



СРПСКИ АРХИВ
ЗА ЦЕЛОКУПНО ЛЕКАРСТВО
SERBIAN ARCHIVES
OF MEDICINE

Address: 1 Kraljice Natalije Street, Belgrade 11000, Serbia

+381 11 4092 776, Fax: +381 11 3348 653

E-mail: office@srpskiarhiv.rs, Web address: www.srpskiarhiv.rs

Paper Accepted*

ISSN Online 2406-0895

Original Article / Оригинални рад

Mitko Mitev^{1,†}, Evelin Obretenov²

Ruptures of trachea and bronchi diagnosed by virtual bronchoscopy with multidetector computed tomography and fiberoptic bronchoscopy – advantages and shortcomings of methods

Руптуре трахеје и бронхија дијагностиковане виртуелном бронхоскопијом са мултидетекторском компјутеризованом томографијом и фиброоптичком бронхоскопијом – предности и недостаци метода

¹Trakia University, Faculty of Medicine, Stoyan Kirkovich University Hospital, Department of Diagnostic Imaging, Department of Medical Physics, Biophysics, Roentgenology and Radiology, Stara Zagora, Bulgaria;

²Trakia University, Faculty of Medicine, Stoyan Kirkovich University Hospital, Clinic of Thoracic Surgery, Department of Special Surgery / Thoracic Surgery, Vascular Surgery, Pediatric Surgery and Orthopedics and Traumatology, Stara Zagora, Bulgaria

Received: May 3, 2019

Revised: May 16, 2020

Accepted: May 28, 2020

Online First: June 1, 2020

DOI: <https://doi.org/10.2298/SARH190503033M>

***Accepted papers** are articles in press that have gone through due peer review process and have been accepted for publication by the Editorial Board of the *Serbian Archives of Medicine*. They have not yet been copy-edited and/or formatted in the publication house style, and the text may be changed before the final publication.

Although accepted papers do not yet have all the accompanying bibliographic details available, they can already be cited using the year of online publication and the DOI, as follows: the author's last name and initial of the first name, article title, journal title, online first publication month and year, and the DOI; e.g.: Petrović P, Jovanović J. The title of the article. Srp Arh Celok Lek. Online First, February 2017.

When the final article is assigned to volumes/issues of the journal, the Article in Press version will be removed and the final version will appear in the associated published volumes/issues of the journal. The date the article was made available online first will be carried over.

†**Correspondence to:**

Mitko MITEV

Department of Diagnostic Imaging, Stoyan Kirkovich University Hospital, Trakia University, 6000 Stara Zagora, Bulgaria

E-mail: mitev.mitko69@gmail.com

Ruptures of trachea and bronchi diagnosed by virtual bronchoscopy with multidetector computed tomography and fiberoptic bronchoscopy – advantages and shortcomings of methods

Руптуре трахеје и бронхија дијагностиковане виртуелном бронхоскопијом са мултидетекторском компјутеризованом томографијом и фиброоптичком бронхоскопијом – предности и недостаци метода

SUMMARY

Introduction/Objective Fiberoptic bronchoscopy often is too aggressive, which requires the use of other noninvasive diagnostic methods. The study presents research results on the diagnostic capabilities of virtual bronchoscopy with multidetector computed tomography and fiberoptic bronchoscopy in traumatic abnormalities of trachea and main bronchi.

Methods During 2013–2017, a total of 21 patients (six males and 15 females) at age of 11–82 years (50.65 ± 19.80) were studied by the methods of virtual bronchoscopy with multidetector computed tomography and fiberoptic bronchoscopy. The diagnostic capabilities of virtual bronchoscopy as compared to fiberoptic bronchoscopy were assessed by established criteria.

Results Ruptures of the trachea and/or bronchi had proven in 21 of patients by fiberoptic bronchoscopy and in 19 of patients by virtual bronchoscopy. The greatest frequency was reported for the post-intubation ruptures (15 patients, 71.42% with virtual bronchoscopy; 16 patients, 76.19% with fiberoptic bronchoscopy), followed by post-traumatic ruptures (3 patients, 14.29%); ruptures of trachea and the left lower lobar bronchus as a result of an advanced neoplasm of the esophagus (one patient, 4.76%), diagnosed by both methods; mucosal erosion after instrumental manipulations (4.76%, after fiberoptic bronchoscopy).

