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Original Article

Improved air trapping evaluation in chest computed tomography in children with cystic fibrosis using real-time spirometric monitoring and biofeedback ☆

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Abstract

Background: The quality of chest Computed Tomography (CT) images in children is dependent upon a sufficient breath hold during CT scanning. This study evaluates the influence of spirometric breath hold monitoring with biofeedback software on inspiratory and expiratory chest CT lung density measures, and on trapped air (TA) scoring in children with cystic fibrosis (CF). This is important because TA is an important component of early and progressive CF lung disease.

Methods: A cross sectional comparison study was completed for chest CT imaging in two cohorts of CF children with comparable disease severity, using spirometric breath hold monitoring and biofeedback software (Copenhagen (COP)) or unmonitored breath hold manoeuvres (Gothenburg (GOT)). Inspiratory–expiratory lung density differences were calculated, and TA was scored to assess the difference between the two cohorts.

Results: Eighty-four chest CTs were evaluated. Mean (95%CI) change in inspiratory–expiratory lung density differences was 436 Hounsfield Units (HU) (408 to 464) in the COP cohort with spirometric breath hold monitoring versus 229 HU (188 to 269) in the GOT cohort with unmonitored breath hold manoeuvres ($p < 0.0001$). The Mean TA (95%CI) score was 6.93 (6.05 to 7.82) in COP patients and 3.81 (2.89 to 4.73) in GOT ($p < 0.0001$) patients.

Conclusions: In children with comparable CF lung disease, spirometric breath hold monitoring during examination yielded a large difference in lung volume between inhalation and exhalation, and allowed for a significantly greater measured change in lung density and TA score, compared to unmonitored breath hold maneuvers. This has implications to the clinical use of chest CT, especially in children with early CF lung disease.

Keywords: Cystic fibrosis; CF lung disease; Computer tomography; Image quality; Breath-hold monitoring; Trapped air

1. Introduction

Chest CT imaging of the lungs is an accepted and sensitive method to evaluate chronic lung disease in children with cystic fibrosis (CF) [1], Structural lung changes in CF are widely known to be closely related to infections with Gram-positive and Gram-negative bacteria [2–6], and to be unevenly distributed in the lungs [7,8]. Trapped air (TA) is an important

Abbreviations: CT, Computer tomography; TA, Trapped air; CF, Cystic fibrosis; HU, Hounsfield units; COP, Copenhagen; GOT, Gothenburg; FEV1, Forced expiratory volume in 1 s; FVC, Forced vital capacity; BMI, Body mass index; SVC, Slow vital capacity; TLC, Total lung capacity; HU, Hounsfield unit; CFCT, Cystic fibrosis computer tomography; ICC, Intraclass correlation coefficient.

☆ The results of this study were presented by Thomas Kongstad in a workshop and a poster at the NACF Congress in Orlando, Florida, USA from 11-October-2012 to 13-October-2012.

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component of chronic airway diseases such as CF. It represents small airways involvement [9,10] and is best visualized on expiratory CT image sequences [11–13]. In recent years different methods of breath hold control have been described: conventional unmonitored breath hold with verbal instructions [3], spirometry triggered CT [14], spirometry monitored CT [15], controlled volume infant CT [6,16–19], and free breathing CT [20,21]. It has been previously reported that lung volume control during scanning improves the value of CT images in children with CF compared with healthy controls [9], but the impact on comparable groups of CF children has not been studied. We hypothesized that discrimination of disease severity from CT images would become more reliable when spirometric breath hold monitoring was used to guide the child during acquisitions of chest CT images. We tested this by comparing chest CT images acquired using "real-time" spirometric breath hold monitoring with biofeedback software to those acquired during unmonitored breath hold manoeuvres. Additionally, we were interested in assessing trapped air (TA) scoring obtained from chest CT scanning during monitored versus unmonitored breath hold manoeuvres.

2. Methods

2.1. Recruitment

Children with CF followed at the CF centre at Copenhagen University Hospital in Rigshospitalet (COP), Denmark, and the CF centre at Sahlgrenska Hospital in Gothenburg (GOT), Sweden, who were between 6 and 18 years of age were eligible for this study, if at least one chest CT examination for disease monitoring was available. A CF diagnosis was confirmed by sweat chloride test >60 mmol/l and/or genotyping for CF mutations.

