

## ORIGINAL ARTICLE

# Results of a phase IIa study of VX-809, an investigational CFTR corrector compound, in subjects with cystic fibrosis homozygous for the *F508del-CFTR* mutation

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► Additional methods, figures and a table are published online only. To view these files please visit the journal online (<http://thorax.bmj.com/content/67/1.toc>).

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## ABSTRACT

**Background** VX-809, a cystic fibrosis transmembrane conductance regulator (CFTR) modulator, has been shown to increase the cell surface density of functional *F508del-CFTR* in vitro.

**Methods** A randomised, double-blind, placebo-controlled study evaluated the safety, tolerability and pharmacodynamics of VX-809 in adult patients with cystic fibrosis (n=89) who were homozygous for the *F508del-CFTR* mutation. Subjects were randomised to one of four VX-809 28 day dose groups (25, 50, 100 and 200 mg) or matching placebo.

**Results** The type and incidence of adverse events were similar among VX-809- and placebo-treated subjects. Respiratory events were the most commonly reported and led to discontinuation by one subject in each active treatment arm. Pharmacokinetic data supported a once-daily oral dosing regimen. Pharmacodynamic data suggested that VX-809 improved CFTR function in at least one organ (sweat gland). VX-809 reduced elevated sweat chloride values in a dose-dependent manner (p=0.0013) that was statistically significant in the 100 and 200 mg dose groups. There was no statistically significant improvement in CFTR function in the nasal epithelium as measured by nasal potential difference, nor were there statistically significant changes in lung function or patient-reported outcomes. No maturation of immature *F508del-CFTR* was detected in the subgroup that provided rectal biopsy specimens.

**Conclusions** In this study, VX-809 had a similar adverse event profile to placebo for 28 days in *F508del-CFTR* homozygous patients, and demonstrated biological activity with positive impact on CFTR function in the sweat gland. Additional data are needed to determine how improvements detected in CFTR function secondary to VX-809 in the sweat gland relate to those measurable in the respiratory tract and to long-term measures of clinical benefit.

**Clinical trial number** NCT00865904

## Key messages

*F508del-CFTR* is the most common cystic fibrosis-causing mutation. Restoring function to *F508del-CFTR* offers a novel treatment strategy for the majority of patients with cystic fibrosis. VX-809 had an adverse event profile similar to placebo in *F508del-CFTR* homozygous CF patients, and reduced sweat chloride values in a dose dependent manner. The findings indicate that *F508del-CFTR* is a viable target for drug development.

## INTRODUCTION

Cystic fibrosis (CF) is the most common autosomal recessive lethal genetic disease in the Caucasian population, with an incidence of 1:3500 births in the USA. The most common cause of morbidity and mortality is lung disease, which is characterised by infection, inflammation and airway damage that leads to respiratory failure.<sup>1</sup>

CF is caused by mutations in the CF transmembrane conductance regulator (*CFTR*) gene,<sup>2 3</sup> which encodes the CFTR protein. CFTR is a member of the ATP-binding cassette protein family and functions as a chloride ion (Cl<sup>-</sup>) channel and a key regulator of salt and water transport across a variety of epithelia.<sup>4-8</sup> The *CFTR* gene has >1600<sup>9</sup> reported disease-associated mutations, with *F508del-CFTR* being the most common. *F508del-CFTR* results from a 3 bp deletion that leads to the omission of phenylalanine at position 508 of the full-length protein.<sup>10</sup> The resulting *F508del* protein product is unstable and susceptible to rapid degradation in the 26S proteasome, with little if any *F508del-CFTR* at the plasma membrane.<sup>11 12</sup> The *F508del-CFTR* mutation is found in the majority of patients with CF,<sup>13</sup> and therefore the consequences

of this mutation on the CFTR protein are important to address in therapeutic development for CF.

CFTR 'correctors' aim to increase the cell surface density of functional CFTR protein, resulting in improved chloride transport and decreased sodium reabsorption.<sup>14–16</sup> VX-809 restores *F508del*-CFTR processing and plasma membrane localisation in primary human bronchial epithelial (HBE) airway cells isolated from patients homozygous for the *F508del*-CFTR mutation, achieving ~15% of wild-type CFTR levels as measured by the amount of chloride channel function and the quantity of fully mature, C-Band CFTR.<sup>17</sup>

In this report, we describe the safety, tolerability, pharmacodynamics and pharmacokinetics (PK) of escalating doses of VX-809 in patients with CF homozygous for the *F508del*-CFTR mutation compared with placebo.

## METHODS

This study was a randomised, double-blind, placebo-controlled, multiple-dose, multicentre, phase IIa study. Institutional Review Board approvals and informed consents were obtained for all study subjects.

## Subjects

Subjects enrolled in the study had a confirmed diagnosis of CF, accompanied by a sweat chloride value of  $\geq 60$  mmol/l. All subjects were  $\geq 18$  years of age, and were required to have the *F508del*-CFTR mutation on both alleles. At screening, subjects were required to have a forced expiratory volume in 1 s (FEV<sub>1</sub>) of at least 40% of predicted normal for age, gender and height (Knudson standards).<sup>18</sup>

## Study design

Subjects were enrolled into two cohorts, group A and group B. Group A subjects were randomised to receive VX-809 once daily at doses of 25 mg or 50 mg, or placebo in a 2:2:1 randomisation ratio. After 15 group A subjects completed 28 days of treatment, a safety review was conducted by an independent Data Monitoring Committee. Enrolment in group B began following the Data Monitoring Committee review. In group B, subjects were randomised to receive VX-809 at doses of 100 mg or 200 mg, or placebo in a 2:2:1 ratio for 28 days. All study sites, the patients, and the sponsor remained blinded to treatment assignment throughout the study.

## End points

The primary objective, evaluation of safety and tolerability of VX-809, was assessed by adverse events (AEs), haematology, clinical chemistry, urinalysis, ECG, vital signs and physical

examinations. Secondary objectives included evaluation of the pharmacodynamic impact of VX-809 on CFTR function. Measures of CFTR activity included sweat chloride and nasal potential difference (NPD).<sup>19</sup> The latter was considered optional. Other secondary end points included spirometry to measure pulmonary function (ie, FEV<sub>1</sub>, forced expiratory flow 25–75% (FEF<sub>25–75%</sub>) and forced vital capacity (FVC)) and the CF Questionnaire-Revised (CFQ-R), a disease-specific patient-reported outcome.<sup>20</sup> The minimal clinically important difference in respiratory domain (MCID) is improvement  $\geq 4$ .<sup>21</sup> The details of CFTR biomarkers and pharmacokinetic analysis are included in the Supplemental Methods section.

## Statistical analyses

Safety data were analysed primarily using descriptive statistics, and efficacy data were analysed primarily using analysis of covariance (ANCOVA) models. The planned total sample size of 90 subjects provided a study power of  $>97\%$  to detect a 20 mmol/l reduction in sweat chloride concentration from baseline, and a probability of 99% to observe at least 1 adverse event in the study. All subjects who received at least one dose of study drug were included in the analyses.

