PULMONARY FUNCTION AFTER EXPOSURE TO THE WORLD TRADE CENTER IN THE NEW YORK CITY FIRE DEPARTMENT

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ABSTRACT

Rationale: On September 11th 2001, the World Trade Center collapse created an enormous urban disaster site with high levels of airborne pollutants. First responders, rescue/recovery workers and residents have since reported respiratory symptoms and developed pulmonary function abnormalities.

Objectives: To quantify respiratory health effects of World Trade Center exposure in the New York City Fire Department.

Measurements: Longitudinal study of pulmonary function in 12,079 New York City Fire Department rescue workers employed on or before 09/11/2001. Between 01/01/1997 and 09/11/2002, 31,994 spirometries were obtained and the forced expiratory volume in one second (FEV1) and forced vital capacity (FVC) were analyzed for differences according to estimated World Trade Center exposure intensity. Adjusted average FEV1 during the first year after 09/11/2001 was compared to the 5 years before 09/11/2001. Median time between 09/11/2001 and a worker's first spirometry afterwards was 3 months; 90% were assessed within 5 months.

Main Results: World Trade Center-exposed workers experienced a substantial reduction in adjusted average FEV1 during the year following 09/11/2001 (372ml; 95% confidence interval 364-381ml; $p<0.001$) This exposure-related FEV1 decrement equaled 12 years of aging-related FEV1 decline. Moreover, exposure intensity assessed by initial arrival time at the World Trade Center site correlated linearly with FEV1 reduction in an exposure intensity-response gradient ($p=0.048$). Respiratory symptoms also predicted a further FEV1 decrease ($p<0.001$). Similar findings were observed for adjusted average FVC.

Conclusions: World Trade Center exposure produced a substantial reduction in pulmonary function in New York City Fire Department rescue workers during the first year following 09/11/2001.

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Key Words:

FEV1 decline, respiratory health consequences of 09/11/2001, rescue worker, building collapse

TEXT

INTRODUCTION

Following September 11th 2001, the dust and smoke clouds produced during and after the World Trade Center (WTC) collapse raised serious health concerns among rescue workers and residents. Throughout the rescue/recovery effort, survivors were exposed to WTC-derived airborne pollutants, including particulate matter composed of pulverized building materials and combustion products [1,2]. Almost 12,000 of the approximately 14,000 Fire Department of New York City (FDNY) workforce (approximately 11,500 Fire and approximately 2,500 Emergency Medical Service (EMS) workers) were present at the WTC site within the first week after 09/11/2001 and reported extensive exposures. Appropriate respiratory protection was initially not readily available; later, compliance was suboptimal [3]. WTC exposure has since been implicated in "WTC Cough", and upper and lower airway inflammation with airway obstruction and bronchial hyperreactivity [4-12].

In a previous cross-sectional stratified random sample of 319 WTC-exposed FDNY rescue workers 3 weeks after 09/11/2001, we described pulmonary function declines that correlated with WTC-Dust exposure intensity [3]. To better define the respiratory consequences of WTC exposure, we now report our analysis of longitudinal pulmonary function course from 1997 to 2002 in the entire FDNY WTC Medical Screening Cohort (n=12,079). Study objectives were to determine whether (1) pulmonary function changed after 09/11/2001, (2) WTC exposure intensity affected (a) pulmonary function, and (b) respiratory symptoms in an exposure intensity-response

pattern after 09/11/2001. Some of the results of this study have previously been reported in the form of an abstract[13].

METHODS

The FDNY Bureau of Health Services (FDNY-BHS) performs periodic medical evaluations on all FDNY rescue workers approximately every 18 months. Since 1997, these evaluations have included spirometry and a respiratory questionnaire. On 10/01/2001, FDNY-BHS started the FDNY WTC Medical Screening Program, which included spirometry and a self-administered questionnaire detailing WTC exposure and respiratory symptoms. Compliance was 85% among incumbent FDNY rescue workers. Participation in this study required written informed consent approved by Montefiore Medical Center's Institutional Review Board.

TOTAL AND WTC-EXPOSED COHORT:

The cohort studied consisted of all FDNY rescue workers employed on or before 09/11/2001 who had at least one spirometric measurement (forced vital capacity [FVC] and/or forced expiratory volume during the first second [FEV1]) from a testing session between 01/01/1997 and 09/11/2002 that met 1994 American Thoracic Society (ATS) guidelines [14] (FDNY cohort, N=12,079). Within the FDNY cohort, 313 rescue workers (2.6%) reported no presence at the WTC site at all during the entire rescue, recovery and cleanup operation from 09/11/2001 to 06/30/2002. Demographics for this non-exposed group differed significantly from those of the WTC-exposed workers. In order to eliminate nonlinear demographic confounders, we therefore modeled FEV1 change from

before to after 09/11/2001 both in the FDNY cohort (N=12,079; 31,994 spirometries) and in the WTC-exposed FDNY subcohort (N=11,766; 31,203 spirometries; fig. 1).

SPIROMETRY:

Before and after 09/11/2001, spirometry (Portascreen, S&M Instruments, Doylestown, PA) was administered using ATS guidelines [14]. The same spirometers were used before 09/11/2001 and during the first year after 09/11/2001. Each spirometer was calibrated daily; calibrations were considered acceptable if 3 volumetric measurements were within 3% of each other. Before and after 09/11/2001, spirograms were considered acceptable if they met ATS criteria[14]**.** The largest FVC and FEV1 from among all acceptable spirometric measurements were selected for electronic archiving. FVC and FEV1 were expressed in absolute values (liters), as percent predicted, and classified as above or equal to versus below the lower limit of normal (LLN, NHANES III[15]). For this cohort study, spirometric measurements for all FDNY rescue workers employed on or prior to 09/11/2001 who consented to data analysis were extracted from the database (figure 1). Among WTC-exposed workers, FEV1 measurements from at least one testing session met ATS criteria in 95% before 09/11/2001 and in 90% after 09/11/2001. The majority (N=7,653; 65% of exposed cohort) had FEV1 measurements that met ATS criteria from at least 2 testing sessions before 09/11/2001, and 92% had 2 or more FEV1 measurements (before and/or after 09/11/2001) that met ATS criteria. During additional quality assurance, paper spirogram recordings were independently reviewed (blinded to identity, WTC arrival time, work assignment, and symptoms; and regardless of whether the spirogram was obtained before or after 09/11/2001) if the values met any of the following criteria: (1) values<70% or >135% predicted, (2) marked variability of serial

values, (3) change rates at the upper/lower 1.5% extreme and (4) a random sample comprising 10% of the remaining database. Rejected spirometric measurements totaled 855 (2.6% of 32,849; figure 1).

