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Preventative Inhalation of Hypertonic Saline in Infants with Cystic Fibrosis (PRESIS): A Randomized, Double-Blind, Controlled Study

Mirjam Stahl[1,2,3], Mark O. Wielpütz[3,4,5], Isabell Ricklefs[6,7], Christian Dopfer[8,9], Sandra Barth[10,11], Anne Schlegtendal[12], Simon Y. Graeber[1,2,3,13,14], Olaf Sommerburg[2,3], Gesa Diekmann[6,7], Johannes Hüsing[15], Cordula Koerner-Rettberg[12], Lutz Nährlich[10,11], Anna-Maria Dittrich[8,9], Matthias V. Kopp[6,7], and Marcus A. Mall[1,2,3,13,14]

[1]Department of Translational Pulmonology, University of Heidelberg, Heidelberg, Germany

[2]Division of Pediatric Pulmonology and Allergy and Cystic Fibrosis Center, Department of Pediatrics, University of Heidelberg, Heidelberg, Germany

[3]Translational Lung Research Center Heidelberg (TLRC), German Center for Lung Research (DZL), Heidelberg, Germany

[4]Department of Diagnostic and Interventional Radiology, University of Heidelberg, Heidelberg, Germany

[5]Department of Radiology, German Cancer Research Center, Heidelberg, Germany

[6]Division of Pediatric Allergology and Pneumology, Department of Pediatrics, Medical University of Lübeck, Lübeck, Germany

[7]Airway Research Center North (ARCN), German Center for Lung Research (DZL), Lübeck, Germany

[8]Department of Pediatric Pneumology, Allergology and Neonatology, Hannover Medical School, Hannover, Germany

[9]Biomedical Research in Endstage and Obstructive Lung Disease (BREATH), German Center for Lung Research (DZL), Hannover, Germany

[10]Department of Pediatrics, Justus-Liebig-University Giessen, Giessen, Germany

[11]Universities Giessen and Marburg Lung Center (UGMLC), German Center for Lung Research (DZL), Giessen, Germany

[12]Department of Pediatric Pulmonology, University Children's Hospital of Ruhr University Bochum at St. Josef-Hospital, Bochum, Germany

[13]Department of Pediatric Pulmonology, Immunology and Intensive Care Medicine, Charité - Universitätsmedizin Berlin, Berlin, Germany

[14]Berlin Institute of Health (BIH), Berlin, Germany

[15]Coordination Center for Clinical Trials (KKS), Heidelberg University Hospital, Heidelberg, Germany

Corresponding author:
Mirjam Stahl, MD, Department of Translational Pulmonology and Division of Pediatric Pulmonology and Allergy and Cystic Fibrosis Center, Translational Lung Research Center Heidelberg (TLRC), University of Heidelberg, Im Neuenheimer Feld 430, 69120 Heidelberg, Germany; Phone: +49-6221-5637049, Fax: +49-6221-565281, E-Mail: mirjam.stahl@med.uni-heidelberg.de

or

Marcus A. Mall, MD, Department of Pediatric Pulmonology, Immunology and Intensive Care Medicine, Charité - Universitätsmedizin Berlin, Augustenburger Platz 1, 13353 Berlin, Germany; Phone: +49-30-450566182, Fax: +49-30-450566931, E-Mail: marcus.mall@charite.de

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AT A GLANCE COMMENTARY

Scientific Knowledge on the Subject:

Cystic fibrosis (CF) lung disease starts in early infancy suggesting that preventive therapy may be most effective. Implementation of CF newborn screening has created a unique window of opportunity to test this concept in clinical trials and recent studies indicated that the lung clearance index (LCI) and chest magnetic resonance imaging (MRI) may be promising outcome measures of early CF lung disease. However, randomized controlled trials (RCT) testing the feasibility, safety and efficacy of preventive therapies in infants with CF are lacking.

What This Study Adds to the Field:

This study demonstrates for the first time that RCT including LCI and chest MRI as quantitative outcome measures of lung disease are feasible in young infants with CF. In addition, this initial RCT supports that preventive treatment with inhaled hypertonic saline is safe and well tolerated, and has therapeutic benefits on lung function and thriving in the first year of life. These findings support the conduct of future RCT to evaluate safety and efficacy of preventive treatment strategies that have the potential to delay or even prevent irreversible lung damage in patients with CF.

This article has an online data supplement, which is accessible from this issue’s table of content online at www.atsjournals.org.

Abstract

Rationale: Cystic fibrosis (CF) lung disease starts in early infancy suggesting that preventive treatment may be most beneficial. Lung clearance index (LCI) and chest magnetic resonance imaging (MRI) have emerged as promising endpoints of early CF lung disease, however, randomized controlled trials testing the safety and efficacy of preventive therapies in infants with CF are lacking.

Objectives: To determine feasibility, safety and efficacy of preventive inhalation with hypertonic saline (HS) compared to isotonic saline (IS) in infants with CF including LCI and MRI as outcome measures.

Methods and Main Results: In this randomized, double-blind, controlled trial 42 infants with CF less than 4 months of age were randomized across 5 sites to twice daily inhalation of 6% HS (n=21) or 0.9% IS (n=21) for 52 weeks. Inhalation of HS and IS was generally well tolerated by CF infants and the number of adverse events did not differ between groups (P=0.49). The change in LCI from baseline to week 52 was larger in CF infants treated with HS (-0.6) compared to IS (-0.1, P<0.05). In addition, weight gain was improved in CF infants treated with HS (P<0.05), whereas pulmonary exacerbations and chest MRI scores did not differ in the HS vs. IS group.

Conclusions: Preventive inhalation with HS initiated in the first months of life was safe and well tolerated, and resulted in improvements in LCI and weight gain in infants with CF. Our results support feasibility of LCI as endpoint in randomized controlled trials in infants with CF.

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Key words: Cystic fibrosis; lung clearance index; lung disease; magnetic resonance imaging; preventive therapy

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Introduction

Previous observational studies in infants and preschool children with cystic fibrosis (CF) demonstrated early onset and progression of lung disease despite multi-disciplinary treatment by experienced CF teams according to current standards of care (1-3). These studies showed that potentially reversible abnormalities such as airway mucus plugging, air trapping, neutrophilic inflammation and bronchial wall thickening are already present in young infants in the first months of life, and that presumably irreversible and progressive bronchiectasis are detected in many children with CF from preschool age (1, 2). These data suggested that preventive therapeutic intervention starting in early infancy may be a promising strategy to delay or even prevent irreversible lung damage in CF (3-5). This hypothesis was supported by preclinical studies showing that preventive therapeutic targeting of airway surface dehydration implicated in the pathogenesis of CF lung disease (6, 7), both with osmotically active hypertonic saline (HS) and the sodium channel blocker amiloride, prevented mucus plugging in mice with CF-like lung disease (8-10).

The implementation of CF newborn screening has created a unique window of opportunity to test this hypothesis in clinical trials (11). So far, trials testing the safety and efficacy of preventive therapies starting in the first months of life in infants with CF have been hampered by the lack of quantitative outcome measures of lung disease in this challenging age group. However, a series of recent studies suggested that the lung clearance index (LCI), a measure of ventilation homogeneity derived from multiple-breath washout (MBW), may be a suitable endpoint for this purpose. These studies showed that LCI is sensitive to detect abnormal lung function in infants, and disease progression and response to therapy with inhaled HS or CFTR modulators in older children with CF (12-20). Further, it was shown that chest magnetic resonance imaging (MRI) is sensitive to detect early abnormalities in lung structure and perfusion in infants and preschool children with CF without radiation exposure (17, 21-27). Recent studies demonstrated feasibility of standardized measurements of LCI and chest MRI in infants and preschool children in a multicenter setting (28, 29).

The aim of this study was to explore the feasibility, safety and initial efficacy of preventive inhalation of HS in young infants with CF using LCI and MRI as outcome measures. Inhaled HS was used as preventive therapeutic intervention because i) inhaled HS counteracts airway surface dehydration and impaired mucociliary clearance constituting important abnormalities in CF airways (30); ii) a preclinical proof-of-concept study demonstrated that early treatment with HS prevented airway mucus plugging, mortality and failure to thrive in mice with CF-like lung disease (8); and iii) inhaled HS was shown to be safe and had beneficial effects on LCI in older infants and preschool children with CF (14, 31-34).