Conclusion Achieved diagnostic accuracy in ruptures of trachea and bronchi by virtual bronchoscopy is 90.47% and by fiberoptic bronchoscopy is 100%. In terms of localization, shape and size, almost complete correspondence of changes with those of fiberoptic bronchoscopy was found. The presence of an abundant amount of secretions in virtual bronchoscopy may be interpreted incorrectly and efficiency of virtual bronchoscopy decreases.

Keywords: diagnostic capabilities; traumatic abnormalities; trachea; bronchi

САЖЕТАК

Увод/циљ Фиброоптичка бронхоскопија често је превише агресивна, што захтева употребу других неинвазивних дијагностичких метода. У раду су приказани резултати истраживања о дијагностичким могућностима виртуелне бронхоскопије са мултидетекторском компјутеризованом томографијом и фиброоптичком бронхоскопијом у трауматским абнормалностима трахеје и главних бронхија.

Метод Укупно 21 болесник (шест мушкараца и 15 жена) у доби од 11 до 82 године ($50,65 \pm 19,8$) проучавани су методама виртуелне бронхоскопије са мултидетекторском компјутеризованом томографијом и фиброоптичком бронхоскопијом. Дијагностичке способности виртуелне бронхоскопије у односу на фиброоптичку бронхоскопију процењене су утврђеним критеријумима.

Резултати Руптуре трахеје и/или бронхија доказане су фиброоптичком бронхоскопијом код 21 болесника и виртуалном бронхоскопијом код 19 болесника. Највећа учесталост забележена је након руптуре после интубације (15 болесника, 71,42% виртуелном бронхоскопијом; 16 болесника, 76,19% фиброоптичком бронхоскопијом), након чега следе посттрауматске руптуре (три болесника, 14,29%); руптуре трахеје и левог доњег лобарног бронха као последица узнапредовале неоплазме једњака (један болесник, 4,76%), дијагностициране обема методама; ерозија слузокоже након инструменталних манипулација (један болесник, 4,76%, након фиброоптичке бронхоскопије).

Закључак Постигнута дијагностичка тачност код руптура трахеје и бронха виртуелном бронхоскопијом је 90,47%, а фиброоптичком бронхоскопијом је 100%. У смислу локализације, облика и величине, пронађена је готово потпуна подударност промена с променама фиброоптичке бронхоскопије. Присуство обилне количине секрета у виртуелној бронхоскопији може се погрешно интерпретирати и ефикасност виртуелне бронхоскопије се смањује.

Кључне речи: дијагностичке могућности; трауматске абнормалности; трахеје; бронхије

INTRODUCTION

Ruptures of trachea and bronchi are rare, difficult to diagnose, lacking well-known clinical signs, but potentially life-threatening [1–10]. They affect more often female patients and patients aged 50 years or more [3, 4]. The outcome of the trauma is favorable if the diagnosis is established at an early stage and accompanied by rapid primary treatment because tracheal and bronchial ruptures are potentially rapidly lethal [9, 11]. At a later stage, the risk of tracheal stenosis, which is often insurmountable, increases [6]. This requires the use of new advanced diagnostic methods and adequately precise equipment. Some of the authors consider Computed Tomography (CT) as an adequate means for assessment of most of the abnormalities of the respiratory tract, however multidetector computed tomography (MDCT) allows for multiplanar reformation, CT bronchoscopy and virtual bronchoscopy (VB). VB as a non-invasive method allows for three-dimensional evaluation of the tracheobronchial tree. It is determined as a more splendid (), more short-term method than fiberoptic bronchoscopy (FB) [12–15]. Diagnosis of ruptures of the trachea is often delayed or omitted, but it is still proven that the success rate associated with the improvement of care for patients has increased. The main causes pointed out for their appearance include blunt traumas, severe cough, vomiting or secondary iatrogenic injuries, post-tracheal intubations, etc. [4]. Research of diagnostic capabilities of VB with MDCT in tracheal ruptures is very scanty [6, 7, 9, 14, 15, 16].