DEMOGRAPHICS AND EXPOSURE QUESTIONNAIRE:

FDNY's database includes birth date, height, race, gender, FDNY tenure and work assignment. WTC exposure intensity was categorized either according to initial arrival time at the WTC site from the self-administered exposure questionnaire or according to work assignment on the self-reported arrival day. Self-report was preferred because FDNY records did not reflect the large-scale recall during week one and the frequent self-deployment throughout the rescue/recovery effort. For the arrival time-based categorization of WTC exposure intensity, FDNY rescue workers had (1) early, high intensity exposure if they arrived during the morning of 09/11/2001 (day 1) and were present during the collapse of North and/or South tower, (2) intermediate intensity exposure if they arrived on day 1after the WTC collapse or during day 2, (3) late, low intensity exposure if they arrived on/after day 3, and (4) no exposure if they reported no presence at the WTC site between 09/11/2001-06/30/2002. For the work assignment-based categorization of WTC exposure intensity, work assignment on the arrival day was categorized as Special Operations Command (SOC; an elite assignment responsible for the most complicated and lengthy rescue/recovery tasks) vs. other non-SOC Fire units vs. EMS units. For assessment of respiratory protection, FDNY rescue workers were considered protected if they reported frequent use of any mask type (disposable hardware store-type dust mask, N95 mask, half face respirator) during their arrival day, and

unprotected otherwise. Non-exposed FDNY rescue workers were considered protected when they were included in the model.

RESPIRATORY HEALTH:

The FDNY WTC Medical Screening Program self-administered questionnaire assessed tobacco use (current, ex-smoker or never smoker) and respiratory symptoms, including "Since the disaster…any new/worsening…. respiratory symptoms" ("daily cough", "nearly constant cough", "wheeze", "shortness of breath", "chest tightness", "sleep disturbance due to any of the above"). An affirmative response to any of the above respiratory symptoms was categorized as symptomatic. Symptom severity analyses were based on a non-weighted summation score providing one point per symptom.

STATISTICAL ANALYSIS:

Data analysis was performed using SPSS version 12.0.

A. CROSS SECTIONAL ANALYSES

We compared age, FDNY tenure (one way ANOVA, independent samples t-test), Caucasian race, and gender (chi square) (1) between workers who did and those who did not participate in the WTC Medical Screening Program, (2) among arrival time-based WTC exposure groups, and (3) between EMS workers and firefighters. Height (one way ANOVA, independent samples t-test), ever smoking, work assignment on 09/11/2001, symptom presence (chi square), and symptom severity (Kruskal-Wallis H, Mann-Whitney U) were compared (1) among arrival time-based WTC exposure groups, and (2) between EMS workers and firefighters. Spirometric means and time difference between last spirometric measurement before and first spirometric measurement after 09/11/2001 were compared between arrival time-based exposure groups (one way ANOVA); the

proportion of workers with measurements below the LLN, mask use frequency, and proportions of workers with respiratory symptoms was compared between arrival time-based exposure groups (chi square).

B. LONGITUDINAL ANALYSES

Within arrival time-based exposure groups, changes in spirometric means from the last measurement before to the first measurement after 09/11/2001 were compared (paired t-test).

The preferred statistical approach to longitudinal spirometric analysis is mixed linear random effects (MLRE) modeling [16,17], because subjects can have unequal numbers of observations at differing times and effect estimates are modified for the correlation between repeated measures in the same subject [18]. Other recent epidemiologic pulmonary investigations have also relied on this method [19,20]. We analyzed (1) difference in average spirometric measurements (FVC or FEV1) from the 5 years before 09/11/2001 to the first year after 09/11/2001, and (2) whether WTC exposure intensity influenced spirometric changes in an exposure intensity-response gradient during the first year following 09/11/2001 using MLRE modeling.

Separate models were run for FEV1 and FVC as dependent variables. Subjects contributed from one to 7 observations to the analysis. The primary predictors of interest were: (1) the contrast between average FEV1 or FVC in the five years before 9/11/2001 and in the first year after 09/11/2001 (modeled with indicator variables), and (2) the interaction with WTC exposure intensity. WTC exposure intensity was measured in two ways: (a) initial arrival time at the WTC site (3 categories), and (b) job assignment on the arrival day (2 categories). We modeled initial WTC arrival time both as a nominal

predictor variable and as an ordinal predictor variable (to test for linear trend) in separate models. Additional predictors were included as possible confounders: gender, race, height, smoking status, and age as of 9/11/2001. All these predictors were included in the models as fixed effects. A random intercept was used to take into account the heterogeneity across subjects and the correlation induced by having repeated observations on the same subjects. In order to explore associations between respiratory symptoms at the time of the FDNY WTC Medical Screening Program and spirometric measurements, additional interactions between average pulmonary function and respiratory symptoms were included in some models.

RESULTS

DEMOGRAPHICS:

Cohort derivation is shown in figure 1, and key demographics are shown in table 1. Between 10/1/2001 and 9/11/2002, 12,543 FDNY rescue workers participated in the FDNY WTC Medical Screening Program (85% compliance);12,063 were incumbent; 480 were retired FDNY rescue worker volunteers. The final analysis included 12,079 FDNY rescue workers (83% of those eligible for the FDNY WTC Medical Screening Program). The 17% of workers who did not participate in the screening exam were significantly older, and more often non-Caucasian, female, and with EMS assignment and longer FDNY tenure. While only 19% of all FDNY rescue workers were EMS, 89% of non-exposed and 33% of late exposure groups had EMS assignments (table 1).

