

# Lobe-Sparing Resection of Multiple Pulmonary Metastases With a New 1318-nm Nd:YAG Laser-First 100 Patients

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**Background.** A new 1318-nm Nd:YAG laser has been developed to utilize the second wavelength (1318 nm; 40 watt) to more precisely cut, coagulate, and seal lung tissue adjacent to pulmonary nodules. This laser allows a precise intraparenchymal nodulectomy with a 5-mm rim of tissue destruction and subsequent lung parenchymal reapproximation to avoid lobar distortion. Resection of multiple, bilateral, and recurrent tumors in the lung is facilitated by this laser technique.

**Methods.** In 100 consecutive patients (53 men, mean age 60 years; 47 women, mean age 61 years) with various primaries (most commonly renal and colorectal), 155 laser resections were performed via anterolateral thoracotomy (staged 3 to 4 weeks, if bilateral) using a new 1318-nm Nd:YAG laser. All palpable and visible masses were removed with 2 to 3-mm visible tumor margins (plus a 5-mm rim of residual lung necrosis secondary to laser energy dispersal) if the tumor or residual lung ratio was judged favorable. No stapling devices or bioadhesives were used.

**Results.** Six hundred thirty-two metastases (6.3 per patient, range 1 to 124) were resected. Despite 41% centrally located metastases, tumor resections were possible in 95% of patients with only a 5% lobectomy rate.

As early as 1967, Minton and colleagues [1] reported on experimental resections of pulmonary metastases in rabbit lungs with pulsed laser energy emitted by a 1064-nm Nd:YAG laser. Although in 1985 LoCicero and co-workers [2] still favored the CO<sub>2</sub> laser, by 1990 he and others agreed that the standard 1064-nm Nd:YAG laser was preferable due to its ability to resect and seal lung tissue simultaneously [3-6]. The absorption coefficient of water and saline of the Nd:YAG second wavelength at 1318 nm is 10 times higher and the extinction coefficient of blood only one-third compared to 1064-nm Nd:YAG. This results in more efficient energy conversion into heat, with less heat dissipation by blood, leading to deeper penetration in tissue [7]. A distinct and broad coagulation zone (approximately 5 mm) develops with the 1318-nm Nd:YAG. A member of our group (A.R.) initially investigated the interaction

Of the 100 patients, 67 were considered "curative" with complete metastasectomy by inspection and palpation, and 23 were judged incomplete from too extensive tumor or residual lung, miliary lung spread, or pleural studding. There were no associated mortalities and two complications, including bleeding (1) and a prolonged airleak (1), both treated conservatively. Follow-up was complete in all patients for a median of 26.5 months with clinic visits and chest computed tomographic scan every 3 to 6 months. Nine recurrences were detected and underwent reoperation. Overall survival in the completely resected "curative" group was 85% at 1 year, 71% at 2 years, 69% at 3 years, 57% at 4 years, and 32% at 5 years; in the completely resected "palliative" group, they were 70% at 1 year, 36% at 2 years, 12% at 3 years, and 0 at 4 years; in the incomplete group, they were 56% at 1 year, 30% at 2 years, and 0 at 3 years.

**Conclusions.** The new 1318-nm Nd:YAG laser is parenchyma-sparing, improves complete resection rates, and potentially improves survival with fewer required lobectomies.

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of the Nd:YAG laser with lung tissue and confirmed that the second wavelength of 1318 nm has a 10-fold higher absorption coefficient in water and saline than the primary 1064-nm wavelength with improved lung tissue determinants of cutting, coagulation, and sealing airleaks [8]. The 1318-nm Nd:YAG laser was subsequently improved with a hand-held applicator to facilitate precision of the dissection within the lung parenchyma. In a phase I pilot study to demonstrate safety (47 patients), we reported that extensive parenchyma resections up to diameters of 14 cm are possible with histologically clear margins and a low complication rate [9]. After further experience, we now report the follow-up on 100 consecutive patients with multiple pulmonary metastases resected for potentially meaningful palliation using the 1318-nm laser.

