                                                    |
|                        | Completers Only – Without Predictions                                            |                                                                                | -0.361<br>(-0.594, -0.127) | 0.9990                                             |
|                        | With Predictions for Missing Values                                              |                                                                                | -0.362<br>(-0.594, -0.129) | 0.9989                                             |

BCI = Bayesian credible interval; BL = baseline; C = control; Mo = month; N = total of number of patients randomized/enrolled/treated; RV = residual volume; SD = standard deviation; T = treatment.

\*Posterior median

**Table S12: SGRQ - Means and Change From Baseline Through 12 Months**

| SGRQ (points)     | Treatment Group                                                        | Control Group                                                    | Difference (T-C)        |                                                    |
|-------------------|------------------------------------------------------------------------|------------------------------------------------------------------|-------------------------|----------------------------------------------------|
|                   | Mean $\pm$ SD (N)<br>[min, median, max]                                | Mean $\pm$ SD (N)<br>[min, median, max]                          | Estimate*,<br>(95% BCI) | Posterior<br>Probability of<br>( $\mu_T > \mu_C$ ) |
| <b>BL</b>         | 57.2 $\pm$ 14.8 (113)<br>[23.6, 59.0, 92.9]                            | 54.6 $\pm$ 13.6 (59)<br>[31.8, 53.2, 84.7]                       |                         |                                                    |
| <b>1 Mo</b>       | 51.0 $\pm$ 16.2 (105)<br>[12.8, 50.8, 86.2]                            | 56.3 $\pm$ 14.8 (50)<br>[24.8, 57.7, 83.7]                       |                         |                                                    |
| <b>3 Mo</b>       | 49.1 $\pm$ 17.2 (106)<br>[5.4, 49.8, 97.9]                             | 56.3 $\pm$ 16.7 (43)<br>[21.4, 57.7, 80.5]                       |                         |                                                    |
| <b>6 Mo</b>       | 49.0 $\pm$ 17.2 (105)<br>[8.7, 47.8, 87.3]                             | 59.4 $\pm$ 15.8 (50)<br>[24.9, 62.6, 84.4]                       |                         |                                                    |
| <b>12 Mo</b>      | 50.7 $\pm$ 18.5 (95)<br>[11.1, 50.5, 86.7]                             | 57.0 $\pm$ 16.6 (41)<br>[26.9, 55.8, 89.9]                       |                         |                                                    |
| <b>1 Mo – BL</b>  | -6.5 $\pm$ 15.9 (105)<br>[-51.0, -5.6, 48.8]                           | 2.8 $\pm$ 8.4 (50)<br>[-13.2, 2.9, 21.2]                         |                         |                                                    |
| <b>3 Mo – BL</b>  | -8.0 $\pm$ 17.6 (106)<br>[-52.0, -6.9, 57.3]                           | 4.2 $\pm$ 10.7 (43)<br>[-22.1, 3.4, 26.0]                        |                         |                                                    |
| <b>6 Mo – BL</b>  | -8.1 $\pm$ 17.1 (105)<br>[-48.3, -5.6, 27.6]<br>95% BCI: (-11.5, -4.8) | 4.8 $\pm$ 10.6 (50)<br>[-16.9, 4.3, 28.2]<br>95% BCI: (1.8, 7.8) |                         |                                                    |
|                   | Completers Only – Without Predictions                                  |                                                                  | -13.0<br>(-17.4, -8.5)  | 1.0000                                             |
|                   | With Predictions for Missing Values                                    |                                                                  | -12.9<br>(-17.3, -8.5)  | 1.0000                                             |
| <b>12 Mo – BL</b> | -5.8 $\pm$ 16.8 (95)<br>[-50.1, -4.7, 36.4]<br>95% BCI: (-9.2, -2.4)   | 3.7 $\pm$ 10.9 (41)<br>[-15.3, 2.4, 33.7]<br>95% BCI: (0.3, 7.2) |                         |                                                    |
|                   | Completers Only – Without Predictions                                  |                                                                  | -9.5<br>(-14.4, -4.7)   | 1.0000                                             |
|                   | With Predictions for Missing Values                                    |                                                                  | -8.7<br>(-13.4, -4.0)   | 0.9999                                             |

BCI = Bayesian credible interval; BL = baseline; C = control; Mo = month; N = total of number of patients randomized/enrolled/treated; SD = standard deviation; SGRQ = St. George's Respiratory Questionnaire; T = treatment.

