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Surgical aspects and techniques of lung volume reduction surgery for severe emphysema

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ABSTRACT: Lung volume reduction surgery (LVRS) has become an accepted procedure for palliative treatment of diffuse, nonbullous emphysema. Single or multiple peripheral segmental wedge resections of the most destroyed areas of the lungs are performed with the use of stapling devices, in order to decrease hyperinflation and restore diaphragmatic function. Median sternotomy, videoendoscopy or anterior muscle sparing thoracotomies have been used as surgical approaches. The functional improvement after bilateral resections exceed those after a unilateral approach. LVRS has demonstrated its potential as an alternative to transplantation, and with growing experience, the indications for the procedure have been widened. In selected patients with peripheral lung cancer who have been considered unsuitable for a surgical resection, the combination of both tumour resection and LVRS has successfully been performed. In contrast to LVRS, laser surgery of the emphysematous lung has been abandoned in most institutions.

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Historical surgical approaches

Surgical interest has been directed to the treatment of patients with emphysema for many years. This has resulted in a remarkable number of curious approaches [1]. The earliest interventions focused on the marked hyperinflation of the lungs with the intention of restoring the normal size of the thoracic cavity using procedures such as costochondrectomy, thoracoplasty, phrenic nerve paralysis or the creation of a pneumoperitoneum [2].

Other procedures were directed towards the treatment of expiratory airway collapse, and consisted of suturing a bone graft or fascia lata to the posterior wall of the trachea and major bronchi, or reinforcing the tracheal wall with a polyethylene prosthesis.

A third approach attempted to overcome the bronchospastic component of the disease. Resections of various parts of the autonomic nervous system, such as the vagus, cervical and stellate ganglions or the posterior pulmonary plexus gave the same poor results as had been achieved with the approaches described above.

Other procedures that can be included are parietal pleurectomy and poudrage, to increase blood supply to the emphysematous parenchyma, and radiotherapy to achieve a shrinking of the enlarged lung.

However, all these approaches were based on misconceptions of the underlying pathophysiology of emphyse-

ma. Therefore, only marginal improvements were achieved in a few patients with the majority experiencing some deterioration of lung function.

As a consequence, surgical interest in the treatment of patients with emphysema has focused on the bullous form of the disease for more than two three decades [3]. In this type of patient, it has been demonstrated that resection of large bullae occupying approximately one-third of the hemithorax resulted in the decompression of adjacent lung parenchyma, reduction in hyperinflation and hence an improvement of lung function. Diffuse, nonbullous emphysema however, was believed to be a clear contra-indication for surgical intervention.

It is even more remarkable that the original idea for the procedure recently introduced under the name "lung volume reduction surgery" (LVRS), had already been formulated by BRANTIGAN *et al.* [4] in the late 1950s. By this time, multiple peripheral lung resections had been applied in patients with chronic obstructive pulmonary disease (COPD), with the intention to reduce overall lung volume and to restore circumferential traction upon both small airways and blood vessels. However, this work failed to achieve widespread acceptance.

It has only been in the last few years that this concept of LVRS has been reintroduced into surgical practice for the treatment of diffuse emphysema [5] and has gained a widespread acceptance. At present, different surgical

approaches and techniques are applied and studied in a large number of institutions worldwide (table 1). The aim of this review is to summarize the surgical experience that has been gained and to address the different techniques used.

Current surgical approaches

Median sternotomy

The standard technique for LVRS uses intubation with a double-lumen endotracheal tube. The operative approach is *via* a median sternotomy, and both pleural spaces are opened in a longitudinal manner. Lung ventilation is installed on one side while the lung on the operative side is deflated. This takes several minutes in emphysematous lungs depending on the extent of air trapping. Usually, the most diseased areas will remain inflated for the longest time and can easily be identified. Mobilization of the pulmonary ligament, together with dissection of any adhesions in most cases, is performed and moist packs are placed behind the hilus to elevate the lung.

Non-anatomical excision of peripheral segments is performed with stapling devices (fig. 1). Resection is directed to the most diseased areas of the lungs, which are usually located at the apex in patients with smokers emphysema, and at the lower parts in patients with α_1 -antitrypsin deficiency. The target areas for resection are identified by chest computed tomography, and confirmed by perfusion scintigraphy and the intraoperative findings. Patients with uniform distribution of emphysematous changes require resection over all lobes.

Fig. 1. – Operative view during lung volume reduction surgery by median sternotomy. The resection lines of the lung, reinforced by bovine pericardium, can be seen.

