Laser resection of lung parenchyma – a new technical and clinical approach

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Abstract

The introduction of a new 1318 nm wavelength Nd: YAG laser has created new possibilities in lung parenchyma surgery. The potentially curative surgical resection of pulmonary metastases in suitably selected cases had been recognized slowly. Using the new laser technology a greater number of patients can now offered salvage surgery. This paper reviews the history of surgical management of pulmonary metastases, development of new laser technology, conventional and extended indications for pulmonary metastasectomy and use of laser in thoracic surgery.

Key words: lung metastasectomy, laser surgery, thoracic surgery.

A long period of time was necessary to establish intended curative resection of metastases to the lung [1]. After chest wall resection for rib sarcoma Weinlechner in 1882 [2] performed the first resection of an isolated metastasis found in the underlying lung. Pulmonary metastasectomy as an independent operation was described in 1926 by Divis [3]. In 1939 Barney and Churchill [4] reported the first successful intentional lobectomy for metastatic kidney cancer, after failure of radiation therapy. Several years later elective surgery of solitary metastasis has been offered to patients selected to long disease free interval to their primaries [4,5]. In 1953 Mannix [6] performed simultaneous resection of multiple synchronous metastases. He removed a total of 6 lesions through lingulectomy and basal segmentectomy. In the beginning with metastasectomies 80% of patients underwent lobectomy or pneumonectomy and mortality was in the range of 10% [7,8]. Due to improvement of surgical techniques and progress to limited resections, a greater number of patients are now candidates for resection.

The effect of the Nd:YAG laser on lung tissue and small pulmonary tumours first was experimentally demonstrated by Minton et al. [9] in 1967. They excised and vaporised metastases implanted to rabbit lungs and successfully resected normal parenchyma of primates. Therefore Minton was the first to recognise this special laser indication that becomes more and more important in lung surgery today. But a lot of technical difficulties prevented the use of lasers in thoracic surgery for nearly 20 years.

In 1985 LoCicero et al. [10] reopend the discussion of clinical application on lung tissue by describing the mechanism of the laser's sealant effect using a CO_2 laser. Laser sealing works by means of a progressive collapse and shrinking of alveols producing a thick, multilayer and air-proof membrane. This result has been tried to achieve either by CO_2 or Neodymium-yttrium-aluminium-garnet (Nd:YAG) laser using low power density and defocussed laser beam. Because of his predominant absorption and low scattering quality in lung tissue the CO_2 laser, however, proved inadequate for lung surgery. Nd:YAG laser beam on the other hand is absorbed and scattered by water, black (anthracotic) structures and hemoglobin pigment thus allowing more coagulating activity up to 4 mm below the surface of the lung. Therefore a number of medical centres in the world and LoCicero as well started experimenting with 1064 nm Nd:YAG lasers using bare fibres and sapphire tips to deliver the radiation to lung parenchyma.

In 1988 Rolle et al. [11] first described the advantages of a new 1318 nm wavelength Nd:YAG laser due to experimental and clinical wedge and segmental resections in 47 patients. The

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standard 1064 nm Nd:YAG laser was employed parallel for peripheral resection of coin lesions by Moghissi et al. [12]. In 1991 Kodama et al. [13] described resection of lung metastases using 1064 nm Nd:YAG laser in 25 patients. Combination of metastasectomy with lobectomy in 51 patients using this laser was described by Branscheid et al. in 1992 [14]. In the same year Kodama et al. [15] reported of 1064 nm laser segmental resections in combination with bioadhesives in 25 patients with poor lung function and bronchial carcinoma. In 1994 Mineo et al. [16] once more emphasised the importance of laser resection of solitary and multiple metastases. In 1998 they reported that laser metastasectomies demonstrate statistically significant influence on tissue loss, postoperative air leakage and hospital stay and they continued to compare the impact of lobectomy versus minimal and versus laser resections to survival after surgery for lung metastases. The results reported in 2001 indicated that patients after limited resections have better survival than having anatomical resections but this comparison did not reach statistically significance [17,18].