The study is aimed at assessing the advantages and shortages of VB with MDCT in the diagnosis of patients with ruptures of trachea and bronchi.

METHODS

Clinical material and equipment

A total of 21 patients (6 males and 15 females aged 11 to 82 years; 50.65 ± 19.80) were studied for ruptures of trachea and bronchi by the methods of VB with MDCT and FB for more than five years (2013–2020 year). They were performed on 64 MDCT “Siemens Definition AS” and with bronchoscope “Olympus BF PE2”, respectively. “Singo.via VB20” workstation was used with the capacity to track and match the images in the axial,

coronary, sagittal planes. Multiplanar reconstructions were performed by applying MIP techniques and capabilities to archive and export images and video.

Optimized standard protocols were used in patients with various abnormalities of trachea and bronchi, and different ages. The best results were achieved with: current strength 80–100 mAs, voltage 120 kV, 3 mm beam collimation, and reconstruction of 3 mm, rotation speed at 0.5 sec, pitch D-FOV Large.

Protocols

Criteria for pathological changes in ruptures of trachea and bronchi used to compare the results of the diagnosis by FB and VB with MDCT include: localization of rupture; disposition; shape of rupture; length of rupture (cm); distance of rupture from the carina (cm); distance of rupture from vocal ligaments (cm); length of changes resulting from the healing of ruptures after medical treatment (cm); number of affected tracheal rings.

Statistical analysis

The variation analysis of quantitative variables includes the factors: for medium-level – arithmetic mean; for dispersal – rank (value range from-to), standard deviation (SD). Non-parametric methods of analysis were applied by The Mann–Whitney test (U test) for comparison of two samples in unknown distributions (e.g. age, sex, various abnormalities of trachea and bronchi, etc.); Kruskal-Wallis test (H test) for comparison of more than two samples of different size. Two-way analysis of variance (Friedman's test, F test) was used to study the determining factor for variation of compared criteria. The Pearson (r) correlation coefficient was used to verify the association between the variables. The software products MS Excel (Microsoft 2010), BioDiversity Pro and Statistica 10 were used for the statistical processing of data [17, 18].

The study was done in accord with standards of the institutional committee on ethics.

RESULTS

Of 21 studied patients, 21 had proven ruptures of trachea and/or bronchi after FB, and 19 after VB. The greatest frequency was reported for the post-intubation ruptures (71.42% with VB - 15 patients, 2 males and 13 females; 76.19% with FB - 16 patients, 2 males and 14 females), followed by post-traumatic ruptures (14.29%) – 3 patients (2 males and 1 female) and ruptures of trachea and the left lower lobar bronchus resulting from an advanced neoplasm of the oesophagus (4.76% – one male), diagnosed by both methods; mucosal erosion after instrumental manipulations (4.76% – 1 male, after FB). No essential differences were found between the two methods in respect of frequency of occurrence of the separate categories of abnormalities ($p > 0.05$).

The results of VB report 21 ruptures in 19 patients, and those of FB: 23 ruptures from 21 patients. Ruptures with localization in the upper part of the trachea (16 patients with FB and 14 with VB) prevail, followed by those with localization in the middle part of the trachea (4 patients each), and with ruptures localized in the upper and middle part of the trachea (1 patient each). 2 ruptures were recorded in one patient, one in the upper part, and one in the lower part, respectively, of the trachea, affecting the left lower lobar bronchus, reported by both methods. 19 patients in FB and 17 patients in VB had longitudinally located ruptures in the membranous part of the trachea. The shape of ruptures established by both methods is predominantly linear (17 patients in FB and 16 patients in VB), and in a small number of cases it is irregular (6 and 5 patients in FB and VB, respectively). Circular interruption of the trachea at the border between the cervical and mediastinal parts was found in one patient. Differences in the length of ruptures (in centimetres), established by both methods, were not significant (Table 1; $p > 0.05$). Similar results were obtained for the distances measured by both methods to *rima vocalis*, distances from the carina, for the size of changes after healing of ruptures following the medical treatment, and the number of affected tracheal rings. Low-grade stenoses (stenoses of grade I) were found in 19% of studied patients (1 male – 5% and 3 females – 14%). Negligible differences in the number of ruptures and the number of patients with true-positive results for ruptures are due to the total reported by VB two patients with false-negative results against those by FB, decreasing the number of patients with ruptures and the reported ruptures by 2 each. In two patients (one male and one female), 2 ruptures were found by VB and FB each (Table 1).