Usually, it is intended to resect ~30% of the lung tissue (fig. 2). Periods of reinflation of the lung allow an estimation of the extent of resection. Care must be taken to direct the resection lines in a way that allows the remaining lung to keep its anatomical shape, to fill the thoracic cavity and to avoid large empty air spaces. At the end of the procedure, the remaining inflated lung should be somewhat smaller than the thoracic cavity. After resection of the first lung is completed, the same procedure is applied on the opposite side. At the end, two pleural drains are placed in each thoracic cavity, and the pleura is closed with running sutures to separate both sides. Compared to the other approaches, the advantage of median sternotomy lies in a single access to both chest

Table 1. – Results after different operative procedures of lung volume reduction surgery

First author [Ref.]	Surgical approach	Type of resection	Buttress	Patients n	Operation mortality %	Mean FEV1 increase %	Duration of chest drainage* days	Patients with air leak >7 days %	Hospital stay* days
COOPER [6]	Sternotomy	Bi	Peri	150	4	51	-	46	13.5
MILLER [7]	Sternotomy	Bi	Peri	53	5.6	96	-	40	10–59
KELLER [8]	Video	Uni	None	25	0	31	7.6±6	32	8.8±6.7
KEENAN [9]	Video	Uni	None	67	5.9	27	13±9.4	46	17±11.1
BINGISSER [10]	Video	Bi	None	20	0	42	6.5	35	15
BRENNER [11]	Video	Bi	Peri	145	4.2	62	-	-	8.8±5.6
WISSER [12]	Sternotomy	Bi	Peri	15	13.3	60	8.7±1.8	-	12.3
	Video	Bi	None	15	6.7	62	8.0±1.9	-	12.5
KOTLOFF [13]	Sternotomy	Bi	Peri	80	4.2	40	16	-	22
	Video	Bi	Peri	40	2.5	37	15.7	-	17.3
DE PARROT [14]	Anterior thoracotomy	Bi	Peri	18	0	54	11	33	21
ARGENZIANO [15]	Both	Uni	Peri	28	3.6	28	-	46	-
	Both	Bi	Peri	64	7.4	70	-	53	-
McKENNA [16]	Video	Uni	Peri	87	3.5	31	-	53	11.4±1
	Video	Bi	Peri	79	2.5	57	-	47	10.0±1
KOTLOFF [17]	Both	Uni	Peri	32	0	24	13.6	-	14.2
	Both	Bi	Peri	119	10	34	14.9	-	21.1
McKENNA [18]	Video/laser	Uni	None	33	0	33	9.8	33	10.6±2
	Video/staple	Uni	Peri	39	2.5	13	13.2	48	13.7±1.9
HAZELRIGG [19]	Video	Uni	Peri	58	0	-	7.9	-	8.6±5.2
	Video	Uni	None	65	0	-	10.4	-	11.4±8.1

*: Data are presented as mean±SD or range. FEV1: forced expiratory volume in one second; Both: sternotomy and video approaches. Bi: bilateral; Uni: unilateral; Peri: pericardium.

Fig. 2. – Typical operative specimen after bilateral lung volume reduction surgery for upper lobe disease. The deflated lung tissue would represent approximately one-third of the whole lung in its expanded shape.

cavities, the limitation of postoperative pain and the good visualization of upper lobes. However, for operations in lower lobe disease, it offers only limited access.

This technique was first described by COOPER *et al.* [5]. They reported an improvement of 44% in 20 patients with a mean preoperative forced expiratory volume in one second (FEV₁) of 25% of the predicted. There was no operative mortality and no major morbidity. All patients had predominant areas of destruction in the upper lobes, and a few had an arterial carbon dioxide tension >6.7 kPa (>50 mmHg). Subsequently, the group reported on a series of 150 patients [6] who had a 90 day mortality of 4% and a 51% improvement in FEV₁ after 6 months. These results prompted several other groups to use LVRS by median sternotomy [7, 20]. With growing experience, the procedure was offered to a larger group of patients, including patients with hypercapnia, patients unable to undergo a preoperative rehabilitation programme and even patients under conditions of mechanical ventilation [21].