In the majority of peripheral 1064 nm Nd:YAG laser resections bleeding or air leakage can be controlled by defocusing the laser beam, but deeper resections going to the centre of the lobe regularly require supplemental hand suturing or bioadhesives. Therefore Rolle et al. [11] started in 1988 to test the second wavelength of the Nd:YAG laser (1318 nm) in animal experiments based on the knowledge that the 1318 nm wavelength significantly differs from the standard wavelength (1064 nm) by its ten times higher absorption in water. On the other hand the 1318 nm laser offers sufficient scattering of laser light due to its proximity to the beginning near infra-red spectrum to satisfy coagulation requirement as well [19].

After a few tests it became clear that the 1318 nm wavelength provided the combination effect needed – cutting and coagulation qualities which could not be achieved by the 1064 nm wavelength. They also found strong lung tissue shrinkage providing two additional advantages: mechanical reinforcement of the coagulation area and closure of air leaks far into the central region of every lobe [20]. Areas coagulated and sealed by defocused 1318 nm laser irradiation were found to withstand artificial ventilation up to pressures of 25 cm H_2O.

To achieve higher laser power output for this 1318 nm wavelength a complete new laser system has been developed. The average energy efficiency of the Nd:YAG laser was almost doubled from 3% to 5%. The beam quality was improved to such an extend that the laser light of this special wavelength could easily be coupled into fibres of diameters less than 0.6 mm without any heat build up or energy losses [21].

The focusing handpiece featuring a four lens system was developed to allow a near one to one projection of fibre diameter relative to the working focus and enabling power densities up to 24 kw/cm^2. To be complete this laser system includes a high performance smog evacuator, which is needed to eliminate great deal of smog, produced by large-scale parenchyma resection [22].

Pulmonary metastasectomy is one of the main indications of potentially curative and palliative thoracic surgery and has been established now for more than 20 years [23]. Outside of centres of thoracic surgery even today it is widely believed that occurrence of lung metastases marks the final stage of the underlying disease so that only short survival times are expected and chemotherapy represents the only feasible treatment option, if any. However, this view has become obsolete. At the time of potential palliative surgical intervention modern patients are usually well informed about the state of their disease and have clear subjective about the state of things. This allows and requires a partnership approach with transparent patient guidance and care [24].

Conventional indication for resection of pulmonary metastases based on the conditions that the primary tumour should be removed completely (RO resection) and extrapulmonary foci can be ruled out by a preceeding examination of abdomen and skeletal system. In the past only patients with single side and long disease free interval to the primary were accepted for surgical treatment. In 2002 Rolle et al. [25] demonstrated that patients with multiple and synchronous metastases (i.e. metastases that are detected together with the primary tumour) are also eligible for surgical treatment. In 100 consecutive patients they showed that in 95% of all cases parenchyma sparing "precision" resection could be performed. Lobectomy was only necessary in the remaining 5% of patients (against an international lobectomy rate of 20% to 30%) [1], even though 6.3 metastases on average and a maximum of 124 metastases were removed per patient.

Due to a careful and comprehensive palpation of the collapsed lung, 25% more nodules could be resected than were indicated in spiral CT scan examination. Classical resection of pulmonary metastases is limited by surgical technique and functional conditions of the patient. Despite the fact that pulmonary metastases tend to grow locally and therefore can be resected with small margin of safety the number of clamp or stapler wedge resections is limited to three or five for one side. The development of this new 1318 nm laser system enables the thoracic surgeon to resect a much greater number of metastases with minimal loss of parenchyma furthermore to remove metastases located deep inside a lobe in an oncologically adequate manner while preserving the function of the lobe [22,25].

The comparison between wedge resection and laser resection was shown in the *Fig. 1*. One metastasis of 2.5 cm diameter located centrally within the lower lobe. Laser precision resection with 0.5 cm distance to the tumor has been demonstrated to be a secure oncological resection followed by a very low local recurrence rate. The parenchymal lost was calculated: 3 cm x 3 cm x 3 cm =27 cm^3 with good ventilation and function of the rest lobe. The parenchymal lost for wedge resection with 1 cm stapler line distance to the tumor was calculated: 4.5cm x 5.5 cm x 7.0 cm =173 cm^3 with no edges left which give problems due to atelectasis. The ratio in parenchymal lost wedge resection to laser resection was 173 cm^3 : 27 cm^3 = 7 : 1. We note a 7 times more parenchymal lost in classical resection of metastasis, which is highly significant.

