Translated by A.P. Strelkova

**Review**

**https://doi.org/10.23934/2223-9022-2024-13-1-99-107**

# Instrumental Tracheal Rupture

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**ABSTRACT** Tracheal rupture is an urgent life-threatening complication that relates to complex and poorly understood areas of trauma surgery. The article presents a review of modern world and domestic literature on instrumental tracheal ruptures, the relevance of early diagnosis and various treatment methods. Based on an analysis of modern literature data, the article describes the issues of conservative and surgical treatment methods, as well as an assessment of their results. The problem of the diagnostic algorithm and the choice of conservative, surgical treatment has not been solved and remains relevant. The issues of treating patients with a defect in the membranous wall of the trachea in intensive care and in need of artificial ventilation in clinical practice remain unresolved. All of the above indicates the relevance of the study.

**AIM OF THE STUDY** To present data from domestic and foreign literature on the diagnosis and treatment of instrumental tracheal ruptures.

**MATERIAL AND METHODS** A review of the literature was carried out for the period from 1993 to 2024 in Russian and English, available on the databases Pubmed, Medline, UpTodate, Scopus, E-library, on topics such as post-intubation tracheal rupture, iatrogenic tracheal rupture, diagnosis and treatment of instrumental tracheal ruptures, closed tracheal injury.

**RESULTS** The concept of the classification system, risk factors, etiopathogenesis is outlined. Information is provided on the diagnostic significance of computed tomography and tracheobronchoscopy. Close attention is paid to the methods and choice of treatment tactics, the principles of intraoperative tactics, and the strategy of conservative treatment. A comparative assessment of treatment results and their complications with a conservative or surgical treatment approach is given.

**CONCLUSION** Thus, an analysis of domestic and foreign literature indicates that the issues of diagnosis and treatment of iatrogenic tracheal injuries remain largely unresolved. There is no generally accepted algorithm for instrumental diagnosis of tracheal ruptures. There are no uniform approaches to determining indications and contraindications for conservative and surgical treatment of tracheal injuries. There are diametrically opposed opinions regarding the choice of treatment tactics. These contradictions create significant difficulties in assessing the results of treatment of this complex category of patients.

**Keywords:** trachea, post-intubation tracheal rupture, instrumental tracheal rupture, pneumomediastinum, emphysema, pneumothorax

**For citation** Khachatryan SA, Chernousov FA, Danielyan ShN. Instrumental Tracheal Rupture. *Russian Sklifosovsky Journal of Emergency Medical Care.* 2024;13(1):99–107. https://doi.org/10.23934/2223-9022-2024-13-1-99-107 (in Russ.)

**Conflict of interest** Authors declare lack of the conflicts of interests

**Acknowledgments, sponsorship** The study has no sponsorship

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ALV – artificial lung ventilation
CT – computed tomography
ECMO – extracorporeal membrane oxygenation
ETT – endotracheal tube
PEEP – positive end expiratory pressure

## ETIOLOGY AND EPIDEMIOLOGY OF TRACHEAL INJURIES

According to the etiology, mechanical injuries to the trachea are divided into iatrogenic and traumatic [1]. In clinical practice, tracheal injuries are more often encountered as a result of wounds and closed neck trauma. With the development of medicine and the expansion of indications for invasive ventilation, the iatrogenic mechanism of injury increasingly predominates in the structure of tracheal damage. There are reports in the literature of extremely rare observations of spontaneous tracheal rupture [2–4].

Tracheal intubation using endotracheal tubes (ETTs) of various designs has remained the standard for providing mechanical ventilation (ALV) for many years [1, 5, 6]. At first glance, this routine invasive procedure is accompanied by the development of complications, including mechanical damage to the trachea and bronchi with a frequency not exceeding 0.05% [7–10]. Excessive inflation of the endotracheal tube cuff is one of the etiopathogenetic factors of iatrogenic tracheal ruptures. The tracheal defect with this mechanism of damage is localized mainly in the proximal segment of the thoracic trachea in the area where the ETT cuff is located [11–14].