Videoendoscopy

The potential advantages of videoendoscopic approaches [22] for LVRS were investigated by a number of groups with experience in this particular field of thoracic surgery. The technique is proposed as a unilateral [8, 9, 18] as well as a bilateral approach [10, 11, 23]. The number of incisions is limited to 3–4 on each side with a length of 1–2 cm. Patients are either operated on in the lateral position and turned over if a bilateral procedure is intended, or the operation is performed simultaneously in the supine position (fig. 3). The resection procedure itself is similar to the open approach and is performed with the use of endoscopic stapling devices. Finally, the trocar incisions are used to insert the chest drainage tubes at the end of the procedure. Optimal access to the upper lobes and in patients with more homogenous disease is achieved. However, especially for lower lobe disease and in patients with significant adhesions, the technique has its clear limitations for surgeons with limited experience in thoracoscopic surgery.

Fig. 3. – Operative setting during videoendoscopic lung volume reduction surgery. The patient is operated on in supine position and both sides can be approached in the one stage procedure.

Functional results reported for the bilateral videoendoscopic technique have been similar to those obtained with median sternotomy. In a study of 30 patients, WISSER *et al.* [12] compared both techniques. A mean FEV₁ increase of 60% was observed in both groups and no major differences in morbidity were found. KOTLOFF *et al.* [13] in a study of 120 patients, also observed no difference in functional improvement, although the authors described a reduction in hospital mortality in the videoendoscopy group.

Lateral thoracotomy

Muscle sparing anterior thoracotomy has been used occasionally by several groups. In patients with significant adhesions, or whenever operative problems occur during videoendoscopic surgery, this approach offers several advantages [24]. The rationales for this approach are excellent visualization of all parts of the lung, together with improved possibilities to palpate the lungs and to deal with any operative problems. Results obtained in a consecutive series of 18 patients operated on by bilateral muscle sparing anterior thoracotomy in a one stage procedure are described by DE PERROT *et al.* [14]. The authors observed no operative mortality and a somewhat extended length of drainage time, probably owing to their initial experience of using LVRS. Functional improvement with a mean increase in FEV₁ of 53% was similar to that reported for other approaches.

A few anecdotal reports about the use of bilateral thoracosternotomy (clamshell incision) have been described [15, 24]. However, no clear prospective investigation has been performed using this procedure, and results of this aggressive approach therefore remain unclear.

Unilateral versus bilateral LVRS

The question of whether LVRS should be performed unilaterally or bilaterally has been investigated by a number of authors. ARGENZIANO *et al.* [15] described a series of 92 patients, of whom 28 were only operated on unilaterally. Indications for unilateral procedures were asymmetric disease distribution, prior thoracic operation on one side, concomitant tumour resection and severe debility. Improvements in exercise capacity and dyspnoea, as well as perioperative mortality and actuarial survival at 24 months were similar in both groups. However, improvements in spirometric indices of pulmonary function were less in patients undergoing unilateral LVRS compared to those after bilateral LVRS.

McKENNA *et al.* [16] reported results for 166 consecutive patients, of whom the first half were operated on unilaterally and the second half bilaterally. Again, operative mortality (3.5% in the unilateral group *versus* 2.5% in the bilateral) and perioperative morbidity were comparable in both groups, but 1 yr mortality especially in highly compromised patients, was higher in the unilateral group (17 *versus* 5%). In addition, functional results were significantly higher after the bilateral procedure (57% increase in FEV₁ *versus* 31% in the unilateral group). The higher functional improvement after bilateral LVRS was confirmed in a separate study by KOTLOFF *et al.* [17]. Based on these results, the bilateral approach is considered to be the standard procedure by most groups, while the unilateral approach remains limited to selected patients [15].

Different techniques

Laser

Laser ablation as a method for shrinking the emphysematous lung was first described by WAKABAYASHI *et al.* [25] in a retrospective series of 22 patients treated with a free-beam carbon dioxide laser. They observed a significant operative mortality of 18% (four out of the 22 patients), and a high perioperative morbidity with the need for postoperative ventilation in almost all patients, combined with large and prolonged air leaks. Functional results were described for only 50% of the patients and were in general poor (FEV₁ increase of only 27%). Similar disappointing functional results were reported by LITTLE *et al.* [26] who found only a 15% increase in FEV₁ and had a high incidence of prolonged postoperative airleaks.

In one of the few randomized prospective trials of stapled lung reduction *versus* laser bullectomy for diffuse emphysema, McKENNA *et al.* [18] compared the efficacy of neodymium–yttrium aluminium garnet (Nd-YAG) contact laser surgery to stapled lung reduction in a group of 72 patients undergoing unilateral LVRS. A significantly greater improvement in FEV₁ after 6 months was demonstrated in the stapled group (33 *versus* 13%), whereas operative

mortality and operative morbidity were similar in both groups. However, an unusually high incidence of delayed pneumothoraces was observed in the laser group. Similar results with laser surgery for this particular indication have also been confirmed in other reports [27].