To achieve this goal, we conducted an initial multicenter, randomized, double-blind, controlled study of inhaled HS vs. isotonic saline (IS) in infants with CF starting in the first four months of life for a duration of 12 months and determined effects on LCI, chest MRI score, anthropometry, pulmonary exacerbation rates, and adverse events between treatment groups. Some of the results have been previously reported in the form of an abstract (35).

Methods

Study Design and Participants

The Preventive Inhalation of Hypertonic Saline in Infants with Cystic Fibrosis Study (PRESIS; clinicaltrials.gov identifier NCT01619657) was a randomized, parallel-group, double-blind, controlled trial of inhalation of HS (6% NaCl) vs. IS (0.9% NaCl) in young infants with CF. The study was conducted at 5 CF centers in Germany within the clinical trial network of the German Center for Lung Research (DZL) (36) and approved by the Ethics Committee of the University of Heidelberg (approval no. S-397/2011) and the Ethics Committees of each participating site. Written informed consent was obtained from parents or legal guardians of all patients included in the study. Demographics and baseline characteristics of the study population are provided

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in Table 1. Exocrine pancreatic sufficiency was defined by fecal elastase ≥ 200 µg/g stool and information on pancreatic status and respective *CFTR* genotypes of study participants is provided in Supplementary Table E1. Key inclusion criteria were a confirmed diagnosis of CF and an age less than 4 months at inclusion. Additional information including a complete list of in- and exclusion criteria is provided in the online supplement.

Randomization and Outcome Measures

Study participants were randomized 1:1 to inhalation of 4 ml HS or IS twice daily for a period of 12 months using a jet nebulizer (Pari LC sprint, Pari GmbH, Starnberg, Germany) and baby face mask (Pari baby face mask size 0-1, Pari GmbH, Starnberg, Germany). The first inhalation of study solution was performed at the study site under supervision of a physician who assessed study participants for cough, wheezing and drop in oxygen saturation, which did not occur in any infant. Key outcome measures were change in LCI, chest MRI score, weight, height, BMI, and rate of pulmonary exacerbations. In addition, we determined change in respiratory rate, oxygen saturation, detection of pathogens, and safety and tolerability of inhaled HS, as determined from adverse events (AE) and serious adverse events (SAE). Adherence to treatment was assessed by a medication diary completed quarterly by the parents/legal guardians.

Multiple-Breath Washout

MBW was performed in sedation with chloral hydrate (100 mg/kg body weight, maximum dose 2 g) using the Exhalyzer D system (Eco Medics AG, Duernten, Switzerland) with 4% sulphur hexafluoride as tracer gas and a face mask as interface with the child lying in a supine position. The LCI was determined from acceptable wash-out curves as previously described (17, 28, 37-41). Details on quality criteria, data acquisition and analysis are provided in the online supplement.

Chest Magnetic Resonance Imaging

Chest MRI was performed on a clinical 1.5T MR scanner (Magnetom Avanto, Siemens Medical AG, Erlangen, Germany; Achieva, Philips Healthcare, Best, Netherlands) using T1- and T2-weighted sequences as previously described (17, 22, 23, 29, 42). Images were assessed for morphological abnormalities (MRI morphology score and subscores) by an independent reader (MOW) blinded for clinical and demographic data as well as treatment group using a dedicated MRI score (23, 42). The MRI protocol did not include perfusion studies because administration of i.v. contrast material was not approved in Germany in children under 12 months of age during the conduct of this study. Details on MRI sequences and scoring are provided in the online supplement.

Sample Size Considerations and Statistical Analysis

No quantitative data on the effect of inhaled HS in infants with CF were available for sample size calculations prior to the initiation of this trial. Based on a previous study on the effect of inhaled HS on LCI in older children with CF with normal spirometry (43) and observational studies providing information on change in LCI in early CF lung disease (44-48), we estimated a mean effect size of inhaled HS on LCI of 0.5 ± 0.5 SD in our study population of CF infants. Based on these estimates we expected that a minimum number of 17 patients per arm will be required to assess efficacy of inhaled HS using LCI as endpoint in our trial. To account for possible drop-outs, we aimed to include at least 20 patients per arm, resulting in a total sample size of 40 patients. This estimated sample size was met in our study and has been supported by the results of a pilot study of inhaled HS in older infants and preschool children with CF that became available after the initiation of our trial (14). Data were analyzed under the guidance of a statistician (J.H.) using SPSS version 22.0 (SPSS Inc., Chicago, IL, USA) and SAS version 9.4 (The SAS Institute, Cary, NC, USA). Parametric data are presented as mean (±SD) and nonparametric data as median (inter-quartile range, IQR). For categorical data, groups were compared with chi-square test or Fisher's exact test and for continuous data with unpaired Student's t-test or one-way ANOVA with least significant difference-Bonferroni post-hoc test or Wilcoxon signed-rank test. Change in anthropometry was compared between trial arms using

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time, trial arm/time interaction and age-specific median as fixed explanatory variables in a hierarchical linear mixed regression model (49, 50). Adverse events were coded according to MedDRA, grouped by System Organ Class and compared between trial arms. The rate of AE, SAE and pulmonary exacerbations was compared between trial arms using a Poisson model allowing for overdispersion, using the baseline radiologic findings and trial arm as explanatory variables. The probability of remaining free of a pulmonary exacerbation was estimated using the Kaplan-Meier method and compared between groups by log-rank test. A P value of < 0.05 was accepted to indicate statistical significance.

Results

Participant Flow and Baseline Characteristics

A total of 42 infants with CF (mean age, 0.26±0.08 years; range, 0.09 – 0.41 years) were enrolled between June 2012 and November 2015 at 5 sites and randomly assigned to receive inhaled HS (n=21) or IS (n=21) (Figure 1). 20 of 21 patients in the HS and 20 of 21 patients in the IS group completed 12 months of treatment. In the HS group, treatment was discontinued in 1 patient after 30 weeks due to unblinding during a pulmonary exacerbation. In the IS group, treatment was discontinued in 1 patient after 34 weeks because the parents declined further sedation for study procedures (Figure 1). Adherence to inhalation with study solution was high and comparable in both groups with 71.8 – 100% in the IS group and 77.2 – 100% in the HS group according to the medication diary quarterly completed by the parents (P=0.863).

Baseline characteristics including age, gender, *CFTR* genotype distribution, mode of diagnosis, and upper airway microbiology were generally similar between the two treatment groups (Table 1; Table E1). In both groups, more than half of the patients were diagnosed preclinically based on CF newborn screening or a positive family history. Mean weight, height, BMI and respiratory rate were comparable between groups (Table 1). Previous MBW studies in healthy infants reported an upper limit of normal (ULN) of the LCI of 8 (41, 51, 52). Mean LCI in our study in infants with CF was normal at baseline and did not differ between groups (IS, 7.2±0.7 vs. HS, 7.5±0.7; *P*=0.230) (Table 1). Despite a normal mean LCI, the LCI was elevated above the ULN of 8 in a subgroup of patients in both groups (IS, range from 6.3 to 9.0 with n=3 above 8; HS, range from 6.0 to 8.7 with n=5 above 8; *P*=0.697) (41, 51, 52). MRI detected morphological abnormalities of the lungs in most patients of both groups (40 out of 42) (Table 1). Consistent with previous studies in infants and preschool children, bronchial wall thickening/bronchiectasis was the most prevalent finding followed by mucus plugging, pleural reaction, mosaic signal intensity and consolidation (Table 1) (17, 22, 23). The median MRI morphology score and MRI subscores for specific abnormalities were in the lower range of the maximum MRI scores possible and did not differ between groups (Table 1).

Efficacy of Preventive Inhalation of HS in Infants with CF

CF infants treated with inhaled HS showed a rapid and sustained decrease in mean LCI from 7.5±0.7 at baseline to 6.9±0.7 at 12 months (*P*<0.01) (Figure 2; Table 2). In the IS group, mean LCI was 7.2±0.7 at baseline and remained at 7.2±0.8 after 12 months of treatment (*P*=0.793) (Figure 2; Table 2). The change in LCI from baseline to 12 months was significantly larger in CF infants treated with inhaled HS compared to IS (HS, -0.6±0.8 vs. IS, -0.1±0.9; *P*<0.05) (Figure 2; Table 2).