The incidence of tracheal injury is higher when performing separate ventilation using a double-lumen endotracheal tube, reaching 0.19% [15, 16].

The frequency of iatrogenic tracheal ruptures during percutaneous dilation tracheostomy is even higher and, according to various sources, reaches 1% [5, 17–19].

During balloon dilatation or bougienage of the trachea, rupture of the tracheal mucosa occurs in almost half of cases, but transmural rupture is rare [20]. Insertion and removal of self-expanding stents may also cause iatrogenic tracheal rupture [21–23]. There are reports of tracheal injuries during rigid tracheoscopy when attempting ultrasound-guided fine-needle aspiration biopsy of mediastinal lymph nodes [24–26]. Other mechanisms of iatrogenic trauma to the trachea include: damage as a result of barotrauma during severe mechanical ventilation, during intraluminal interventions (neoplasms or strictures, foreign bodies), as well as during operations on the neck and upper mediastinum, including on the thyroid gland, esophagus, when performing mediastinoscopy [7, 27–30].

Of particular note are iatrogenic tracheal ruptures in critically ill patients in intensive care units who require long-term mechanical ventilation. Mortality in this category of patients reaches 71.4% [8].

## CLASSIFICATION

Based on the depth of damage, iatrogenic tracheal ruptures are divided into transmural and incomplete ruptures.

Currently, there is no unified classification of iatrogenic tracheal injuries, which creates certain difficulties in choosing treatment tactics. At the same time, a number of authors in their scientific studies refer to the morphological classification *of Cardillo G. et al.* [31], according to which there are four degrees of tracheal injury (Figure):

I degree - rupture of the mucous and submucous membranes of the trachea without mediastinal emphysema and without damage to the esophagus;

II degree - rupture of the trachea to the muscular layer with subcutaneous emphysema or mediastinal emphysema, without damage to the esophagus or mediastinitis;

III *A* degree - transmural rupture of the trachea with prolapse of the mediastinal or esophageal tissue into the tracheal lumen without trauma to the esophagus or mediastinitis;

III *B* degree - tracheal rupture of any depth and location with damage to the esophagus or mediastinitis.

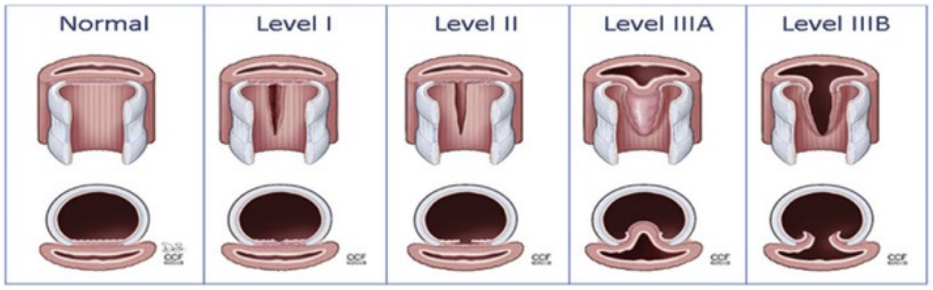


Figure. Morphological classification of tracheal injury (Cardillo G. et al., 2009)

### RISK FACTORS FOR TRACHEAL INJURY

It should be noted that tracheal injuries also occur during technically flawless intubation. At the same time, the risk of tracheal injury increases with difficult intubation. Causes of difficult laryngoscopy and tracheal intubation include: inability to lie on the back, acromegaly, pregnancy (third trimester), rheumatoid arthritis, ankylosing spondylitis, laryngeal abnormalities, macroglossia, deep and narrow oropharynx, protruding incisors and canines, short thick neck, micrognathia and others [32]. In general, risk factors for tracheobronchial damage can be divided into two large groups: mechanical and anatomical. Mechanical factors, in turn, are divided into subjective (inexperience of the doctor, multiple attempts at tracheal intubation) and instrumental (use of a guide during intubation, inappropriate size of the endotracheal tube, use of a double-lumen tube). Anatomical risk factors include a number of developmental anomalies, including congenital tracheal diverticula, *Mounier – Kuhn syndrome*, and deformation or external compression of the trachea due to neoplasms of the neck and upper mediastinum.