Both methods reported a prolapse of mediastinal tissues in 9 patients, as a result of which changes occurred in them, reported during the study. In three of the patients, we found a higher disposition of the distal linear surfaces corresponding to the granulations formed.

A total, 4 of the surveyed patients were operated (3 patients with closed thoracic trauma (posttraumatic) and one patient with iatrogenic post-intubation trauma of more than 3.5 cm, located on the membranous part of the trachea) by surgical readings. After diagnosis with CT, FB and VB confirmation, 3 of these patients (post-traumatic) were found to have large, extensive lesions and uncontrollable gas syndrome (manifested by the presence of an intense pneumothorax, pneumomediastinum) leading to tracheal stenoses and the main bronchi, proven by CT, FB and VB. One of these patients has established atelectasis on the right. In 3 of the operated patients, intubation was performed under the lesion. This avoids the continuous movement of the ruptured part and achieves rapid recovery (healing of the lesions for 4 days). For the fourth patient, an operative suture was imposed. All other rupture patients are conservatively treated with dynamic clinical follow-up by a specialist. The investigated patients (including the operated patients) are followed clinically and radiographically (by CT, FB and VB). All patients with the presented at the manuscript ruptures have been discharged from hospital clinically healthy.

DISCUSSION

The presented study evidence for ruptures of trachea and bronchi of the patients diagnosed by VB and FB, significantly higher results of those reported by other authors [19]. Traumatic abnormalities of the trachea and main bronchi are rarely met in medical practice: in about 0.8 up to 2% of the cases, but they can still be serious life-threatening conditions. They can be treated successfully if diagnosed at the earliest possible stage. Tracheal and tracheobronchial ruptures represent a serious injury which is often neglected in the initial post-traumatic period. Ruptures create a risk of stenoses at a later stage which is insurmountable [4, 6, 9, 10, 12, 16, 19–22].

FB has been established as a time-tested method (“golden standard”) in the diagnostic practice allowing for direct visualization in the lumen of the respiratory tract, detection and diagnosis of pathological changes in the tracheobronchial tree [7, 23–26]. FB, however, as an invasive method, is inapplicable with patients in a heavy condition where it may lead to more

serious complications and to aggravating the outcome of treatment. In such cases, where FB is considered too aggressive (young children, elderly people with poor health status, etc.), it is obligatory to apply other safer and quick diagnostic methods, possessing the same or better efficiency [12, 14, 21, 22, 27].

VB as a relatively recent (the mid-1990s), non-invasive method based on the use of multi-detector computed tomography and follow-up 3D reconstruction of respiratory tract allows for real visualization, high resolution of tracheobronchial tree, assessment of the trachea and main bronchi wall integrity, as well as assessment of changes in their lumen, even in areas inaccessible to FB [1, 23, 27].

Studies on the diagnostic capabilities of VB in traumatic abnormalities of trachea and bronchi are scanty. There is almost no data on the advantages and shortages of VB and FB in ruptures of trachea and bronchi [12, 22, 23, 27].

VB is shown as a more practical, more short-term and more precise method than FB for assessment of trachea and main bronchi, allowing for 3-dimensional assessment of the tracheobronchial tree. VB is indicated as a better method than FB for diagnosis of ruptures of the trachea in patients with pneumomediastinum [9].

