



Carinal resection and reconstruction: now and in the future

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Even today, one of the most technically challenging surgical procedures for thoracic surgeons is carinal resection and reconstruction. This surgery is mainly performed for neoplasms that affect the distal trachea and the carina. Carinal tumors, as a subcategory of tracheal tumors, are even less common. With the decrease in squamous cell carcinoma resulting from the declining smoking rate, the frequency of central airway tumors is further decreasing. Therefore, carinal resection is one of the operations that is very difficult to standardize. There is a limit to the cartilage rings that can be excised, cartilage healing is poor, and there are intraoperative respiratory management problems, such as the need for intubation of the surgical field.

In recent years, the morbidity and mortality have decreased by advances in anesthesia technique, improved intensive care, and strict surgical indications based on detailed preoperative examination. In intraoperative anesthesia management, high inspiratory oxygen concentrations,

multiple collapses and re-expansions, hypoxic pulmonary vasoconstriction and hypoperfusion of the ipsilateral lung, and fluid overload must be avoided (1). Some ideas regarding respiratory management during carinal resection and anastomosis have also been reported. Macchiarini *et al.* reported the apneic (hyper) oxygenation technique, in which patients are preoxygenated and hyperventilated with 100% oxygen for about 10 min before completing the dissection and are then completely apneic. During the anastomosis, hyperoxygenation is initiated by placing a small catheter across the surgical field into the contralateral main bronchus and connecting it to a sterile line delivering 10 to 15 L/min O₂ continuously under minimal breathing pressure (0 to 1 mmHg) (2). *Table 1* shows some of the main reports of carinal resection for the last 30 years (2-8). Carinal resection is more frequently associated with pulmonary resection such as right or left pneumonectomy, but the method of carinal reconstruction differs greatly depending on whether it is

Table 1 Summary of recent reports of carinal resection with lobectomy or without lung resection

Author	Time period	Carinal resection with lobectomy or without lung resection (n)	Morbidity	Mortality
Macchiarini <i>et al.</i>	1999–2003	16	10 (63%)	1 (6%)
Porhanov <i>et al.</i>	1979–2001	40	12 (30%)	3 (7.5%)
Mitchell <i>et al.</i>	1973–1998	23	10 (43%)	2 (8.7%)
de Perrot <i>et al.</i>	1981–2004	14	56 (47%)*	9 (7.6%)*
Regnard <i>et al.</i>	1983–2002	5	1 (20%)	0 (0)
Yamamoto <i>et al.</i>	1989–1999	14	7 (50%)	1 (7.1%)
Costantino <i>et al.</i>	1997–2017	22	26 (58%)*	0 (0)

*, including carinal pneumonectomy cases.

accompanied by pneumonectomy, and the postoperative course is also different. Since most reports include carinal pneumonectomy, only those with carinal resection with lobectomy or without lung resection were extracted. In these series, the morbidity rate was still relatively high, but the mortality rate was acceptable. These series indicated that induction chemotherapy and the presence of mediastinal lymph nodes metastasis (N2) were associated with increased risk of complications.

Although carinal resection often requires right or left pneumonectomy, lung parenchyma must be preserved as much as possible if oncologically acceptable and anatomically possible. Various methods for carinal reconstruction have been reported, including: double-barrel method; end-to-end left main bronchus with trachea and end-to-side bronchus intermedius to trachea; end-to-end left main bronchus with trachea and end-to-side bronchus intermedius to left main bronchus; and end-to-end right main bronchus with trachea and end-to-side left main bronchus to right main bronchus (1-8). Yamamoto *et al.* also reported an alternative technique (7). After the tracheal carina is resected, two thirds of the circumference of the trachea and the left main bronchus are anastomosed and after trimming the remaining one third of the circumference, the right bronchus is anastomosed to this trimmed orifice in end-to-side fashion. In either case, the most important thing is to reduce tension on the anastomotic site and maintain sufficient blood flow. Especially when anastomosing the bronchus to the side of trachea, it is necessary to raise the residual lung considerably to the cranial side. The release maneuvers (e.g., inferior pulmonary ligament release, inferior U-shaped hilar release, pericardiophrenic release) are mandatory (1).

