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ORIGINAL ARTICLE / ОРИГИНАЛНИ РАД

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

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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 A total of 21 patients (six males and 15 females) at the ages of 11–82 years (50.65 ± 19.8) 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 were proven by fiberoptic bronchoscopy in 21 patients and by virtual bronchoscopy in 19 patients. 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 (three 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 it is 100%. In terms of localization, shape and size, almost complete correspondence of changes with those of fiberoptic bronchoscopy was found. The presence of abundant secretion in virtual bronchoscopy may be interpreted incorrectly and efficiency of virtual bronchoscopy decreases.

Keywords: diagnostic capabilities; traumatic abnormalities; trachea; bronchi

INTRODUCTION

Ruptures of trachea and bronchi are rare, difficult to diagnose, lack well-known clinical signs but are 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) to be an adequate means for assessing 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 noninvasive method allows for three-dimensional evaluation of the tracheobronchial tree. It is determined as a finer, more short-term method than fiberoptic bronchoscopy (FB) [12–15]. The 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 present study is aimed at assessing the advantages and shortcomings of VB with MDCT in diagnosing patients with ruptures of the trachea and bronchi.

METHODS

Clinical material and equipment

A total of 21 patients (six males and 15 females aged 11–82 years; 50.65 ± 19.80) were studied

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for ruptures of trachea and bronchi by the methods of VB with MDCT and FB for more than five years (2013–2020). The methods were carried out on 64 MDCT Siemens Definition AS (Siemens Healthineers, Erlangen, Germany) and on Olympus BF PE2 bronchoscope (Olympus Corporation, Tokyo, Japan), respectively. Syngo.via VB20 (Siemens Healthineers) workstation, with the capacity to track and match the images in the axial, coronary, sagittal planes, was used. Multiplanar reconstructions were performed by applying maximum intensity projection 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 the following: localization of the rupture; disposition; shape of the rupture; length of the rupture (cm); distance of the rupture from the carina (cm); distance of the rupture from vocal ligaments (cm); length of changes resulting from the healing of the ruptures after medical treatment (cm); the number of affected tracheal rings.

Statistical analysis

The variation analysis of quantitative variables includes the following factors: for the 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 the comparison of two samples in unknown distributions (e.g. age, sex, various abnormalities of trachea and bronchi, etc.); Kruskal–Wallis test (H-test) for the comparison of more than two samples of different sizes. Two-way analysis of variance (Friedman's test, F-test) was used for determining the 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 (MS Office 2010; Microsoft Corporation, Redmond, WA, USA), 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, two males and 13 females; 76.19% with FB – 16 patients, two males and 14 females), followed by post-traumatic ruptures (14.29%) – three patients (two males and one female) and ruptures of trachea and the left lower lobar bronchus resulting from an advanced neoplasm of the esophagus (4.76% – one male), diagnosed by both methods; mucosal erosion after instrumental manipulations (4.76% – one male, after FB). No significant 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 reported 21 ruptures in 19 patients, and those of FB 23 ruptures in 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 (four patients each), and with ruptures localized in the upper and middle part of the trachea (one patient each). Two ruptures were recorded in one patient, one in the upper part and one in the lower part of the trachea, affecting the left lower lobar bronchus, reported by both methods. Nineteen patients diagnosed by FB and 17 patients diagnosed by VB had longitudinally located ruptures in the membranous part of the trachea. The shape of ruptures established by both methods was predominantly linear (17 patients diagnosed by FB and 16 patients diagnosed by VB), and in a small number of cases it was irregular (six and five patients diagnosed by 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 centimeters), 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*, for the distances from the carina, for the size of changes after healing of ruptures following the medical treatment, and for the number of affected tracheal rings. Low-grade stenoses (stenoses of grade I) were found in 19% of the studied patients (one male – 5%, and three 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 of two patients with false-negative results reported by VB against those reported by FB, decreasing the number of patients with ruptures and the reported ruptures by two each. In two patients (one male and one female), two ruptures were found by VB and FB each (Table 1).

Both methods reported a prolapse of mediastinal tissues in nine patients, as a result of 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 of four of the surveyed patients were operated on [three 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]. After the diagnosis confirmation with CT, FB, and VB, three of these patients (post-traumatic) were found to have large, extensive lesions and 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 side. In three of the patients who were operated on,

Table 1. Criteria and factors for assessment of abnormalities in ruptures of the trachea and the 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 *rima vocalis* – 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
	rank (average ± SD)	0.72–4 (1.45 ± 1.33)	0.72–4 (1.37 ± 1.31)
Number of affected tracheal rings (number of patients – 21/23)	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)

intubation was performed under the lesion. This avoids the continuous movement of the ruptured part and achieves rapid recovery (healing of the lesions for four days). For the fourth patient, an operative suture was imposed. All other rupture patients were conservatively treated with dynamic clinical follow-up by a specialist. The investigated patients (including the patients who were operated on) have been followed-up clinically and radiographically (by CT, FB, and VB). All the patients with ruptures presented in the paper have been discharged from hospital clinically healthy.