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## Material and Methods

The average efficiency of a primary 10M-nm Nd:YAG laser is approximately 3%. The energy efficiency of the 1318-nm emission wavelength is only 34% that of the primary 1064-nm wavelength. In order to achieve sufficient laser output power at 1318 nm, for lung parenchymal dissection, the system's efficiency must be increased to 5%. The following design features were incorporated to develop a 1318-nm commercial design (Hüttinger Medizintechnik, Umkirch, Germany). The second wavelength is first generated by adapted reflection of the laser mirrors. High beam quality allows coupling into thin (less than 0.6 mm) optical quartz fibers with minimum losses. For flexible transmission to the area of application, special water-free quartz fibers are required as laser light absorption in water is 10 times higher at the 1318-nm wavelength [10, 11]. A four-lens focusing handpiece was developed to concentrate the laser light and allow manual manipulation of the beam onto lung tissue to keep the working-point focus on the tissue at 4 mm while avoiding heat generation in the focusing handpiece. The extremely high laser power density of 24 kW/cm<sup>2</sup> allows fast and precise cutting with simultaneous coagulation and sealing of lung tissue. A high performance smoke evacuation system eliminates the vaporization fumes which are unavoidable during parenchyma dissection with this laser.

All patients gave informed consent for thoracotomy with exploration and attempted laser pulmonary metastasectomy. Since previous reports documented the safety of this laser wavelength (1318 Dm) for lung parenchymal dissection, use of this device was considered "best therapy" by the primary surgeon (A.R.) for this consecutive series.

This study was designed as a prospective follow-up of technical application and outcome in consecutive patients judged suitable for pulmonary metastasectomy. All patients had a known histologically confirmed primary tumor (renal, colorectal, breast, and lung) with complete initial resection of the primary. Between March 1996 and November 1998 (32 months), we identified consecutive patients with controlled primary tumors and suspected pulmonary metastasis. Preoperative evaluation included history, physical exam, chest computed tomography (CT), pulmonary function tests, and bone scan. If signs or symptoms were suggestive, head CT was obtained. Patients with identified extrapulmonary metastasis were excluded from surgery. An exception was the group considered "palliative" where the primary was initially controlled. Subsequent brain or liver metastasis were completely resected or irradiated for complete control, then presented with pulmonary metastasis as the only site of disease. We consider these 10 patients separately. Patients who initially qualified for laser metastasectomy and proceeded to thoracotomy but were

found to be unresectable or who underwent laser metastasectomy for palliation of symptoms despite known remote cancer were excluded from this study. For completeness, we included data on the feasibility and follow-up on these subgroups.

We identified all patients with known primary malignancies and suspected lung metastases. Prior to metastasectomy, all patients met two criteria: (1) the primary tumor was completely resected initially; (2) patients were judged able to tolerate the planned thoracotomy and loss of lung parenchyma. The group considered "palliative" allowed brain or liver metastases which had been completely resected or irradiated.

Using the 1318-nm Nd:YAG laser, all resections were performed using a double lumen endotracheal tube via limited anterolateral thoracotomy (staged 3 to 4 weeks, if bilateral). Median sternotomy and clamshell incisions were avoided by physician preference and to be consistent throughout the series. At thoracotomy, all visible and palpable nodules were noted and a tumor or residual lung ratio determined to estimate the patient's ability to tolerate the resections necessary for complete removal. In the collapsed lung, all palpable and visible masses were dissected from the lung parenchyma by the most direct route with 2 to 3-mm tumor margins (plus a 5-mm rim of residual lung necrosis secondary to laser energy dispersal) if the tumor or residual lung ratio was judged favorable. No stapling devices or bioadhesives were used. Exposed bronchial branches at the segmental level were oversewn with absorbable suture (4-0 Vicryl; Ethicon, Somerville, NJ) and segmental vessels ligated. The lung architecture and orientation was reconstructed following each nodular resection by reapproximating the visceral pleura with a running absorbable suture (4-0 Vicryl). This technique avoided distortion of the lung tissue to allow consistent orientation and palpation of the initially noted lung nodules. We evaluated the postresection lung by measuring the rate of airleak, complications, completeness of resection, and required lobectomies. During this series, suspected pulmonary metastases were confirmed as malignant at thoracotomy by frozen section. Once malignancy was confirmed, the remainder of the nodules resected were sent for permanent histological evaluation. In a few cases (n = 13), the nodules were benign disease and the patients were excluded from this study. We currently prefer CT, bronchoscopic, or endoscopic ultrasound (EUS)-guided fine-needle aspiration or core-needle biopsy to confirm malignancy prior to thoracotomy.