Chest MRI demonstrated that the prevalence of morphological abnormalities remained high and the median MRI morphology score tended to increase slightly from baseline to 12 months in the HS (1.9±5.2; *P*=0.117) and IS group (0.5±6.7; *P*=0.740) (Figure 3; Table 2). This change in MRI morphology scores did not differ between the HS and IS group (*P*=0.462). Overall, MRI subscores for bronchial wall thickening/bronchiectasis, mucus plugging and mosaic signal intensity tended to increase, whereas subscores for consolidation and pleural reaction tended to decrease from baseline to 12 months in both groups (Table 2). These changes in MRI subscores did not differ between the HS and IS group (Table 2).

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Anthropometric measurements showed that weight gain was improved in CF infants treated with inhaled HS compared to IS (*P*<0.05) (Figure 4 A; Table 2). Gain in height (*P*=0.175) and BMI (*P*=0.919), and change in z-scores for weight, height and BMI tended to be increased in the HS group, but this trend did not reach statistical significance (Figure 4 B & C; Table 2). Further, no differences were detected between treatment groups in the change of oxygen saturation (*P*=0.602) or respiratory rate (*P*=0.443) (Table 2).

During the 12 months study period, 6 patients in the HS group and 9 patients in the IS group experienced a total of 21 vs. 23 pulmonary exacerbations resulting in a pulmonary exacerbation rate of 1.1 (95% CI, 0.0-2.1) vs. 1.2 (95% CI, 0.4-1.9) per person-year for CF infants randomized to receive HS vs. IS (*P*=0.862). Figure 4 displays the probability of remaining free of a pulmonary exacerbation in both treatment arms.

Microbiology of nasal and pharyngeal samples showed that the prevalence and acquisition of upper airway infection with pro-inflammatory pathogens such as *Staphylococcus aureus, Haemophilus influenzae, Pseudomonas aeruginosa, Streptococcus pneumoniae* and *Aspergillus species* (53) was low in infants with CF and did not differ between treatment groups (Table E2).

Safety of Preventive Inhalation of HS in Infants with CF

Inhalation with HS and IS was generally well tolerated in infants with CF. Adverse events were reported in all patients from both groups and were mostly of mild (81.3%) or moderate severity (12.9%) and 5.7% of AE were rated as severe. The proportion of patients with reported AE was similar in the HS and IS group, with cough being the most common AE (Table 3). SAE were reported in 6 (28.6%) patients in the HS group and 7 (33.3%) patients in the IS group. A detailed summary of all AE with an incidence > 5% in any treatment group and all SAE reported during this study is provided in Table 3. In all cases, the rating as SAE was due to necessity of hospitalization and none was rated as related to study treatment.

Discussion

Randomized controlled trials (RCT) are considered the gold standard for the assessment of safety and efficacy of therapeutic interventions, but have so far not been conducted to evaluate preventive treatment strategies in young infants with CF, in part due to the lack of quantitative endpoints in this challenging age group. PRESIS is the first RCT testing feasibility, safety and initial efficacy of preventive treatment of lung disease initiated in the first months of life in infants with CF using LCI and MRI as quantitative outcome measures of early lung disease. This study demonstrates that RCT starting in early infancy including regular treatment with inhalation solutions and repeated LCI and MRI measurements over a period of 12 months are feasible and well accepted by the parents (Figure 1). Second, this study shows that preventive inhalation of HS from early infancy was safe and well tolerated (Table 3; Table E2) and indicates that this early intervention had beneficial effects on lung function and thriving in infants with CF (Figures 2 and 4). Third, this study suggests that LCI is more sensitive to detect response to preventive treatment of CF lung disease than MRI morphology scores or clinical outcomes such as pulmonary exacerbations in infants with CF (Figures 2-4). The results of this initial RCT support the concept of preventive therapy and inform future trials starting in young infants that are warranted to leverage the window of opportunity provided by CF newborn screening and determine the most efficacious therapies to delay or even prevent irreversible lung damage in patients with CF.

Inhaled HS was previously tested in the Infant Study of Inhaled Saline in Cystic Fibrosis (ISIS) in older infants and preschool children with CF (4 to 60 months of age; mean age at baseline 2.2 years) who received inhaled HS vs. IS for 48 weeks (34). The ISIS trial did not show

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differences between treatment groups for the rate of pulmonary exacerbations as primary endpoint, nor for secondary endpoints including height, weight, respiratory rate, or oxygen saturation (34). In the PRESIS trial, the age range and mean age were substantially lower (0 to 4 months of age; mean age at baseline 0.28 years) (Table 1). Similar to the ISIS trial, the pulmonary exacerbation rate, respiratory rate, or oxygen saturation did not differ between treatment groups in our study (Figure 4; Table 2). However, unlike the ISIS trial, the absolute change in weight was significantly increased (500 g higher mean weight at month 12) and absolute change in height tended to be greater (1.5 cm higher mean height at month 12) in CF infants treated with inhaled HS vs. IS (Figure 4). This observation is reminiscent of previous studies in mice with CF-like lung disease showing beneficial effects of inhaled HS on growth (8). As thriving is a global parameter of well-being in infants, we speculate that this finding may reflect therapeutic benefits of preventive HS inhalation in early CF lung disease. Of note, it is an established phenomenon that when children with chronic diseases associated with failure to thrive are started on an effective therapy, they typically gain weight before they start showing catch-up growth in height (54-59). We therefore speculate that this known delay in catch-up growth in height vs weight may explain why weight diverted from 3 months onward, whereas height started diverting after 9 months between the two treatment arms (Figure 4). This difference between our study and the ISIS trial suggests that there may be a unique window of opportunity for preventive treatment of CF lung disease initiated in the first months of life. However, future RCT comparing benefits of therapeutic interventions initiated in different age groups from early infancy to preschool ages are required to substantiate this hypothesis. Similar to results from ISIS in older infants and preschool children, detection of pro-inflammatory pathogens was rare and did not differ between treatment groups (34). Also consistent with the ISIS study, adherence to inhalation therapy was high (70 to 100%) and drop-out rates were low with only 1 out of 21 patients discontinuing the study early in each group and the remainder completing 12 months of treatment and all endpoint measurements (Figure 1 and Table 2). Adverse event profiles in our study were also consistent with those previously observed in older children in the ISIS trial with the most common treatment-emergent adverse events being cough, rhinorrhea, obstructive bronchitis and nasal congestion with frequencies that did not differ between groups (Table 3). These data support that preventive treatment with inhaled HS is safe and feasible from early infancy and suggest that more sensitive outcome measures are needed to assess therapeutic benefits on early lung disease in young infants with CF.

In this context, the LCI has previously been shown to detect abnormal ventilation in infants and progression of lung disease in preschool children with CF (13, 15, 41, 60). Further, a single center substudy of the ISIS trial demonstrated that on average LCI decreased in the HS group and remained stable in the IS group with an overall significant treatment effect observed for the LCI z-score in older infants and preschool children with CF (14). Based on these findings, we included longitudinal measurements of LCI as outcome measure in the PRESIS trial. In young infants with CF included in our study, LCI at baseline was normal in both treatment groups. Initiation of inhaled HS in the first four months of life resulted in a rapid and sustained decrease in LCI in the range of 0.5 units that was already observed at the first measurement after 3 months of HS inhalation and persisted throughout the study, whereas LCI in the IS group remained unchanged during the course of the study (Figure 2, Table 2). Notably, the change in LCI from baseline was significantly different between the HS and IS group from 9 months onward supporting therapeutic benefits of inhaled HS on lung function in the first year of life. Of note, this pattern of improvement in LCI observed with inhaled HS in our study in young infants with CF (< 4 months) differs from the pattern observed in a subgroup of 10 older infants with CF (4 to 16 months) that were included in the ISIS MBW pilot study that showed no change in LCI in the HS group, but worsening in the IS group (14). Based on the LCI trajectories in healthy infants, as well as infants with CF during the first years of life (52, 61) (61), we speculate that this difference is related to the timing of the intervention. The decrease in LCI observed in our study in infants of the HS group was also observed in healthy infants (52). Further, in longitudinal MBW studies in the AREST CF cohort the LCI dropped (improved) by ~0.5 units between 3 months and 2 years in CF infants that were never infected, whereas

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LCI did not change substantially in infants ever infected with pro-inflammatory pathogens (61). When viewed in combination with LCI trajectories in healthy infants, the AREST CF study and the ISIS pilot study (14, 52, 61), we speculate that early initiation of inhaled HS in the first months of life may prevent or delay the onset of early CF airways disease and thus result in a physiological drop in LCI during infancy, whereas initiation of HS in older infants that may already have early airway obstruction may prevent or delay early disease progression, but not reverse early CF lung disease. Collectively, these data support LCI as a sensitive outcome measure in interventional studies testing effects of preventive therapies for CF from early infancy.

