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RESEARCH

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Application of 320-row multidetector free-breathing cine CT in diagnosis of pediatric expiratory central airway collapse

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Abstract

Background: Pediatric expiratory central airway collapse poses diagnostic challenge due to non-specific clinical presentation with further investigations needed for definite diagnosis. The purpose of this cross-sectional study was to determine the diagnostic accuracy of 320-row multidetector free-breathing cine CT in diagnosis of pediatric expiratory central airway collapse utilizing its advantageous wide *z*-axis coverage. End-inspiratory and end-expiratory measurement of cross-sectional area at certain points of airway was done to calculate the percentage of expiratory central airway collapse. Flexible bronchoscopy was done thereafter as a gold standard technique for comparison.

Results: Among the thirty-eight pediatric patients (20 males and 18 females) enrolled in this study, free-breathing cine CT correctly diagnosed expiratory central airway collapse in 32 patients with a sensitivity of 84.2%. However, a statistically significant difference was found between the results of bronchoscopy and free-breathing cine CT as regard the site, morphology and severity of airway collapse.

Conclusions: 320-row multidetector free-breathing cine CT is still considered an effective noninvasive imaging modality in diagnosis of expiratory central airway collapse in pediatric population, despite the differences in perceived morphology and severity when compared to flexible bronchoscopy.

Keywords: Cine CT, 320-row, Expiratory central airway collapse, Bronchoscopy, Free-breathing

Background

Expiratory central airway collapse is a clinical syndrome characterized by excessive narrowing of airway lumen during exhalation. It consists of two entities tracheobronchomalacia and excessive dynamic airway collapse (EDAC) which are different in morphology, etiology and pathophysiology [1].

Clinical manifestations of expiratory central airway collapse are nonspecific, and the diagnosis can be difficult to make unless a high index of suspicion is held. Symptoms such as cough, wheeze and dyspnea are nonspecific and overlap with other pulmonary disorders [2].

Flexible bronchoscopy is considered by pediatric pulmonologist a gold standard technique in diagnostic work up of expiratory central airway collapse. It allows for the real-time evaluation of the tracheal and bronchial tree with tidal respirations and with forced expiratory maneuvers. However, its invasive nature makes noninvasive diagnostic tools high in demand [3].

Recent advances in CT imaging offer new opportunities to noninvasively diagnose expiratory central airway collapse in pediatric population. End-expiratory chest CT acquisition had been used traditionally in adults for diagnosis of tracheomalacia. Dynamic CT acquisition during inspiration and end expiration was found later on by

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many authors to be more sensitive than static end-expiratory CT for revealing the maximum degree of airway collapse. However, both techniques are suitable for adults who can cooperate with breathing instructions which is a difficult issue in pediatric population and hence real-time free-breathing cine CT acquisition was introduced by different CT vendors [4].

320-row multidetector CT scanner has wide detector that can cover up to 16 cm in *z*-axis direction during single gantry rotation, which is quiet sufficient to scan the entire chest of neonates and infants or even major tracheo-bronchial tree in older children. By utilizing this unique feature together with real-time 4D CT acquisition, assessment of tracheo-bronchial tree was made possible during free breathing in pediatric patients [5].

Our goal was to determine the diagnostic accuracy of 320-row multidetector free-breathing cine CT in diagnosis of expiratory central airway collapse in pediatric population with flexible bronchoscopy considered as a gold standard technique for comparison.

Methods

Study design and population

This prospective cross-sectional comparison study enrolled 38 pediatric patients with their age below 16 years; we included those who had symptoms and signs suggestive of expiratory central airway collapse including one or more of the following: persistent stridor, persistent wheeze, barking cough, anoxic spells, recurrent pulmonary infections, apnea and persistent respiratory noisy breathing, rattling or grunting. Critical patients who had been intubated due to severe airway compromise were excluded from this study as assessment of dynamic airway changes was not possible in the presence of endotracheal tube. The selected patients underwent free-breathing cine chest CT and flexible bronchoscopy thereafter with a duration no more than two weeks between both. They did not receive any empirical steroid treatment till bronchoscopy was done. The duration of the study was two years starting from July 2016 till July 2018.