Fig. 2a, *2b* and *2c* shows five metastases distributed in one lobe (peripheral and central location). In such case lobectomy is unavoidable in conventional resection technique. Laser precision resection is easy to perform by saving the lobe even in a higher number of metastases, due to simultaneous sealing and coagulation. The lung architecture and orientation was reconstructed following each nodular resection by reapproximating

Figure 1. **Sketch of the patient's metastasis. This is located centrally, within the lower lobe, where the lobe is on its thickest. Comparison between wedge resection and laser resection**

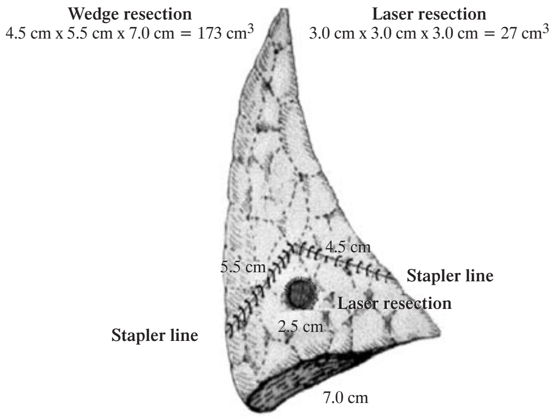

Figure 2a. **Sketch of five metastases distributed in one lobe**

Figure 2b. **Sketch of the laser resection zone after removel of metastases**

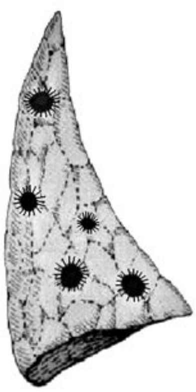

Figure 2c. **Sketch of suturing the pleura visceralis**

the visceral pleura with a running absorbable suture. The rest of the lobe remains in function without atelectasis.

On condition that all metastases are complete resected there is no evidence of worse prognosis for patients with bilateral metastases. In cases of multiple and bilateral resections two staged operation via anterolateral, muscle sparing thoracotomy should be planned. The authors suggest to start resection at the side with the higher number or the more centrally located metastases. The other side is operated in the same manner in an average of four weeks later. This two staged approach ensures healing of the lung treated first under physiotherapy so that it can reliably take over the function of the other collapsed lung during the second operation. Overall this treatment significantly reduces the complication rate [26].

Metastases detected more than three years after removal of the primary tumour probably indicate an oncologically retarded disease process with more favourable prognosis. On the other hand metastases that develop within the first 12 months or are even diagnosed together with the primary tumour (so-called synchronous) are said to be followed by shorter survival. Rolle et al. [25] found complete resection to be the most important independent prognostic factor and suggested that patients with synchronous metastases should not be excluded from resection. Due to the parenchyma sparing and lobe saving effect of this laser operations it is possible to perform repeated resections in patients with recurrent metastases. If resection is complete once again there is no evidence of poor outcome after multiple thoracotomies. The indication of pulmonary metastasectomy can be extended to patients with previous complete resection of extrapulmonary metastases (brain, liver) [26].

This new 1318 nm laser system enables the thoracic surgeon to seal persistent air leakage from primary or secondary pneumothorax, to cut adhesions, to resect bullae and perform photothermal pleurectomy. This technique can now be used as well in open thoracic as in videothoracic assisted surgery [26,27].

Compared to traditional resection techniques this laser system offers notable advantages. Blood loss and air leaks are remarkably lower in patients undergoing laser resection of deep located tumours or in patients with underlying severe emphysema. Due to more rapid reexpansion of residual lung parenchyma laser resection allows reduction of chest drainage time and thus leads to lower morbidity rate and shorter hospitalisation time. The use of this laser is the method of choice for the resection of multiple metastases and can successfully be applicated in all kinds of parenchymal resections.

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