These surgeries have been performed with mainly through a right posterolateral thoracotomy or a median sternotomy. However, the rise of minimally invasive surgery in recent years has made it possible to perform these surgeries also under thoracoscopic or robotic-assisted surgery, although there have been only small series in limited institutions. Video-assisted thoracoscopic surgery (VATS) has proven to be safe and effective and recognized as a standard procedure for lung resection, but the use of VATS for extended surgery such as tracheal, bronchial, and carinal procedures and angioplasty remains limited (9-12). However, reducing postoperative pain and less damage to the respiratory muscles would help with early recovery, fewer postoperative complications, and shortening the length of the postoperative hospital stay. Li *et al.* reported

VATS resection and reconstruction of the carina and trachea for malignant or benign disease in 12 patients (11). Of these 12 cases, they performed right main bronchus resection and carinal reconstruction in 2, right main bronchus resection and partial carinal resection in 3, and left main bronchus resection and carinal reconstruction in 1. In those series, no in-hospital mortality or major morbidity occurred. In this report, several key issues were described. Since all anastomoses in these series were performed by single continuous suture, matching of anastomosis orifices between the bronchial opening and the tracheal or carinal opening after resection was important. They used the Aortic Punch (Medtronic, Inc., Minneapolis, MN, USA) to enlarge the orifices. They also reported thoracoscopic surgery for tracheal and carinal resection and reconstruction under spontaneous ventilation (12). In this series, they performed four carinal resections and reconstructions without intubation. Patients were anesthetized using intravenous anesthesia (propofol, remifentanyl and sufentanil), they were allowed to breathe spontaneously, and no muscle relaxant was used. A laryngeal mask was used to assist airway management. They demonstrated that without the endotracheal tube, the trachea is more flexible, with a wider range of motion during resection and anastomosis. Moreover, it gives surgeons the advantage of an unobstructed view of the surgical field and can improve the anastomosis and operating times.

Whereas multiport VATS is mainstream, uniportal VATS (U-VATS) has emerged as a minimally invasive procedure with less postoperative pain. Gonzalez-Rivas reported anatomical lung resection, and it has developed to more complex surgery, such as segmentectomy and sleeve resection (13-15). Gonzalez-Rivas *et al.* recently reported 5 cases of U-VATS lung-sparing tracheal-bronchial and carinal sleeve resections (16). In U-VATS, the camera is always at the posterior side of the incision with the same angle as the operator's viewpoint, providing a similar view to open surgery. Moreover, the use of forceps and energy devices designed and developed for U-VATS enabled the operator to carry out dissection effectively. In airway management, they used a jet ventilation catheter that permits unobstructed visualization and manipulation of the stumps during the reconstruction.

In recent years, robotic-assisted thoracoscopic resection and reconstruction of the carina have also been reported (17,18). Since the first reported use of the da Vinci robotic system for thoracic surgery in 2002 (19), the application of robotic surgical techniques has become increasingly

widespread. Li *et al.* demonstrated that with the robotic arm's extra maneuverability, anastomosis suturing was relatively easier than with the VATS approach, and 3D visualization also enhanced the procedure's accuracy compared with VATS, the routine 2D display (18). Currently, there are only a few case reports, but it is necessary to accumulate cases and verify the role of robot-assisted thoracoscopic surgery (RATS) in the future.

In conclusion, carinal resection and reconstruction are rarely performed. Strict surgical indications, cooperation with anesthesiologists, dedicated postoperative care, and technical expertise in high-volume centers are needed. Minimally invasive surgery has been reported in this area, whether VATS or RATS, and it will take some time before it becomes generally widespread. However, given the characteristics of RATS (e.g., excellent three-dimensional vision with magnification, articulating instruments), it may replace thoracotomy in the future.

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