Informed consent was obtained from parents of the individuals participating in this study after explanation of the benefits and possible risks of the procedures. The study was approved by our local institutional ethical committee.

Cine chest CT imaging technique

Patient preparation

Children older than 5 years of age were cooperative after verbal reassurance and simple explanation of the procedure. Neonates and infants were sedated using oral chloral hydrate with a dose of 50–100 mg/kg.

CT acquisition parameters

All chest cine CT examinations were performed using 320-row multidetector CT scanner (Aquilion One, Canon Medical Systems, Japan). Dynamic volume scanning technique was used to scan the entire chest without table movement during free-breathing continuously for three seconds to ensure that inspiratory and expiratory phases were captured. Number of detector rows used was selected according to cranio-caudal length of the chest with maximum *z*-axis coverage of 16 cm. For radiation dose reduction which is of utmost concern in pediatric population, pediatric chest CT protocol was implemented using 80 kVp, variable mA automatically set by scanner according to patient's body built using Sure-Exposure feature with low dose setting and 0.35 s gantry rotation time. Furthermore, number of detector rows used was minimized to scan the chest including trachea from thoracic inlet level down to diaphragm. Images were reconstructed at 0.5-mm slice thickness with no gap using sharp and soft reconstruction kernels.

Postprocessing technique

The reconstructed axial images were transferred to a dedicated workstation (Vitrea Fx, Vital Images, USA) for postprocessing and image analysis. Multiplanar reformatted images were created at sagittal and coronal planes and viewed at mediastinal and lung window settings. Minimum intensity projection images in coronal and sagittal planes as well as surface rendered external views were created for detection of airway stenosis if present. Endoluminal virtual bronchoscopy views were also obtained to resemble bronchoscopic views.

Image analysis

Image analysis and interpretation were done independently by consultant radiologist with 15 years of experience in general radiology who is familiar with different postprocessing tools and techniques. The reconstructed dataset was viewed as a cine loop in axial and coronal planes first to determine the inspiratory and expiratory phases by visual assessment of maximal chest inflation and deflation at axial images and also noting the position of diaphragm at coronal images. The scan with the maximum chest inflation was selected as inspiratory phase, whereas the scan with maximal chest deflation was considered the expiratory phase. The two selected inspiratory and expiratory phases were used thereafter for image analysis. The cine loop was helpful for dynamic visualization of airway during inspiration and expiration at different levels (Additional file 1: Video 1).

Three different airway levels were selected for cross-sectional area measurement: trachea at aortic arch level, carina level and bronchus intermedius. Cross-sectional area was calculated using double oblique method to ensure that the obtained image is a true axial cross section of the desired airway segment. A region of interest (ROI) was drawn thereafter manually at lung window setting to outline airway lumen (Fig. 1). The process was repeated in the selected levels during inspiratory and expiratory phases. Another ROI was drawn at the area of maximal airway collapse if it were located at another different airway region. The shape of tracheal collapse was noted as well either crescent, circumferential or saber sheath.

The percentage of luminal collapse (LC) was calculated according to the method proposed by Lee et al. [8]: $LC = (IA - EA)/IA \times 100$, where IA is inspiratory cross-sectional area and EA is expiratory cross-sectional area. Significant expiratory central airway collapse was diagnosed if LC was 50% or greater. The degree of expiratory airway collapse was divided into four categories according to severity: (a) mild (< 50%), (b) moderate (50–69%), (c) severe (70–99%) and (d) total collapse.

Calculation of radiation dose

The effective dose in mSv for each individual was calculated by multiplying dose length product (DLP) in mGy.cm by chest k-factor for each specific age group.

Flexible bronchoscopy

Flexible fiber optic bronchoscopy was carried out on all included 38 pediatric patients by their referring pediatric pulmonologists after cine chest CT. They used two sizes of flexible bronchoscopy (Olympus BF-3C160 video bronchoscope with external diameter 3.7 mm and working channel 1.2 mm) or (Karl Storz with external diameter 2.8 mm and working channel 1.2 mm) according to patient's age under general anesthesia with laryngeal mask ventilation and spontaneous respiration. Bronchoscopic findings as regard degree of airway collapse and shape were considered a gold standard for comparison with CT findings.