\*Posterior median

**Table S13: mMRC Dyspnea Score - Means and Change From Baseline Through 12 Months**

| mMRC Score        | Treatment Group                                                    | Control Group                                                   | Difference (T-C)        |                                                    |
|-------------------|--------------------------------------------------------------------|-----------------------------------------------------------------|-------------------------|----------------------------------------------------|
|                   | Mean $\pm$ SD (N)<br>[min, median, max]                            | Mean $\pm$ SD (N)<br>[min, median, max]                         | Estimate*,<br>(95% BCI) | Posterior<br>Probability of<br>( $\mu_T > \mu_C$ ) |
| <b>BL</b>         | 2.7 $\pm$ 0.7 (113)<br>[1.0, 3.0, 4.0]                             | 2.7 $\pm$ 0.6 (59)<br>[2.0, 3.0, 4.0]                           |                         |                                                    |
| <b>1 Mo</b>       | 2.3 $\pm$ 1.0 (106)<br>[0.0, 2.0, 4.0]                             | 2.7 $\pm$ 0.7 (50)<br>[1.0, 3.0, 4.0]                           |                         |                                                    |
| <b>3 Mo</b>       | 2.2 $\pm$ 1.1 (106)<br>[0.0, 2.0, 4.0]                             | 2.7 $\pm$ 0.7 (45)<br>[1.0, 3.0, 4.0]                           |                         |                                                    |
| <b>6 Mo</b>       | 2.1 $\pm$ 1.0 (107)<br>[0.0, 2.0, 4.0]                             | 2.6 $\pm$ 0.9 (50)<br>[1.0, 3.0, 4.0]                           |                         |                                                    |
| <b>12 Mo</b>      | 2.1 $\pm$ 1.1 (94)<br>[0.0, 2.0, 4.0]                              | 2.9 $\pm$ 0.8 (41)<br>[1.0, 3.0, 4.0]                           |                         |                                                    |
| <b>1 Mo – BL</b>  | -0.4 $\pm$ 0.9 (106)<br>[-3.0, 0.0, 2.0]                           | 0.0 $\pm$ 0.6 (50)<br>[-1.0, 0.0, 2.0]                          |                         |                                                    |
| <b>3 Mo – BL</b>  | -0.5 $\pm$ 1.0 (106)<br>[-4.0, 0.0, 2.0]                           | 0.1 $\pm$ 0.5 (45)<br>[-1.0, 0.0, 1.0]                          |                         |                                                    |
| <b>6 Mo – BL</b>  | -0.6 $\pm$ 1.0 (107)<br>[-3.0, -1.0, 2.0]<br>95% BCI: (-0.8, -0.4) | -0.0 $\pm$ 0.6 (50)<br>[-2.0, 0.0, 1.0]<br>95% BCI: (-0.2, 0.1) |                         |                                                    |
|                   | Completers Only – Without Predictions                              |                                                                 | -0.6<br>(-0.9, -0.3)    | 1.0000                                             |
|                   | With Predictions for Missing Values                                |                                                                 | -0.6<br>(-0.9, -0.3)    | 1.0000                                             |
| <b>12 Mo – BL</b> | -0.6 $\pm$ 1.1 (94)<br>[-4.0, 0.0, 1.0]<br>95% BCI: (-0.9, -0.4)   | 0.2 $\pm$ 0.6 (41)<br>[-1.0, 0.0, 2.0]<br>95% BCI: (0.0, 0.4)   |                         |                                                    |
|                   | Completers Only – Without Predictions                              |                                                                 | -0.9<br>(-1.2, -0.6)    | 1.0000                                             |
|                   | With Predictions for Missing Values                                |                                                                 | -0.8<br>(-1.1, -0.5)    | 1.0000                                             |

BCI = Bayesian credible interval; BL = baseline; C = control; mMRC = Modified Medical Research Council; Mo = month; N = total of number of patients randomized/enrolled/treated; SD = standard deviation; T = treatment.