The non-exposed group was small and differed markedly from WTC-exposed groups in several demographic characteristics (table 1). Thus, it was not optimally suited for reliable comparisons with the remaining majority of FDNY rescue workers who had experienced WTC exposure. In order to base comparisons on the most representative group within the FDNY cohort, we used the late arrival, low exposure group as the principal comparison/referent group because of larger size (N=1,921; 15.9% of FDNY cohort), and because demographics did not differ as markedly from more exposed groups. This choice of referent provided a more conservative estimate of WTC exposure effects, since a group who already had experienced WTC exposure itself (albeit low intensity exposure) served as the comparison group.

SPIROMETRY IN WTC-EXPOSED FDNY WORKERS:

An FEV1 of less than 60% predicted was found in 45 WTC-exposed FDNY rescue workers (0.4% of exposed cohort) on at least one occasion during the 5 years of occupational monitoring before 09/11/2001, and in 93 WTC-exposed FDNY rescue workers (0.8% of exposed cohort) in the first year after 09/11/2001. The median time between 09/11/2001 and a worker's first spirometry afterwards was 3 months, and 90% of the cohort was assessed during the first 5 months after 09/11/2001.

When adjusted average FEV1 during the 5 years before 09/11/2001 was compared to adjusted average FEV1 during the first year after 09/11/2001 in WTC-exposed workers**,** a substantial loss of 372ml was observed following 09/11/2001 (95% confidence interval [95% CI] 364-381ml; $p<0.001$). The decrement in adjusted average FEV1 after 09/11/2001 was equal in magnitude to 12 years of aging-related FEV1 decline in this cohort (longitudinally computed aging-related FEV1 decline rate before

09/11/2001 was 31ml/year). Similar results were obtained (1) when the non-exposed FDNY workers were included in the analyses, and (2) when FVC served as outcome variable. (Please refer to the online supplement for a complete presentation of analyses with FVC as outcome variable.)

FEV1 REDUCTION AND WTC ARRIVAL TIME:

Within arrival time-based exposure groups, means of the first FEV1 measurement after 09/11/2001 (in liters and percent predicted) were significantly lower than those of the last measurement before 09/11/2001 ($p<0.001$; table 2, figure 2). The percentage of FDNY rescue workers with FEV1 measurements below the LLN increased by at least two-fold within each exposure group from before to after 09/11/2001 ($p<0.001$; table 2).

In order to explore whether WTC exposure intensity affected adjusted average FEV1 following 09/11/2001, we included an estimate of WTC exposure intensity based on initial arrival time at the WTC site in comparisons of adjusted average FEV1 during the 5 years before 09/11/2001 to adjusted average FEV1 during the first year after 09/11/2001. We observed substantial FEV1 reductions after 09/11/2001, with a significant exposure intensity-response gradient between FDNY rescue workers with increasing arrival time-based WTC exposure intensities (figure 3A). Early arrival, high intensity exposure workers experienced an average reduction of 388ml (95% CI, 370-406ml). Intermediate intensity exposure workers experienced an average reduction of 372ml (95% CI 363-381ml). Workers with late arrival, low intensity exposure experienced an average decrement of 357ml (95% CI 339-374ml). This linear trend in exposure intensity-response was statistically significant ($p=0.048$, likelihood ratio test). Similar effects of arrival time on average adjusted spirometric measurements after

09/11/2001 were also observed (1) when the non-exposed FDNY workers were included in the analyses, and (2) when FVC served as outcome variable (though not statistically significant).

FEV1 REDUCTION AND WORK ASSIGNMENT:

In order to further substantiate that WTC exposure resulted in adjusted average spirometric decrements following 09/11/2001, we included another estimate of WTC exposure intensity based on work assignment in other comparisons of adjusted average FEV1 during the 5 years before 09/11/2001 to adjusted average FEV1 during the first year after 09/11/2001. We again observed substantial FEV1 reductions after 09/11/2001, with significant differences according to work assignment (figure 3B, $p<0.001$). Firefighters had an average adjusted decrement of 383ml (95% CI, 374-393ml) - significantly lager compared to EMS workers, who experienced an average reduction of 319ml (95% CI 299-340ml). We did not find significant differences between firefighters who were and who were not assigned to SOC units. Significantly lower average adjusted spirometric measurements after 09/11/2001 for Fire compared to EMS workers were also found when (1) the non-exposed workers were included in the analyses, and (2) FVC served as outcome variable.

RESPIRATORY PROTECTION:

Frequent use of respiratory protection was uncommon in the first days after the collapse and became more common as time progressed, with only 22% of workers who arrived early reporting frequent mask use on their arrival day, while 32% of workers with intermediate arrival and 50% of workers with late arrival times reported frequent mask

use upon arrival ($p<0.001$). Our analyses did not identify a protective effect of mask use frequency on adjusted average FEV1 or FVC after 09/11/2001.

RESPIRATORY SYMPTOMS:

Early and intermediate arrival time-based WTC exposure groups had significantly more frequent and significantly more severe (i.e. greater number) respiratory symptoms than the late group ($p<0.001$ for both; table 3, figure 4A). Symptoms were also more prevalent and severe in Fire compared to EMS workers ($p<0.001$ for both; figure 4B). We compared adjusted average FEV1 reduction between FDNY rescue workers with increasing symptom severity in order to determine whether objective spirometric measurements correlated with clinical complaints. Each added symptom was associated with a significant additional adjusted average FEV1 decrease (26ml for each symptom, 95% CI 20-32ml; $p<0.001$). In further analyses, presence of any symptom was associated with an additional 48ml adjusted average FEV1 decrement after 09/11/2001 (95% CI 30-67ml; $p<0.001$).

DISCUSSION

The WTC collapse created a disaster site with WTC-derived pollutants that were highest during the collapse and then gradually dissipated [1,2]. Adequate respiratory protection was not immediately available [3], and many rescue workers and residents have respiratory symptoms and physiologic airway abnormalities [4-12]. This study demonstrates substantial reductions in average adjusted FEV1 and FVC in FDNY rescue workers during the year following 09/11/2001. In addition, WTC exposure intensity, assessed by

arrival time or work assignment, predicted further pulmonary function loss and respiratory symptoms. WTC exposure had clinically and statistically significant effects on pulmonary function after 09/11/2001 – we observed a reduction in average adjusted FEV1 that was equal in magnitude to 12 years of aging-related FEV1 decline in this cohort. The validity of these findings is strongly supported by large cohort size (N=12,079) and availability of almost 5 years of pre-exposure spirometries.