In previous cross-sectional studies, we demonstrated that chest MRI is sensitive to detect abnormalities in lung structure and perfusion in early CF lung disease (17, 22). These studies identified bronchial wall thickening/bronchiectasis, mucus plugging and abnormal lung perfusion as the most prevalent changes in clinically stable preschool children with CF (17, 22). The present study shows for the first time that MRI-defined morphological abnormalities such as bronchial wall thickening and mucus plugging are already prevalent in the first four months of life (Figure 3, Table 1 and 2). However, the MRI morphology score did not differ between the HS and IS group after 12 months of inhalation therapy. We speculate that several reasons may explain why MRI was less sensitive then LCI to detect response to treatment in the PRESIS trial. First, we were not able to perform MRI perfusion studies, as the use of contrast material was not approved in Germany in infants under the age of 12 months at the time of the study. Our previous studies indicated that abnormal lung perfusion due to hypoxic pulmonary vasoconstriction in areas of abnormal ventilation may be a sensitive surrogate parameter for small airway mucus plugging (17, 22). Further, contrast material enhanced the signal of morphological abnormalities. Therefore, the lack of perfusion studies may have reduced the sensitivity of MRI in the present study. Second, whereas the current semi-quantitative MRI morphology score was sensitive to detect response to antibiotic therapy for acute pulmonary exacerbation in older children with CF, this three-grade scoring system may still be too coarse to detect more moderate changes in clinically stable infants with CF, as these may not exceed the limit of 50% of lobar involvement that differentiates between scoring grade 1 and 2 (17, 22, 42). Thus, additional studies will be required to determine the role of MRI perfusion studies and the granularity of the scoring system on the sensitivity of MRI as outcome measure in early intervention trials in CF infants. These studies should also include longitudinal assessment of clinically stable infants and preschool children with CF to establish the trajectories and variability of abnormalities detected by chest MRI in early CF lung disease over time.

This study has limitations. First, IS is an active comparator rather than true placebo that may have therapeutic benefits itself, which may lead to underestimation of treatment effects of inhaled HS in our study. However, the use of an active comparator was necessary for blinding of inhalation solutions in this RCT. Second, because this was the first RCT conducted in young infants with CF, it was not possible to perform formal sample size calculations to power the study for the outcome measures used. However, our estimated sample size for LCI as outcome measure that was based on a previous HS study in older children with CF and observational studies on changes in LCI in infants and young children with CF (43-48), is supported by the results of a pilot study of inhaled HS in older infants and preschool children with CF (14), as well as the data obtained in our study. Further, our data provide estimates for sample size calculations for the endpoints included in our study for the design of future trials in young infants with CF. Third, our trial was underpowered to determine effects of inhaled HS on pulmonary exacerbations. Moreover, the applicability of current definitions of pulmonary exacerbations, including the modified Fuchs definition used in our study, as well as the EPIC definition put forward for preschool and school age children, remains limited for studies in infants with CF due to inclusion of criteria such as spirometry and hemoptysis (62, 63). Fourth, the duration of this initial efficacy trial was limited to 12 months and longer observation times will be necessary to substantiate therapeutic benefits of preventive treatment with inhaled HS and other emerging therapies including CFTR modulators in early CF lung disease (64). In this

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context, it will be of interest to determine to what extent preventive therapies can delay the onset and long-term progression of irreversible structural lung damage in patients with CF.

In summary, this study shows for the first time that RCT including LCI and MRI as quantitative outcome measures of early lung disease are feasible in young infants with CF. Further, this initial RCT supports that preventive treatment with inhaled HS starting in the first months of life is safe and has therapeutic benefits on lung function and thriving of CF infants. These data support the conduct of future RCT to determine safety and efficacy of preventive treatment strategies that have the potential to delay or prevent progressive lung damage in patients with CF.

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Figure Legends

Figure 1. Flow diagram displaying the progress of all participants through the PRESIS trial.

Figure 2. Effect of preventive inhalation of hypertonic saline on lung clearance index. Absolute change from baseline in lung clearance index (LCI) in infants with CF treated with inhaled hypertonic saline (HS, triangles) or isotonic saline (IS, circles). Decrease in LCI indicates improvement. Error bars are 95% confidence intervals. Dashed line indicates baseline level. *$P<0.05$ between groups compared to baseline.

Figure 3. Effect of preventive inhalation of hypertonic saline on MRI morphology score. MRI morphology scores of individual infants with CF at baseline and after 12 months of treatment with inhaled hypertonic saline (HS, triangles) or isotonic saline (IS, circles). Horizontal lines represent group median.

Figure 4. Effect of preventive inhalation of hypertonic saline on anthropometry and pulmonary exacerbations in infants with CF. (A-C) Absolute change from baseline in weight (A), height (B) and body mass index (BMI) (C) at 3, 6, 9 and 12 months of treatment with inhaled hypertonic saline (HS, triangles) or isotonic saline (IS, circles). Data are shown as mean with 95% confidence intervals. (D) Kaplan-Meier plot of time to first pulmonary exacerbation by treatment group. Probability of remaining free of pulmonary exacerbation in the HS group (continuous line) and in the IS group (dotted line) ($P=0.78$). *$P<0.05$ between groups from baseline through month 12.

Tables

Table 1. Demographics and baseline characteristics of study population

		Isotonic saline (n=21)	Hypertonic saline (n=21)
Age, years		0.26 (0.07)	0.26 (0.08)
range, years		0.09 – 0.35	0.10 – 0.41
Sex, n (males/females)		10/11	10/11
CFTR genotype			
F508del/F508del		11 (52.4)	11 (52.4)
F508del/other		8 (38.1)	6 (28.6)
other/other		2 (9.5)	4 (19.0)
Pancreatic insufficient		20 (95.2)	17 (81.0)
Anthropometry			
Weight, kg		5.2 (1.1)	5.3 (1.1)
Weight z-score		-0.7 (0.9)	-0.6 (1.1)
Height, cm		59.8 (4.0)	59.8 (5.1)
Height z-score		-0.7 (1.2)	-0.6 (1.1)
BMI, kg/m^2		14.4 (1.6)	14.7 (1.6)
BMI z-score		-1.0 (1.0)	-0.8 (1.1)
Mode of diagnosis*			
Positive CF newborn screening		10 (47.6)	10 (47.6)
Meconium ileus/atresia small intestine		3 (14.3)	6 (28.6)
Prenatal/positive family history		2 (9.5)	4 (19.0)
Failure to thrive		4 (19.0)	1 (4.8)
Respiratory symptoms		2 (9.5)	0 (0.0)
Positive respiratory culture†			
Staphylococcus aureus		6 (28.6)	4 (19.0)
Haemophilus influenzae		0 (0.0)	0 (0.0)
Pseudomonas aeruginosa		0 (0.0)	0 (0.0)
Streptococcus pneumoniae		0 (0.0)	0 (0.0)
Aspergillus species		0 (0.0)	1 (4.8)
Resting respiratory rate, breaths/min		41.3 (11.5)	39.2 (10.7)
Oximetry, %		98.8 (1.1)	98.5 (1.3)
LCI		7.2 (0.7)	7.5 (0.7)
Chest MRI			
Morphology	Prevalence	95.2 (20/21)	95.2 (20/21)
	Score	8.0 (4.0 - 13.5)	3.0 (2.0 – 12.0)

AJRCCM Articles in Press. Published on 09-November-2018 as 10.1164/rccm.201807-1203OC

Wall thickening/bronchiectasis	Prevalence	95.2 (20/21)	95.2 (20/21)
	Subscore	4.0 (3.0 – 5.0)	2.0 (2.0 – 4.5)‡
Mucus plugging	Prevalence	76.2 (16/21)	57.1 (12/21)
	Subscore	2.0 (0.5 – 3.5)	1.0 (0.0 - 2.0)
Consolidation	Prevalence	33.3 (7/21)	28.6 (6/21)
	Subscore	0.0 (0.0 - 1.0)	0.0 (0.0 - 1.0)
Pleural reaction	Prevalence	52.4 (11/21)	33.3 (7/21)
	Subscore	1.0 (0.0 - 2.0)	0.0 (0.0 - 1.0)
Mosaic signal intensity	Prevalence	47.6 (10/21)	33.3 (7/21)
	Subscore	0.0 (0.0 – 3.5)	0.0 (0.0 - 2.0)

Definition of abbreviations: *CFTR* = cystic fibrosis transmembrane conductance regulator; BMI = body mass index; LCI = lung clearance index; MRI = magnetic resonance imaging. MRI scores are presented as median (IQR) and prevalence of abnormal MRI scores as percentage (proportion); other data are presented as mean (SD) or number (percentage).