\*Posterior median

**Table S14: 6MWT - Means and Change From Baseline Through 6 Months**

| 6MWT (m)         | Treatment Group                                                         | Control Group                                                           | Difference (T-C)        |                                                    |
|------------------|-------------------------------------------------------------------------|-------------------------------------------------------------------------|-------------------------|----------------------------------------------------|
|                  | Mean $\pm$ SD (N)<br>[min, median, max]                                 | Mean $\pm$ SD (N)<br>[min, median, max]                                 | Estimate*,<br>(95% BCI) | Posterior<br>Probability of<br>( $\mu_T > \mu_C$ ) |
| <b>BL</b>        | 303.5 $\pm$ 84.6 (113)<br>[118.0, 302.0, 508.0]                         | 306.9 $\pm$ 104.2 (59)<br>[78.0, 283.5, 557.0]                          |                         |                                                    |
| <b>3 Mo</b>      | 301.3 $\pm$ 88.4 (104)<br>[60.0, 300.0, 520.0]                          | 327.5 $\pm$ 95.7 (45)<br>[154.0, 314.0, 542.0]                          |                         |                                                    |
| <b>6 Mo</b>      | 306.8 $\pm$ 100.4 (102)<br>[61.0, 315.8, 604.0]                         | 307.5 $\pm$ 122.9 (48)<br>[60.0, 308.4, 553.0]                          |                         |                                                    |
| <b>3 Mo – BL</b> | -6.6 $\pm$ 68.0 (104)<br>[-263.0, 6.5, 120.0]                           | 0.3 $\pm$ 49.3 (45)<br>[-221.7, 3.0, 114.0]                             |                         |                                                    |
| <b>6 Mo – BL</b> | -4.4 $\pm$ 76.7 (102)<br>[-289.0, 0.0, 331.0]<br>95% BCI: (-19.4, 10.7) | -11.3 $\pm$ 51.4 (48)<br>[-161.0, -6.0, 126.0]<br>95% BCI: (-26.2, 3.6) |                         |                                                    |
|                  | Completers Only – Without Predictions                                   |                                                                         | 6.9<br>(-14.2, 28.2)    | 0.7438                                             |
|                  | With Predictions for Missing Values                                     |                                                                         | 5.0<br>(-16.2, 26.2)    | 0.6821                                             |

6MWT = Six-minute walk test; BCI = Bayesian credible interval; BL = baseline; C = control; Mo = month; N = total of number of patients randomized/enrolled/treated; SD = standard deviation; T = treatment.