The WTC plume was most intense on day one and then dissipated, with marked reduction after it rained on 09/14/2001 [1,2]. This environmental measure of airborne WTC pollutant intensity corresponds well with the arrival time-based linear exposure intensity-response gradient we observed.-More than 400 chemicals have been identified in WTC-derived airborne pollution [1,2]. Induced sputum from FDNY firefighters and cellular and animal models all demonstrate inflammation [21-23]. Resulting clinical (cough, wheeze, dyspnea, chest tightness, gastroesophageal reflux) and physiologic (low FEV1/FVC, bronchodilator response, nonspecific hyperreactivity) correlates have been reported in smaller occupational [3, 5-9, 11,12] and community-based cohorts [4,10, 24] during the first year following 09/11/2001.

In contrast to our current study, prior WTC-related reports [3-12] have been limited by: (1) cross sectional design (2) small sample sizes and/or (3) lack of objective lung function documentation before the WTC exposure. In our study, we analyzed spirometric measurements for 83% of all FDNY rescue workers and included all measurements in a 6-year longitudinal design. The 17% of workers who did not contribute spirometric measurements were significantly older, and more often non-Caucasian and female with longer FDNY tenure and EMS assignment. We observed a sizable spirometric loss of

372ml when adjusted average FEV1 during the first year after 09/11/2001 was compared to the same measure during the preceding 5 years. While there is evidence for abnormal spirometry[25, 26], and airway inflammation[27] or hyperreactivity[28, 29] in case series and smaller cohorts after irritant exposures, there are only occasional reports that describe changes in such parameters from before to after an exposure for more than a few persons[30-32]. The largest relevant non-WTC study reported FEV1 decrements as large as 130ml during a fire season in 52 wildland firefighters[32]. In a prior stratified sample of 319 WTC-exposed FDNY firefighters, we reported a mean FEV1 reduction of 264ml from the last measurement before to the first measurement after 09/11/2001[3].

In addition to the substantial loss of average adjusted FEV1 for all WTC-exposed FDNY rescue workers, further WTC exposure intensity-related (arrival time- or work assignment-based) average adjusted FEV1 decrements were also evident. The earlier a worker arrived at the WTC site, the greater the spirometric reduction. While the arrival time-based exposure intensity-response gradient in our cohort was statistically significant, it was rather small. Several factors likely reduced this gradient's magnitude. Most importantly, the amount of WTC exposure in the late arrival group was heterogeneous, since this group included any worker who arrived after the first 48 hours. Since most FDNY rescue workers arrived within the first 48 hours, and because later arrival times were more prone to recall bias, we did not further partition the arrival time-based exposure categorization. Second, there was no adjustment for cumulative exposure because official work records are incomplete, and cumulative work hours are more difficult to remember than initial arrival time. Third, even with identical arrival and cumulative work times, large individual differences in airway deposition may have

existed because of physiologic variations in minute ventilation, body habitus-related differences in airway branching angles[33] and spatial and temporal heterogeneity of airborne substance concentrations[34].

Work assignment-based WTC exposure intensity was an alternative predictor of additional spirometric loss, with firefighters experiencing larger decrements than EMS workers. This was likely due to higher intensity WTC exposure associated with fire suppression and/or rescue activities as opposed to emergency medical tasks. In contrast to the pronounced influence of arrival time and work assignment, respiratory protective equipment had no appreciable effect on spirometric reductions following 09/11/2001. No doubt, initial lack of adequate equipment and subsequent compliance problems [3] diminished any protective impact.

In the current study, we describe spirometric reductions in the FDNY cohort during the sub-acute period following 09/11/2001, with a median time of 3 months between 09/11/2001 and a worker's first spirometry afterwards, and with 90% of the cohort assessed during the first 5 months after 09/11/2001. Potential pathogenetic mechanisms for these sub-acute spirometric decrements include airway inflammation and remodeling[6,7,8,19,35,36]. Our findings that hyperreactivity persisted 2 years after 09/11/2001 in a smaller FDNY rescue worker cohort may be a sign of persistent inflammation and/or early remodeling[37]. The current investigation does not address how long-term spirometric changes will evolve in the entire WTC-exposed FDNY cohort. Prior longitudinal investigations have shown nonlinear patterns, with slowing of spirometric decrease after cessation of inhaled irritant exposure [38] and during anti-

inflammatory treatment [39]. Long-term spirometric patterns for the FDNY cohort will undoubtedly be influenced by genetics, new inhaled irritant exposures and treatment.

In summary, we demonstrated significant, clinically important, detrimental effects of WTC exposure on respiratory health during the first year after 09/11/2001 in WTC-exposed FDNY rescue workers. The FDNY cohort experienced the most intense WTC exposure and is the only group with pre-exposure spirometry available for systematic comparison. Findings should be extrapolated with caution to other, less exposed populations, but since even our least exposed group showed spirometric reductions after 09/11/2001, continued medical monitoring would be prudent for all exposed populations. In addition to future spirometric surveillance, screening for physiologic and/or biochemical conditions associated with accelerated spirometric decline [40-42] may help to identify subgroups with greater likelihood for airway disease development/progression in this high-risk setting.

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FIGURE LEGENDS

Figure 1 – Study Cohort Derivation

Figure 2 – FEV1 Distribution in FDNY Cohort Before and After 09/11/2001:

There was a leftward shift in the distribution of percent predicted FEV1 (grouped by decile) for the FDNY cohort.

Figure 3A –WTC-Related Average Adjusted FEV1 Losses During the Year Following 09/11/2001 by Arrival Time Exposure Category:

WTC-related adjusted average FEV1 losses with standard errors are depicted. We observed substantial FEV1 reductions after 09/11/2001, with a significant exposure intensity-response gradient between FDNY rescue workers with increasing arrival time-based WTC exposure intensities. Early arrival, high intensity exposure workers experienced an average reduction of 388ml (95% CI, 370-406ml). Intermediate intensity exposure workers experienced an average reduction of 372ml (95% CI 363-381ml). Workers with late arrival, low intensity exposure experienced an average decrement of 357ml (95% CI 339-374ml). This linear trend in exposure intensity-response was statistically significant (p=0.048). Average FEV1 losses are adjusted for gender, race, height, age and smoking status.