Statistical analysis

Data were collected, revised and edited into a master table using Microsoft Excel 2013. Data were then revised, coded and entered to the Statistical Package for Social Science (SPSS) software version 22. Patient demographic characteristics were presented as mean and standard deviation for continuous variables with normal distribution, median and interquartile range (IQR) for continuous variables with non-normal distributions and as proportions (percentages) for categorical variables. The distributions of quantitative variables were tested for normality using Kolmogorov–Smirnov test, Shapiro–Wilk test and D'Agstino test, also Histogram and QQ plot were used for vision test. If it reveals normal data distribution, parametric tests were applied. If the data were abnormally distributed, nonparametric tests were used. Related sample testing was done to compare results of both diagnostic modalities. The confidence interval was set to 95%, and the margin of error accepted was set to 5%. So, the *p* value was considered significant if it is < 0.05.

Results

Thirty-eight pediatric patients (20 males and 18 females) were enrolled in this study who presented with clinical picture suggestive of expiratory central airway collapse, and their age ranged from 3 to 39 months with a mean of 17.2 ± 12.1 SD.

Cine chest CT findings were concordant with bronchoscopic findings for the presence of expiratory central airway collapse in 32 out of 38 patients, indicating a sensitivity of 84.2%. The remaining six patients who had negative CT results were diagnosed with EDAC only at bronchoscopy.

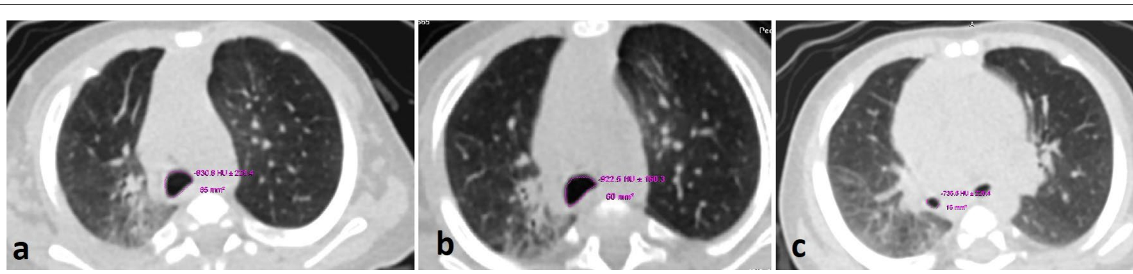

Fig. 1 Cross-sectional area measurements by cine CT. Three predefined areas were selected for measurement at end-inspiratory phase: **a** at aortic arch level, **b** at carina and **c** at bronchus intermedius. Measurements were obtained at lung window setting by manually drawing ROI outlining airway lumen at end-inspiratory phase. Double oblique method was used to ensure true axial section of the airway measured. The same measurements at the same levels were repeated during end-expiratory phase (not shown) to calculate the percentage of airway collapse

Different sites of expiratory airway collapse encountered in cine CT is demonstrated in Table 1 with their corresponding bronchoscopy results. A statistically significant difference is noted between both diagnostic modalities as regard the site with right main bronchus being the commonest site of discordant result. Additional file 2: Video 2 demonstrates significant expiratory collapse of trachea at aortic arch level diagnosed by cine loop of free-breathing CT.

The morphological analysis at the sites of expiratory central airway collapse revealed statistically significant difference between cine chest CT and bronchoscopy (Table 2). Nineteen patients had concordant results of both diagnostic modalities indicating a degree of sensitivity of 50% of cine chest CT in detecting accurate morphology. The main reason of discordance is that 15 patients (39.5%) had crescent-shaped narrowing by bronchoscopy that were perceived as circumferential narrowing by cine chest CT.

Different degrees of expiratory central airway collapse were diagnosed by cine CT at different airway levels (Fig. 2). However, there was a statistically significant difference between cine chest CT and bronchoscopy as regard the severity of expiratory central airway collapse. Only 14 (36.8%) patients out of the included 38 had concordant results of both diagnostic modalities indicating a sensitivity of 36.8% of cine CT chest in estimating the accurate degree of airway collapse (Fig. 3). Out of the remaining 24 (63.2%) patients, 23 patients had bronchoscopic results of higher degree of expiratory airway collapse than perceived by CT (Fig. 4), whereas the remaining patient had airway collapse of lower degree than estimated by cine CT. Cross-tabulation of cine chest CT results against those of bronchoscopy as regard severity of expiratory central airway collapse is shown at Table 3. Details of the degree of expiratory airway collapse perceived by cine CT at the three predefined levels of cross-sectional area measurement is shown in Fig. 5.