HAZELRIGG *et al.* [28] reported the results of 141 patients operated on with unilateral contact-tip laser bullectomy in four different institutions. Only a modest improvement in FEV₁ of 16% was observed and the authors abandoned the use of laser for this indication at their institutions.

All these results contribute to the generally accepted opinion, that the use of laser surgery has no place in the treatment of diffuse as well as bullous emphysema.

Staplers and buttressing

The use of mechanical stapling devices has significantly improved operative surgical results for emphysema compared to the previously applied suturing techniques. Currently, a number of different staplers are available, all providing different features. Resections in open procedures are usually performed with 60–75 mm staplers, which have the advantage of a long resection line, but are sometimes difficult to use. Several surgeons, therefore, tend to use endoscopic stapling devices in open procedures as well. The 45 mm endolinear cutter (Ethicon Endo-Surgery (Johnson and Johnson), Cincinnati, OH, USA) represents the standard device for videoendoscopic surgery, and helps to overcome problems in application. In addition, they own the advantage of 3 rows of staplers on each side, which helps to improve airtightness. As an alternative the Endo GIA 30–60 autosuture (United States Surgical Corporation, Norwalk, CT, USA) can be used.

Several different approaches towards the reduction of postoperative airleaks have been undertaken. Buttressing of the staple line with different materials is the most promising. Bovine pericardial strips were initially applied in open surgery by COOPER [29]. Their use, although not proven in a prospective randomized trial, was believed to reduce both the incidence and duration of postoperative airleaks. The effect of buttressing of endoscopic staplers with bovine pericardium was investigated in a randomized trial of unilateral thoracoscopic LVRS in 123 patients by HAZELRIGG *et al.* [19]. Comparable postoperative complications were reported, with the exception of duration in postoperative airleaks, which was found to be significantly shorter in the buttressed group. Although no operative problems or disadvantages are reported for the use of bovine pericardium as a buttressing material, intraoperative experience in patients undergoing transplantation after LVRS has shown that the number and severity of adhesions is markedly enhanced (unpublished data).

As an alternative to bovine pericardium, several artificial materials are currently under investigation. The use of expanded polytetrafluoroethylene (PTFE) [30] has demonstrated satisfying clinical results in a series of 26 patients.

Peri- and postoperative management

Adequate anaesthesiological management is at least as important for good postoperative outcome, as surgery [31]. It starts with the optimal preoperative preparation of the

patient, which consists of optimal standard antiobstructive pharmacotherapy. Loosening of secretions is achieved with humidifiers, systemic hydration, and the optional use of mucolytic drugs. Finally, extensive chest physiotherapy improves the removal of secretions.

Monitoring of the patient during the operation is usually performed with a radial artery canula and a central venous line. An epidural catheter for intra- and postoperative pain therapy is inserted at the level of Th4–Th5. The correct position of this catheter is particularly important and must be checked with a test dose of lidocaine 2% plus adrenaline 1:200,000. Prevention of bronchospasm, together with optimal analgesia and extubation of the patient on the operating table are the main goals of the anaesthesiological procedure. Isoflurane is the drug of choice for the maintenance of anaesthesia, as it is a potent bronchodilator. Muscle relaxation should be performed with pancuronium and vecuronium as both do not release histamine and have a very short half-life. Analgesia is provided *via* the epidural catheter using bupivacaine 0.25% together with sufentanil.

Immediate postoperative management in the intensive care unit is focused on extensive chest physiotherapy, early mobilization and sufficient analgesia. Prophylactic antibiotics are given for several days in all cases. Frequent therapeutic sessions of chest vibration and percussion are followed by periods of rest. In order to enable early mobilization, pain therapy has to be efficient. This is performed *via* the epidural catheter with continuous infusions of bupivacaine 0.25% together with two or three bolus dosages of sufentanil during the day. Chest drainage tubes are connected to Heimlich valves (Laboratoire Plastimed, Saint-Leu La Foret, France) only and in cases of significant air leak, suction can be applied at 10 or 20 cmH₂O. Drains should be removed as soon as there are no air leaks and only moderate secretions are observed. The use of Heimlich valves [32] helps to mobilize patients early and, in cases of prolonged air leaks, it offers the possibility to discharge the patients even with a persistent air leak.

LVRS and transplantation

LVRS has been introduced into surgical practice only after lung transplantation was already a well established procedure for the treatment of patients with end-stage emphysema. The two procedures now complement each other in three different ways.