## RESULTS

### Subjects

A total of 109 adult subjects with CF who were homozygous for the *F508del*-CFTR mutation (based on screening medical history) were screened and 89 were randomised to one of four VX-809 dose groups (25 mg (n=18), 50 mg (n=18), 100 mg (n=17), 200 mg (n=19)) or to placebo (n=17). Confirmatory genotyping identified one subject randomised to the 50 mg VX-809 group who was heterozygous for *F508del*-CFTR despite a medical history indicating homozygosity. Safety and efficacy data obtained from this subject were included in the final analysis. The identity of this subject's non-*F508del* allele was not available (based on parameters of the informed consent document for that study site). Baseline characteristics are provided in table 1. Median sweat chloride values and FEV<sub>1</sub> percentage predicted were similar between the different groups and consistent with the values reported in the literature for patients homozygous for the *F508del*-CFTR mutation. The baseline median sweat chloride was 103.5 mmol/l and the median baseline FEV<sub>1</sub> was 71% predicted. The study groups were well matched except for trends towards less severe lung disease in the placebo and 25 mg dose groups.

### Safety and AE profile

The incidence of AEs was similar between dose groups (table 2). Respiratory events were the most commonly reported type of

**Table 1** Baseline demographic and clinical characteristics of the study subjects

| Characteristic                                 | Placebo n=17         | VX-809            |                       |                    |                    | Total n=89           |
|--|----------------------|-------------------|-----------------------|--------------------|--------------------|----------------------|
|  |                      | 25 mg n=18        | 50 mg n=18            | 100 mg n=17        | 200 mg n=19        |                      |
| Male, n (%)                                    | 11 (65)              | 9 (50)            | 9 (50)                | 12 (71)            | 12 (63)            | 53 (60)              |
| Caucasian, n (%)                               | 17 (100)             | 18 (100)          | 18 (100)              | 17 (100)           | 19 (100)           | 89 (100)             |
| Age, years, median (range)                     | 28 (19–49)           | 25.5 (18–50)      | 24.5 (19–49)          | 26 (18–54)         | 25 (18–42)         | 26 (18–54)           |
| BMI, kg/m <sup>2</sup> , median (range)        | 23 (19–31)           | 22 (16–34)        | 22 (19–31)            | 23 (16–31)         | 21 (19–27)         | 22 (16–34)           |
| FEV <sub>1</sub> , % predicted, median (range) | 78.4 (48.8–124.9)    | 78.4 (34.2–104.5) | 61.5 (35.2–120.7)     | 61.5 (40.0–128.3)  | 68.2 (37.9–99.1)   | 71 (34.2–128.3)      |
| Sweat chloride, mmol/l, median (range)         | 106.5 (80.0–125.5)   | 100 (86.0–109.0)  | 102.3 (76.0–120.0)    | 106 (66.0–129.0)   | 98.3 (72.0–122.5)  | 103.5 (66.0–129.0)   |
| NPD—chloride-free iso, mV, median (range)      | 1.55 (–10.6* to 8.6) | 1.6 (–3.7 to 9.5) | 2.48 (–19.6* to 11.1) | 0.98 (–7.4 to 6.1) | 1.33 (–7.4 to 6.3) | 1.48 (–19.6 to 11.1) |

\*High confidence analysis removed two outliers but did not change efficacy analysis.

BMI, body mass index; FEV<sub>1</sub>, forced expiratory volume in 1 s; NPD, nasal potential difference.

**Table 2** Frequency of occurrence of adverse events occurring in more than one subject in any VX-809 treatment group (listed alphabetically by MedRA term)

| Adverse event, n (%)              | Placebo (n=17) | VX-809 25 mg (n=18) | VX-809 50 mg (n=18) | VX-809 100 mg (n=17) | VX-809 200 mg (n=19) | Total (n=45) |
|-----------------------------------|----------------|---------------------|---------------------|----------------------|----------------------|--------------|
| Cough                             | 7 (41.2)       | 10 (55.6)           | 6 (33.3)            | 7 (41.2)             | 10 (52.6)            | 40 (88.9)    |
| Headache                          | 3 (17.6)       | 4 (22.2)            | 5 (27.8)            | 2 (11.8)             | 5 (26.3)             | 19 (42.2)    |
| Rales                             | 1 (5.9)        | 6 (33.3)            | 2 (11.1)            | 3 (17.6)             | 3 (15.8)             | 15 (33.3)    |
| Productive cough                  | 3 (17.6)       | 2 (11.1)            | 0                   | 4 (23.5)             | 6 (31.6)             | 15 (17.8)    |
| Dyspnoea                          | 1 (5.9)        | 5 (27.8)            | 3 (16.7)            | 2 (11.8)             | 4 (21.1)             | 15 (33.3)    |
| Pulmonary exacerbation*           | 2 (11.8)       | 4 (22.2)            | 2 (11.1)            | 2 (11.8)             | 4 (21.1)             | 14 (31.1)    |
| Fatigue                           | 2 (11.8)       | 3 (16.7)            | 3 (16.7)            | 2 (11.8)             | 3 (15.8)             | 13 (28.9)    |
| Fever                             | 2 (11.8)       | 2 (11.1)            | 1 (5.6)             | 1 (5.9)              | 5 (26.3)             | 11 (24.4)    |
| Nasal congestion                  | 3 (17.6)       | 2 (11.1)            | 1 (5.6)             | 2 (11.8)             | 2 (10.5)             | 10 (22.2)    |
| Wheezing                          | 3 (17.6)       | 1 (5.6)             | 4 (22.2)            | 1 (5.9)              | 0                    | 9 (20)       |
| Diarrhoea                         | 3 (17.6)       | 3 (16.7)            | 1 (5.6)             | 2 (11.8)             | 0                    | 9 (20)       |
| Oropharyngeal pain                | 3 (17.6)       | 0                   | 3 (16.7)            | 0                    | 2 (10.5)             | 8 (17.8)     |
| Upper respiratory tract infection | 1 (5.9)        | 2 (11.1)            | 1 (5.6)             | 3 (17.6)             | 0                    | 7 (15.6)     |
| Sinus congestion                  | 2 (11.8)       | 1 (5.6)             | 2 (11.1)            | 0                    | 1 (5.3)              | 6 (13.3)     |
| Respiration abnormal              | 0              | 1 (5.6)             | 1 (5.6)             | 0                    | 4 (21.1)             | 6 (13.3)     |
| Haemoptysis                       | 2 (11.8)       | 1 (5.6)             | 1 (5.6)             | 0                    | 2 (10.5)             | 6 (13.3)     |
| Constipation                      | 0              | 2 (11.1)            | 2 (11.1)            | 1 (5.9)              | 1 (5.3)              | 6 (13.3)     |
| Abdominal pain                    | 1 (5.9)        | 3 (16.7)            | 1 (5.6)             | 0                    | 1 (5.3)              | 6 (13.3)     |
| Myalgia                           | 1 (5.9)        | 0                   | 3 (16.7)            | 0                    | 1 (5.3)              | 5 (11.1)     |
| Post-tussive vomiting             | 0              | 0                   | 2 (11.1)            | 1 (5.9)              | 1 (5.3)              | 4 (8.9)      |
| Nausea                            | 0              | 3 (16.7)            | 0                   | 0                    | 1 (5.3)              | 4 (8.9)      |
| Nasopharyngitis                   | 0              | 1 (5.6)             | 0                   | 1 (5.9)              | 2 (10.5)             | 4 (8.9)      |
| Dizziness                         | 0              | 1 (5.6)             | 0                   | 2 (11.8)             | 1 (5.3)              | 4 (8.9)      |
| Back pain                         | 0              | 2 (11.1)            | 1 (5.6)             | 0                    | 1 (5.3)              | 4 (8.9)      |
| Abdominal pain upper              | 1 (5.9)        | 0                   | 0                   | 1 (5.9)              | 2 (10.5)             | 4 (8.9)      |
| Sputum abnormal                   | 0              | 2 (11.1)            | 0                   | 0                    | 1 (5.3)              | 3 (6.7)      |
| Epistaxis                         | 1 (5.9)        | 0                   | 0                   | 0                    | 2 (10.5)             | 3 (6.7)      |
| C-reactive protein increased      | 0              | 1 (5.6)             | 0                   | 2 (11.8)             | 0                    | 3 (6.7)      |
| Paranasal sinus hypersecretion    | 0              | 2 (11.1)            | 0                   | 0                    | 0                    | 2 (4.4)      |
| Lung hyperinflation               | 0              | 0                   | 0                   | 2 (11.8)             | 0                    | 2 (4.4)      |