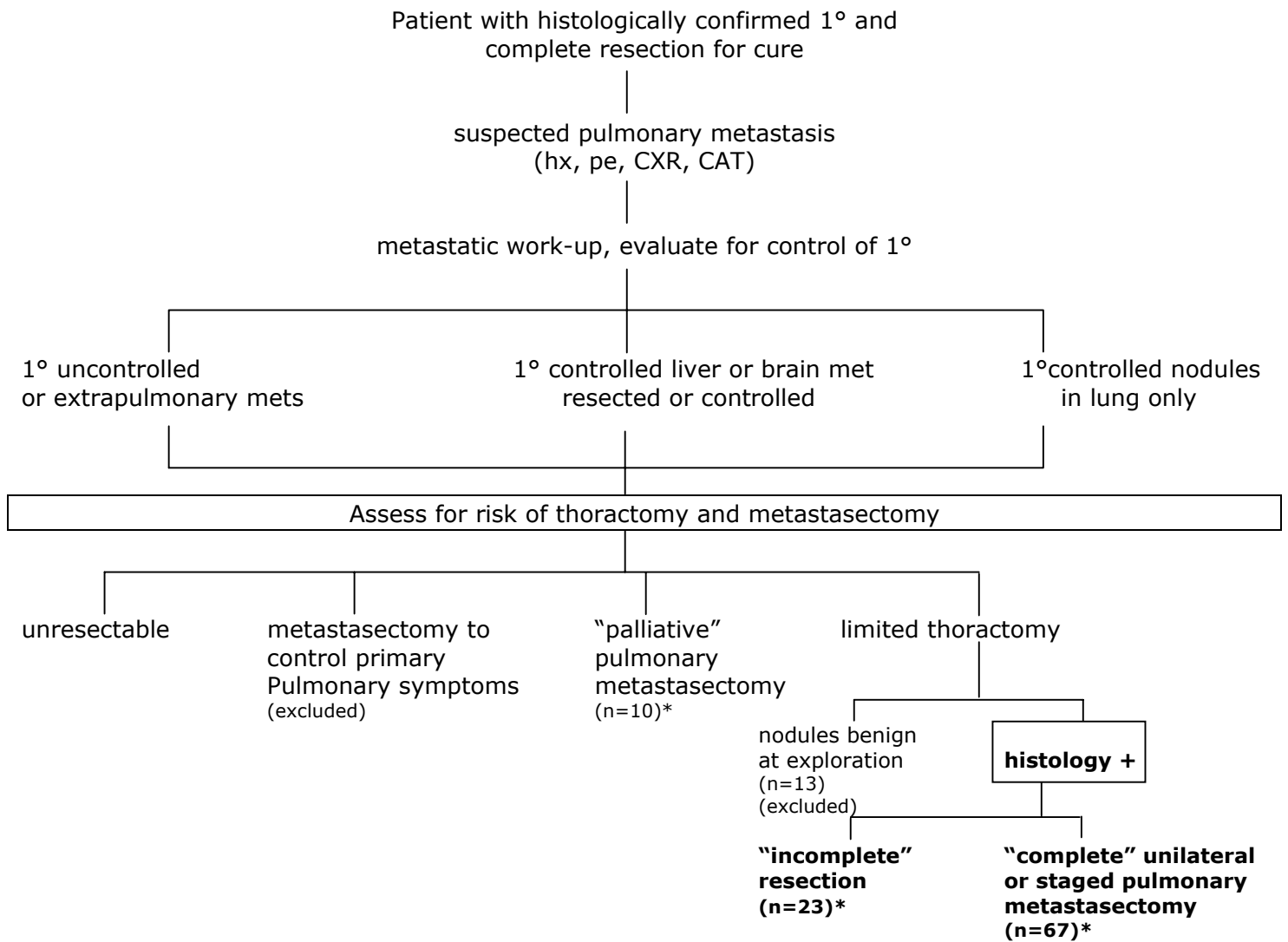


Fig. 1 Algorithm of patient selection for pulmonary metastasectomy. \*n = 100 total as subjects of this report (n = 10 „palliative“ + n = 23 „incomplete“ + n = 67 „complete“). CAT = CT scan; CXR = chest x-ray; hx = history; met = metastasis; pe = physical exam.

## Results

Between March 1996 and November 1998 (32 months), we performed complete laser resection of all visible and palpable nodules in consecutive patients. One hundred patients (53 men, mean age 60 years; 47 women, mean age 61 years) met the criteria outlined for control of the primary and histologically confirmed metastatic disease limited to the lung (Fig 1 algorithm). One hundred fifty-five laser resections were performed via anterolateral thoractomy (staged 3 to 4 weeks, if bilateral) using the new 1318-nm Nd:YAG laser with a total of 632 metastases (6.3 per patient, range 1 to 124) resected.

Despite 41 % centrally-located metastases, resections were possible in 95% of patients with only a 5% lobectomy rate. Of the 100 consecutive patients who qualified for this study, 77 were considered "curative" with complete metastasectomy by inspection and palpation, and an margins histologically negative for tumor, while 23 were judged incomplete at thoractomy from too extensive tumor of residual lung, positive margins, miliary lung spread, or pleural studding.

There were no associated mortalities and two complications, including bleeding (1) and a prolonged airleak (1), both treated conservatively. Follow-up was complete in all patients for median of 26.5 months with clinic visits every 3 months and chest CT scan every 3 to 6 months. Nine recurrences were detected