The effective radiation dose for cine chest CT examination ranged from 0.5 mSv to 1.3 mSv with a mean of 0.97 mSv ± 0.26 SD. The radiation dose was kept as low as reasonably achievable by the use of 80 kVp setting, limiting scan range to the area of interest and limiting exposure time to only three seconds to include inspiratory and expiratory phases.

Discussion

Expiratory central airway collapse (ECAC) in pediatric population poses a diagnostic challenge in pediatric population due to non-specific clinical presentation, with flexible bronchoscopy being the gold standard for diagnosis. However, it is an invasive procedure that carries certain risks to pediatric population and hence a noninvasive imaging modality is high in demand [6, 7].

Table 1 Sites of expiratory airway collapse detected by cine CT compared to bronchoscopy

Site of expiratory airway collapse	Bronchoscopy		Cine CT		Chi-square	
	No	%	No	%	X^2	*p* value
Trachea at thoracic inlet	4	12.5	7	21.8	85.168	< 0.0001
Trachea at aortic arch	3	9.4	5	15.6		
Carina	4	12.5	6	18.8		
Right main bronchus	14	43.7	4	12.5		
Bronchus intermedius	3	9.4	4	12.5		
Left main bronchus	4	12.5	6	18.8		
Total	32	100.00	32	100.00		

Table 2 Results of morphological classification of both bronchoscopy and cine CT

Morphology	Bronchoscopy		Cine CT		Chi-square	
	No	%	No	%	X^2	*p* value
Normal	0	0	6	15.8	55.324	< 0.0001
Circumferential	3	7.9	16	42.1		
Crescent	34	89.5	15	39.5		
Sabre-sheath	1	2.6	1	2.6		
Total	38	100.00	38	100.00		

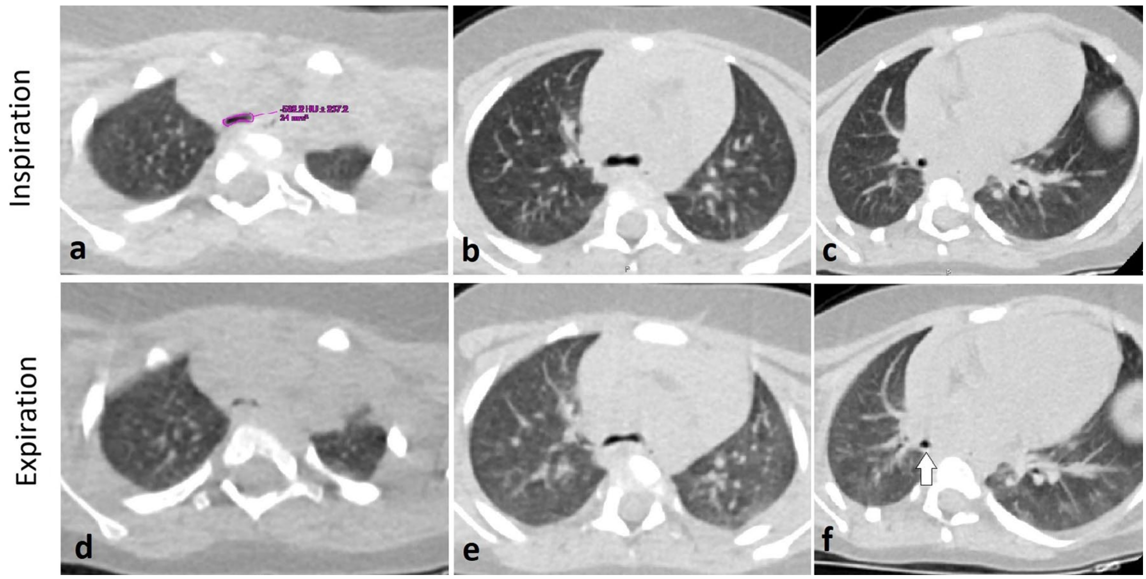

Fig. 2 Different degrees of expiratory central airway collapse perceived by cine CT at different airway levels. Free-breathing cine CT images obtained at end-inspiratory and end-expiratory phases revealed class 3 (≥ 70–99%) expiratory airway collapse at thoracic inlet level (**a**, **d**), class 2 (≥ 50–70%) airway collapse at carina level (**b**, **e**) and class 1 (< 50%) airway collapse at bronchus intermedius level (**c**, **f**). At bronchus intermedius level, mild airway collapse is diagnosed by flattening of its posterior wall during expiratory phase (arrow)