Figure 3B –WTC-Related Average Adjusted FEV1 Losses During the Year Following 09/11/2001 by Work Assignment Exposure Category:

WTC-related adjusted average FEV1 losses with standard errors are depicted.

We observed substantial FEV1 reductions after 09/11/2001, with significant differences according to work assignment. Firefighters had an average adjusted decrement of 383ml (95% CI, 374-393ml) - significantly lager compared to EMS workers, who experienced an average reduction of 319ml (95% CI 299-340ml). We did not find significant differences between firefighters who were and who were not assigned to SOC units.

.Average FEV1 losses are adjusted for gender, race, height, age and smoking status.

Figure 4A –Respiratory Symptoms During the Year Following 09/11/2001 by Arrival Time Exposure Category:

Rescue workers with early or intermediate exposure had significantly more respiratory symptoms compared to workers with late exposure ($p<0.001$).

Figure 4B –Respiratory Symptoms During the Year Following 09/11/2001 by Work Assignment Exposure Category:

Firefighters had significantly more respiratory symptoms compared to EMS workers ($p<0.001$).

TABLES

Table 1 – Demographic Characteristics of FDNY Cohort by Arrival Time-Based WTC Exposure

Characteristic; (Units)	***Early Exposure***	***Intermediate Exposure***	***Late Exposure***	***Non-Exposed***	**Total**
Demographics					
Number (percent of FDNY cohort)	1,660 (13.7%)	8,185 (67.8%)	1,921 (15.9%)	313 (2.6%)	12,079 (100%)
Age on 09/11/01 (years)	40.0±7.6	39.7±7.5	40.2±8.3*	40.7±9.0†	39.7±7.7
Height (cm)	179.3±7.6	179.6±7.4	178.3±8.4*	174.0±9.1‡	178.3±7.6
Gender (percent male)	96.7%	97.1%	91.9%*	71.2%‡	95.6%
Race (percent Caucasian)	86.2%	88.3%	78.2%*	55.3%‡	85.6%
Ever Smokers (percent)	28.9%	27.5%	33.4%*	39.9%‡	29.0%
Work Assignment on 09/11/01 (percent EMS)	18.1%	13.8%	33.0%*	88.8%‡	19.4%
FDNY Tenure on 09/11/01 (years)	11.2±7.9	11.1±7.9	10.4±8.3*	6.4±5.3‡	10.9±8.3

*-$p<0.05$ between early, intermediate, and late exposure groups (ANOVA for age, height and FDNY tenure; chi square for gender, race, and ever smoking)

†-$p=0.006$ between early, intermediate, late and non-exposed groups (ANOVA)

‡-$p<0.001$ between early, intermediate, late and non-exposed groups (ANOVA for height and FDNY tenure; chi square for gender, race, and ever smoking)

Table 2 – FEV1 Characteristics of WTC-Exposed FDNY Rescue Workers by Arrival Time-Based WTC Exposure

Arrival Time-Based WTC Exposure	**Last FEV1 Before 09/11/2001** (Median, Interquartile Range/Percent)			**First FEV1 After 09/11/2001** (Median, Interquartile Range/Percent)		
	Liters	***Percent Predicted***	***Percent Below Lower Limit of Normal***	***Liters***	***Percent Predicted***	***Percent Below Lower Limit of Normal***
Early Exposure N=1,660	4.21 (3.64-4.73)	101 (92-111)	7.7	3.85* (3.34-4.36)	93* (84-102)	19.2*
Intermediate Exposure N=8,185	4.32 (3.83-4.83)	101 (92-111)	6.4	3.96* (3.52-4.42)	93* (85-102)	16.3*
Late Exposure N=1,921	4.27 (3.78-4.76)	100 (91-110)	7.8†	3.87*,‡ (3.42-4.32)	92*,‡ (83-102)	17.8*,†
Total	4.30 (3.80-4.80)	101 (92-111)	6.8	3.93 (3.47-4.40)	93 (85-102)	15.3

Mean (±SD) time interval between last measurement before and first measurement after 09/11/2001 was 2.13±0.83 years and did not differ significantly between exposure groups

*-$p<0.001$ between last measurement before and first measurement after 09/11/2001 within exposure group (paired t-test for FEV1 in liters or percent predicted; McNemar's test for percentage below lower limit of normal)

†-$p<0.001$ between early, intermediate and late exposure groups (ANOVA for FEV1 in liters or percent predicted; chi square for percentage below lower limit of normal)

‡-$p<0.05$ between early, intermediate, and late exposure groups (ANOVA for FEV1 in liters or percent predicted; chi square for percentage below lower limit of normal)

Table 3 – Respiratory Symptoms of WTC-Exposed FDNY Rescue Workers by Arrival Time-Based WTC Exposure

Respiratory Symptom	***Early Exposure*** *N=1,660*	***Intermediate Exposure*** *N=8,185*	***Late Exposure*** *N=1,921*	**Total**
Cough	63.3%	51.1%	31.6%*	49.7%
Wheeze	32.9%	24.9%	14.0%*	24.2%
Chest Pain or Tightness	33.6%	20.4%	9.6%*	20.5%
Exertional Dyspnea	55.9%	43.0%	23.3%*	41.6%
Any Lower Respiratory Symptom	76.5%	64.1%	40.5%*	62.0%

*-$p<0.001$ between early, intermediate and late exposure groups (chi square)