\*Physician-reported pulmonary exacerbation; coded as cystic fibrosis lung according to MedRA term.

AE, with cough occurring in 46% of VX-809-treated subjects and 41% of placebo-treated subjects. There was no difference in the incidence of physician-diagnosed pulmonary exacerbations between VX-809- and placebo-treated subjects (17% of VX-809 subjects compared with 12% of placebo subjects;  $p=0.62$ ). AEs that occurred in more than one subject in any VX-809 treatment arm are included in table 2. Eight AEs were considered

severe, including fatigue, sinus congestion, musculoskeletal discomfort, two events of cough and three events of acute pulmonary exacerbation. All pulmonary exacerbations were considered serious.

Four of 89 (5%) subjects discontinued study drug during the study, one subject in each of the VX-809 dose groups. No placebo-treated subjects withdrew from treatment.

**Table 3** VX-809 Pharmacokinetic parameters following once-daily dosing of VX-809 for 28 days

| Dose   | Parameter | Day 1                          |               |  | Day 28                         |                 |  | Day 28/day 1      |                  |                        | AUC AR |
|--------|-----------|--------------------------------|---------------|--|--------------------------------|-----------------|--|-------------------|------------------|------------------------|--------|
|        |           | $C_{max}$ ( $\mu\text{g/ml}$ ) | $t_{max}$ (h) | $AUC_{0-24\text{ h}}$ ( $\mu\text{g}\times\text{h/ml}$ ) | $C_{max}$ ( $\mu\text{g/ml}$ ) | $t_{max}^*$ (h) | $AUC_{0-24\text{ h}}$ ( $\mu\text{g}\times\text{h/ml}$ ) | $CL_{ss}/F$ (l/h) | $V_z/F$ (litres) | $t_{1/2\lambda_z}$ (h) |        |
| 25 mg  | n         | 18                             | 18            | 18   | 17                             | 17              | 17   | 17                | 17               | 17                     | 17     |
|        | Mean      | 0.760                          | 3.5*          | 7.20   | 1.10                           | 4.0*            | 12.9   | 2.20              | 62.6             | 18.3                   | 1.85   |
|        | SD        | 0.280                          | 1.5–9.0†      | 2.19   | 0.44                           | 2.9–12.0†       | 4.9  | 0.80              | 99.0             | 20.5                   | 0.70   |
| 50 mg  | n         | 18                             | 18            | 18   | 17                             | 17              | 17   | 17                | 17               | 17                     | 17     |
|        | Mean      | 1.85                           | 3.1*          | 16.6   | 2.66                           | 3.1*            | 28.8   | 2.31              | 54.6             | 17.3                   | 1.67   |
|        | SD        | 0.70                           | 1.5–12.1†     | 6.3  | 1.01                           | 0.8–9.0†        | 13.1   | 1.48              | 35.2             | 8.9                    | 0.49   |
| 100 mg | n         | 17                             | 17            | 17   | 16                             | 16              | 16   | 16                | 16               | 16                     | 16     |
|        | Mean      | 2.93                           | 3.0*          | 29.0   | 4.62                           | 3.1*            | 54.0   | 2.40              | 48.4             | 15.2                   | 1.81   |
|        | SD        | 0.92                           | 1.6–6.2†      | 11.5   | 1.84                           | 1.5–6.0†        | 31.5   | 1.30              | 25.4             | 7.2                    | 0.60   |
| 200 mg | n         | 19                             | 19            | 19   | 18                             | 18              | 18   | 18                | 18               | 18                     | 18     |
|        | Mean      | 6.41                           | 4.0*          | 59.6   | 10.3                           | 3.0*            | 118  | 2.09              | 46.0             | 15.6                   | 2.01   |
|        | SD        | 2.55                           | 1.5–6.0†      | 26.3   | 4.5                            | 1.5–6.1†        | 73   | 0.86              | 22.6             | 5.3                    | 0.64   |

\*Median.

†Min–Max range.

AR, accumulation ratio;  $AUC_{0-24\text{ h}}$ , area under the plasma concentration versus time curve from time 0 to 24 h;  $C_{max}$ , maximum observed drug concentration;  $CL_{ss}/F$ , oral clearance at steady state;  $t_{1/2\lambda_z}$ , apparent terminal half-life;  $t_{max}$ , time to reach  $C_{max}$  after dosing;  $V_z/F$ , apparent volume of distribution.

All discontinuations were due to the occurrence of respiratory AEs. There were no clinically significant changes in laboratory findings during the study.

### PK results

Plasma concentrations of VX-809 were measured by a fully validated bioanalytical method. PK parameters estimated at the four dose levels of VX-809 on days 1 and 28 are summarised in table 3. VX-809 appeared to be slowly absorbed from the gut in subjects with CF with median time to reach maximum concentration ( $t_{max}$ ) values ranging from 3 to 4 h across all doses on days 1 and 28. Based on predose PK samples collected from day 1 to day 28, plasma steady-state concentrations appeared to be reached by day 7 at all dose levels with a mean accumulation ratio ranging from 1.7 to 2.0 on day 28 (based on area under the curve (AUC) over the 24 h dosing period,  $AUC_{0-24\text{ h}}$ ). The time to reach steady state and the extent of accumulation observed in this study were consistent with a terminal half-life approaching 24 h. The estimated mean values of this PK parameter in this study were slightly lower (range from 15 to 18 h) which may be explained by the low number of PK samples collected beyond 24 h on the last dosing day. The estimated oral VX-809 clearance (ie, volume of plasma purified per unit of time) at steady state was relatively low (<2% hepatic blood flow) and comparable for all doses. The estimated volume of distribution of VX-809 at steady state ( $V_z/F$ ) suggested a potential diffusion of the drug into tissues.