\*Posterior median

**Table S15: Forced Vital Capacity (FVC) - Means and Change From Baseline Through 12 Months**

| FVC (L)                 | Treatment Group                                   | Control Group                                      | Mean Difference (T-C)<br>P value |
|-------------------------|---------------------------------------------------|----------------------------------------------------|----------------------------------|
|                         | Mean $\pm$ SD (N)<br>[min, median, max]           | Mean $\pm$ SD (N)<br>[min, median, max]            |                                  |
| <b>Baseline</b>         | 2.492 $\pm$ 0.754 (113)<br>[0.960, 2.390, 4.930]  | 2.633 $\pm$ 0.757 (59)<br>[1.050, 2.630, 4.580]    |                                  |
| <b>6 Mo</b>             | 2.666 $\pm$ 0.790 (106)<br>[1.090, 2.535, 5.660]  | 2.593 $\pm$ 0.741 (50)<br>[1.130, 2.560, 4.320]    |                                  |
| <b>12 Mo</b>            | 2.663 $\pm$ 0.790 (86)<br>[1.030, 2.480, 5.820]   | 2.522 $\pm$ 0.729 (39)<br>[1.010, 2.610, 4.230]    |                                  |
| <b>6 Mo – Baseline</b>  | 0.147 $\pm$ 0.485 (106)<br>[-1.010, 0.100, 1.820] | -0.098 $\pm$ 0.252 (50)<br>[-0.600, -0.105, 0.540] | 0.245<br>P=0.001                 |
| <b>12 Mo – Baseline</b> | 0.097 $\pm$ 0.536 (86)<br>[-1.180, 0.090, 1.980]  | -0.103 $\pm$ 0.369 (39)<br>[-1.010, -0.080, 0.600] | 0.200<br>P=0.037                 |

T= Treatment; C = control; Mo = month; N = total of number of patients randomized/enrolled/treated; SD = standard deviation; FVC = Forced Vital Capacity.

**Table S16: COPD Assessment Test (CAT) - Means and Change From Baseline Through 12 Months**

| COPD Assessment Test (points) | Treatment Group                                                      | Control Group                                                   | Difference (T-C)        |                                                    |
|-------------------------------|----------------------------------------------------------------------|-----------------------------------------------------------------|-------------------------|----------------------------------------------------|
|                               | Mean $\pm$ SD (N)<br>[min, median, max]                              | Mean $\pm$ SD (N)<br>[min, median, max]                         | Estimate*,<br>(95% BCI) | Posterior<br>Probability of<br>( $\mu_T > \mu_C$ ) |
| <b>Baseline</b>               | 21.8 $\pm$ 6.8 (113)<br>[7.0, 21.0, 38.0]                            | 20.0 $\pm$ 6.3 (59)<br>[7.0, 19.0, 31.0]                        |                         |                                                    |
| <b>6 Mo</b>                   | 18.9 $\pm$ 7.5 (106)<br>[4.0, 18.0, 38.0]                            | 21.7 $\pm$ 7.0 (50)<br>[7.0, 23.0, 34.0]                        |                         |                                                    |
| <b>12 Mo</b>                  | 19.8 $\pm$ 7.7 (91)<br>[3.0, 20.0, 39.0]                             | 23.2 $\pm$ 7.5 (41)<br>[8.0, 25.0, 36.0]                        |                         |                                                    |
| <b>6 Mo – Baseline</b>        | -3.0 $\pm$ 7.8 (106)<br>[-25.0, -2.0, 17.0]<br>95% BCI: (-4.5, -1.5) | 1.6 $\pm$ 5.3 (50)<br>[-11.0, 1.5, 11.0]<br>95% BCI: (0.1, 3.1) |                         |                                                    |
|                               | Completers Only – Without Predictions                                |                                                                 | -4.5<br>(-6.6, -2.4)    | 1.0000                                             |
|                               | With Predictions for Missing Values                                  |                                                                 | -4.4<br>(-6.5, -2.4)    | 1.0000                                             |
| <b>12 Mo - Baseline</b>       | -2.3 $\pm$ 8.1 (91)<br>[-20.0, -2.0, 20.0]<br>95% BCI: (-4.0, -0.6)  | 3.0 $\pm$ 5.7 (41)<br>[-5.0, 2.0, 17.0]<br>95% BCI: (1.3, 4.8)  |                         |                                                    |
|                               | Completers Only – Without Predictions                                |                                                                 | -5.3<br>(-7.8, -2.9)    | 1.0000                                             |
|                               | With Predictions for Missing Values                                  |                                                                 | -4.7<br>(-7.1, -2.3)    | 1.0000                                             |

BCI = Bayesian credible interval; BL = baseline; C = control; Mo = month; N = total of number of patients randomized/enrolled/treated; SD = standard deviation; T = treatment.