In cases of iatrogenic tracheal rupture in the absence of anatomical prerequisites and technical errors during intubation, we speak of weakness of the membranous wall of the trachea. Factors that contribute to the development of tracheal membranous wall weakness and increased risk of iatrogenic injury include: long-term use of inhaled corticosteroid drugs, older age, inflammatory diseases of the trachea, and high body mass index [33–35].

According to a number of researchers, it has been found that women over 65 years of age and emergency tracheal intubation are the most significant risk factors for iatrogenic tracheal ruptures [8, 31, 36–40]. Specific training of nursing staff and patient selection are key factors in reducing the incidence of iatrogenic tracheal complications.

### DIAGNOSIS OF IATROGENIC TRACHEAL RUPTURES

Typical clinical symptoms of tracheal trauma include respiratory distress, subcutaneous emphysema, pneumomediastinum, pneumothorax, and less commonly, pulmonary hemorrhage, pneumoperitoneum [38, 41–44]. Clinical signs of tracheal rupture in the form of gas syndrome appear immediately or some time after extubation or manipulation of the ETT. The immediate or late manifestation of gas syndrome depends on the position of the ETT cuff; if the ETT cuff covers the tracheal defect and prevents air from leaking into the mediastinum, gas syndrome will not be observed until extubation or dislocation of the ETT cuff.

Computed tomography (CT) and tracheobronchoscopy have high sensitivity in diagnosing tracheal trauma, while conventional radiography can only document radiation signs of gas syndrome [36, 45–47].

According to *Fauer A. et al*. [48], having analyzed the CT results in 1356 patients with at least one clinical or radiological sign suspicious of tracheal injury, came to the conclusion that the high sensitivity of the CT method and the absence of false negative results suggest that there is no need to perform an endoscopic examination to confirm the

CT scan. diagnosis of tracheal rupture. At the same time, tracheoscopy is indicated for all patients with clinical signs of tracheal injury with negative CT data [48].

According to a number of authors, CT is not a reliable method for diagnosing tracheal ruptures [36, 49, 50], and endoscopic examination is mandatory in the presence of suspicious clinical and radiological symptoms.

In all cases of transmural tracheal rupture, evaluation of the esophagus for damage is very important. In spontaneously breathing patients, esophageal radiography or CT with oral contrast is advisable [51]. In unconscious patients and on mechanical ventilation, esophagoscopy is performed for this purpose [8, 27].

Despite the value of the information obtained from tracheobronchoscopy, endoscopic examination is an invasive method that has a number of limitations in use due to the risk of progression of gas syndrome and worsening respiratory failure [52, 53]. However, endoscopic examination is a mandatory procedure for tracheal rupture in intensive care patients to assess the depth, extent and localization of the defect, if possible, followed by displacement of the ETT cuff below the defect under visual control. Thus, there is no uniform approach to diagnosing iatrogenic tracheal injuries.

### TREATMENT TACTICS FOR PATIENTS WITH IATROGENIC TRACHEAL INJURIES

The management of patients with instrumental tracheal injuries involves the use of conservative or surgical treatment [38, 41, 54–57]. It is based on two key factors: the need to provide mechanical ventilation and the tolerability of surgical intervention on the trachea, depending on the nature of the underlying pathology and the severity of the somatic status.

The essence of surgical treatment is to seal the trachea by suturing the defect through a transcervical and (or) right-sided transthoracic approach, depending on the location of the damage [58–61].

