Respiration

Interventional Pulmonology

Respiration 2021;100:52–58
DOI: 10.1159/000511599

Received: September 2, 2020
Accepted: September 4, 2020
Published online: January 7, 2021

Joint Statement of the German Respiratory Society and German Society of Thoracic Surgery in Cooperation with the German Radiological Society: Structural Prerequisites of Centres for Interventional Treatment of Emphysema

Wolfgang Johannes Gesierich[a] Kaid Darwiche[b] Felix Döllinger[c] Ralf Eberhardt[d, e] Stephan Eisenmann[f] Christian Grah[g] Claus Peter Heußel[e, h, i] Ralf-Harto Huebner[j] Julia Ley-Zaporozhan[k] Franz Stanzel[l] Stefan Welter[m] Hans Hoffmann[n]

[a]Department of Pulmonology, Asklepios Fachkliniken Munich-Gauting, Center for Pulmonology and Thoracic Surgery, Munich-Gauting, Germany; [b]Department of Interventional Pulmonology, Ruhrlandklinik – University Medicine Essen, Essen, Germany; [c]Department of Radiology, Charité – University Medicine Berlin, Berlin, Germany; [d]Department of Pulmonology and Respiratory Medicine, Thoraxklinik, Heidelberg University, Heidelberg, Germany; [e]Lung Research Center (TLRC), Member of German Center for Lung Research (DZL), Heidelberg, Germany; [f]Department of Internal Medicine I/Pulmonology, University Hospital, Halle (Saale), Germany; [g]Department of Respiratory Medicine and Lung Cancer Center, Gemeinschaftskrankenhaus Havelhöhe, Berlin, Germany; [h]Department of Diagnostic and Interventional Radiology, Heidelberg University, Heidelberg, Germany; [i]Department of Diagnostic and Interventional Radiology with Nuclear Medicine, Thoraxklinik, Heidelberg University, Heidelberg, Germany; [j]Department of Infectious Diseases and Respiratory Medicine, Charité – University Medicine Berlin, Berlin, Germany; [k]Department of Radiology, University Hospital LMU Munich, Munich, Germany; [l]Department of Pulmonology – Thoracic Endoscopy, Lung Clinic, Hemer, Germany; [m]Department of Thoracic Surgery, Lung Clinic, Hemer, Germany; [n]Division of Thoracic Surgery, Department of Surgery, University Hospital Rechts der Isar, Technical University of Munich, Munich, Germany

Keywords
Emphysema · Interventional treatment · Bronchoscopic lung volume reduction · Lung volume reduction surgery · Structural prerequsites

Abstract
Interventional treatment of emphysema offers a wide range of surgical and endoscopic options for patients with advanced disease. Multidisciplinary collaboration of pulmonology, thoracic surgery, and imaging disciplines in patient selection, therapy, and follow-up ensures treatment quality. The present joint statement describes the required structural and quality prerequisites of treatment centres. This is a translation of the German article "Positionspapier der Deutschen Gesellschaft für Pneumologie und Beatmungsmedizin und der Deutschen Gesellschaft für Thoraxchirurgie in Kooperation mit der Deutschen Röntgengesellschaft: Strukturvoraussetzungen von Zentren für die interventionelle Emphysemtherapie" *Pneumologie*. 2020;74:17–23.

karger@karger.com
www.karger.com/res

Wolfgang Johannes Gesierich
Department of Pneumonology, Asklepios Fachkliniken Munich-Gauting, Center for Pneumonology and Thoracic Surgery, Robert-Koch-Allee 2
DE–82131 Munich-Gauting (Germany)
wolfgang.gesierich@yahoo.com

Table 1. Overview of the structural and quality requirements of a centre for interventional emphysema therapy