Maximum ( $C_{max}$ ) and total ( $AUC_{0-24\text{ h}}$ ) exposure to VX-809 increased proportionally with VX-809 dose increases from 25 to 200 mg over the 28 days of treatment. The intersubject variability observed for VX-809 in subjects with CF appeared to be moderate and comparable across all doses for  $C_{max}$  (30–40%) but with a trend to increase slightly with dose for  $AUC_{0-24\text{ h}}$  (from 40% to 60%) on day 28.

### CFTR bioactivity

The effects of VX-809 on *F508del-CFTR* processing and function were evaluated throughout the trial. The assessments included measurements of sweat chloride concentration (in all subjects) and NPD (in 71 subjects). The relative amounts of the immature (B-Band) and mature (C-Band) forms of *F508del-CFTR*, which are markers of protein maturation beyond the endoplasmic reticulum and Golgi, were measured in biopsies of the rectal epithelium in 34 subjects.

### Sweat chloride

Figure 1 shows changes in sweat chloride values, which were reduced in a dose-dependent manner ( $p=0.0013$ ) in VX-809-treated subjects. The reduction in sweat chloride values was rapid and sustained, with measurable changes seen within 7 days of VX-809 dosing (figure 1A). The mean change from baseline in sweat chloride concentration (mmol/l) after 7 days was 2.2 in the placebo group,  $-0.5$  in the 25 mg group,  $-3.7$  in the 50 mg group (95% CI  $-7.1$  to  $-0.28$ ,  $p=0.03$ ),  $-2.3$  in the 100 mg group and  $-6.6$  in the 200 mg group (95% CI  $-10.27$  to  $-2.83$ ,  $p=0.0008$ ). At day 28, the mean treatment differences from baseline ( $-$ placebo) for the 25, 50, 100 and 200 mg groups were  $+0.10$ ,  $-4.61$ ,  $-6.13$  (95% CI  $-12.25$  to  $-0.01$ ) and  $-8.21$  mmol/l (95% CI  $-14.33$  to  $-2.10$ ), respectively (figure 1B). These differences were statistically significant versus placebo for the 100 mg ( $p<0.05$ ) and 200 mg ( $p<0.01$ ) groups. Following 7 days of drug washout, mean sweat chloride values returned to approximately pretreatment levels (figure 1A).

The number of subjects whose sweat chloride values were reduced by the threshold ('responder') values was evaluated

using predefined and posthoc study criteria. Using a posthoc responder criterion of  $\geq 10$  mmol/l reduction, six subjects (38%) in the 200 mg group and six subjects (40%) in the 100 mg group responded compared with none of the placebo-treated patients ( $p=0.02$  for both VX-809 treatment groups). In the 25 and 50 mg dose groups, there were no subjects classified as responders by either criterion. Using the predefined responder criterion, only one subject (6.3%, in the 200 mg dose group) had a  $\geq 20$  mmol/l response to VX-809 ( $p=NS$ ).

### Nasal potential difference

Seventy-one subjects underwent NPD measurements throughout the study. There was no significant change in CFTR-dependent NPD parameters (chloride or sodium transport) in any of the dose groups. Supplementary figure 1 summarises the CFTR chloride ion transport parameters (change in chloride-free isoproterenol response) for the VX-809 treatment groups from baseline to day 28 after removing the change in the placebo group (treatment difference).

### CFTR B- to C-Band maturation

Thirty-four subjects provided rectal biopsy tissue for evaluation of *F508del-CFTR* maturation. Among the 33 subjects who were homozygous for the *F508del-CFTR* allele, no mature C-Band was detected (supplementary figure 2). Only one subject in the highest dose group (VX-809 200 mg) provided rectal biopsy tissue.

### Clinical outcomes

#### Spirometry

There were no significant changes in lung function ( $FEV_1$ , FVC,  $FEF_{25-75\%}$ ) in any of the dose groups, including changes in percentage predicted values versus baseline and placebo, or raw measures of litre flow (data not shown). Figure 2 shows the percentage change relative to baseline  $FEV_1$  (percentage predicted) for each study group across all study visits. After 28 days of treatment, the mean percentage change from baseline in  $FEV_1$  percentage predicted was 0.07,  $-2.46$ ,  $-2.15$ , 0.32 and 0.47 in the placebo, 25, 50, 100 and 200 mg dose groups, respectively ( $p=NS$ ).