*Multiple answers were possible; list reflects first abnormality leading to diagnosis.

†Isolated any time prior to enrolment.

‡*P*<0.05 vs. isotonic saline.

Table 2. Effects of preventive inhalation of hypertonic saline versus isotonic saline in infants with CF

	Isotonic saline (n=20)	Hypertonic saline (n=20)	Treatment difference vs. isotonic saline
Absolute change in LCI at month 12	-0.1 (-0.5 to 0.4)	-0.6 (-1.0 to 0.2)**	-0.5 (-1.1 to 0.0)*
Absolute change in MRI morphology score at month 12	0.5 (-3.0 to 3.6)	1.9 (-0.5 to 4.3)	1.4 (-2.4 to 5.3)
Absolute change in MRI wall thickening/bronchiectasis subscore at month 12	0.8 (0.3 to 1.4)**	1.6 (0.9 to 2.3)***	0.8 (-0.1 to 1.6)
Absolute change in MRI mucus plugging subscore at month 12	0.3 (-0.6 to 1.3)	0.8 (0.0 to 1.5)*	0.5 (-0.7 to 1.6)
Absolute change in MRI consolidation subscore at month 12	-0.5 (-1.0 to 0.0)	-0.6 (-1.1 to 0.0)	-0.1 (-0.8 to 0.6)
Absolute change in MRI pleural reaction subscore at month 12	-0.2 (-0.7 to 0.3)	-0.2 (-0.6 to 0.3)	0.1 (-0.6 to 0.7)
Absolute change in MRI mosaic signal intensity subscore at month 12	0.0 (-1.8 to 1.5)	0.3 (-0.7 to 1.2)	0.3 (-1.5 to 2.0)
Absolute change in weight (kg) through month 12	4.3 (4.0 to 4.7)***	4.8 (4.1 to 5.5)***	0.5 (-0.3 to 1.2)*
Absolute change in weight z-score through month 12	-0.1 (-0.4 to 0.2)	0.3 (-0.4 to 0.9)	0.3 (-0.3 to 0.1)
Absolute change in height (cm) through month 12	18.5 (17.4 to 19.5)***	20.0 (17.3 to 22.6)***	1.5 (-1.3 to 4.3)
Absolute change in height z-score through month 12	0.3 (-0.1 to 0.6)	0.9 (-0.3 to 2.1)	0.6 (-0.6 to 1.8)
Absolute change in BMI (kg/m^2) through month 12	1.1 (0.3 to 1.9)**	1.2 (0.5 to 1.9)**	0.2 (-0.9 to 1.2)
Absolute change in BMI z-score through month 12	0.2 (-0.5 to 0.8)	0.3 (-0.2 to 0.8)	0.1 (-0.7 to 0.9)
Absolute change in resting respiratory rate (breaths/min) at month 12	-9.9 (-15.7 to -3.9)***	-10.3 (-16.6 to -4.0)**	-0.4 (-8.5 to 7.7)

AJRCCM Articles in Press. Published on 09-November-2018 as 10.1164/rccm.201807-1203OC

Absolute change in oximetry (%) at month 12	-1.6 (-2.4 to -0.9)***	-1.3 (-2.3 to -0.2)*	0.4 (-0.9 to 1.7)

Definition of abbreviations: LCI = lung clearance index; MRI = magnetic resonance imaging; BMI = body mass index. All data shown are change from baseline. Values are mean (95% confidence interval). *P<0.05, **P<0.01, ***P<0.001 within group or vs. isotonic saline.

Table 3. Treatment-emergent adverse events

	Isotonic saline (n=21)		**Hypertonic saline (n=21)**	
	Affected infants	**Occurred events**	**Affected infants**	**Occurred events**
All adverse events	21 (100)	240 (100)	21 (100)	219 (100)
All adverse events with incidence > 5% in any treatment group:				
Infection of upper respiratory tract without fever	17 (81.0)	52 (21.7)	16 (76.2)	41 (18.7)
Rhinorrhea	10 (47.6)	17 (7.1)	17 (81.0)	31 (14.2)
Cough	12 (57.1)	34 (14.2)	14 (66.7)	25 (11.4)
Infection of upper and lower respiratory tract without fever	7 (33.3)	9 (3.8)	9 (42.9)	13 (5.9)
Infection of upper respiratory tract with fever	8 (38.1)	13 (5.4)	7 (33.3)	9 (4.1)
Infection of upper and lower respiratory tract with fever	7 (33.3)	8 (3.3)	6 (28.6)	10 (4.6)
Abdominal distension / flatulence	4 (19.0)	4 (1.7)	8 (38.1)	8 (3.7)
Fever	6 (28.6)	7 (2.9)	5 (23.8)	10 (4.6)
Diarrhea	6 (28.6)	7 (2.9)	5 (23.8)	9 (4.1)
Infection of lower respiratory tract without fever	6 (28.6)	7 (2.9)	3 (14.3)	10 (4.6)
Conjunctivitis	5 (23.8)	9 (3.8)	2 (9.5)	3 (1.4)
Gastroenteritis	3 (14.3)	4 (1.7)	4 (19.0)	7 (3.2)
Otitis media	4 (19.0)	7 (2.9)	3 (14.3)	3 (1.4)
Obstructive bronchitis	4 (19.0)	9 (3.8)	1 (4.8)	1 (0.5)
Abdominal pain	3 (14.3)	5 (2.1)	2 (9.5)	2 (0.9)
Constipation	3 (14.3)	4 (1.7)	2 (9.5)	3 (1.4)
Dyspnea	2 (9.5)	4 (1.7)	3 (14.3)	3 (1.4)
First detection of *P. aeruginosa*	2 (9.5)	2 (0.8)	3 (14.3)	3 (1.4)
Nasal congestion	2 (9.5)	2 (0.8)	3 (14.3)	3 (1.4)
Candida nappy rash	1 (4.8)	1 (0.4)	3 (14.3)	3 (1.4)
Exanthema subitum	2 (9.5)	2 (0.8)	2 (9.5)	2 (0.9)
Iron deficiency anemia	3 (14.3)	3 (1.3)	1 (4.8)	1 (0.5)
Salt loss syndrome	2 (9.5)	3 (1.3)	1 (4.8)	1 (0.5)
Urticaria	2 (9.5)	2 (0.8)	1 (4.8)	1 (0.5)
Bronchopulmonary secretion	1 (4.8)	1 (0.4)	2 (9.5)	2 (0.9)

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Vomiting or emesis	1 (4.8)	2 (0.8)	2 (9.5)	2 (0.9)
Poor growth	2 (9.5)	3 (1.3)	0 (0.0)	0 (0.0)
Refusal to eat or drink	0 (0.0)	0 (0.0)	2 (9.5)	2 (0.9)
Steatorrhea	2 (9.5)	2 (0.8)	0 (0.0)	0 (0.0)
Tympanic effusion	2 (9.5)	2 (0.8)	0 (0.0)	0 (0.0)
All serious adverse events:	7 (33.3)	12 (100)	6 (28.6)	21 (100)
First detection of *P. aeruginosa*	2 (9.5)	2 (16.7)	3 (14.3)	3 (14.3)
Obstructive bronchitis	2 (9.5)	3 (25.0)	1 (4.8)	1 (4.8)
Salt loss syndrome	2 (9.5)	2 (16.7)	1 (4.8)	1 (4.8)
Infection of upper and lower respiratory tract with or without fever	0 (0.0)	0 (0.0)	2 (9.5)	7 (33.3)
Gastroenteritis	0 (0.0)	0 (0.0)	2 (9.5)	4 (19.0)
Infection of lower respiratory tract without fever	0 (0.0)	0 (0.0)	2 (9.5)	2 (9.5)
Brain concussion	1 (4.8)	1 (8.3)	0 (0.0)	0 (0.0)
Cholangitis	0 (0.0)	0 (0.0)	1 (4.8)	1 (4.8)
Refusal to eat or drink	0 (0.0)	0 (0.0)	1 (4.8)	1 (4.8)
Hypoxemia	0 (0.0)	0 (0.0)	1 (4.8)	1 (4.8)
Partial bowel obstruction	1 (4.8)	1 (8.3)	0 (0.0)	0 (0.0)
Poor growth	1 (4.8)	1 (8.3)	0 (0.0)	0 (0.0)
First detection of *P. oryzihabitans*	1 (4.8)	1 (8.3)	0 (0.0)	0 (0.0)
Pyelonephritis	1 (4.8)	1 (8.3)	0 (0.0)	0 (0.0)

Values are n (%).