\*Posterior median

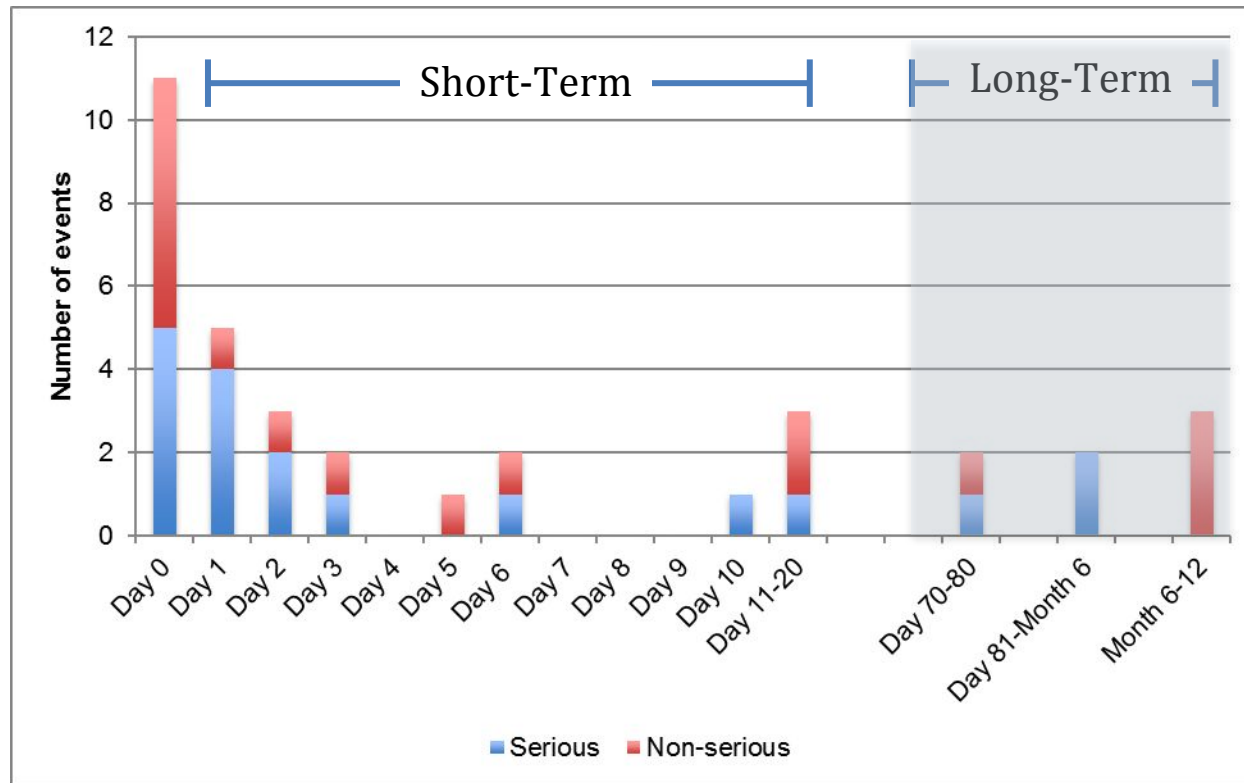


Appendix 12. Additional Results: Safety Assessments

Table S17: Composite of Thoracic SAEs – Short-Term (0-6 Months) and Long-Term (6-12 Months)