#### Patient-reported outcomes

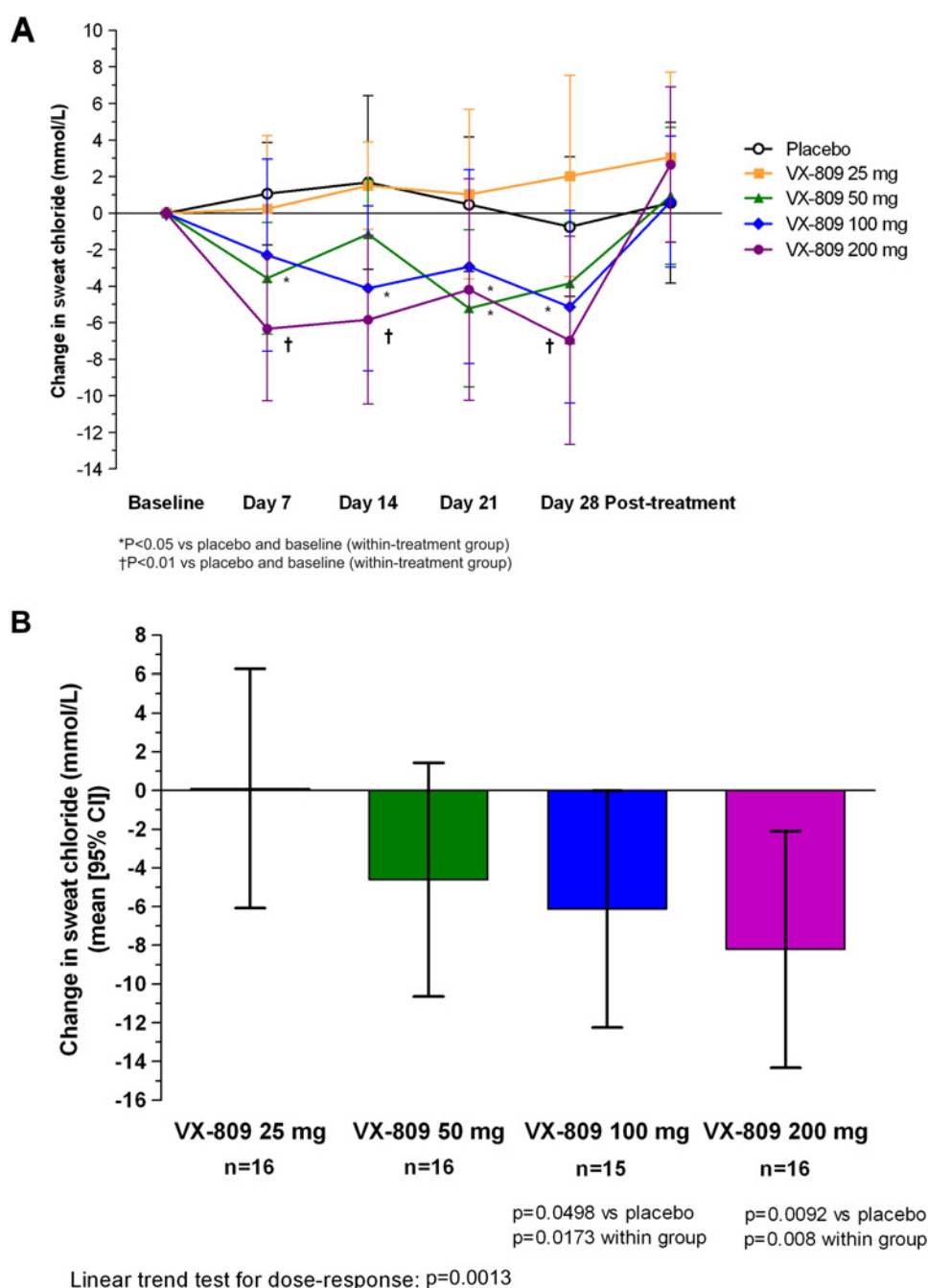
Supplementary table 1 summarises the change in CFQ-R measures (day 28 vs baseline) across the placebo- and VX-809-treated subjects. There were no clear or sustained changes in the respiratory domain or in any other subdomains of the CFQ-R in any dose group. After 28 days, the respiratory domain score in the placebo group increased by 4.5. After 28 days of treatment in the 25, 50, 100 and 200 mg dose groups, the changes were  $-5.2$ ,  $-6.3$ ,  $-1.30$  and  $+2.2$ , respectively.

### DISCUSSION

These data provide evidence of a safety and tolerability profile sufficient to support further clinical evaluation of VX-809 in subjects with CF homozygous for the *F508del-CFTR* mutation, the most common CF mutation worldwide. Over a dosing range of 25–200 mg, study participants reported symptoms and AEs that were similar to those in the placebo group, and similar to those commonly found in adult patients with CF. One subject in each of the four dose groups developed a pulmonary exacerbation during the 28 day period of treatment, and the incidence of symptoms such as cough was similar across the dose groups and to that of the placebo group.



**Figure 1** (A) Change in sweat chloride measurements from baseline for placebo- and VX-809-treated subjects. Mean values are shown ( $\pm$  95% CI, based on analysis of covariance (ANCOVA) analysis) predose, at weekly intervals over the course of treatment, and 1 week following discontinuation of study drug. (B) Sweat chloride change from baseline to day 28 treatment, difference versus placebo (mean (95% CI, based on ANCOVA analysis)). Sweat  $\text{Cl}^-$  changes were seen as early as day 7 of treatment (data not shown), and reached statistical significance for the 100 and 200 mg dose groups ( $p < 0.05$  and  $p < 0.01$ , respectively).

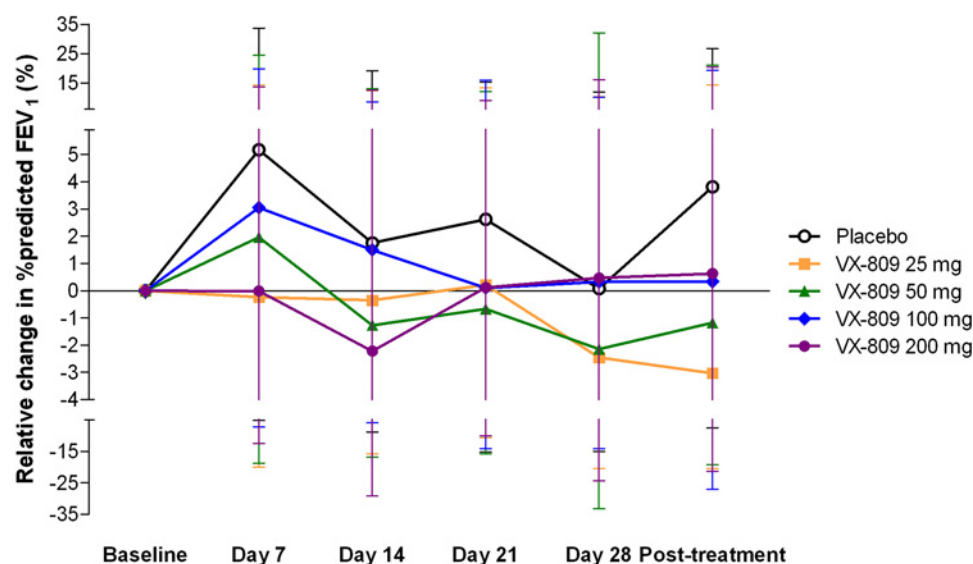


Sweat chloride concentration measurements demonstrated modest, statistically significant improvements in VX-809-treated subjects. This effect was dose dependent, sustained during the treatment period and rapidly reversed following discontinuation of VX-809. This suggests that VX-809 increased the chloride transport function of CFTR in the sweat gland, and supports the idea that VX-809 is bioactive in the sweat gland of patients homozygous for the *F508del-CFTR* mutation. These results also support the hypothesis that small molecule correction of *F508del-CFTR* is feasible. The results provide support for the use of previously obtained CFTR biomarker data sets for study planning of new CFTR modulators. Using this paradigm, the treatment effects on sweat chloride reported with the CFTR potentiator VX-770 in patients with CF with the *G551D-CFTR* mutation were successfully used to power the current study to detect improvements in sweat chloride (within-group comparisons and with placebo). It is not clear if the reductions in sweat

chloride in this study achieved a peak effect (figure 1), and this raises the question of whether higher doses of VX-809 may produce greater effects on *F508del-CFTR*. The peak corrective effect of VX-809 on *F508del-CFTR* in primary HBE cells has been estimated at 3  $\mu\text{M}$  (F. Van Goor, personal communication, 2011). Such concentrations of VX-809 were observed in the plasma of patients in the 100 and 200 mg dose cohorts at steady state. However, the drug exposure levels achieved in patient target tissues at these doses of VX-809 is not known.