As a result of the performed study, it is found that for all four groups of abnormalities, VB in ruptures of trachea and bronchi in 90.47% of cases showed results utterly comparable to those of FB. In terms of localization, shape and size, almost complete correspondence of changes with those of FB was found. The presence of the abundant amount of secretions in VB may be interpreted incorrectly. Age is not defining in terms of the size of ruptures ($p > 0.05$). Significant differences between the length of ruptures in both sexes (U test, $p = 0.04$) were obtained. Significant differences were found between the length of ruptures and: distance to the carina (U test, $p = 0.0$); distance to the rima (U test, $p = 0.04$); length of changes after healing of ruptures (U test, $p = 0.01$); number of affected tracheal rings (U test, $p = 0.03$); between the distances to the carina and rima (U test, $p = 0.0004$). Significant differences were also found in terms of distances to the carina and: length of changes after healing of ruptures (U test, $p = 0.0$); the number of affected tracheal rings (U test, $p = 0.0$). Differences were significant as established between the length of the rima and the length of the changes after healing of ruptures (U test, $p = 0.0$), as well as with the number of affected tracheal rings (U test, $p = 0.0003$). In general, significant differences were found between the

length of ruptures-distances to the carina-distances to the rima-length of changes after healing-number of affected tracheal rings (H test, $p = 0.0$). The length of ruptures is a determining factor with impact over the values of distances to the carina, distances to the rima, length of changes after healing of ruptures and number of affected tracheal rings (F test, $p = 0.0$). Generally, a high negative correlation was reported between the length of ruptures and the distances to the carina ($r = -0.74$), and high positive correlation was established between the length of changes after healing of and the number of affected tracheal rings ($r = 0.84$). No significant differences were found between the results obtained by the application of both methods (FB, VB; $p > 0.05$).

This is also reported by the studies of other authors, according to which data obtained from FB and VB are comparable, but whereas an advantage of FB are the immediate symptoms of colour, vascularity and mobility, VB predominates in circumventing obstructions and providing an excellent view, away from obstructive ruptures or stenotic segments, as well as in determining the optimal path for passing the instruments into ruptures outside the field of vision [1].

The results presented from the performed VB in ruptures of trachea and bronchi are of higher sensitivity and precision against the studies of other authors (68 – 89%) [23, 27]. This is most likely due to the optimization of standard operating protocols and the high-tech equipment used in recent years, with an individual approach to the technical specifications for each patient.

In recent years, a number of authors (14, 22, 28, 29) have applied the VB method to ruptures of the trachea and bronchi using optimized low-dose protocols that achieve good visualization of the bronchi of 6–7 order. Thin-cut and ultra-high-definition studies allow lower and more final-order bronchi to be seen, with better resolution and low noise, but the dose obtained is high and radiation-intensive to perform periodic follow-up of patients with the possibility of attenuated treatment [30].

The equipment and low-dose protocols used are in accordance with the goals and objectives of our study. With the applied optimized low-dose protocols, a good visualization of the bronchi of 6–7 order is obtained. High comparability of the results with those of the performed fibro-optical bronchoscopy is also achieved. This corresponds to the objectives of the study and is sufficient to determine the location of the ruptures, their shape, size, distance

from the carina and the treatment behaviour - operative or non-operative attenuated treatment, with follow-up of patients.

According to data from the literature, confirmed also by the performed study, the diagnostic capabilities of FB and VB increase with the increase of the degree of obturation, however, VB has a greater sensitivity than FB in heavy cases of stenoses. VB is presented as a supplementary technique enhancing the capabilities for visualization with the improvement of the success rate of diagnosis and treatment in conditions of urgency, especially in patients with life-threatening injuries.

This study gives reason to accept that VB is a successful method for diagnosis of traumatic injuries of the trachea and main bronchi. The success rate is closely related to the localization and size of ruptures and is higher in ruptures sized ≥ 0.5 cm (the least reported size in this study).