1	Respiratory diagnostics	– Medical history: symptom load, limitations in exercise capacity, smoking status, comorbidities, anticoagulation, and alpha-1 antitrypsin status – Lung function: post-bronchodilator spirometry and body plethysmography, diffusion capacity, and blood gas analysis – 6-min walking distance – Screening for nocturnal hypercapnia
2	Respiratory therapy	– Optimized drug therapy including patient training – Smoking cessation – Respiratory physiotherapy – LOT – CPAP therapy and NIV – Personnel requirements: continuous 24-h pneumological specialist care, specialized respiratory physiotherapist, or respiratory therapist
3	Cardiological diagnostics	– Echocardiography – Access to invasive cardiological diagnostics, especially right-heart catheter
4	Radiology and nuclear medicine	– High-resolution spiral CT of the lungs (non-enhanced, slice thickness ≤1.5 mm) – Quantitative CT analysis: emphysema distribution, volumetry, and fissure status – Perfusion scintigraphy with SPECT images
5	Multidisciplinary conference	– Discussion of all patients planned to undergo a bronchoscopic or surgical intervention – Participants: pneumologist with expertise in interventional bronchology, radiologist, and thoracic surgeon
6	Interventional pulmonology	– Expertise in the following techniques – Bronchoscopic measurement of collateral ventilation – Endobronchial valves – At least 1 team member has performed 25 bronchoscopic interventions for volume reduction – At least 500 bronchoscopies, of these at least 25 interventions for volume reduction per year – 24-h stand by for flexible and rigid bronchoscopy and insertion of thoracic drainages
7	Thoracic surgery	– VATS technique – 24-h thoracic surgical stand-by
8	Intensive care and mechanical ventilation	– Intensive care unit on-site – Possibility of invasive ventilation
9	Participation in clinical studies	– Participation in current registries and clinical studies – Provision of appropriate structures (study nurse)
10	Cooperation with a lung transplant centre	– Methods of volume reduction as bridging for transplantation – Timely presentation of patients in the terminal stage at the transplant centre
11	Structured follow-up	– At least 1 follow-up visit 1–3 months after the intervention at the centre with assessment of efficacy and complications – Further follow-up in cooperation with resident pneumologists
12	Documentation	– Compilation of a SOP considering the individual situation at the centre – Reports of the treatment decision by the multidisciplinary conference

SOP, stand operating procedure; LOT, long-term oxygen therapy; CT, computed tomography; VATS, video-assisted thoracoscopic surgery; NIV, non-invasive ventilation.

Introduction

Chronic obstructive pulmonary disease (COPD) and pulmonary emphysema are characterized by irreversible, structural damage to the airways and lung parenchyma. Accordingly, conservative treatment of the disease has limited efficacy. Due to the large unmet clinical need, a wide range of interventional treatment options has developed, which includes bronchoscopic and surgical techniques [1–3]. Treatment success depends on the selection of suitable patients and the most suitable interventional method in each case using a variety of clinical and radiological criteria on the basis of a diagnostic and therapeutic algorithm [4–6].

On December 19, 2019, the Joint Federal Committee ("Gemeinsamer Bundesausschuss"), the highest body of

joint self-government in the German health system, published a guideline on quality assurance for inpatient care with procedures for bronchoscopic lung volume reduction (BLVR). The rules laid down herein also form the basis for reimbursement of the bronchoscopic methods within the German system.

Requirements for the structural and process quality of centres for interventional emphysema therapy will therefore be defined more precisely. The professional societies involved in this position paper see it as their task to play a decisive role in shaping this process and define the following prerequisites that an emphysema centre should fulfil in the interdisciplinary cooperation between pulmonology, thoracic surgery, and imaging disciplines (Table 1). The statements of this position paper refer to both bronchoscopic and surgical methods.

Respiratory Diagnostics

The selection of suitable patients for interventional emphysema therapy begins with taking a comprehensive history. Particular attention must be paid to the burden of symptoms, limitation of exercise capacity and activities of daily life, and comorbidities (in particular, cardiovascular disease and need for anticoagulant therapy). Smoking status should be explored (number of pack years, smoking cessation, and abstinence time). The non-smoking status of the patient must be demonstrated by determination of carboxyhemoglobin in the blood gas analysis and/or the stable nicotine metabolite cotinine in serum or urine. The patient's alpha-1 antitrypsin status must be recorded and, if previously unknown, determined by appropriate laboratory diagnostics.

Next step in the evaluation is the confirmation of severe, non-reversible bronchial obstruction, and pulmonary hyperinflation. This requires comprehensive lung function testing, which is standardized according to international quality criteria [7], including post-bronchodilator spirometry and body plethysmography, measurement of the diffusion capacity for carbon monoxide, capillary or arterial blood gas analysis, and determination of the 6-min walking distance.