The other biomarkers of CFTR activity (NPD, immunoblot from rectal biopsy tissue) failed to demonstrate changes over the course of VX-809 treatment. This may reflect the trial's lack of power to detect a predicted change in these measurements based on in vitro results with VX-809 in *F508del/F508del* primary HBE cells (maximum of  $\sim 15\%$  of wild-type CFTR function).<sup>17</sup> The intrinsically greater variability of NPD measurement (potentially compounded by the large number of NPD sites used in this

**Figure 2** Percentage change from baseline in forced expiratory volume in 1 s (FEV<sub>1</sub>) % predicted (95% CI, based on analysis of covariance (ANCOVA) analysis). No significant changes in FEV<sub>1</sub> compared with baseline or placebo were seen for any of the VX-809 dose groups over the course of the study.



trial (n=19)) led to a greater likelihood of Type 2 error in analysing biomarker responses. To minimise a Type 2 error and attain an 80% power to detect a chloride-free isoproterenol response approximating 30% of that seen with VX-770 in patients with CF with the *G551D-CFTR* mutation, the current study would have required >50 subjects per study group undergoing the NPD.<sup>17 22</sup>

In vitro studies also suggest that measurement of the effect of VX-809 on CFTR may be below the lower limits of sensitivity of immunoblot assays performed on small biopsy samples.<sup>17</sup> Pretrial studies indicated that the assay developed here was capable of detecting ~10% of C-Band CFTR relative to wild-type levels (ex vivo dilution experiments using human rectal biopsy specimens obtained from non-CF study subjects; see online supplement, figure 2B). The sensitivity of this assay to detect *F508del-CFTR* correction relative to functional measurements in vivo is unknown, but in vitro studies in a variety of model systems suggest that biochemical detection of *F508del-CFTR* correction may be less robust than functional measures in intact epithelia.<sup>17 23</sup> The failure to detect VX-809 effects on *F508del-CFTR* outside of the sweat gland could also reflect tissue-specific differences in VX-809 bioavailability and/or *F508del-CFTR* responsiveness to VX-809 treatment.

No improvements in clinical outcomes, including lung function and quality of life (CFQ-R), were observed over the course of this study. The trial was not powered to detect such improvements in these measures, and longer or larger trials of VX-809 (alone or in combination with CFTR potentiators) may be necessary to determine the clinical effect of these CFTR modulators.

Previous trials of systemically dosed CFTR modulators have frequently described discordant effects on CFTR-dependent biomarkers and pulmonary outcome measures. For example, PTC124 has been shown to have detectable bioactivity by NPD over 2 weeks of treatment in patients with CF possessing premature termination codons in CFTR, while sweat chloride measurements remained unchanged.<sup>24</sup> Improvements in lung function and cough frequency were not observed until months of treatment were completed.<sup>25</sup> Systemic gentamicin has also been shown to suppress PTCs<sup>26</sup> and improve NPD parameters in two pilot studies, but effects on sweat chloride were predominantly limited to a subset of patients with the Y122X mutation.<sup>27 28</sup> Using a separate CFTR modulator strategy, Rubenstein and colleagues treated *F508del-CFTR* homozygous patients with

CF with the *F508del-CFTR* modulator 4-phenyl butyrate. Improvements in NPD-dependent chloride secretion were seen, but there were no effects on sweat chloride.<sup>29</sup> The reasons for discrepancies in CFTR biomarkers across different CFTR modulator strategies are not clear, but suggest that organ effects may vary due to tissue drug availability, CFTR regulation in different cell types or the responsiveness of mutant CFTR across different tissue compartments and modulator strategies. These uncertainties should be considered in future study planning, as should the selection and continued development of CFTR biomarkers to demonstrate study drug bioactivity.

In conclusion, the results provide support for the continued evaluation of VX-809 in patients with CF with the *F508del-CFTR* mutation. This study demonstrated that VX-809 has an acceptable safety profile. It also provided evidence of the effect of VX-809 on improving CFTR function based on dose-dependent reductions in *F508del-CFTR* activity in the sweat gland using a CFTR corrector administered orally to subjects with CF, and further investigation is warranted to evaluate the potential of this therapeutic strategy to increase *F508del-CFTR* activity.

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**Correction notice** This article has been corrected since it was published Online First. The author name Kris DeBoeck has been corrected to Kris De Boeck.

**Competing interests** None.

**Ethics approval** This study was conducted with the approval of the Institutional Review Board at each site.

**Provenance and peer review** Not commissioned; externally peer reviewed.

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## **SUPPLEMENTAL METHODS**

### **CFTR outcome measures**

NPD was performed by qualified operators based on a Therapeutics Development Network Standard Operating Procedure originally described by Knowles et al., modified for the conduct of a placebo controlled trial.<sup>1</sup> The modified technique included use of an agar nasal probe catheter, electronic data capture (AD Instruments, Colorado City, CO), and interpretation by a single reviewer blinded to treatment assignment, as previously described.<sup>2</sup> Sweat chloride was conducted by pilocarpine iontophoresis using the Macroduct collection device in two separate arm locations for each measurement and analyzed in a central analysis laboratory blinded to treatment assignment.<sup>3</sup> Rectal biopsy to detect fully mature, C-band F508del-CFTR by immunoblot was performed in some of the subjects as an optional exploratory endpoint.

### **Pharmacokinetic Analyses**

Blood samples for PK analysis were collected predose and at 0.75, 1.5, 3, 4, 6, 9, 12, and 24 hours on Day 1, and pre-dose and at 0.75, 1.5, 3, 4, 6, 9, 12, 24, 30 to 60 and 120 to 180 hours post last dose on Day 28. In addition, predose blood samples were taken on Day 7, Day 14, and Day 21. Pharmacokinetic (PK) analysis was performed using a non-compartmental approach implemented in WinNonlin® 5.1.1 (Pharsight Corporation, Mountain View, USA).

For NPD purposes, a sample size of 21 subjects per dose group was suitable to detect a – 4 mV change in chloride-free + isoproterenol with 80% power (within group comparisons).



**Exclusion criteria**

Subjects were excluded if they had a potentially confounding history of illness; ongoing acute illness, including acute respiratory infections; a pulmonary exacerbation or changes in therapy for pulmonary disease within 14 days before the first dose of study drug; liver function tests greater than three times the upper limit of normal; or a history of abnormal renal function in the year prior to enrollment. Subjects were also excluded if they had a change in treatment with intranasal medication or systemic antibiotics in the 14 days prior to study drug dosing; required use of continuous (24 hours per day) supplemental oxygen; or utilized any inhibitors or inducers of cytochrome P450 3A4.