The results of performed studies give us the reason to summarize that VB will be more often relied on in establishing the therapeutic diagnostic algorithm in patients with abnormalities of trachea and bronchi. However, it should be remembered that the efficiency of the method decreases in the presence of an abundant amount of secretions in the lumen of airways. VB has applied also as a non-invasive method for establishing the size of the findings in the course of the healing process. Virtual bronchoscopy is essential for the screening of some chronic lung diseases, such as chronic obstructive pulmonary disease, pulmonary fibrosis, etc., found to accompany traumatic abnormalities of trachea and bronchi. Because of the accurate visualization of the tracheobronchial tree, the method can also be used for training. A shortage of the method is that it cannot determine changes in the mucosa in case of superficial injuries.

CONCLUSION

CT virtual bronchoscopy is a valuable method that complements the tracheal evaluation with axial cuts and multiplanar reconstructions. The non-invasive character of the method of VB allows for its application in life-threatening conditions and control of the healing process. VB provides similar visual information with FB but in a non-invasive way. Changes in

bronchial mucosa may cause differences in the quantitative assessment of changes. The efficiency of VB decreases substantially in the presence of an abundant amount of secretions.

Conflict of interest: None declared.

Paper accepted

REFERENCES

1. Allah MF, Hussein SR, El-Asmar AB, Zoair HM, Mohamed GA, Metwaly AM, et al. Role of Virtual Bronchoscopy in the Evaluation of Bronchial Lesions. *J Computer Assisted Tomography*. 2012; 36(1):94–99. doi: 10.1097/RCT.0b013e31824443b2 PMID: 22261777
2. Marty-Ané Ch, Picard E, Jonquet O, Mary H. Membranous tracheal rupture after endotracheal intubation. *The Annals of Thoracic Surgery*. 1995; 60(5):1367–1371. [https://doi.org/10.1016/0003-4975\(95\)00643-Y](https://doi.org/10.1016/0003-4975(95)00643-Y) PMID: 8526628
3. Kumar S, Goel S, Bhalla AS. Spontaneous Tracheal Rupture in a Case of Interstitial Lung Disease (ILD): A Case Report. *Journal of Clinical and Diagnostic Research*. 2015; 9(6):TD01-TD02. doi: 10.7860/JCDR/2015/11320.5996 PMID: 26266186
4. Kucuk G, Ufuk A, Gulnur G, Aydin Y. Conservative management of tracheal rupture in a child after blunt trauma. *Arch Argent Pediatr*. 2016; 114(6):e454–e456. [https://doi.org/10.1016/S0003-4975\(00\)02453-X](https://doi.org/10.1016/S0003-4975(00)02453-X) PMID: 27869433
5. Lim H, Kim JH, Kim D, Lee J, Son JS, Kim DC, et al. Tracheal rupture after endotracheal intubation – A report of three cases. *Korean J Anesthesiol*. 2012; 62(3):277–280. <http://dx.doi.org/10.4097/kjae.2012.62.3.277> PMID: 22474557
6. Maniatis PN, Triantopoulou CC, Tsalafoutas IA, Lamprakis CK, Malagari KS, Konstantinou K, et al. Virtual Bronchoscopy versus Thin-Section Computed Tomography in Evaluation of Moderate and Low-Grade Stenoses: Receiver Operating Characteristic Curve Analysis. *Acta Radiologica*. 2005;47(1):48–57. <https://doi.org/10.1080/02841850500406837> PMID: 16498933