In addition, the symptom load and quality of life are to be recorded with scales and questionnaires. Appropriate instruments for this can be the modified Medical Research Council dyspnoea scale (mMRC scale) [8], the COPD Assessment Test (CAT) [9], and the Saint-George Respiratory Questionnaire (SGRQ) [10].

In case of clinical suspicion of a sleep-related respiratory disorder or chronic ventilatory failure, appropriate screening methods should be used to determine whether there is an indication for CPAP therapy or non-invasive ventilation (NIV). In this context, the centre should have the possibility of cardiorespiratory polygraphy and transcutaneous CO_2 measurement.

Before a definitive intervention, appropriate patients should undergo flexible bronchoscopy in local anaesthesia with the question of the extent of secretion, germ colonization, endobronchial early carcinomas, and findings that may render the intervention more difficult, such as instability of the central airways ("excessive dynamic airway collapse"). If indicated, a catheter-based measurement of collateral ventilation (Chartis© measurement) can already be performed in this examination [11–13].

Respiratory Therapy

The centre must have extensive expertise in the conservative treatment of COPD in accordance with national and international guidelines [14]. This comprises the optimization of drug therapy including patient training, support in smoking cessation, specialized respiratory physiotherapy, establishing an exercise program (to support this, in Germany in some regions specialized lung sports groups are available), and, if indicated, the possibility to initiate and follow up long-term oxygen therapy, CPAP therapy, or NIV in cooperation with a sleep laboratory or a unit for mechanical ventilation.

For this, the following personnel requirements must be fulfilled: the medical team of the centre must guarantee a continuous 24-h respiratory-specialist care by board-certified pulmonologists, which can, if necessary, also be provided by means of a call service. It must have at least 1 specialized respiratory physiotherapist or respiratory therapist. One member of the team should have a qualification for structured smoking cessation (the German Medical Association for instance offers a curriculum on "medically accompanied tobacco cessation").

Cardiological Diagnostics

For the differential diagnosis of dyspnoea and for the assessment of individual risk, the centre must have access to cardiological diagnostics, possibly via external cooperation. Echocardiography and determination of NT-pro-BNP represent the basis. In the case of significantly

increased right cardiac pressure, a right-heart catheter examination should be available. If indicated, there should be access to further invasive cardiological diagnostics.

Radiology and Nuclear Medicine

Once the clinical and functional suitability of a patient for interventional emphysema therapy has been established, imaging diagnostics are required. The basis for emphysema analysis from image data is the acquisition of a complete spiral computed tomography (CT) of the thorax in maximum inspiration. The following quality requirements must be observed: a multi-slice CT scanner (at least 16 rows) must be used with the fastest possible tube rotation and a pitch factor of up to 2 in order to keep the breath-hold as short as possible for the frequently dyspnoeic COPD patients. The examination must be carried out in non-enhanced technique as the administration of contrast material increases physical lung density and impairs computer-assisted emphysema quantification [15]. A volumetric dataset with a slice thickness ≤1.5 mm and overlapping slices must be acquired. In patients with COPD 3–4, the same series can be repeated in expiratory breath-hold in order to provide evidence of tracheobronchial collapse and the so-called "air trapping." Multiplanar reformat and maximal/minimal intensity projections should be available for visual image analysis. For visual and quantitative analysis, both edge-enhanced and soft reconstructions are to be made. Dose-saving techniques like iterative reconstructions [16] can be used. However, ultra-low-dose examinations are usually unsuitable due to the unfavourable image noise in the low-contrast range of emphysema.

The CT scan must be visually assessed by an experienced thoracic radiologist. However, since visual analysis is user-dependent and error-prone, particularly when there are small regional differences in emphysema distribution [17, 18], it must be supplemented by a computer-assisted quantitative analysis [19–21]. This can be done directly at the centre, but due to the complexity of the required software [22] and expertise, it can also be carried out by external cooperation partners.

The quantitative analysis should comprise detection of the lung volume and percentage of emphysema (i.e., the proportion of all voxels with a CT density below a defined threshold, e.g., −950 HU) for each lobe and an assessment of the completeness of the interlobar fissures. In the visual analysis, attention should also be paid to other relevant findings, such as pneumonia, effusion, previous surgery, nodules suspicious of malignancy, relevant bronchiectasis, signs of interstitial lung disease or pulmonary hypertension, and pleural thickening and pronounced post-inflammatory scaring. If the CT demonstrates suspicious nodules, further diagnostic work-up according to current guidelines must be carried out prior to interventional emphysema therapy. If CT follow-up is selected for this purpose, the currently valid recommendations of the Fleischner-Society [23] can be applied.