The report by *Angelillo-Mackinlay T.* [54] describes the observation of successful surgical treatment of post -intubation rupture of the distal trachea from a transcervical approach with longitudinal intersection of the proximal eight half-rings along the anterior wall, suturing the defect of the membranous wall of the trachea with a continuous vicryl thread (4–0) from the lumen side and restoration of the integrity of the anterior wall by applying separate interrupted sutures.

A report by *Sung Kwang Lee et al*. [62] analyzed the results of treatment of 11 patients with iatrogenic tracheal trauma (with an average defect length of 4.18 ± 2.6 cm), including those resulting from tracheostomy (3) and orotracheal intubation (8). For postintubation tracheal rupture, the standard approach was a right thoracotomy in the fifth intercostal space, with the exception of a single observation of a distal tracheal rupture extending to the left main bronchus, which required a left thoracotomy. In 3 patients with tracheal damage as a result of tracheostomy, the membranous wall defect was sutured using a transcervical approach with a transverse tracheotomy. The authors note that the mortality rate during surgical treatment is not higher than the world data on conservative therapy, and conclude that in patients with instrumental injuries of the trachea, surgical intervention should be performed in the absence of positive dynamics against the background of conservative therapy.

In the surgical treatment of tracheal trauma, various methods of plastic surgery are widely used. To strengthen the sutures of the cervical trachea, flaps from the sternocleidomastoid or other neck muscles on a vascular pedicle are most often used. To strengthen a large tracheal defect, *Kalkwarf K. et al*. [63] used a double intercostal flap. The successful use of a diaphragmatic flap for intraoperative damage to the membranous wall of the trachea with a length of 8 cm was described by *Westaby S. et al.* [64]. Flaps from the parietal pleura are used less frequently due to the difficulty of forming a well-supplied plastic material. Kovalenko P.P. [65] reports 9 observations of the use of this technique.

Reported *by Manuel F. et al*. [15] analyzed the results of surgical treatment of iatrogenic tracheal rupture in 35 patients. The tracheal defect was sutured in all cases; it is noted that in 29 patients (83%) artificial tissues (*TachoSil*, *TachoComb*, *Sulmycin)* were used to strengthen the tracheal sutures, including in 9 additional autologous tissues (flaps from the pleura, pericardium, thymus, latissimus dorsi and stylohyoid).

A study *by Carretta A. et al.* [66], devoted to a comparative analysis of the results of surgical and conservative treatment of tracheal ruptures, did not reveal any statistically significant differences. The study included 50 cases of tracheal trauma, including 36 of iatrogenic etiology. Surgical treatment was performed in 30 patients, conservative treatment in 20.

Indications for conservative treatment of iatrogenic tracheal rupture are [8, 31, 37, 41, 67]:

— stable respiratory and hemodynamic parameters;

— spontaneous breathing or the prospect of transferring the patient to spontaneous breathing in the near future;

— absence of esophageal lesion;

— absence of progressive gas syndrome;

— absence of signs of sepsis and (or) mediastinitis.

An absolute indication for emergency surgery is tracheal rupture with simultaneous damage to the esophagus [8, 41, 67].

A number of experts agree that surgical treatment is indicated for patients with a tracheal defect more than 4 cm in length [8, 44, 68].

*Minambres et al.* [34] believe that surgery should be performed when the length of the tracheal defect is more than 2 cm, while conservative treatment is recommended for damage of shorter length.

In a comparative study, *Gomez-Caro et al*. [69] found that the results of treatment of iatrogenic tracheal injuries do not depend on the extent of the defect.

According to Parshin V.D. et al. [41], surgery for iatrogenic tracheal ruptures is indicated in the following cases:

1) bleeding into the respiratory tract, not stopped by inflating the cuff of the endotracheal tube and associated (possibly) with damage to a large vessel;

2) progression of gas syndrome;

3) widespread rupture of the membranous part with transition to the tracheal bifurcation, main bronchus or with interposition of paratracheal tissues;

4) simultaneous damage to the esophagus;

5) rupture of the membranous part of the trachea during intubation before thoracotomy or detection of a rupture during thoracotomy for another reason.