DISCUSSION

The presented study evidence of ruptures of trachea and bronchi in patients diagnosed by VB and FB offers significantly higher results than those reported by other authors [19]. Traumatic abnormalities of the trachea and main bronchi are rarely met in medical practice (in about 0.8–2% 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 in patients in a serious condition, where it may lead to more serious complications and to aggravating the outcome of the 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 MDCT and the follow-up three-dimensional reconstruction of the respiratory tract allows for real visualization, high resolution of the 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 shortcomings 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 the assessment of the trachea and the main bronchi, allowing for three-dimensional assessment of the tracheobronchial tree. VB is indicated as a better method than FB for diagnosing 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, in 90.47% of ruptures of trachea and bronchi cases VB showed results utterly comparable to those of FB. Almost complete correspondence with FB was found in terms of localization, shape and size of the changes. The presence of abundant secretion may be interpreted incorrectly with VB. Age is not defining in

terms of the size of ruptures ($p > 0.05$). Significant differences between the length of the ruptures in both sexes (U-test, $p = 0.04$) were obtained. Significant differences were found between the length of the ruptures and the following: the distance to the carina (U-test, $p = 0.0$); the distance to the rima (U-test, $p = 0.04$); the length of changes after healing of the ruptures (U-test, $p = 0.01$); the number of affected tracheal rings (U-test, $p = 0.03$); the distances between the carina and rima (U-test, $p = 0.0004$). Significant differences were also found in terms of distances to the carina and the following: the length of the changes after healing of the ruptures (U-test, $p = 0.0$); the number of affected tracheal rings (U-test, $p = 0.0$). The differences were significant regarding the length of the rima and the length of the changes after healing of the ruptures (U-test, $p = 0.0$), as well as the number of affected tracheal rings (U-test, $p = 0.0003$). In general, significant differences were found between the length of ruptures and distances to the carina, the distances to the rima, the length of changes after healing, the number of affected tracheal rings (H-test, $p = 0.0$). The length of ruptures is a determining factor with impact on the values of distances to the carina, distances to the rima, the length of changes after healing of the ruptures and the number of affected tracheal rings (F-test, $p = 0.0$). Generally, a high negative correlation was reported between the length of the ruptures and the distances to the carina ($r = -0.74$), and high positive correlation was found between the length of changes after healing and the number of affected tracheal rings ($r = 0.84$). No significant differences were found between the results obtained by the application of either method (FB, VB; $p > 0.05$).

This was also reported by studies of other authors, according to which data obtained from FB and VB are comparable, but whereas the advantages of FB are the immediate symptoms of color, vascularity, and mobility, VB predominates in circumventing obstructions and in 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 than those in studies of some of the 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 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 the sixth–seventh order [14, 22, 28, 29]. Thin-cut and ultra-high-definition studies allow lower and more final-order bronchi to be seen, with better resolution and low noise, but to perform the periodic follow-up of the patients with the possibility of attenuated treatment, the dose obtained is high and radiation-intensive [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 the sixth–seventh order is obtained. High comparability of the results with those of the performed FB is also achieved. This corresponds with 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 behavior – 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 greater sensitivity than FB in more difficult 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 urgent conditions, especially in patients with life-threatening injuries.

This study gives reason to accept that VB is a successful method for diagnosing traumatic injuries of the trachea and the 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 the trachea and the bronchi. However, it should be remembered that the efficiency of the method decreases in the presence of abundant secretion in the lumen of airways. VB has also been applied as a non-invasive method for establishing the size of the changes in the course of the healing process. VB 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 the trachea and the bronchi. Because of the accurate visualization of the tracheobronchial tree, the method can also be used for training. A limitation of the method is that it cannot determine changes in the mucosa in case of superficial injuries.

CONCLUSION

CT VB 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 as 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 abundant secretion.

Conflict of interest: None declared.

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

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САЖЕТАК

Увод/Циљ Фиберoптичка 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 фиберoптичком бронхоскопијом у трауматским абнормалностима трахеје и главних бронхија.

Методе Укупно 21 болесник (шест мушкараца и 15 жена) у доби од 11 до 82 године (50,65 ± 19,8) проучаван је методама виртуелне бронхоскопије са мултидетекторском компјутеризованом томографијом и фиберoптичком бронхоскопијом. Дијагностичке способности виртуелне бронхоскопије у односу на фиберoптичку бронхоскопију процењене су утврђеним критеријумима.

Резултати Руптуре трахеје и/или бронхија доказане су фиберoптичком бронхоскопијом код 21 болесника и виртуелном бронхоскопијом код 19 болесника. Највећа учесталост забележена је након руптуре после интубације (15 болесника, 71,42% виртуелном бронхоскопијом; 16 болесника, 76,19% фиберoптичном 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%), дијагностификоване обема методама; ерозија слузокоже после инструменталних манипулација (један болесник, 4,76%, после фиберoптичке бронхоскопије).

Закључак Постигнута дијагностичка тачност код руптура трахеје и бронха виртуелном бронхоскопијом је 90,47%, а фиберoптичком бронхоскопијом је 100%. У смислу локализације, облика и величине, пронађена је готово потпуна подударност промена с променама фиберoптичке 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