CT assessment of emphysema morphology is to be supplemented by an imaging method that allows an assessment of regional perfusion in the target region of the intervention. Normally, perfusion scintigraphy with technetium-labelled albumin particles (Tc-99m-MAA) is used [24–26]. Both planar and SPECT images should be available for visual analysis. Hybrid techniques such as SPECT-CT are desirable, if available, due to superior spatial resolution. Alternatively, time-resolved contrast-enhanced MRI sequences ("4D-MRA") or contrast-enhanced perfusion CT can be used for perfusion assessment.

Multidisciplinary Conference ("Emphysema Board")

For all patients undergoing an interventional emphysema therapy at the centre, a documented therapy decision from an interdisciplinary case conference must be available. This requirement applies equally to patients undergoing both endoscopic and surgical interventions. At least 1 pulmonologist with expertise in interventional bronchology, a radiologist, and a thoracic surgeon must attend the conference.

In addition, there are optional cooperation partners, which can be called upon as required. These include intensive care physicians, nuclear medicine specialists, infectiologists, rehabilitation physicians, transplantation physicians, respiratory therapists, physiotherapists, lung sports group trainers, and psychologists.

Interventional Pulmonology

Interventional pulmonology at the centre must have practical expertise in all common and approved BLVR procedures. These include, in particular, the bronchoscopic measurement of collateral ventilation with the Chartis© system (Pulmonx, Redwood, CA, USA) and the implantation of endobronchial valves. Other techniques (e.g., lung volume reduction coils and broncho-

scopic thermal vapour ablation/BTVA) should be known.

At least 1 member of the interventional pulmonology team's medical staff must have performed a minimum of 25 procedures in the field of the BLVR (also possible via an internship). The centre should perform at least 500 bronchoscopies per year, of which at least 25 should be interventions for emphysema therapy. In the bronchoscopy unit, there must be direct PACS access to the patient's imaging, and the examiner must have access to it during the procedure. The centre must maintain a continuous 24-h standby for flexible and rigid bronchoscopy as well as for the insertion of thoracic drainages. For effective pneumothorax management, the centre should have digital thoracic drainage systems available.

Thoracic Surgery

Thoracic surgery is becoming increasingly important in interventional emphysema therapy as the limits of endoscopic methods are being better defined and the complication rate has been significantly reduced in experienced centres due to less invasive surgical approaches and improved stapling devices as compared to the surgical techniques used in the NETT trial [27] published in 2003 [28–30]. Cases with heterogeneous emphysema not involving an entire lobe, the presence of very large bullae, a paraseptally accentuated empyhsema or suspicious nodules in the target region, are a domain for surgical therapy.

The surgical intervention is performed preferably using minimally invasive video-assisted thoracoscopic surgery and, if necessary, an open thoracotomy approach may be utilized. The preferred surgical measure is "lung shaving" by atypical, peripheral lung resections using endoscopic stapling devices, with staple line reinforcement where appropriate. If necessary, also anatomical pulmonary resection (segmental resection or lobectomy) can be performed. Thoracic surgery also plays an important role in complication management, especially of pneumothorax, if it cannot be controlled by drainage therapy alone. Thoracic surgery must be capable of maintaining a continuous 24-h thoracic surgical standby. In order to ensure this, at least 2 board-certified thoracic surgeons should be employed full-time at the centre. The centre may cooperate with an external department of thoracic surgery if the on-site pulmonology is experienced in the emergency management of pneumothorax, in particular, the insertion of thoracic drainages.

Intensive Care and Mechanical Ventilation

The centre must have a unit for intensive care and mechanical ventilation on site. Pre-interventionally, this department has the task of initiating NIV in the event of chronic ventilatory failure in accordance with current guidelines [31]. Post-interventionally, intensive monitoring and interdisciplinary management of complications must be possible, if necessary. Due to the potentially severe respiratory failure of emphysema patients, in addition to the possibility of invasive ventilation, there should also be access to methods of extracorporeal oxygenation and CO_2 elimination (ECMO). The latter can also be realized via external cooperation.