7. Obretenov E, Arabadzhiev G, Vylcheva S. Postintubation Trachea Lesion – A Modern Behavior Algorithm. *J Bulg Thor Card and Vasc Surg*. 2014; 1:15–23.
8. Rousié C, Van Damme H, Radermecker MA, Reginster P, Tecqmenne C, Limet R. Spontaneous Tracheal Rupture: a Case Report. *J Acta Chirurgica Belgica*. 2016; 104(2):204–208. <https://doi.org/10.1080/00015458.2004.11679537> PMID: 15154580
9. Mitev M. Studies on the application of the Virtual bronchoscopy method for tracheal and bronchial ruptures. *Trakia J Sci*. 2020; 18(1):81–89. Doi:10.15547/tjs.2020.01.013
10. Zhu R, Lang F, Li M, Gu W. Postintubation Tracheal Rupture Detected by Virtual Endoscopy and Curved Planar Reformation. *Anesthesiology* 2020; 132(2): 375–376. doi:<https://doi.org/10.1097/ALN.0000000000002994>
11. Moser JB, Stefanidis K, Vlahos I. Imaging Evaluation of Tracheobronchial Injuries. *RadioGraphics*. 2020; 40(2). <https://doi.org/10.1148/rg.2020190171>
12. Unverdi Z, Kervancioglu R, Unverdi S, Menzilioglu MS. In the evaluation of tracheobronchial lesions, MDCT virtual bronchoscopy with fiber optic bronchoscopy comparison. *Med Sci and Discovery*. 2019; 6(8):136–44. Doi: 10.17546/msd.584332
13. Gagov E. Multidetector computerized-generated virtual bronchoscopy. *Roentgenologia. Radiologia*. 2013; 52(1):36–43. ISSN 0486-400X
14. Mitev MA. Virtual bronchoscopy with Multidetector computed tomography. *Trakia University-Stara Zagora: PhD These; Stara Zagora, 2017: 180.*
15. Chay L, Criales JL, Peña J, Páramo R, Navarro F, Cicero R. Correlation between virtual bronchoscopy and fiberoptic bronchoscopy in non-neoplastic stenosis of the larger airways. *Rev Inst Nal Enf Resp Mex*. 2005; 18(1):22–26. ISSN 0187-7585
16. Nakamori Y, Toshiaki H, Satoshi F, Kazuhiko S, Chikako T, Hiroshi O, et al. Tracheal rupture diagnosed with virtual bronchoscopy and managed nonoperatively: a case report. *The J Trauma and Acute Care Surg*. 2002; 53(2):369–371. DOI: 10.1097/01.TA.0000021530.02435.20
17. McAleece N, Gage JDG, Lamshead PJD, Peterson GLJ. *BioDiversity Professional statistics analysis software*. Scottish Association for Marine Science and Natural History Museum, London:1997. <http://www.sams.ac.uk>.
18. StatSoft, Inc. *STATISTICA (data analysis software system), version 10: 2011*. www.statsoft.com.
19. Romano L, Pinto A, Acampora C, Gagliardi N, Fulciniti S, Silva M. Airway Injuries. In: Miele V, Trinci M (eds) *Diagnostic Imaging in Polytrauma Patients*, Springer, Cham, 2018: 157–170. https://doi.org/10.1007/978-3-319-62054-1_7
20. Burke JF. Early Diagnosis of Traumatic Rupture of the Bronchus. *JAMA*. 1962; 181(8):682–686. PMID: 5934834
21. Mitev MA, Trajkova N, Arabadzhiev D, Valkanov S, Georgieva N, Obretenov E. Diagnostic capabilities of the Virtual Bronchoscopy at the advanced neoplastic process of Esophagus with the formation of tracheobronchial Fistula: description of a case. *Trakia J Sci*. 2017a; 3(56):258–261. doi:10.15547/tjs.2017.03.015
22. Mitev MA, Trajkova N, Arabadzhiev D, Valkanov S, Obretenov E. Virtual computed tomography bronchoscopy in tracheal ruptures. *Roentgenologia. Radiologia*. 2017b; 3(56):177–184. ISSN 0486-400X