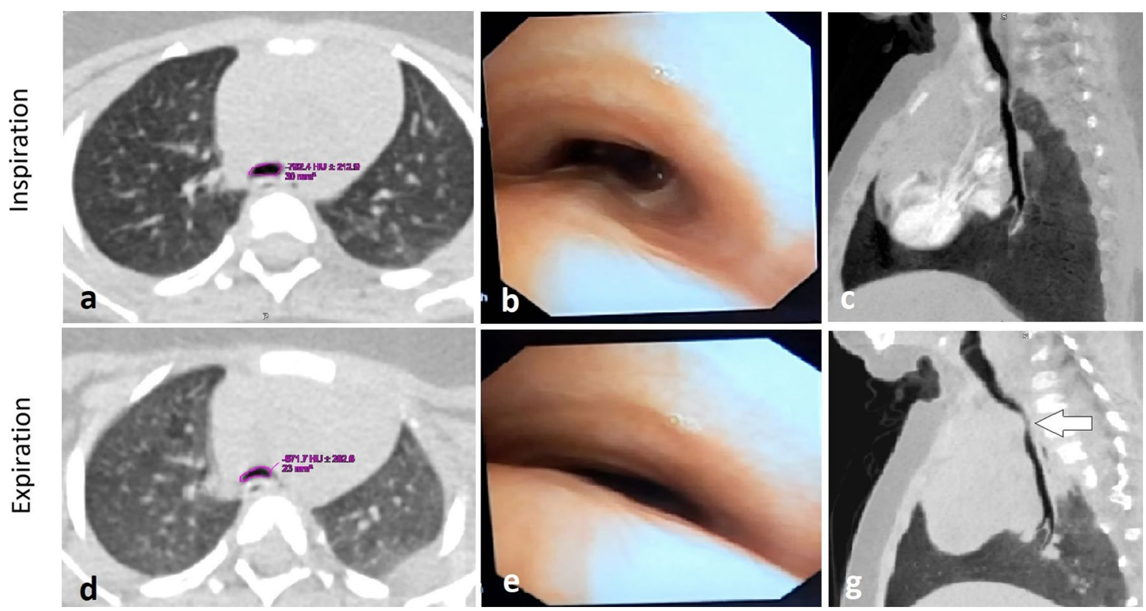

Fig. 3 Expiratory central airway collapse at aortic arch level. Cross-sectional area measurement of trachea at aortic arch level using cine CT during end-inspiratory (**a**) and end-expiratory phases (**d**) revealed significant expiratory airway collapse that was calculated to be 60% cross-sectional area reduction. Corresponding flexible bronchoscopy images are shown (**b**, **e**) confirming the presence of significant expiratory airway collapse with almost the same degree perceived by CT. Sagittal MinIP images (**c**, **g**) shows the significant expiratory airway collapse at the same level (arrow)

The introduction of 320-row MDCT scanner had made chest cine acquisition possible due to its wide detector, which is sufficient to scan the entire chest of an infant and even young child in a fraction of a second, with minimal breathing artifacts. The use of free-breathing cine CT acquisition by these scanners now allows investigation of dynamic airway changes in infants and children [8–10].