and underwent reoperation. Overall survival rates of those metastasectomies considered complete (n = 67) were 85% at 1 year, 71 % at 2 years, 69% at 3 years, 57% at 4 years, and 32% at 5 years (Fig 2). Those with incomplete resections (n = 23), or "palliative" resections with remote disease (n = 10) faired much worse with identical survival rates of 25% at 2 years.

Table 1 shows the distribution of primary cancers in an patients. In 13 cases, we found benign lesions representing fibrous scar tissue and tuberculomas, so these patients were excluded from statistical consideration. No complications were seen in this subgroup.

Six hundred thirty-two metastatic nodules (6.3 per patient, range 1 to 124) were excised from the 100 study patients. Solitary metastases were present in 28%. The diameters of the resected metastases ranged from 3 to 60 mm.

Forty-one percent of all nodules were central or deep-seated (not visible and not palpable during inflation of the lung), so 59% were easily approachable due to their peripheral location. In 95%, it was possible to perform a limited resection. Of the 155 operations in the 100 study patients, 6 patients required a lobectomy due to number and size of metastases (for example, lower lobe with 13 metastases and 1 middle lobe with a 5-cm tumor), and 2 patients required sleeve lobectomy due to infiltration of the bronchus.

In order to measure the rate of air leaks, we recorded the chest tube duration of every patient.

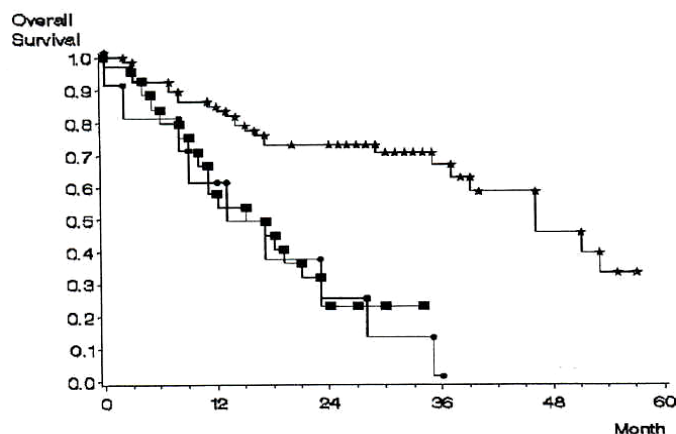


Fig 2. Kaplan-Meier curve showing survival according to resection for 100 patients. (Bullets = complete palliative; squares = incomplete; stars = complete curative.)