Participation in Clinical Studies

Interventional emphysema therapy is an evolving clinical field. On the one hand, the evidence base of the already approved methods needs to be expanded. On the other hand, some methods are currently only available in the context of clinical studies. These include, for example, BTVA [32], volume reduction by instillation of polymer foam [33], and targeted lung denervation [34].

The centre should therefore strive to participate in ongoing clinical studies. Patients should also be treated as far as possible in studies and registries when already approved methods are applied. For this purpose, the centre should provide appropriate structures, and staff trained in the conduct of clinical studies (study coordinator and study nurse) should be available.

Cooperation with a Lung Transplant Centre

The methods of interventional emphysema therapy are used at an advanced stage of the disease with limited treatment options. On the one hand, the methods can be used as a bridging to transplant [35, 36]. On the other hand, in terminal stages of the disease, the right time point for referral to a transplant centre must not be missed. The Emphysema centre should therefore cooperate with a lung transplant centre. The exchange of patients can take place in both directions.

Structured Follow-Up

The effective follow-up of interventional patients requires the special expertise of the multidisciplinary team at the centre. This must therefore offer and ensure structured follow-up care in close cooperation with the resident pneumologists. In the context of clinical studies, follow-up is specified by the study protocol. Outside of clinical trials, at least 1 follow-up visit must take place 1–3 months after the intervention at the centre. This visit is intended to identify and treat complications and to assess the effectiveness of the interventional measures carried out using suitable radiological methods, lung function tests, blood gas analysis, determination of the 6-min walk distance, recording the symptom load and quality of life with questionnaires, and, if necessary, flexible bronchoscopy.

Further regular follow-up checks are necessary at least once a year. If these cannot be carried out at the centre itself, further care can be handed over to the resident pneumologist in case of an uncomplicated course and treatment efficacy in the expected range. Otherwise, the centre has to search for causes and optimize interventional therapy as far as possible or switch to alternative treatment options. These patients are to be reintroduced to the interdisciplinary case conference.

Documentation

The centre must compile a standard operating procedure for the evaluation, treatment, and follow-up of patients, which takes into account the individual situation at the centre. The protocols of the interdisciplinary case conference ("emphysema board") must contain a comprehensible documentation of the treatment decision. It is suggested that the centre should document all patients in an own database and/or include its own data in regional and supra-regional registries, as far as these are available. The participating medical societies support and promote the establishment of such registries.

Statement of Ethics

The authors have no ethical conflicts to disclose.

Conflict of Interest Statement

W. Gesierich has received speaker fees and travel support from PulmonX, PneumRx/BTG, and Astra Zeneca. K. Darwiche has received research support and speaker fees from PulmonX, PneumRx/BTG, and Boston Scientific as well as speaker fees and travel support from Olympus and Böhringer Ingelheim. C.-P. Heußel has received speaker fees from Novartis, Basilea, and Bayer. R.-H. Hübner has received speaker fees from PneumRx/BTG and PulmonX and a travel fee from Uptake Medical. He is a principal investigator of industry-sponsored clinical trials of the companies PneumRx (Elevate), PulmonX (Stage), and Uptake (BTVA Registry). He is a board member of the Lung Emphysema Registry e. V.S. Eisenmann has received speaker fees from PulmonX, Astra Zeneca, Boehringer Ingelheim, and Actelion and travel support from Uptake Medical. F. Döllinger, R. Eberhardt, C. Grah, J. Ley-Zaporozhan, F. Stanzel, S. Welter, and H. Hoffmann report no conflict of interest.

Funding Sources

There was no financial funding to this work. The executive committees of the 3 involved medical societies approved the final version of manuscript.

Author Contributions

All authors contributed substantially to writing the manuscript. All authors approved the final version of the manuscript. The consensus process was led by W.G., who edited the final version of the manuscript.