|                                                                             | Treatment Group<br>(N = 113) | Control Group<br>(N = 59) | Difference<br>(T–C) |              | Treatment Group<br>(N = 103) | Control Group<br>(N = 47) | Difference<br>(T–C) |              |
|-----------------------------------------------------------------------------|------------------------------|---------------------------|---------------------|--------------|------------------------------|---------------------------|---------------------|--------------|
|                                                                             | %                            | %                         | %                   | (95% BCI)    | %                            | %                         | %                   | (95% BCI)    |
|                                                                             | Short-Term (0 – 6 Months)    |                           |                     |              | Long-Term (6 – 12 Months)    |                           |                     |              |
| Acute exacerbation of COPD                                                  | 16.8                         | 10.2                      | 6.6                 | (-5.1, 16.0) | 13.6                         | 8.5                       | 5.1                 | (-7.4, 14.2) |
| Death from procedure or device                                              | 0.0                          | 0.0                       | 0.0                 | (-5.3, 2.3)  | 1.0                          | 0.0                       | 1.0                 | (-5.9, 4.1)  |
| Pneumonia in the valve-treated lobe                                         | 1.8                          | 0.0                       | 1.8                 | (-3.9, 5.2)  | 1.0                          | 0.0                       | 1.0                 | (-5.9, 4.1)  |
| Pneumonia not in the valve-treated lobe                                     | 7.1                          | 1.7                       | 5.4                 | (-2.4, 11.1) | 7.8                          | 2.1                       | 5.6                 | (-3.8, 11.9) |
| Pneumothorax requiring surgical intervention or prolonged air leak > 7 days | 12.4                         | 0.0                       | 12.4                | (4.6, 18.6)  | 0.0                          | 0.0                       | 0.0                 | (-6.6, 2.4)  |
| Tension pneumothorax                                                        | 1.8                          | 0.0                       | 1.8                 | (-3.9, 5.2)  | 0.0                          | 0.0                       | 0.0                 | (-6.6, 2.4)  |
| Respiratory failure                                                         | 2.7                          | 0.0                       | 2.7                 | (-3.2, 6.4)  | 1.0                          | 0.0                       | 1.0                 | (-5.9, 4.1)  |
| TOTAL                                                                       | 31.0%                        | 11.9%                     | 19.1%               | (5.9, 29.7)  | 21.4%                        | 10.6%                     | 10.7%               | (-3.0, 21.2) |

BCI = Bayesian credible interval; C = control; COPD = chronic obstructive pulmonary disease; N = total of number of patients randomized/enrolled/treated; SAE = serious adverse event; T = treatment.

**Figure S1. Pneumothorax Events Through 12 Months**

**Table S18. Composite of Thoracic SAE Rates – Short-Term (0-6 Months) and Long-Term (6-12 Months)**

|                                                                                                                                                                             | <b>Treatment<br/>Group<br/>(N = 113)</b> | <b>Control<br/>Group<br/>(N = 59)</b> | <b>Treatment<br/>Group<br/>(N = 103)</b> | <b>Control<br/>Group<br/>(N = 47)</b> |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|---------------------------------------|------------------------------------------|---------------------------------------|
|                                                                                                                                                                             | (Pt-Yrs = 63.52)                         | (Pt-Yrs = 30.47)                      | (Pt-Yrs = 48.81)                         | (Pt-Yrs = 22.17)                      |
|                                                                                                                                                                             | Events/Pt-Yr (95% BCI)                   |                                       |                                          |                                       |
|                                                                                                                                                                             | <b>Short-Term (0 – 6 Months)</b>         |                                       | <b>Long-Term (6 – 12 Months)</b>         |                                       |
| <b>Acute exacerbation of COPD that is acute onset, life threatening, and requires hospitalization</b>                                                                       | 0.35 (0.20, 0.49)                        | 0.20 (0.09, 0.43)                     | 0.41 (0.26, 0.62)                        | 0.18 (0.06, 0.43)                     |
| <b>Death from the procedure or device</b>                                                                                                                                   | 0.0                                      | 0.0                                   | 0.02 (0.00, 0.10)                        | 0.0                                   |
| <b>Pneumonia in the valve-treated lobe that requires hospitalization, IV antibiotics, and valve removal.</b>                                                                | 0.03 (0.01, 0.10)                        | 0.0                                   | 0.02 (0.00, 0.10)                        | 0.0                                   |
| <b>Pneumonia NOT in the valve-treated lobe that is life-threatening, acute onset, and requires hospitalization and IV antibiotics</b>                                       | 0.16 (0.08, 0.28)                        | 0.03 (0.00, 0.15)                     | 0.23 (0.12, 0.39)                        | 0.05 (0.00, 0.21)                     |
| <b>Pneumothorax requiring surgical intervention or prolonged air leak &gt; 7 days defined as the time from chest tube insertion to the time the air leak is not present</b> | 0.25 (0.15, 0.40)                        | 0.0                                   | 0.0                                      | 0.0                                   |
| <b>Respiratory failure that requires mechanical ventilatory support for &gt; 24 hours</b>                                                                                   | 0.08 (0.03, 0.17)                        | 0.0                                   | 0.02 (0.00, 0.10)                        | 0.0                                   |
| <b>Tension pneumothorax that is life-threatening, acute onset, and requires hospitalization and treatment</b>                                                               | 0.03 (0.01, 0.10)                        | 0.0                                   | 0.0                                      | 0.0                                   |
| <b>Composite</b>                                                                                                                                                            | <b>0.90 (0.69, 1.15)</b>                 | <b>0.23 (0.10, 0.45)</b>              | <b>0.70 (0.49, 0.96)</b>                 | <b>0.23 (0.09, 0.49)</b>              |