FIGURES

Figure 1

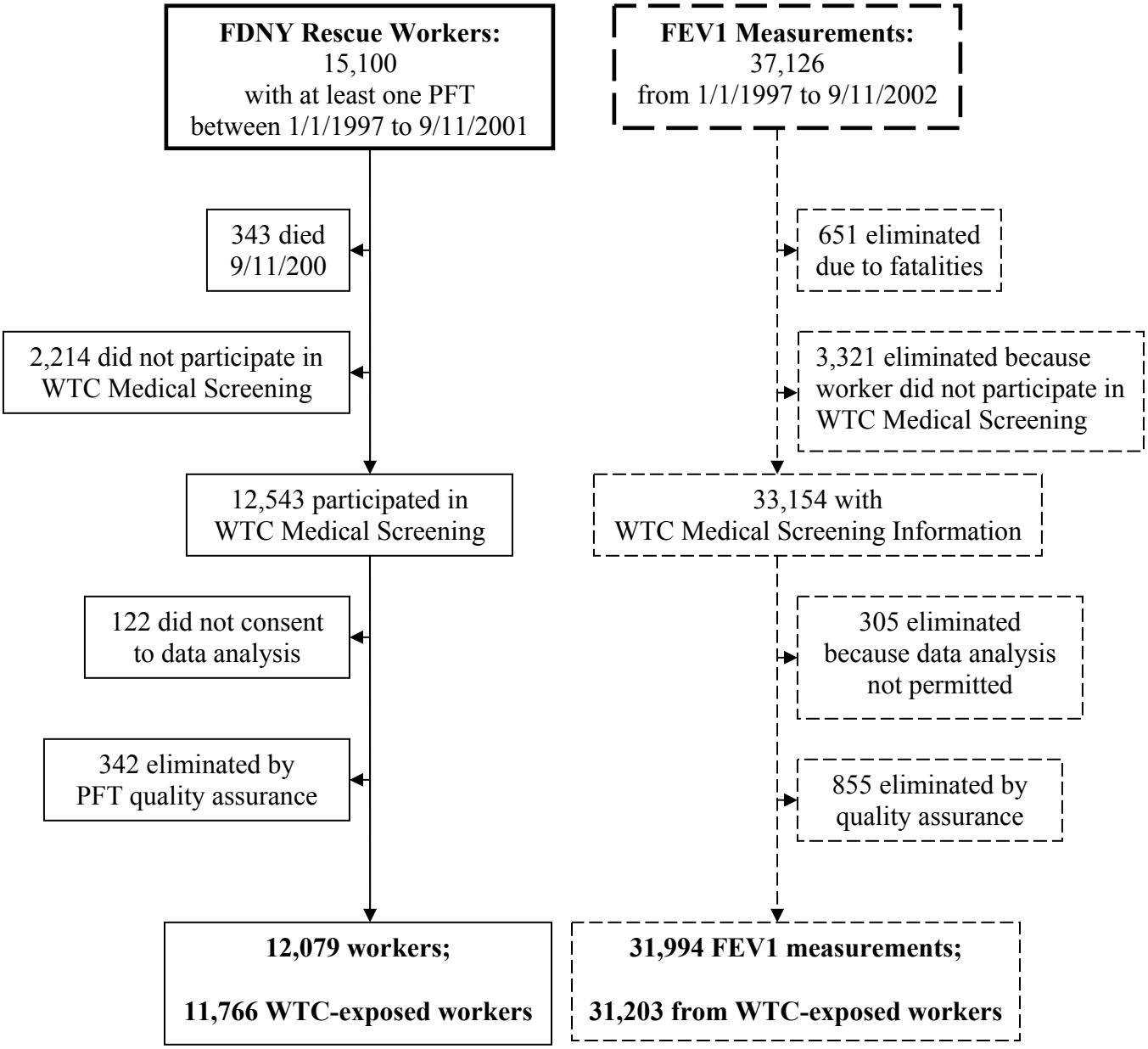


Figure 2

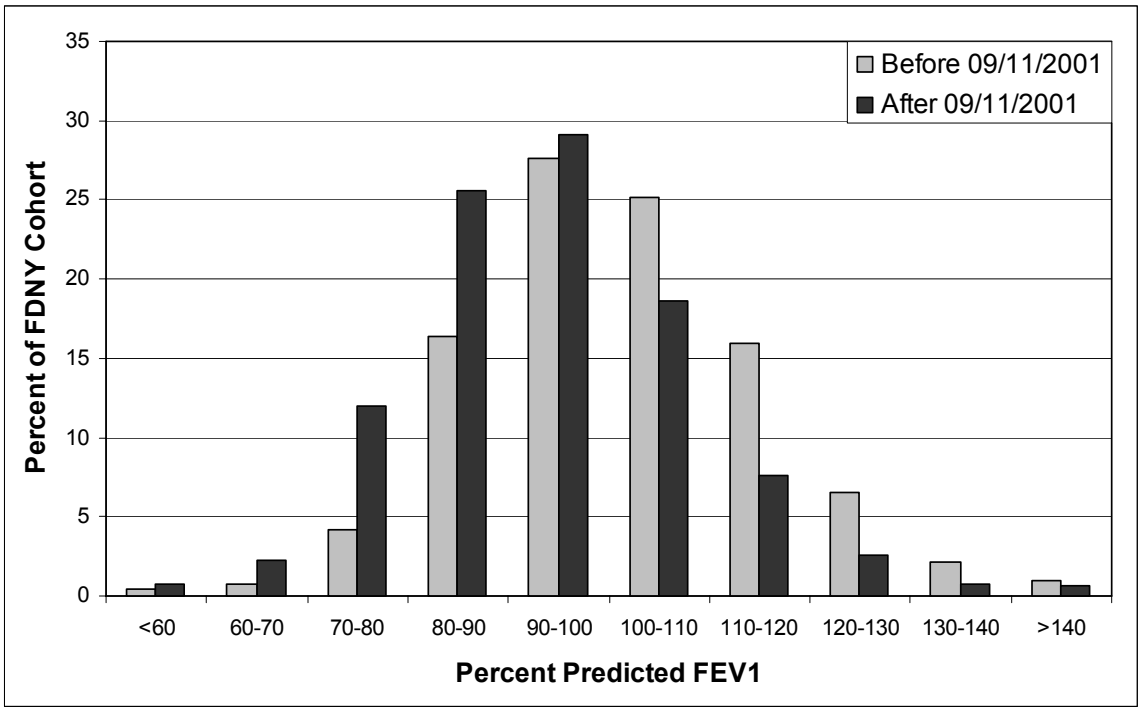

Before 09/11/2001
After 09/11/2001
Percent of FDNY Cohort
35
30
25
20
15
10
5
0
<60
60-70
70-80
80-90
90-100
100-110
110-120
120-130
130-140
>140
Percent Predicted FEV1