23. Adali F, Uysal A, Bayramoglu S, Guner NT, Yilmaz G, Cimilli T. Virtual and fiberoptic bronchoscopy in patients with an indication for tracheobronchial evaluation. *Ann Thorac Med.* 2010; 5(2):104–109. doi: 10.4103/1817-1737.62474 PMID: 20582176
24. Barnes D, Chacoff JG, Benegas M, Perea RJ, de Caralt TM, Ramirez J, et al. Central airway pathology: clinic features, CT findings with pathologic and virtual endoscopy correlation. *Insights Imaging.* 2017; 8:255–270. DOI 10.1007/s13244-017-0545-6 PMID: 28197883
25. Fiorelli A, Raucci A, Cascone R, Reginelli A, Di Natale D, Santoriello C, et al. Three-dimensional virtual bronchoscopy using a tablet computer to guide real-time transbronchial needle aspiration. *Interactive CardioVascular and Thoracic Surgery.* 2017; 24:567–575. doi: 10.1093/icvts/ivw404 PMID: 28040772
26. Su SC, Brent I, Buntain H, Frawley K, Sarikwal A, Watson D, et al. A comparison of virtual bronchoscopy versus flexible bronchoscopy in the diagnosis of tracheobronchomalacia in children. *Pediatr Pulmonol.* 2017; 52:480–486. <https://doi.org/10.1002/ppul.23606> PMID: 27641078
27. Heyer CM, Nuesslein TG, Jung D, Peters SA, Lemburg SP, Rieger CHL, et al. Tracheobronchial anomalies and stenoses: detection with low-dose multidetector CT with virtual tracheobronchoscopy-comparison with flexible tracheobronchoscopy. *Radiology.* 2007; 242(2):542–549. <https://doi.org/10.1148/radiol.2422060153> PMID: 17255423
28. Kotlyarov PM. Virtual Bronchoscopy for Tumors and Traumatic Lesions of the Airways [Online First], *IntechOpen*, 2019. DOI: 10.5772/intechopen.84562.
29. Shallik N, Labib A, Ganaw A, Shaikh N, Moustafa A, Hammad Y. Virtual Bronchoscopy and 3D Reconstruction in Critical Care Setting. *Qatar Med J.* 2020; 2019(2). <https://doi.org/10.5339/qmj.2019.qccc.81>
30. Adachi T, Machida H, Nishikawa M, Arai T, Kariyasu T, Koyanagi M, et al. Improved delineation of CT virtual bronchoscopy by ultrahigh-resolution CT: comparison among different reconstruction parameters. *Japan J Radiology.* 2020. <https://doi.org/10.1007/s11604-020-00972-y>

Table 1. Criteria and factors for assessment of abnormalities in ruptures of trachea and bronchi

Criteria	Factors	Ruptures	
		Fiberoptic bronchoscopy	Virtual bronchoscopy
Localization (number of ruptures – 21/23, respectively)	the upper part of the trachea	14	16
	the middle part of the trachea	4	4
	the upper and middle part of the trachea	1	1
	the upper and lower part	2	2
Disposition (number of ruptures – 21/23)	along the length of the trachea in its membranous part	17	19
	in the area of cartilage rings in the transverse direction	3	3
	total circular interruption cervical/ mediastinal part	1	1
Shape (number of ruptures – 21/23)	linear with smooth edges	16	17
	irregular with uneven edges	5	6
Length of rupture (number of ruptures – 21/23)	0.5–3 cm	14	16
	3–5 cm	5	5
	above 5 cm	2	2
	rank (average ± SD)	0.5–7.1 cm (2.82 ± 1.73)	0.5–7.1 cm (2.42 ± 1.68)
Distance <i>rima vocalis</i> – upper edge of rupture (cm) (number of ruptures – 21/23)	up to 3 cm	7	8
	3–5 cm	11	12
	above 5 cm	3	3
	rank (average ± SD)	0.1–13.7 (3.90 ± 2.81)	0.1–13.7 (3.71 ± 2.78)
Distance from carina (number of ruptures – 21/23)	up to 3 cm	2	2
	3–5 cm	7	7
	above 5 cm	12	14
	rank (average ± SD)	2.0–13 (6.38 ± 2.87)	2.0–13 (6.64 ± 2.94)
Length of changes after healing of ruptures (cm) (number of changes – 16/17)	up to 3 cm	12	13
	3–5 cm	3	3
	above 5 cm	1	1
	0 cm	6	7
Number of affected tracheal rings (number of patients – 21/23)	rank (average ± SD)	0.72–4 (1.45 ± 1.33)	0.72–4 (1.37 ± 1.31)
	1	11	13
	2	6	6
	3	3	3
	0	1	1
	rank (average ± SD)	1–3 (1.52 ± 0.81)	1–3 (1.47 ± 0.79)