BCI = Bayesian credible interval; C = control; COPD = chronic obstructive pulmonary disease; IV = intravenous; N = total of number of patients randomized/enrolled/treated; Pt-Yrs = patient-years; SAE = serious adverse event.

**Table S19. Composite of Non-Thoracic SAEs – Short-Term (0-6 Months) and Long-Term (6-12 Months)**

|                                                                                                       | <b>Treatment Group<br/>(N = 113)</b> | <b>Control Group<br/>(N = 59)</b> | <b>Difference<br/>(T–C)</b> |                     | <b>Treatment Group<br/>(N = 103)</b> | <b>Control Group<br/>(N = 47)</b> | <b>Difference<br/>(T–C)</b> |                      |
|-------------------------------------------------------------------------------------------------------|--------------------------------------|-----------------------------------|-----------------------------|---------------------|--------------------------------------|-----------------------------------|-----------------------------|----------------------|
|                                                                                                       | %                                    | %                                 | %                           | (95% BCI)           | %                                    | %                                 | %                           | (95% BCI)            |
|                                                                                                       | <b>Short-Term (0 – 6 Months)</b>     |                                   |                             |                     | <b>Long-Term (6 – 12 Months)</b>     |                                   |                             |                      |
| <b>Acute onset abdominal pain requiring urgent hospitalization or extended hospitalization</b>        | 0.0                                  | 0.0                               | 0.0                         | (-5.3, 2.3)         | 2.9                                  | 0.0                               | 2.9                         | (-4.3, 6.9)          |
| <b>Cardiac rhythm disturbance requiring acute medical intervention</b>                                | 0.9                                  | 0.0                               | 0.9                         | (-4.6, 3.8)         | 2.9                                  | 0.0                               | 2.9                         | (-4.3, 6.9)          |
| <b>Death from any cause not from the investigational procedure or device</b>                          | 5.3**                                | 1.7                               | 3.6                         | (-3.9, 8.9)         | 2.9                                  | 6.4                               | -3.5                        | (-13.9, 3.0)         |
| <b>Emergent surgery that is not due to trauma</b>                                                     | 0.0                                  | 1.7                               | -1.7                        | (-8.2, 1.3)         | 1.0                                  | 0.0                               | 1.0                         | (-5.9, 4.1)          |
| <b>Infection at any site that is life threatening and requires hospitalization and IV antibiotics</b> | 3.5                                  | 0.0                               | 3.5                         | (-2.5, 7.7)         | 1.0                                  | 0.0                               | 1.0                         | (-5.9, 4.1)          |
| <b>Thrombosis or thromboembolism requiring medical management and acute hospitalization</b>           | 0.0                                  | 0.0                               | 0.0                         | (-5.3, 2.3)         | 1.0                                  | 0.0                               | 1.0                         | (-5.9, 4.1)          |
| <b>Other</b>                                                                                          | 7.1                                  | 3.4                               | 3.7                         | (-4.9, 9.9)         | 5.8                                  | 6.4                               | -0.6                        | (-11.4, 6.7)         |
| <b>TOTAL</b>                                                                                          | <b>11.5%</b>                         | <b>3.4%</b>                       | <b>8.1%</b>                 | <b>(-1.1, 15.2)</b> | <b>12.6%</b>                         | <b>12.8%</b>                      | <b>-0.1%</b>                | <b>(-13.4, 10.0)</b> |