Figure 3A

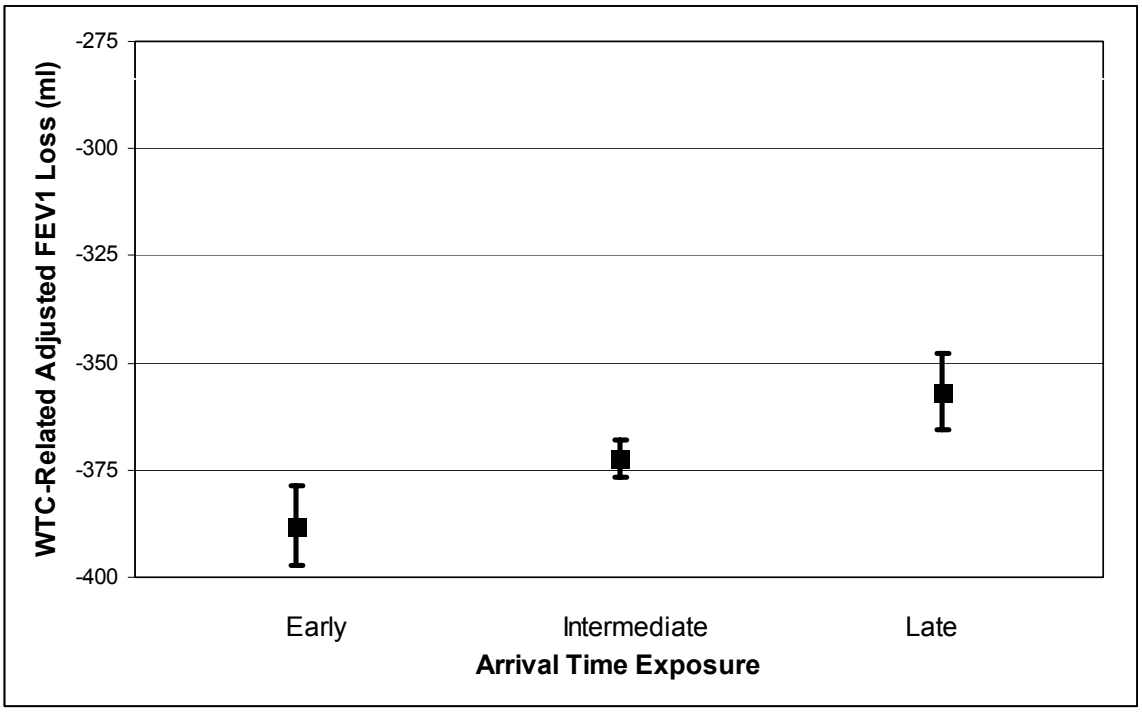


Figure 3B

Figure 4A

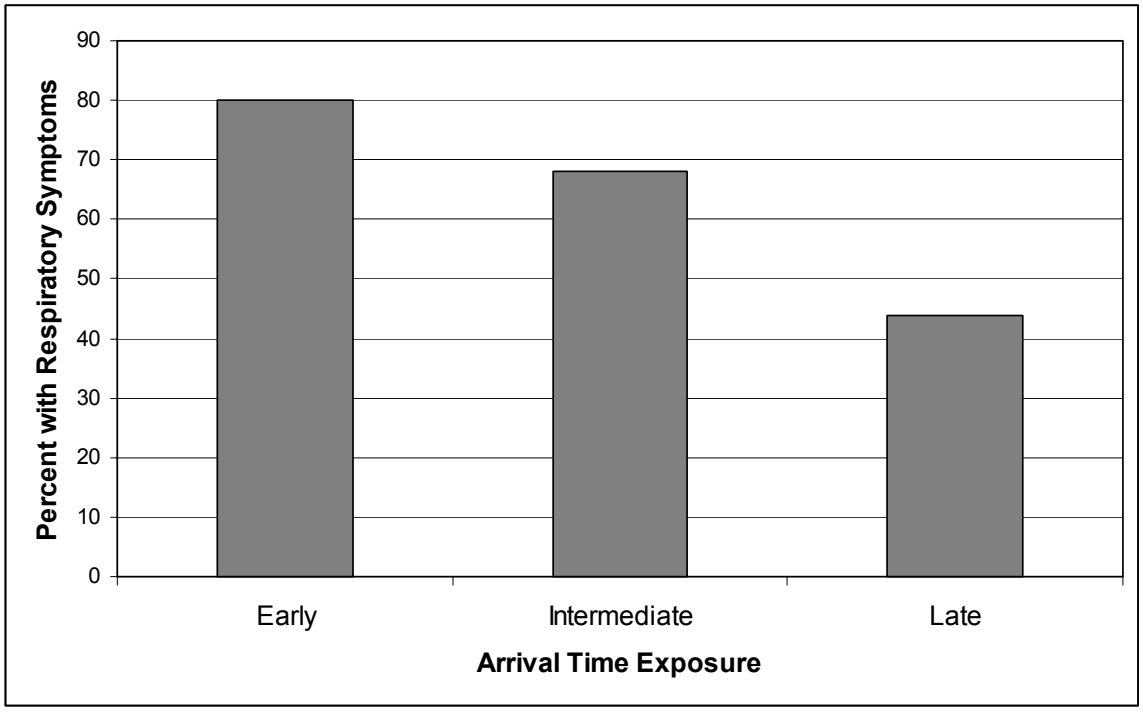
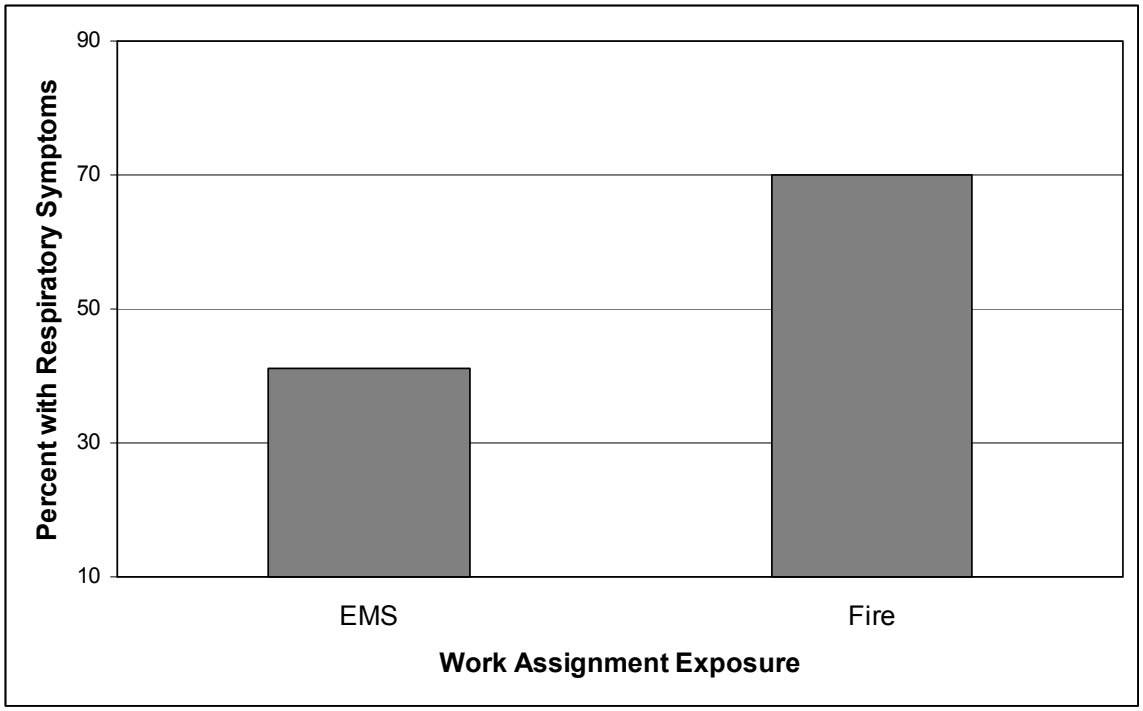