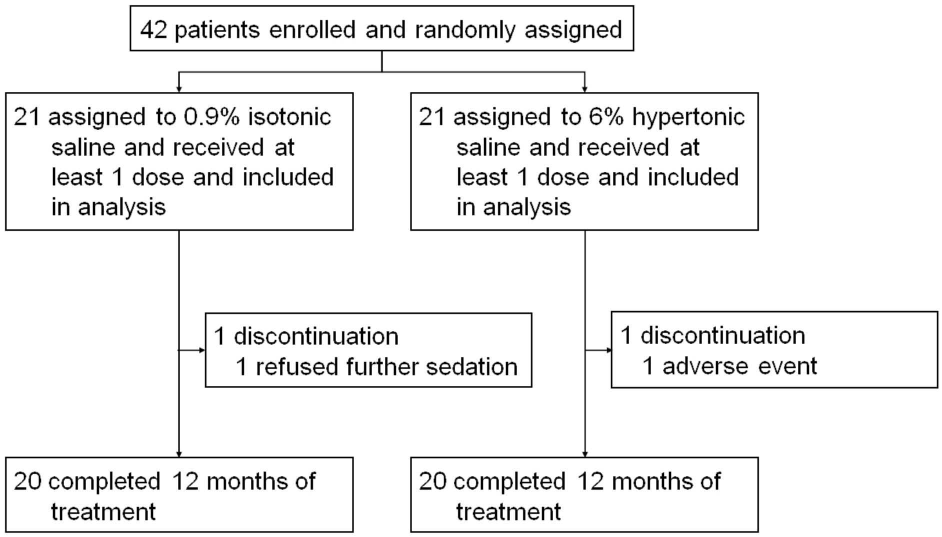

Figure 1

450x280mm (72 x 72 DPI)

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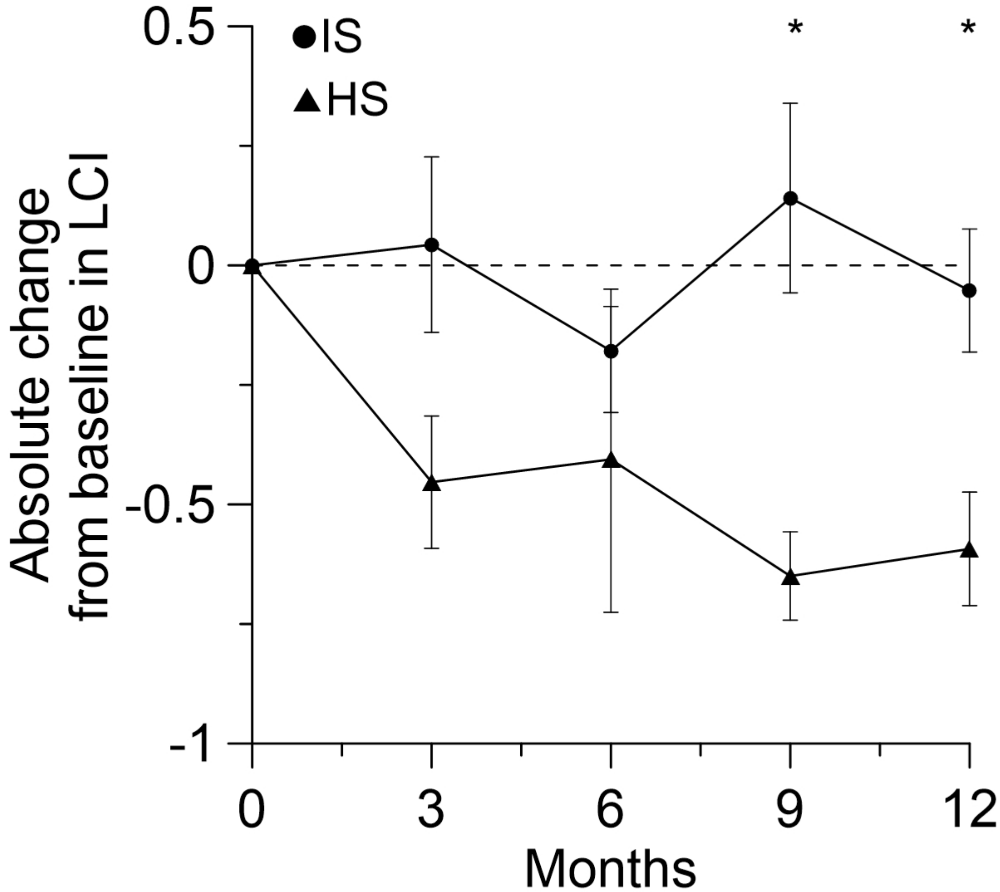

Figure 2

212x191mm (144 x 144 DPI)

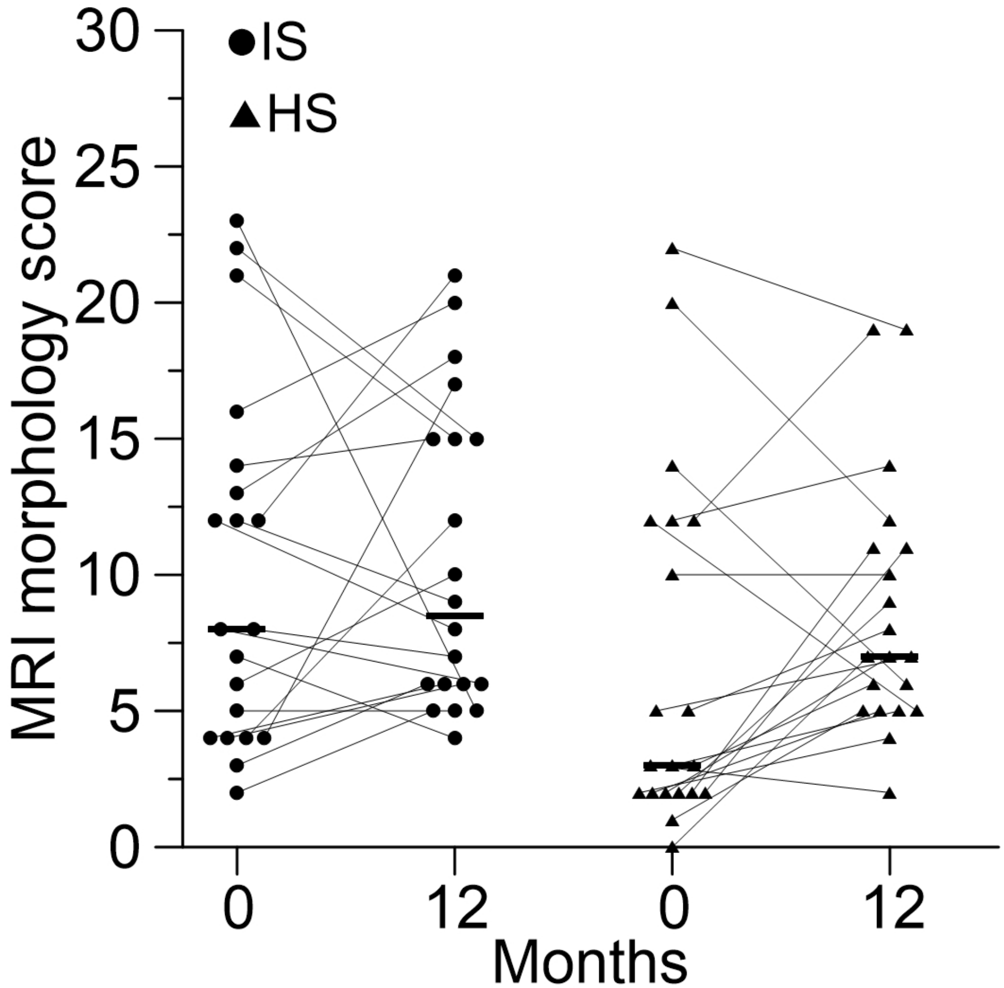

Figure 3

186x186mm (144 x 144 DPI)