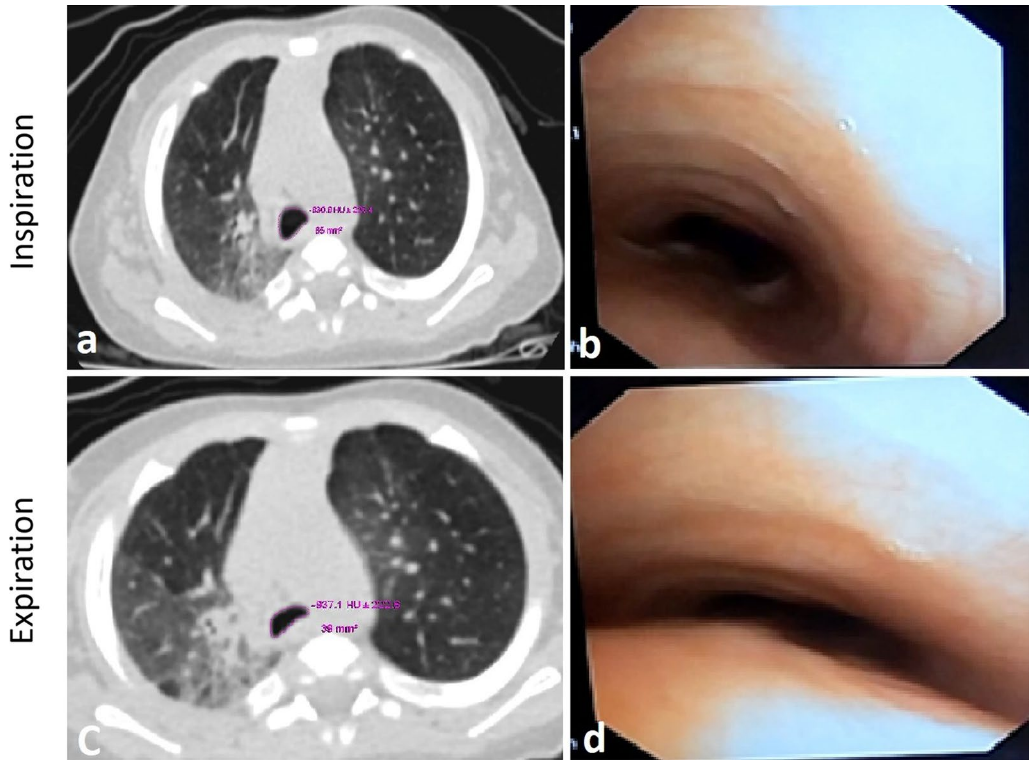

Fig. 4 Expiratory central airway collapse with mildly discordant result of cross-sectional area reduction between CT and bronchoscopy. Cross-sectional area measurement of trachea at aortic arch level using cine CT during end-inspiratory (**a**) and end-expiratory phases (**c**) revealed significant expiratory airway collapse that was calculated to be 50% cross-sectional area reduction at CT. Corresponding flexible bronchoscopy images (**b**, **d**) confirms the presence of expiratory central airway collapse but with slightly higher degree than that perceived with CT. However, both results are still within the same severity score (class 2; ≥ 50–70% cross-sectional area reduction)

Table 3 Cross-tabulation of results of severity classification of both bronchoscopy and cine chest CT

		Severity* by Cine chest CT				***p* value**
		1	**2**	**3**	**4**	
Severity* by Bronchoscopy	**1**	0	0	0	0	< 0.001
	2	2	5	2	0	
	3	4	13	7	1	
	4	0	1	1	2	

*Severity score: 1 (no abnormal airway collapse), 2 (50–75% airway collapse), 3 (76–99% airway collapse) and 4 (100% total airway collapse)

In our study, we compared the results of cine chest CT as regard the site, morphology and severity of airway collapse with those obtained with flexible bronchoscopy; the later acted as a gold standard technique for comparison.

As regard the site of expiratory airway collapse, we found concordant results between cine CT and flexible bronchoscopy in 68.8% of patients, which is nearly the same result obtained by Tan et al. [10] who reported concordant results between both modalities in 66.6% of their studied patients.

As regard the morphological classification of collapsed airway, we found concordant results of both CT and bronchoscopy in 50% of patients. Goo [5] in his study on young children did CT in bronchoscopy-proven tracheomalacia, and he found 51.9% had crescentic-shaped trachea, rounded in 11.1% and lunate in 37%. Those with discordant results in our study may be attributed to the absence of forced end-expiratory phase which could provoke more degree of airway collapse and hence change in morphology for example from spherical to crescent shape.