References

1 Brantigan OC, Mueller E. Surgical treatment of pulmonary emphysema. Am Surg. 1957;23(9):789–804.
2 Cooper JD, Trulock EP, Triantafillou AN, Patterson GA, Pohl MS, Deloney PA, et al. Bilateral pneumectomy (volume reduction) for chronic obstructive pulmonary disease. J Thorac Cardiovasc Surg. 1995;109(1):106–9.
3 van Geffen WH, Slebos DJ, Herth FJ, Kemp SV, Weder W, Shah PL. Surgical and endoscopic interventions that reduce lung volume for emphysema: a systemic review and meta-analysis. Lancet Respir Med. 2019;7(4):313–24.
4 Herth FJ, Slebos DJ, Rabe KF, Shah PL. Endoscopic lung volume reduction: an expert panel recommendation. Respiration. 2016;91(3):241–50.
5 Herth FJF, Slebos DJ, Criner GJ, Shah PL. Endoscopic lung volume reduction: an expert panel recommendation: update 2017. Respiration. 2017;94(4):380–8.
6 Herth FJF, Slebos DJ, Criner GJ, Valipour A, Sciurba F, Shah PL. Endoscopic lung volume reduction: an expert panel recommendation: update 2019. Respiration. 2019;97(6):548–57.