BCI = Bayesian credible interval; C = control; IV = intravenous; N = total of number of patients randomized/enrolled/treated; SAE = serious adverse event; T = treatment.

\*\*One death adjudicated as “possibly” device related.

**Table S20. Summary of Deaths 0-6 Months**

| Study Group | Days from Enrolled | CEC Device Relationship | CEC Procedure Relationship | Details                                                                                                                                                                                              |
|-------------|--------------------|-------------------------|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Control     | 156                | Definitely not related  | Definitely not related     | Subject died prior to their 6M study visit from complications following surgery on the jaw (cancer).                                                                                                 |
| Treatment   | 26                 | Definitely not related  | Definitely not related     | Subject died due to complications during hospitalization for exacerbation of COPD including arrhythmia, staph infection, renal failure, ileus & volvulus, and septic shock with multi-organ failure. |
| Treatment   | 189                | Probably not related    | Definitely not related     | Subject died as a result of bilateral pleural effusion and hypercapnic respiratory failure, complicated by MRSA infection.                                                                           |
| Treatment   | 188                | Definitely not related  | Definitely not related     | Subject died as a result of a myocardial infarction.                                                                                                                                                 |
| Treatment   | 178                | Definitely not related  | Definitely not related     | Subject died as a result of aspiration leading to infection and respiratory failure.                                                                                                                 |
| Treatment   | 179                | Definitely not related  | Definitely not related     | Subject died due to complications during hospitalization for exacerbation of COPD.                                                                                                                   |
| Treatment   | 95                 | Possibly related        | Probably not related       | Subject died due to right-sided (contralateral) pneumothorax which did not resolve and led to hypoxia and cardiac arrest.                                                                            |

**Table S21. Summary of Deaths 6-12 Months**

| Study Group | Days from Enrolled | CEC Device Relationship | CEC Procedure Relationship | Details                                                                                                      |
|-------------|--------------------|-------------------------|----------------------------|--------------------------------------------------------------------------------------------------------------|
| Control     | 303                | Definitely not related  | Definitely not related     | Subject died in hospice due to declining health.                                                             |
| Control     | 336                | Definitely not related  | Definitely not related     | Subject died due to unknown reasons –death certificate or medical records were not obtainable.               |
| Control     | 233                | Definitely not related  | Definitely not related     | Subject died as a direct result of trauma sustained in a car accident.                                       |
| Treatment   | 353                | Probably related        | Definitely not related     | Subject died from treatment of an acute lung abscess in the valve-treated left lower-lobe.                   |
| Treatment   | 342                | Probably not related    | Definitely not related     | Subject “coded” in the parking lot of the hospital and was not resuscitated due to a DNR.                    |
| Treatment   | 271                | Definitely not related  | Definitely not related     | Subject died from complications related to pneumonia in the ipsilateral lobe.                                |
| Treatment   | 281                | Probably not related    | Definitely not related     | Subject died in hospice after hospitalization for COPD exacerbation leading and chronic respiratory failure. |

## References:

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3. Saville BR, Connor JT, Ayers GD, Alvarez J, "The utility of Bayesian predictive probabilities for interim monitoring of clinical trials," *Clinical Trials* (2014), 11, 485-493