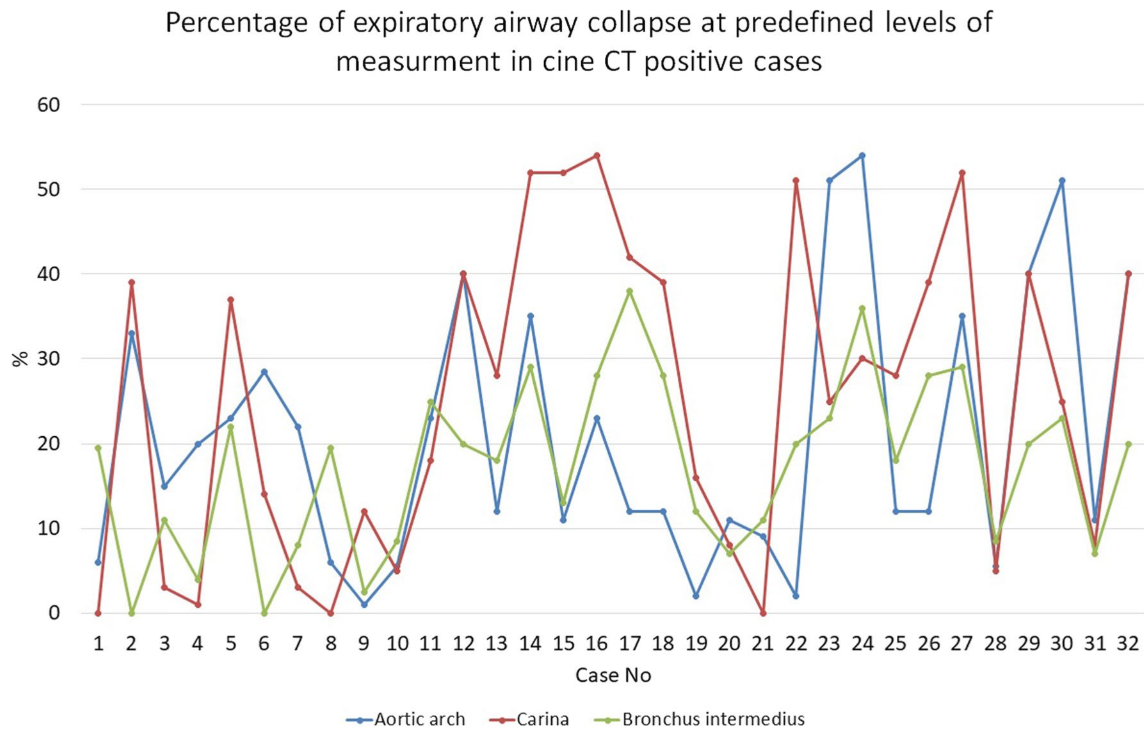

Fig. 5 Percentage of expiratory central airway collapse at the three predefined locations of cross-sectional area measurement. The degree of expiratory central airway collapse was higher at carina in most of cases compared to other levels of measurement

To categorize the severity of ECAC, we used the cut-off value ≥ 50% reduction in the cross-sectional area of airway to diagnose significant ECAC. Four categories were used for ECAC grading in our study; class 1: no abnormal airway collapse, class 2: 50%–75% airway collapse, class 3: 76%–99%" airway collapse and class 4: total airway collapse. Sanchez et al. [6] categorized the severity of airway malacia as: mild, subjectively approximated 50–75% collapse, moderate > 75% collapse and severe, near or complete occlusion of the tracheal lumen during expiration. And these are similar to staging described by Mair and Parsons [11] who suggested quantification of pediatric tracheomalacia as mild (< 70%), moderate (70–90%) and severe (> 90%).