7 Miller MR, Crapo R, Hankinson J, Brusasco V, Burgos F, Casaburi R, et al. General considerations for lung function testing. Eur Respir J. 2005;26(1):153–61.
8 Bestall JC, Paul EA, Garrod R, Garnham R, Jones PW, Wedzicha JA. Usefulness of the medical research council (MRC) dyspnoea scale as a measure of disability in patients with chronic obstructive pulmonary disease. Thorax. 1999;54(7):581–6.
9 Kon SS, Canavan JL, Jones SE, Nolan CM, Clark AL, Dickson MJ, et al. Minimum clinically important difference for the COPD assessment test: a prospective analysis. Lancet Respir Med. 2014;2(3):195–203.
10 Meguro M, Barley EA, Spencer S, Jones PW. Development and validation of an improved, COPD-specific version of the St. George respiratory questionnaire. Chest. 2007;132(2):456–63.
11 Koster TD, van Rikxoort EM, Huebner RH, Doellinger F, Klooster K, Charbonnier JP, et al. Predicting lung volume reduction after endobronchial valve therapy is maximized using a combination of diagnostic tools. Respiration. 2016;92(3):150–7.
12 Gesierich W, Samitas K, Reichenberger F, Behr J. Collapse phenomenon during Chartis collateral ventilation assessment. Eur Respir J. 2016;47(6):1657–67.
13 Herzog D, Thomsen C, Poellinger A, Doellinger F, Schreiter N, Froeling V, et al. Outcomes of endobronchial valve treatment based on the precise criteria of an endobronchial catheter for detection of collateral ventilation under spontaneous breathing. Respiration. 2016;91(1):69–78.
14 Vogelmeier C, Buhl R, Burghuber O, Criee CP, Ewig S, Godnic-Cvar J, et al. unter Mitwirkung der folgenden wissenschaftlichen Fachgesellschaften: Deutsche Gesellschaft für Arbeitsmedizin und Umweltmedizin e V, Deutsche Gesellschaft für Rehabilitationswissenschaften e V. [Guideline for the diagnosis and treatment of COPD patients: issued by the German respiratory society and the German Atemwegsliga in cooperation with the Austrian society of pneumology]. Pneumologie. 2018;72:253–308.
15 Heussel CP, Kappes J, Hantusch R, Hartlieb S, Weinheimer O, Kauczor HU, et al. Contrast enhanced CT-scans are not comparable to non-enhanced scans in emphysema quantification. Eur J Radiol. 2010;74(3):473–8.
16 Martin SP, Gariani J, Hachulla AL, Botsikas D, Adler D, Karenovics W, et al. Impact of iterative reconstructions on objective and subjective emphysema assessment with computed tomography: a prospective study. Eur Radiol. 2017;27(7):2950–6.
17 Slebos DJ, Cicenia J, Sciurba FC, Criner GJ, Hartman JE, Garner J, et al. Predictors of response to endobronchial coil therapy in patients with advanced emphysema. Chest. 2019;155(5):928–37.
18 Mascalchi M, Diciotti S, Sverzellati N, Camiciottoli G, Ciccotosto C, Falaschi F, et al. Low agreement of visual rating for detailed quantification of pulmonary emphysema in whole-lung CT. Acta Radiol. 2012;53(1):53–60.
19 Mets OM, de Jong PA, van Ginneken B, Gietema HA, Lammers JW. Quantitative computed tomography in COPD: possibilities and limitations. Lung. 2012;190(2):133–45.
20 Mascalchi M, Camiciottoli G, Diciotti S. Lung densitometry: why, how and when. J Thorac Dis. 2017;9(9):3319–45.
21 Heussel CP, Herth FJ, Kappes J, Hantusch R, Hartlieb S, Weinheimer O, et al. Fully automatic quantitative assessment of emphysema in computed tomography: comparison with pulmonary function testing and normal values. Eur Radiol. 2009;19(10):2391–402.
22 Lim HJ, Weinheimer O, Wielpütz MO, Dinkel J, Hielscher T, Gompelmann D, et al. Fully automated pulmonary lobar segmentation: influence of different prototype software programs onto quantitative evaluation of chronic obstructive lung disease. PLoS One. 2016;11(3):e0151498.
23 MacMahon H, Naidich DP, Goo JM, Lee KS, Leung ANC, Mayo JR, et al. Guidelines for management of incidental pulmonary nodules detected on CT images: from the Fleischner Society 2017. Radiology. 2017;284(1):228–43.
24 Thomsen C, Theilig D, Herzog D, Poellinger A, Doellinger F, Schreiter N, et al. Lung perfusion and emphysema distribution affect the outcome of endobronchial valve therapy. Int J Chron Obstruct Pulmon Dis. 2016;11:1245–59.
25 Argula RG, Strange C, Ramakrishnan V, Goldin J. Baseline regional perfusion impacts exercise response to endobronchial valve therapy in advanced pulmonary emphysema. Chest. 2013;144(5):1578–86.
26 Chandra D, Lipson DA, Hoffman EA, Hansen-Flaschen J, Sciurba FC, Decamp MM, et al. Perfusion scintigraphy and patient selection for lung volume reduction surgery. Am J Respir Crit Care Med. 2010;182(7):937–46.
27 Fishman A, Martinez F, Naunheim K, Piantadosi S, Wise R, Ries A, et al. A randomized trial comparing lung-volume-reduction surgery with medical therapy for severe emphysema. N Engl J Med. 2003;348(21):2059–73.
28 Stanifer BP, Ginsburg ME. Lung volume reduction surgery in the post-national emphysema treatment trial era. J Thorac Dis. 2018;10(Suppl 23):S2744–7.
29 Perikleous P, Sharkey A, Oey I, Bilancia R, Tenconi S, Rathinam S, et al. Long-term survival and symptomatic relief in lower lobe lung volume reduction surgery. Eur J Cardiothorac Surg. 2017;52(5):982–8.
30 Fujimoto T, Teschler H, Hillejan L, Zaboura G, Stamatis G. Long-term results of lung volume reduction surgery. Eur J Cardiothorac Surg. 2002;21(3):483–8.
31 Windisch W, Dreher M, Geiseler J, Siemon K, Brambring J, Dellweg D, et al. für die Leitliniengruppe "Nichtinvasive und invasive Beatmung als Therapie der chronischen respiratorischen Insuffizienz." [Guidelines for non-invasive and invasive home mechanical ventilation for treatment of chronic respiratory failure: update 2017]. Pneumologie. 2017;71:722–95.
32 Herth FJ, Valipour A, Shah PL, Eberhardt R, Grah C, Egan J, et al. Segmental volume reduction using thermal vapour ablation in patients with severe emphysema: 6-month results of the multicentre, parallel-group, open-label, randomised controlled STEP-UP trial. Lancet Respir Med. 2016;4(3):185–93.
33 Come CE, Kramer MR, Dransfield MT, Abu-Hijleh M, Berkowitz D, Bezzi M, et al. A randomised trial of lung sealant versus medical therapy for advanced emphysema. Eur Respir J. 2015;46(3):651–62.
34 Valipour A, Shah PL, Pison C, Ninane V, Janssens W, Perez T, et al. Safety and dose study of targeted lung denervation in moderate/severe COPD patients. Respiration. 2019:1–11.
35 Fuehner T, Clajus C, Fuge J, Jonigk D, Welte T, Haverich A, et al. Lung transplantation after endoscopic lung volume reduction. Respiration. 2015;90(3):243–50.
36 Tutic M, Lardinois D, Imfeld S, Korom S, Boehler A, Speich R, et al. Lung-volume reduction surgery as an alternative or bridging procedure to lung transplantation. Ann Thorac Surg. 2006;82(1):208–13.