Figure 4B



PULMONARY FUNCTION AFTER EXPOSURE TO THE WORLD TRADE CENTER IN THE NEW YORK CITY FIRE DEPARTMENT

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ONLINE SUPPLEMENT

SPIROMETRY IN WTC-EXPOSED FDNY WORKERS:

When adjusted average FVC during the 5 years before 09/11/2001 was compared to adjusted average FVC during the first year after 09/11/2001 in WTC-exposed workers**,** a substantial loss of 405ml was observed following 09/11/2001 (95% confidence interval [95% CI] 395-415ml; $p<0.001$). The decrement in adjusted average FVC after 09/11/2001 was equal in magnitude to13 years of aging-related FVC decline in this cohort (longitudinally computed aging-related FVC decline rate before 09/11/2001 was 31ml/year).

FVC REDUCTION AND WTC ARRIVAL TIME:

Within arrival time-based exposure groups, means of the first FVC measurement after 09/11/2001 (in liters and percent predicted) were significantly lower than those of the last measurement before 09/11/2001 ($p<0.001$; table A). The percentage of FDNY rescue workers with FVC measurements below the LLN increased nearly two-fold within each exposure group from before to after 09/11/2001 ($p<0.001$; table A).

In order to explore whether WTC exposure intensity affected adjusted average FVC following 09/11/2001, we included an estimate of WTC exposure intensity based on initial arrival time at the WTC site in comparisons of adjusted average FVC during the 5 years before 09/11/2001 to adjusted average FVC during the first year after 09/11/2001. We observed substantial FVC reductions after 09/11/2001; however, the exposure intensity-response gradient between FDNY rescue workers with increasing arrival time-based WTC exposure intensities was not statistically significant ($p=0.257$). Early arrival, high intensity exposure workers experienced an average reduction of 415ml (95% CI, 394-436ml). Intermediate intensity exposure workers experienced an average reduction

of 404ml (95% CI 394-414ml). Workers with late arrival, low intensity exposure experienced an average decrement of 394ml (95% CI 374-414ml).

FVC REDUCTION AND WORK ASSIGNMENT:

In order to further substantiate that WTC exposure resulted in adjusted average spirometric decrements following 09/11/2001, we included another estimate of WTC exposure intensity based on work assignment in other comparisons of adjusted average FVC during the 5 years before 09/11/2001 to adjusted average FVC during the first year after 09/11/2001. We again observed a substantial reduction (320ml; 95% CI 297-345ml) in all WTC-exposed FDNY rescue workers after 09/11/2001 ($p<0.001$). In addition to this significant decrement, we found further FVC reductions for Fire (101ml for firefighters not assigned to SOC units, 99ml for SOC firefighters) compared to EMS workers (figure 3B; $p<0.001$). We did not find significant differences between firefighters who were and who were not assigned to SOC units.

RESPIRATORY SYMPTOMS:

We compared adjusted average FVC reduction between FDNY rescue workers with increasing symptom severity in order to determine whether objective spirometric measurements correlated with clinical complaints. Each added symptom was associated with a significant additional adjusted average FVC decrease (8ml for each symptom, 95% CI 0.2-17ml; $p=0.044$).

Table E1 – FVC Characteristics of WTC-Exposed FDNY Rescue Workers by Arrival Time-Based WTC Exposure

Arrival Time-Based WTC Exposure	**Last FVC Before 09/11/2001** (Median, Interquartile Range/Percent)			**First FVC After 09/11/2001** (Median, Interquartile Range/Percent)		
	Liters	***Percent Predicted***	***Percent Below Lower Limit of Normal***	***Liters***	***Percent Predicted***	***Percent Below Lower Limit of Normal***
Early Exposure N=1,660	5.02 (4.43-5.58)	93 (85-103)	18.5	4.60* (4.07-5.15)	86* (78-95)	36.8*
Intermediate Exposure N=8,185	5.08 (4.52-5.68)	95 (86-104)	16.0	4.70* (4.17-5.25)	88* (80-97)	31.6*
Late Exposure N=1,921	4.95† (4.29-5.57)	95 (86-104)	17.0‡	4.56*,† (3.95-5.18)	88*,‡ (79-97)	32.1*,†
Total	5.03 (4.45-5.63)	95 (86-104)	16.8	4.65 (4.10-5.21)	88 (80-96)	32.7

*-$p<0.001$ between last measurement before and first measurement after 09/11/2001 within exposure group (paired t-test for FVC in liters or percent predicted; McNemar's test for percentage below lower limit of normal)

†-$p<0.001$ between early, intermediate and late exposure groups (ANOVA for FVC in liters or percent predicted; chi square for percentage below lower limit of normal)

‡-$p<0.05$ between early, intermediate, and late exposure groups (ANOVA for FVC in liters or percent predicted; chi square for percentage below lower limit of normal)