Our study compared the severity classification in both CT and bronchoscopy, and we noticed concordant results of both diagnostic modalities in 14 (36.8%) patients (four with mild ECAC and the other ten with moderate-to-severe ECAC), while 24 (63.2%) patients had discordant results of severity. The difference in severity results between CT and bronchoscopy may be due to the absence of forced end-expiratory phase at free-breathing CT acquisition that could reveal more degree of expiratory airway collapse. Su et al. [12] diagnosed 37 patients out of 56 with ECAC by flexible bronchoscopy and found that 33 (89.5%) of their patients had mild ECAC, moderate in three (7.9%) and severe in one (2.6%). But they compared this result with that obtained by CT virtual bronchoscopy, and they found that virtual bronchoscopy detected airway malacia in 20 children (mild in 19 [95%] and moderate in one [5%]). Out of these 20 cases detected, two cases had moderate and one had severe tracheomalacia on flexible bronchoscopy, while the remaining 17 cases diagnosed with mild tracheomalacia on flexible bronchoscopy were positive on virtual bronchoscopy as well.

Regarding the sensitivity of 320-row CT in detecting expiratory airway collapse, our CT findings were concordant with bronchoscopic findings for the presence and extent of ECAC in 32 out of 38 patients, indicating a sensitivity of 84.2%. Our results are in consistency with the results done by Ullmann et al. [4] who reported agreement between bronchoscopy and the dynamic CT scan in 89% of patients and the sensitivity of CT was 100%. Lee et al. [8] found that CT findings were concordant with bronchoscopic findings for the presence and distribution of airway malacia in 28 (97%) out of 29 patients.

We measured the cross-sectional area on axial CT images at predefined three levels like the method proposed by Represas et al. [13], namely at aortic arch level, carina and bronchus intermedius in order to assess the degree of dynamic airway collapse during end inspiration and end expiration by cine CT. But we noticed in certain cases that the site of maximal expiratory airway collapse was at areas other than the three predefined areas for measurement, including right main bronchus in four cases, left main bronchus in six cases and thoracic inlet in seven cases.

We did a comparison between the degree of airway collapse at the levels of aorta, carina and bronchus intermedius; and we found that the degree of airway collapse was higher at the level of carina in most of cases in comparison with that at aortic arch level and bronchus intermedius level (Fig. 5). Nygaard et al. [14] in their study measured the cross-sectional area every 1 cm from the carina up to thoracic inlet to determine the localization of maximal expiratory collapse, and they reported that the most optimal location to measure is the distal level of the trachea, as 78% of their patients had their maximal collapse there.

Limitations

This study has certain limitations. First, cine CT was performed during free breathing which does not include the forced end-expiratory phase that could reveal more degree of expiratory airway collapse at CT images and hence increasing the accuracy of CT to detect the degree of airway collapse perceived and also could alter the result of describing the morphology of collapsed airway. Further studies using pneumatic compression devices to obtain forced end expiration during CT acquisition may be recommended to investigate such issue thoroughly. Second, the lumen size during bronchoscopy was subjectively estimated by anteroposterior diameter and not quantitatively measured by cross-sectional area which could alter the result of severity scoring of airway collapse in bronchoscopy and hence the discordant results with CT findings.

Conclusions

Being capable of free-breathing dynamic whole chest acquisition, 320-row multidetector cine CT is still considered a relatively sensitive noninvasive imaging modality in diagnosis of children with expiratory central airway collapse, despite the perceived difference in morphology and degree of airway collapse when compared to flexible bronchoscopy.

Abbreviations

4D: Four-dimensional; CT: Computed tomography; DLP: Dose length product; EA: Expiratory area; ECAC: Expiratory central airway collapse; EDAC: Excessive dynamic airway collapse; IA: Inspiratory area; LC: Luminal collapse; mSv: Millisievert; ROI: Region of interest; SD: Standard deviation.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43055-022-00903-z.

Additional file 1: Cine loop of free-breathing chest CT.

Additional file 2: Significant expiratory tracheal collapse at aortic arch level by free-breathing cine CT.

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Author contributions

RE collected and analyzed patient's data throughout research process, NF suggested the idea of this research work and performed flexible bronchoscopy, AA revised study design and supervised research work, and AM prepared the manuscript for publishing and made CT image postprocessing on workstation. All authors have read and approved the manuscript.

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Availability of data and materials

The datasets used and analyzed in this study are available from corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Research Ethics Committee of Faculty of Medicine at Tanta University in Egypt. Parents of all patients included in this study gave written informed consent to participate in this research.

Consent for publication

Parents of all patients participated in this study gave written consent to publish the data in this study. The authors grant the publisher the consent for publication of this work.

Competing interests

Authors declare no competing interests.

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