Firstly a significant number of patients who primarily present as candidates for both procedures can effectively be improved symptomatically by LVRS in such a way that there is no immediate need for transplantation. LVRS in these patients can be seen as an alternative to transplantation, providing the improvement remains stable over a long period of time. ZENATI *et al.* [33] have performed LVRS in 35 patients, who were accepted as candidates for both LVRS and lung transplantation. Twenty of these patients were removed from the transplant list owing to their significant improvement after LVRS.

Secondly, for patients who had undergone LVRS with only a marginal or temporary improvement, the role of LVRS is an effective bridge until the time of transplantation. This is of importance especially in North America, where the waiting time for a donor organ can exceed 2 yrs.

Patients with α_1 -antitrypsin deficiency who are prone to recurrent infections appear to benefit from such a strategy.

Finally patients undergoing single lung transplantations occasionally have problems with progressive hyperinflation of the native lung, especially when the transplanted organ is subjected to chronic rejection. Contralateral hyperinflation can significantly add to impaired graft function. In these patients, LVRS of the native lung, either from the technique described above or from a lobectomy or even pneumonectomy [34, 35], has been reported to restore function of the single lung graft and improve exercise tolerance. TODD *et al.* [36] reported on two patients in whom a simultaneous single lung transplantation and contralateral volume reduction was performed. An improvement in lung function similar to that after bilateral lung transplantation was observed in both patients.

LVRS and cardiac surgery

During the evaluation process of patients for LVRS, significant coronary artery disease and other cardiac problems can be detected in a number of patients. Whereas significantly elevated pulmonary artery pressures are generally considered as a contra-indication, isolated coronary artery problems do not necessarily exclude the patient from the procedure. Several groups have performed combined coronary artery revascularization and LVRS through median sternotomy or dilatation and stenting of coronary artery stenoses followed by LVRS [37]. A staged operation with LVRS followed by coronary artery bypass grafting after 3 months has also been described [38]. Additionally, cardiac valve surgery in emphysema patients has been successfully performed in combination with LVRS [37]. However, the individual success in these few reported cases should not alter the generally accepted concept that severe cardiac disease represents a contra-indication for LVRS.

LVRS and lung cancer surgery

Smoking is the primary cause of lung cancer and emphysema, and some patients with both diseases can be identified during the evaluation process. McKENNA *et al.* [39] resected lung nodules in 51 (16%) patients out of a series of 325 patients who underwent LVRS. Forty-two patients had benign lesions, whereas 11 patients had clinical stage I non-small cell lung cancers. An even higher incidence of lung nodules (39%) in a series of 281 patients undergoing LVRS was reported by HAZELRIGG *et al.* [40]. In 13 (6.4%) of these patients primary lung cancers were mostly identified only during the pathological examination, and were subsequently resected.

From these observations, it is evidenced that a solitary peripheral lung tumour does not preclude LVRS. If the lesion is within the target areas of resection, both LVRS and nodule resection can easily be combined. On the other hand, the experience that has been gained with LVRS allows the indications for cancer resection to be extended to patients not previously considered to be candidates owing to their impaired and limited lung function.

LVRS in ventilated patients

During the development of LVRS, mechanically ventilated patients were excluded from the operation. However, growing experience and a better pathophysiological understanding have now allowed the procedure to be offered to a few highly selected patients. CRINER *et al.* [41] reported on three patients who underwent LVRS after 11–16 weeks of mechanical ventilation. All patients were successfully weaned from the respirator and discharged. In addition, there are a number of anecdotal reports [42] about patients who have had different forms of noninvasive or invasive mechanical ventilation prior to LVRS. However, these patients should only be accepted for the procedure under otherwise ideal conditions.

Summary

Lung volume reduction surgery has reached a state of widespread application. The growing experience with the procedure has resulted in its use in a large number of patients [27]. Although the basic principles of patient care have been well defined, there are many issues under investigation. From the published reports, it appears that the applied techniques of lung volume reduction surgery, median sternotomy, lateral thoracotomy or videoendoscopy are of less importance for its overall success. Bilateral applications offer better functional results compared to unilateral ones. The use of lasers for the treatment of emphysema is now a subject of the past, whereas adequate surgical strategies to avoid prolonged air leaks have since evolved. Lung volume reduction surgery together with transplantation has now expanded the treatment possibilities for patients with end-stage emphysema. Although initial reports are promising, the application of lung volume reduction surgery in patients with concomitant diseases should be restricted to highly selected cases.

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