The insertion of two chest tubes was standard, and the minimal chest tube duration was 2 days for the first tube and 3 days for the second. In this series of 100 patients, we registered 2.29 days for the removal of the first chest tube and 3.68 days for the second. Mortality in this series was 0%. There was one postoperative hemorrhage (redo surgery with decortication) and one pneumothorax at 7 days (treated by observation). Local recurrences at the laser resection area or infection of the laser necrosis zone were not observed, with the longest follow-up to 5 years.

## Comment

Endobronchial laser coagulation and vaporization of obstructing tumors with standard wavelength 1064-nm Nd:YAG lasers has been established since the 1980s. We demonstrated, in experimental and clinical studies, that the second wavelength of the Nd:YAG laser (1318 nm) shows much better cutting, coagulation, and sealing of lung tissue than the standard wavelength of 1064 nm [7,8]. The 1318-nm wavelength allows precision resection of an intraparenchymal lung mass of 2 to 3-mm distance from the tumor with an additional 5-mm coagulation and necrosis zone.

Table 1 Distribution of Primary Cancers

Site	No. of Patients / %
Kidney	29
Colorectal	25
Breast	9
Lung	8
Melanoma	7
Sarcoma	4
Gynecological	4
Thyroid	4
Head /neck	3
Other	4
Bladder	3
	100

With the 1318-nm wavelength, only segmental arteries and their direct subsegmental branches require suturing. All parenchymal resections achieve hemostasis and sealing of airleaks allowing atraumatic and clear margins of deep-seated tumors. In contrast, when the 1064-nm wavelength is applied to lung parenchyma, hemorrhages can be seen even after cutting through only 1 to 2cm of lung. Therefore, the usage of this wavelength often requires additional conventional control of bleeding such as suturing, purse-string ligatures, or metal clips. Poor control of airleaks is also noted with the 1064-nm wavelength [12, 13]. In summary, the 1318-nm wavelength enables the surgeon to cut through the collapsed lung to achieve an additional coagulation zone, achieve hemostasis, and convincingly seal the lung surface.

The most important prognostic indicator, as well as most constant single variable reflecting prolonged survival, is complete resectability of pulmonary metastases [14]. Our data confirms this observation. If the primary is controlled, and the lung is the only demonstrable site of metastases, complete resection of the metastases is the goal of palliation. Our data also reiterates a poor outcome with an incomplete resection or known remote sites of metastatic involvement. Compared to the International Registry of Lung Metastases [15], we had a higher incomplete resection rate (23% versus 12%) presumably due to our willingness to explore patients with a large number of metastases imaged by chest CT. More follow-up time and a greater number of patients are needed to stratify the results by the primary tumor.

The 1318-nm Nd:YAG laser for resection of pulmonary metastases demonstrates a significant influence on conservation of tissue during metastasectomy and appeals to minimize complications. Notably, 95% of all resections were performed as nodulectomies. There was no mortality and few complications. The total lobectomy rate of 5% is significantly lower than the 20% to 30% reported in the literature [15-18].

Laser resection may expand the score of surgical treatment for pulmonary metastases, allowing more complete resection. Indications for laser resection may expand to include patients who are not considered ideal candidates for lung metastasectomy because of poor residual lung function or multifocal pulmonary disease. Multicenter prospective randomized clinical trials will be necessary to stratify patient subpopulations by risk or benefit and determine whether the 1318-nm Nd:YAG laser will allow expanded indications for pulmonary metastasectomy.

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