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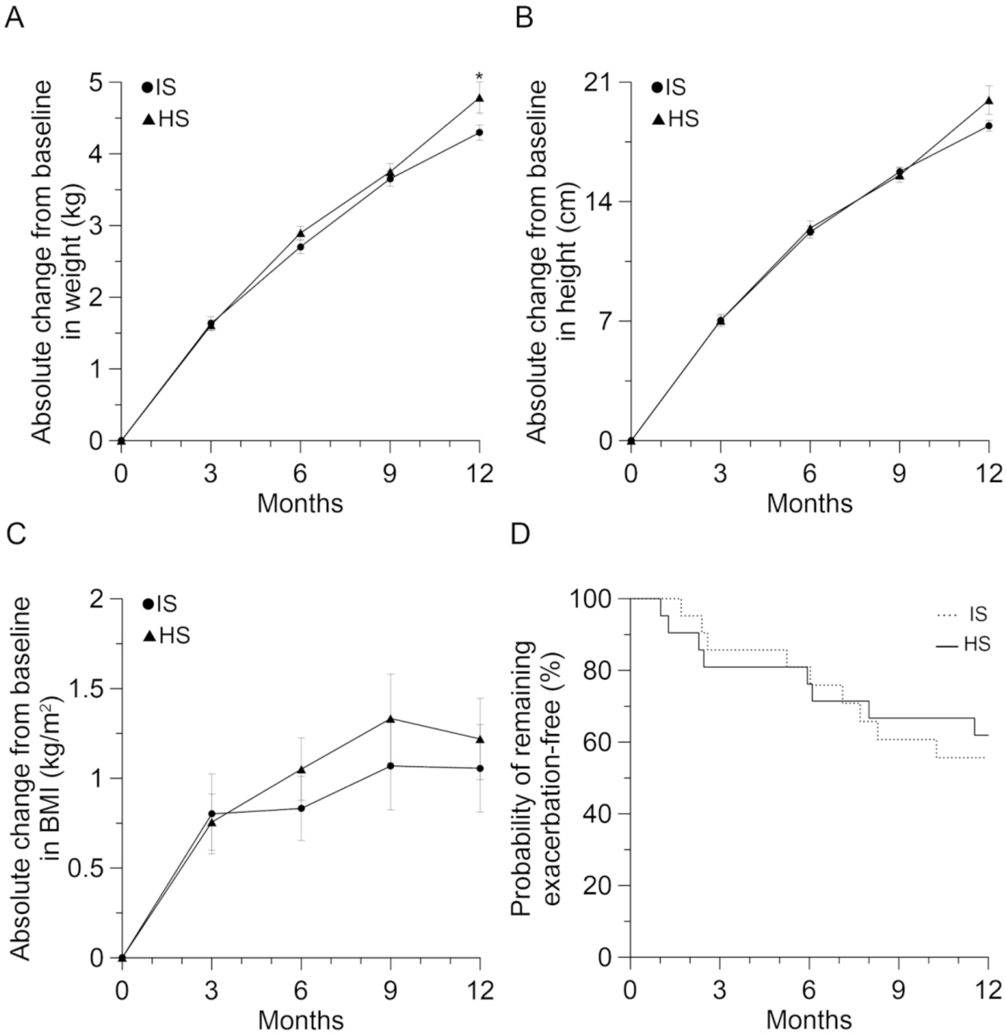

Figure 4

566x585mm (72 x 72 DPI)

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Preventative Inhalation of Hypertonic Saline in Infants with Cystic Fibrosis (PRESIS): A Randomized, Double-Blind, Controlled Study

Mirjam Stahl, Mark O. Wielpütz, Isabell Ricklefs, Christian Dopfer, Sandra Barth, Anne Schlegtendal, Simon Y. Graeber, Olaf Sommerburg, Gesa Diekmann, Johannes Hüsing, Cordula Koerner-Rettberg, Lutz Nährlich, Anna-Maria Dittrich, Matthias V. Kopp, and Marcus A. Mall

Online Data Supplement

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SUPPLEMENTAL METHODS

Study Design

Inclusion and Exclusion Criteria. Infants with a confirmed diagnosis of cystic fibrosis (CF) were eligible for inclusion during the first four months of life. All infants were screened and included in the study with informed consent during the first four months of life and the baseline visit was performed as timely as possible thereafter, generally on the same day. Due to organizational reasons (availability of MRI capacity and admission to day-clinic) baseline visits had to be postponed in two infants (one from each treatment arm) until they were four months old resulting in an age range at the baseline visit of 0.09 – 0.35 years in the IS group and 0.10 – 0.41 years in the HS group (Table 1). Patients and parents had to be able to comply with inhalations, study visits and study procedures as judged by the investigator. Patients were excluded if they fulfilled at least one of the pre-defined exclusion criteria: born <30 weeks of gestation; prolonged mechanical ventilation in the first three months of life; a significant medical disease or condition other than CF likely to interfere with the child's ability to complete the entire protocol; previous major surgery except for meconium ileus or atresia of the small intestine; other major organ dysfunction excluding pancreatic or hepatic dysfunction or other organ dysfunctions related to cystic fibrosis; physical findings that would compromise the safety of the subject or the quality of the study data as determined by the investigator; history of adverse reaction to sedation, known intolerance to study treatment; participation in another interventional study at the same time.

Randomization, Blinding and Treatment Regimen. First patient in was on August 14, 2012, last patient in on November 13, 2015 and last patient out on November 17, 2016. Participants were randomized 1:1 to receive hypertonic saline (HS, 6% NaCl; Pari Pharma GmbH, Starnberg, Germany) vs. isotonic saline (IS, 0.9% NaCl; Inqua GmbH, Seefeld, Germany), based on a randomization list prepared by a biostatistician of the Coordination Center for Clinical Studies (KKS) Heidelberg not involved in the study. The randomization list contained subsequent randomization numbers automatically generated by a dedicated randomization web service (http://randomizer.at) for the multicenter setting. The random assignment was not stratified for site or prognostic factors. HS and IS inhalation solutions were supplied by Pari GmbH, Starnberg, Germany, as identically packaged 4 ml plastic ampullae. Blinding was done by the hospital pharmacy of Heidelberg University Hospital. Each participant was supplied with a Pari LC Sprint nebulizer (red insert), baby bend, size-adapted Pari Baby face mask size 0-1, connection tubing (2.2 m) and a Pari Boy SX compressor (total output rate: 600 mg/min, mass median diameter: 3.5µm, mass percentage < 5µm: 67% according to manufacturer's information; all devices from Pari GmbH, Starnberg, Germany) for inhalation over 52 weeks. Inhalation with 4 ml of the study solution was performed twice daily until the nebulizer was empty or for a maximum of 15 minutes. To minimize the risk of bronchial hyperreactivity associated with HS inhalation, parents (or guardians) were instructed to pre-treat their infant with salbutamol (100 µg/puff) or ipratropium bromide (20 µg/puff), 1 puff via a metered dose inhaler using a valved holding chamber (Vortex, Pari GmbH, Starnberg, Germany) with face mask prior to each inhalation of saline solution. Parents were provided with step-by-step verbally and written instructions for set up, maintenance and cleaning of the nebulizer, compressor, accessories and holding chamber, and administration of bronchodilators and saline solutions. All standard therapies for the treatment of CF and for intercurrent illnesses were allowed during the course of the study.

Clinical Evaluation at Study Visits. All infants with CF fulfilling inclusion and exclusion criteria in a prescreening visit were invited for the baseline visit (Figure 1 in the main manuscript). Infants with CF included in the study returned for evaluation at 3, 6, 9 and 12 months after enrolment. At the baseline visit, after randomization and pretreatment with a bronchodilator, tolerance to inhalation of study solution was evaluated by a physician in all participants. Study visits were based on routine quarterly CF clinic visits to reduce the burden for participating families. All visits following randomization occurred within 14 days of the nominal date. At the baseline visit, the medical history and demographics were recorded. At all visits, a physical

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examination was performed and information was recorded on interim history (including respiratory culture results), medications (including courses of antibiotics), symptoms from the lung, nose, sinuses and gastrointestinal tract, adverse events (AE), interim hospitalizations and serious adverse events (SAE) using a questionnaire. The physical exam included anthropometry using commercially available infant scales and rods to determine weight and length from which body-mass-index was calculated. After enrolment, monthly telephone interviews were conducted to assess respiratory symptoms, medication, tolerability of study inhalation and AE. Further, parents or guardians completed a medication diary quarterly to document frequency of treatment, problems that occurred during inhalation of study solution and new, concomitant therapies.