**Rectal biopsy and Western blot**

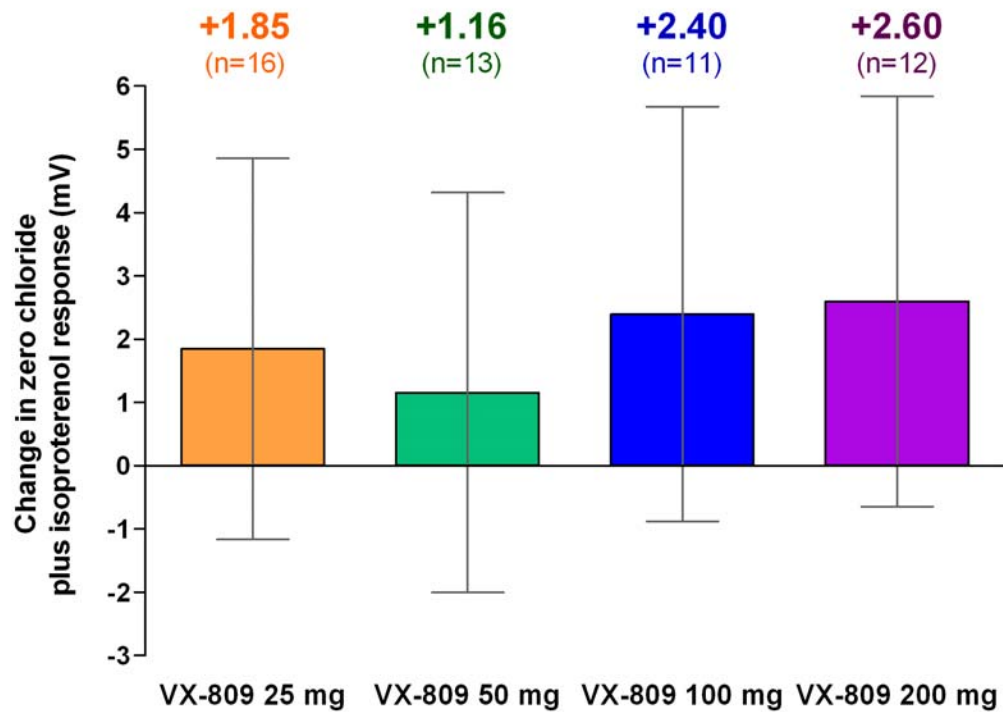
Up to four rectal biopsies were collected prior to initiation of study drug dosing (“pre-dose”) and following 21 or 28 days of VX-809 or placebo (“post-dose”) from consented subjects in the trial. The post-dose biopsy procedure was performed 20-24 hours post-oral dosing. The biopsies were frozen on dry ice and stored at -80°C until centralized and batched analysis. Briefly, individual rectal biopsy samples (blinded) were lysed with lysis buffer (200mM Tris, pH 7.5 [Invitrogen, Cat. #-15567-027], 10nM NaCl [Sigma, Cat. #-5316], 1mM EDTA [Vertex Chemical Supplies], 0.5% sodium deoxycholate [Pierce, Cat. #-89905], 1% NP-40 [Pierce, Cat. #-28324] using a 2mL dounce homogenizer in the presence of protease inhibitors (Complete, EDTA-free protease inhibitors [Roche, Cat. #-5056489001]). Samples were subjected to SDS-PAGE and immunoblot analysis for CLCN2 (mouse anti-CLCN2 antibody, Abnova, Cat. #-H00001181-M01) and GAPDH (mouse anti-GAPDH antibody, Chemicon, Cat. #-mAB374). CLCN2 expression was

used as an indicator of epithelia cell content. A pair of rectal biopsy samples (one pre-dose and one post-dose) were selected for each subject based on CLCN2 expression levels, and further analyzed to determine the presence or absence of CFTR C band. To detect B and C Band CFTR, samples were probed with Riordan-769 anti-CFTR (1:1000 dilution of antibody in TBST/5% milk (5% dry milk powder in Tris buffered saline, pH 7.5 with 10% Tween-20). The total protein load was adjusted for each sample to achieve similar CLCN2 loading between the paired rectal biopsy samples. CFTR standard samples were created by spiking in appropriate amounts of wild-type rectal biopsy protein lysates into a F508del rectal biopsy lysate pool. 10 mcg of each standard were loaded per lane and analyzed in parallel to determine the sensitivity for each blot. Rectal biopsies from normal subjects were obtained from adult patients undergoing clinically indicated sigmoidoscopy/colonoscopy as part of cancer screening or evaluation of lower GI symptoms. IRB approval and informed consent were obtained under a separate protocol at two study sites.