Children followed at the CF centre in COP had chest CT imaging performed as part of a clinical prospective longitudinal CT study, that compared clinical parameters to the evolution of lung changes visualized on CT. All CT examinations were performed using spirometric monitoring. Full informed written consent was obtained from the parents or guardians of the children.

In GOT, routine CT examinations have been performed since 1997 [3] and CT images were selected from a group of CF children matched according to age, gender and lung function (FEV_1 and FVC, % predicted) at the day of CT scanning.

In order to achieve all possible matches of patient age and lung function between the two cohorts, two examinations from five individual GOT patients were allowed, since the examinations were at least 3 years apart.

2.2. Test procedures

Chest CT examinations were preceded by measurements of weight, height, lung function, and clinical evaluation. Body mass index (BMI) was calculated from the anthropometric data. At both centres CT scanning was performed in CF children who were clinically stable. In case of a pulmonary exacerbation, CT scanning was postponed at least 4 weeks.

2.3. Lung function

Spirometry (Jaeger Masterscreen PFT, CareFusion, Hoechberg, Germany) was performed on the day of the chest CT scanning utilizing ATS/ERS guidelines [22], and FEV_1 and FVC were recorded. The "all ages" reference equations were used to calculate the percent predicted values [23].

2.4. Chest CT acquisition at COP

All scans were done by volumetric spiral CT imaging on a Toshiba Aquillion 64 CT scanner (Toshiba Corporation, Tokyo, Japan), (100 kVp, mAs-modulation (SD = 19 in inspiratory and SD = 27 in expiratory sequences, rotation 0.4 s). The average total radiation dose for the inspiratory and expiratory CT scans was 1.41 mSv (range 0.78– 4.05). Images were reconstructed using a medium soft kernel (FC12) for 3 mm slices and a sharp kernel (FC52) for 1 mm CT slices. A full description of the scan protocol can be found online.

2.5. Real-time spirometric monitoring and biofeedback

Prior to chest CT scanning, an optimal supine slow vital capacity (SVC) measurement was obtained, and 10% and 90% of SVC values were calculated. An advanced breath hold technique was achieved by spirometric monitoring (JAEGER pneumotachograph connected to a portable computer) and biofeedback software, developed particularly for this purpose by the biomedical department and the authors (further description of software can be found online). The values from SVC were entered into the biofeedback software and displayed on a screen. Dynamic pulmonary volumes were displayed during breathing as a smiley-animation on a volume-time curve on the screen (Video still 1) (Fig. 1), to improve the incentive for the child to follow the instructions. Breath hold control was considered successful when the child reached the designated thresholds of below the 10% line

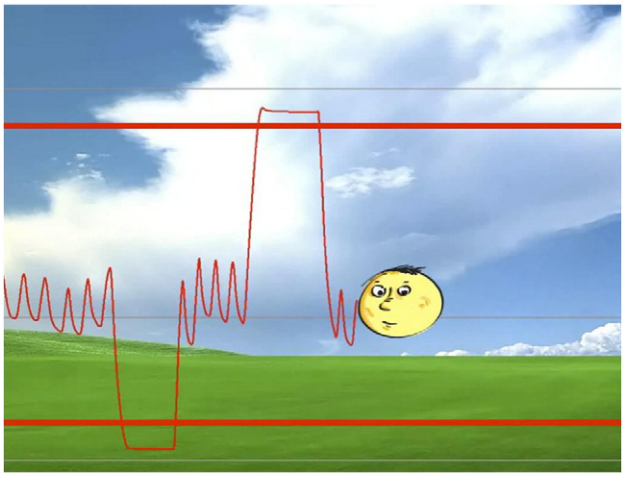

Fig. 1. Computer biofeedback displaying dynamic volume-time curve during scanning. The red lines mark the 10% and 90% of Slow Vital Capacity volumes to be reached for expiratory and inspiratory sequences. Refer to online supplement for a short video of the bio-feedback animation. Volume-time data are stored for documentation and post-processing.