Multiple-Breath Washout

The multiple-breath washout (MBW) protocol was harmonized at all sites prior to the start of PRESIS (E1). The Exhalyzer D system (Eco Medics AG, Duernten, Switzerland) was used for MBW testing with 4% sulphur hexafluoride (SF_6) as tracer gas (dead space reducer set 1; spiroware 2), as previously described (E1-E4). SF_6-MBW was performed in sedation with chloral hydrate (100 mg/kg body weight, maximum dose 2 g) using a face mask as interface with the child lying in a supine position at baseline and at 3, 6, 9 and 12 months (E3, E5). The MBW equipment was leak tested and calibrated prior to each measurement. All wash-in/wash-out curves were saved but only recordings that met quality criteria were used to derive the lung clearance index (LCI) (E2). Acceptability criteria were: no evidence of leak, sighs, hiccoughing, swallowing or arousal and a difference in functional residual capacity of less than 10% in relation to the lower value of the other curves if the LCI was determined from ≥ 3 curves and a difference of less than 5% if only 2 curves were meeting the other acceptability criteria. Mean LCI was determined by dedicated data acquisition and analysis software (WBreath, version 2.0.0.0, ndd Medical Technologies, Zurich, Switzerland) with a recently-validated improved algorithm (E2, E6, E7).

Chest Magnetic Resonance Imaging

The magnetic resonance imaging (MRI) protocol used was established and harmonized at all sites prior to the start of the study (E8). Chest MRI was generally performed in the same sedation required for MBW at baseline and after 12 months. Infants were examined using a non-breath-hold protocol on a clinical 1.5T MR scanner (Magnetom Avanto, Siemens Medical AG, Erlangen, Germany; Achieva, Philips Healthcare, Best, Netherlands) comprising a balanced steady-state free-precession sequence in 3 planes (TrueFISP, Siemens Medical AG, Erlangen, Germany), T1-weighted turbo-spin echo (TSE, Siemens Medical AG, Erlangen, Germany) sequences in two planes, and a navigated T2-weighted sequence with single-shot half-Fourier turbo-spin echo acquisition (HASTE, Siemens Medical AG, Erlangen, Germany) in two planes as previously described (E4, E9-E11). Administration of i.v. contrast material was not approved in Germany in children under 12 months of age during the conduct of this study. Therefore, perfusion studies were not included in the MRI protocol. Images were assessed by an independent reader (MOW) blinded for clinical and demographic data as well as treatment group using a dedicated MRI score (E9, E11). The MRI morphology score comprises subscores for (i) bronchial wall abnormalities (wall thickening and/or bronchiectasis), (ii) mucus plugging, (iii) sacculations and abscesses, (iv) consolidations, (v) pleural reaction including effusion, and (vi) mosaic signal intensity. The extent of these structural abnormalities is rated in each lobe as 0 (no abnormality), 1 (<50% of the lobe involved), or 2 (≥50% of the lobe involved), leading to maximum subscores of 12, resulting in a maximum morphology score of 72.

Microbiology

Microbiological diagnostics were performed quarterly by culture of throat and nose swabs to assess for CF pathogens such as *Haemophilus influenzae, Staphylococcus aureus, Pseudomonas aeruginosa, Streptococcus pneumoniae and Aspergillus species* (Table E2).

Pulmonary Exacerbations

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Pulmonary exacerbations were defined using modified Fuchs criteria (E12) extending the necessity of an antibiotic therapy to all application forms (oral, intravenous, inhaled) as previously described in this age group (E13). Specifically, a pulmonary exacerbation in an infant with CF was diagnosed, if the patient was treated with antibiotics because of at least 4 out of the following 12 criteria/symptoms: (i) change in sputum (amount, color); (ii) hemoptysis (new/more); (iii) increased cough; (iv) new/increased dyspnea; (v) malaise, fatigue or lethargy; (vi) body temperature > 38°C; (vii) anorexia or weight loss; (viii) sinus pain or tenderness; (ix) change in sinus discharge; (x) change in physical examination of the chest; (xi) decrease in pulmonary function by 10% or more from a previously recorded value; (xii) radiographic changes indicative of pulmonary infection.

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SUPPLEMENTAL TABLES

Table E1. Summary of *CFTR* genotypes of study population according to treatment group and pancreatic status

Isotonic saline, n=21				**Hypertonic saline, n=21**			
Pancreatic insufficient		**Pancreatic sufficient**		**Pancreatic insufficient**		**Pancreatic sufficient**	
***CFTR* Genotype**	**n**	***CFTR* Genotype**	**n**	***CFTR* Genotype**	**n**	***CFTR* Genotype**	**n**
F508del/F508del	11	F508del/R347P	1	F508del/F508del	11	3905insT/R334W	1
F508del/1717-1G>A	1			F508del/N1303K	2	F508del/4251delA	1
F508del/621+1G>T	1			F508del/1811+1.6kbA->G	1	I507del/3849+10kbC>T	1
F508del/CFTRdele17a-17b	1			F508del/CFTRdele2,3	1	621+1G>T/3850-2477C>T	1
F508del/I507del	1			F508del/G542X	1		
F508del/L1335P	1			N1303K/N1303K	1		
F508del/N1303K	1						
F508del/Q1035X	1						
CFTRdele2,3/1078delT	1						
E92X/R347P	1						

Abbreviations: *CFTR* = cystic fibrosis transmembrane conductance regulator.

AJRCCM Articles in Press. Published on 09-November-2018 as 10.1164/rccm.201807-1203OC

Table E2. Detection of pro-inflammatory pathogens in infants with CF treated with preventive inhalation of hypertonic saline versus isotonic saline

	Isotonic saline						Hypertonic saline					
	Pre-study (n=21)	Baseline (n=21)	Months 3 (n=21)	Months 6 (n=20)	Months 9 (n=20)	Months 12 (n=20)	Pre-study (n=21)	Baseline (n=21)	Months 3 (n=21)	Months 6 (n=20)	Months 9 (n=20)	Months 12 (n=20)
Positive respiratory culture, n (%)												
Staphylococcus aureus	6 (28.6)	10 (47.6)	7 (33.3)	4 (20.0)	6 (30.0)	6 (30.0)	4 (19.0)	11 (52.4)	8 (38.1)	3 (15.0)	4 (20.0)	1 (5.0)
Haemophilus influenzae	0 (0.0)	1 (4.8)	1 (4.8)	1 (5.0)	2 (10.0)	3 (15.0)	0 (0.0)	0 (0.0)	2 (9.5)	2 (10.0)	1 (5.0)	1 (5.0)
Pseudomonas aeruginosa	0 (0.0)	0 (0.0)	1 (4.8)	0 (0.0)	1 (5.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (4.8)	1 (5.0)	0 (0.0)	1 (5.0)
Streptococcus pneumoniae	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Aspergillus species	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (4.8)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Positive respiratory culture in previously negative infants, n (%) of previously negative infants												
Staphylococcus aureus		7 (46.7)	2 (25.0)	0 (0.0)	0 (0.0)	0 (0.0)		7 (41.2)	1 (10.0)	0 (0.0)	1 (11.1)	0 (0.0)
Haemophilus influenzae		1 (4.8)	1 (5.0)	1 (5.3)	1 (5.9)	1 (6.3)		0 (0.0)	2 (9.5)	2 (10.5)	1 (6.3)	1 (6.7)
Pseudomonas aeruginosa		0 (0.0)	1 (4.8)	0 (0.0)	1 (5.3)	0 (0.0)		0 (0.0)	1 (4.8)	1 (5.0)	0 (0.0)	1 (5.3)
Time to first detection in previously negative infants, mean ± SD (range), years												
Staphylococcus aureus	0.1 ± 0.1 (0.0 – 0.3)						0.1 ± 0.3 (0.0 – 0.8)					
Haemophilus influenzae	0.5 ± 0.4 (0.0 – 1.0)						0.5 ± 0.3 (0.2 – 1.0)					
Pseudomonas aeruginosa	0.5 ± 0.4 (0.3 – 0.8)						0.6 ± 0.4 (0.2 – 1.0)					