Parshin V.D. et al. [41] came to the conclusion that surgical treatment for isolated post-intubation tracheal ruptures should be treated with rather restraint.

The article *by Conti M. et al.* [37] analyzed the results of treatment of 30 patients with post-intubation tracheal rupture. Patients who were breathing independently at the time of diagnosis (15 observations) were treated with conservative therapy. Their tracheal defect healed without complications. Two (13.3%) of the 15 mechanically ventilated patients were operated on due to their resectability, while inoperable patients (13) were treated conservatively with endoscopic EET positioning. Nine (69%) of 13 inoperable patients who received conservative therapy recovered completely. The authors concluded that conservative treatment should be considered in patients with postintubation tracheal rupture who are breathing spontaneously or when tracheal extubation is planned within 24 hours of diagnosis. Surgical repair of the tracheal defect should be performed if adequate oxygenation cannot be achieved using non-invasive ventilation or advancement of the endotracheal tube cuff below the tracheal defect.

*Cardillo G. et al.* [31] analyzed treatment tactics based on their proposed classification of tracheal injuries. For grades I, II and IIIA ruptures, 1–2 ml of sealant (*Tissucol W, Baxter, Deerfield, MA, USA)* was endoscopically applied throughout the tracheal defect, covering it with a continuous layer. For grade III *B* tracheal rupture, a right posterolateral

thoracotomy and suturing of the defect were performed. Antibacterial therapy, cough suppression, and total parenteral nutrition were administered until bronchoscopic confirmation of healing of the tracheal defect on the 7th postoperative day.

According to *Deja M. et al*. [8], in case of transmural rupture of the trachea with prolapse of mediastinal or esophageal tissue into the tracheal lumen without damage to the esophagus in patients on mechanical ventilation, conservative therapy should be carried out using positive end-expiratory pressure (PEEP). The authors perform tracheal intubation under endoscopic control with the cuff positioned distal to the injury zone. They recommend continuous monitoring of endotracheal tube cuff pressure at the lowest possible values. Spontaneous ventilation with an adequately controlled level of sedation can reduce airway pressure and minimize the risk of complications.

In the article *by Welter S. et al*. [70] reported a unique experience of intraluminal suturing of a tracheal defect using an endoscopic needle holder. The device consists of a rigid *HOPKINS telescope* fixedly attached to an endoscopic needle holder.

Over 10 years, the authors used this technique in 18 patients with iatrogenic grade III a tracheal rupture according to the *Cardillo G.* classification, which indicated transmural damage to the membranous wall of the trachea without damage to the esophagus. According to the authors, the main advantages of this minimally invasive method are: the absence of extensive traumatic surgical access, the possibility of early extubation of the trachea and transfer to spontaneous breathing with adequate lung and heart function, reduced postoperative pain and a cosmetic effect. The authors report that all patients were discharged after treatment.

There are isolated publications on the use of extracorporeal membrane oxygenation (ECMO) in patients with tracheal ruptures. Currently, veno-venous ECMO is recognized as an effective method of pulmonary function replacement in patients with severe respiratory failure when it is impossible to provide adequate ventilation [71–73]. However, ECMO-associated complications are life-threatening, which significantly limits the use of the method in routine practice.

## CONCLUSION

Thus, an analysis of domestic and foreign literature indicates that the issues of diagnosis and treatment of iatrogenic tracheal injuries remain largely unresolved. There is no generally accepted algorithm for instrumental diagnosis of tracheal ruptures. There are no uniform approaches to determining indications and contraindications for conservative and surgical treatment of tracheal injuries. There are diametrically opposed opinions regarding the choice of treatment tactics. These contradictions create significant difficulties in assessing the results of treatment of this complex category of patients.

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**Received on 04/19/2023**
**Review completed on 05/10/2023**
**Accepted on 05/04/2023**