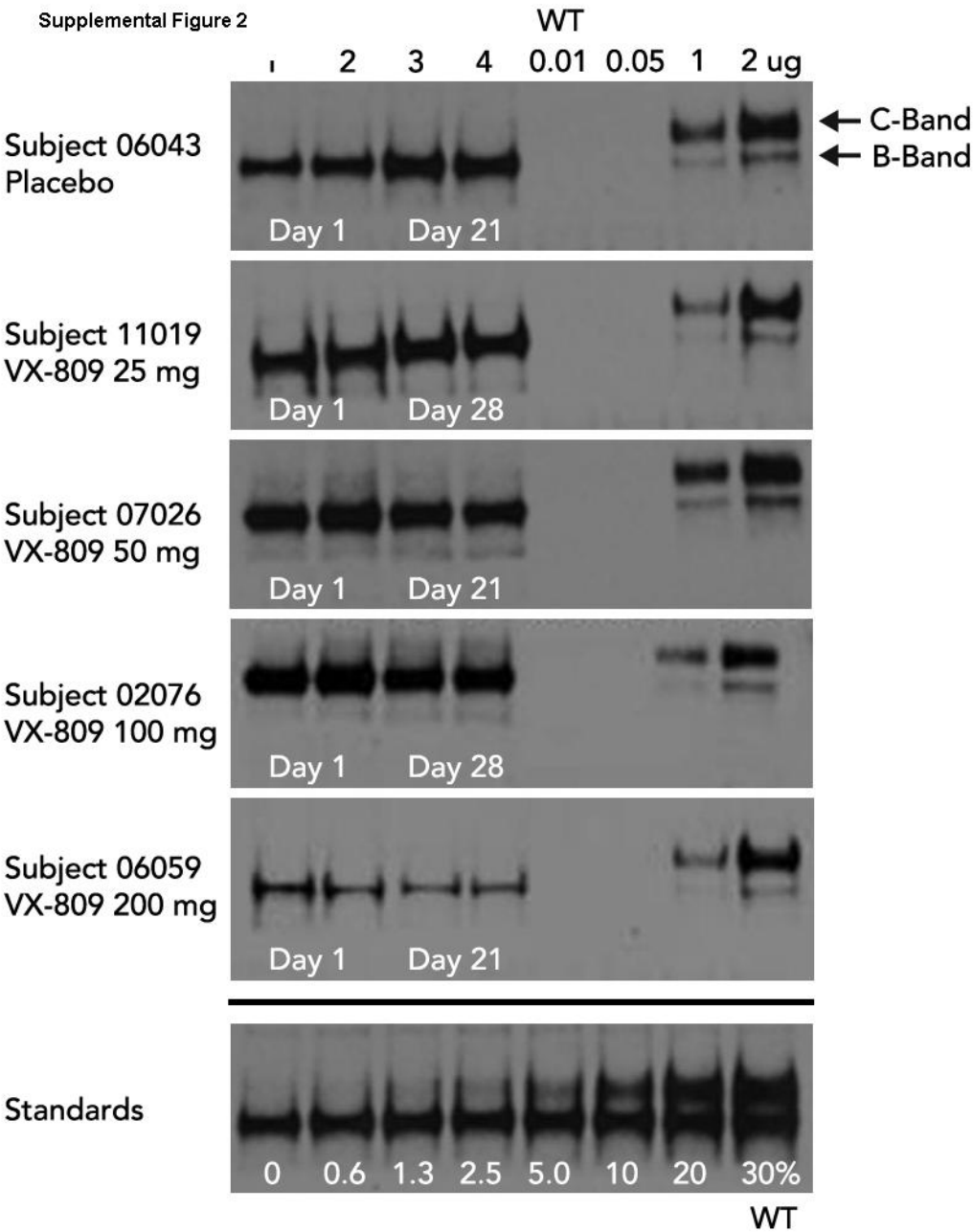
**Supplemental Figure Legends:**

**Supplemental Figure 1: NPD chloride-free plus isoproterenol response change from baseline to Day 28 (mean [95% CI]) treatment difference versus placebo (ANCOVA analysis).** No significant changes in CFTR-dependent chloride transport were seen at 28 days vs baseline or placebo. No differences in CFTR-dependent sodium or chloride transport were seen at days 14 and 28 compared with baseline or placebo for any of the dose groups (data not shown).

**Supplemental Figure 2:** Examples of immunoblots of rectal biopsies in F508del/F508del study subjects across the five study groups. The left four lanes are from study subjects on day 01, day 21, or day 28 as indicated, and the lanes to the right are spiked samples from subjects without CF (WT). Dilutional rectal biopsy standards from non-CF subjects (WT) are shown at the bottom of the figure ('Standards').

**Supplemental Figures:****Supplemental Figure 1:**





**Supplemental Table 1: Subject-reported QoL (CFQ-R): Mean change from baseline to Day 28 (ANCOVA analysis).** Although isolated statistically different values were measured for subdomains of the CFQ-R, no clear drug or dose related changes were apparent.

| <b>Domain</b>                  | <b>VX-809<br/>200 mg<br/>(n = 18)</b> | <b>VX-809<br/>100 mg<br/>(n = 16)</b> | <b>VX-809<br/>50 mg<br/>(n = 17)</b> | <b>VX-809<br/>25 mg<br/>(n = 17)</b> | <b>Placebo<br/>(n = 17)</b> |
|--------------------------------|---------------------------------------|---------------------------------------|--------------------------------------|--------------------------------------|-----------------------------|
| <b>Body</b>                    | 0.06                                  | 2.61                                  | -1.63                                | -0.21                                | -1.34                       |
| <b>Digestion</b>               | 2.58                                  | 0.25                                  | -0.72                                | 2.28                                 | 4.62                        |
| <b>Eating</b>                  | -2.58                                 | 3.24                                  | - 7.27*†                             | -3.66                                | 2.11                        |
| <b>Emotion</b>                 | -2.62                                 | 3.49                                  | -1.36                                | -3.22                                | 4.86                        |
| <b>Health perceptions</b>      | -1.9                                  | -0.44                                 | - 6.97*†                             | -2.84                                | 5.03                        |
| <b>Physical</b>                | -0.98                                 | -3.46                                 | - 7.38*                              | -5.97                                | 1.23                        |
| <b>Respiratory<sup>α</sup></b> | 2.22                                  | -1.29                                 | - 6.32*†                             | - 5.22†                              | 4.53                        |
| <b>Role</b>                    | - 6.53*†                              | 1.1                                   | -4.6                                 | - 5.94*†                             | 2.21                        |
| <b>Social</b>                  | -2.64                                 | 0.47                                  | -1.01                                | 0                                    | -0.55                       |
| <b>Treatment burden</b>        | -0.68                                 | 1.42                                  | - 5.96*†                             | 4.19                                 | 2.46                        |
| <b>Vitality</b>                | 0.73                                  | -1.52                                 | - 7.23*                              | -4.65                                | -2.18                       |
| <b>Weight</b>                  | -4.19                                 | 8.83                                  | 2.18                                 | 5.41                                 | 0.3                         |

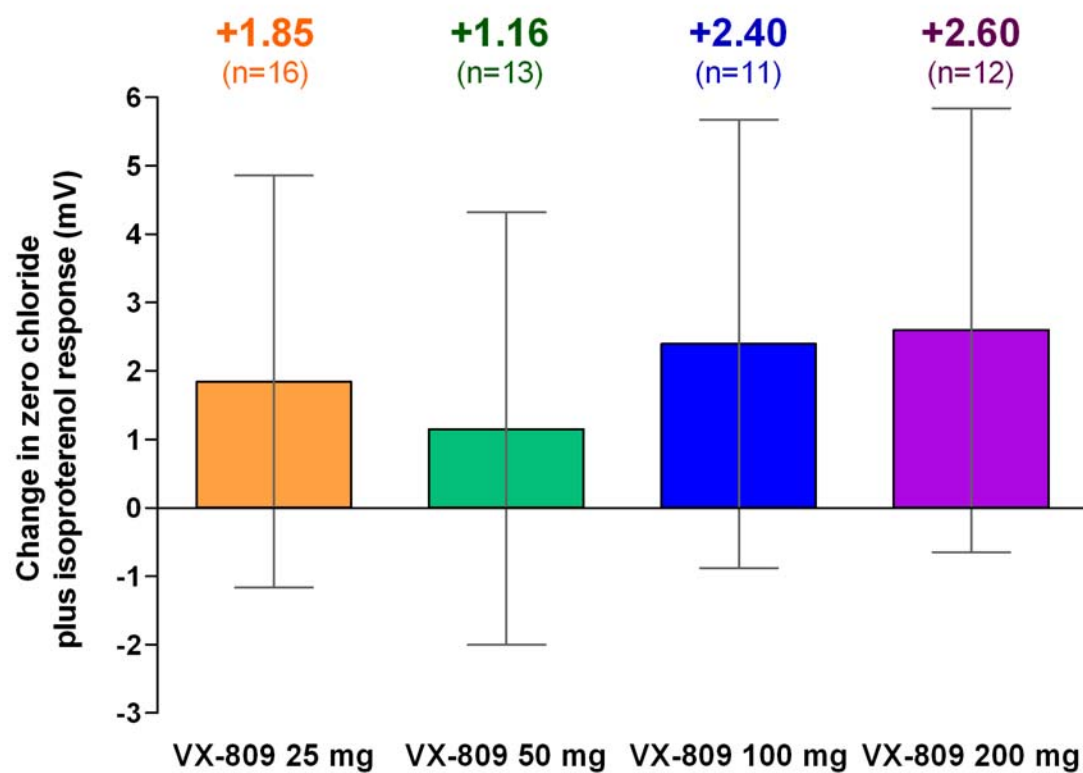
<sup>α</sup> MCID in Respiratory domain is improvement  $\geq 4$

\* P < 0.05 within-subject; † P < 0.05 versus placebo

**Supplemental References**

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## Supplemental Figure 1





Supplemental Figure 2

