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Evaluation of Pulmonary Function among Workers Engaged in the Manufacture of Hydraulic Fracking Ceramic Proppant

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Evaluation of Pulmonary Function among Workers Engaged in the Manufacture of Hydraulic Fracking Ceramic Proppant

by

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
with a concentration in Toxicology and Risk Assessment
Department of Environmental and Occupational Health
College of Public Health
University of South Florida

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Keywords: proppant, unconventional gas, horizontal drilling, spirometry, NHANES III, carbo ceramic

DEDICATION

This dissertation work is dedicated to my mother, lawyer, Syeda Morjina Khatun, who always encouraged me to fight against all the odds and to do my best, to my uncle Syed Torab Ali Sojol who was my greatest inspiration and passed away in June, 2013, to my father Dr. Habibur Rahman, my brothers Dr. Niat M Rahman and Shahriar Rahman Dipon, and my friends who were always loved me and be there for me unconditionally. I would also like to dedicate the dissertation to my great inspiration in the school; Dean Donna Petersen for her positive vibe for me towards the degree.

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ABSTRACT

Workers involved in hydraulic fracking processes are exposed to various types of chemicals and dusts in their workplaces, such as proppants, which hold open the fissures created in the fracking process. Recently, ceramic proppants have been developed that may be less hazardous to workers than traditional proppants. Pulmonary function testing of workers producing ceramic proppant was used to assess the potential inhalation hazards of ceramic proppant. Male workers (n = 100) from a producer of ceramic proppant were evaluated with pulmonary function test data collected and evaluated using The American Thoracic Society (ATS) acceptability criteria. A comparison group was selected from the Third National Health and Nutrition Examination Survey (NHANES III) spirometry laboratory subset. No pulmonary function deficits were found in the worker group in comparison to the NHANES III population. Multiple linear regression analysis showed that the mean FEV1 and FVC values in workers were 0.11 and 0.08 liters respectively, and were greater as compared to the NHANES III population. Curiously, an FEV1/FVC ratio of less than 0.8, when compared to the NHANES III group, produced an odds ratio of 0.44 in worker group, indicating less risk of preclinical pulmonary dysfunction. Overall, exposure to ceramic proppant was not found to produce an adverse impact on pulmonary function in workers engaged in the manufacture of ceramic proppant.

CHAPTER ONE:

INTRODUCTION

1.1 Hydraulic Fracturing

Hydraulic fracturing, also known as hydraulic fracking, is defined as "the process of fracturing subterranean rock by the injection of water into existing fissures at high pressure, usually in order to facilitate the passage of fluid (esp. oil or gas) through an otherwise impermeable barrier" (Evensen et al., 2014). In 2010, approximately 80% of energy source used worldwide was fossil fuel (IEA., 2011).The reserve sources of conventional gas and oil are continually decreasing due to increasing energy demands (API., 2010). Scientist are continuously looking for alternative resources to meet the global energy demands of the 21st century. Recovering gas and oil from deep wells in ways safer for workers and area residents alike poses challenges to meet the increasing modern lifestyle need (GEAS., 2011a; GEAS., 2011b).

In hydraulic fracking, fluids are injected under high pressure inside wells to break up less porous or less permeable rock, so as to increase the rock's permeability and obtain the access to the trapped gas. Large amounts of water, proppant, and chemicals are inserted into the wellbore at the beginning of hydraulic fracking process. The chemicals used for the fracking process play multiple roles, such as bacterial growth prevention, reduction of well mineral scaling and facilitation of pumping proppant deep inside the wells as well as inside fissures formed due to fracture (King., 2012; API., 2010). Any consideration of which proppant to use must include knowledge of the proppants' potential interactions with hydraulic fracking chemicals, and the proppant's ability to withstand high pressures and hydraulic forces; The choice of proppant must also pose the lowest possible health threats to workers and area residents.

1.2 Proppant

Proppant are tiny granules which settle in fissures either as a single layer or as a closed pack form to ensure continuous gas or oil collection (Mader., 1989). Ceramic and sand are the two primary type of proppants used in the industry. Aluminum, resins, and "ultralights" are used to a lesser extent, due to their chemical interactions, cost issues and limited availability. The geological forces that increase with the depth and that may distort the cracks are controlled by the mechanical strength that is provided by the proppants. The permeability nature of the proppants avoid the obstruction of the oil and gas flow when extracted from the well. Certain processes such as densification and higher aluminum percentage in proppant have been used to increase the strength of proppants. But such properties of higher density which make them harder and therefore expensive than more porous proppants (O'Brian.,2014). All proppants, however, have distinct strengths and weakness associated with their use.

1.2.1 Sand Proppant

Currently, hydraulic fracking primarily uses sand due to its cost effectiveness and availability. Sand can hold the crack or fissures formed by fracking processes that operate at low pressures, generally around 4,000 pounds per square inch (psi) (O'Brian., 2014).Silica sand is the most common type of proppant used in hydraulic fracking process (Nebergal et al., 1972).

Use of sand gained early popularity in hydraulic fracking because of its availably in nature and its comparative lower costs (O'Brian., 2014).

Despite its advantages in cost and availability, sand use is susceptible to collapse inside rock fissures. The fine silica particles produced due to collapse may migrate and can block the fissures created in the hydraulic fracking process. Hence, the collapsed particles obstruct the flow of oil and gas passage through the propped fissure. Closure stress inside rock varies with the depth of drilling processes, making sand proppant less than ideal for holding open fissures more than 5,000 feet below from soil surface (Youngman et al., 2002).

Exposure to silica in workers who are involved in hydraulic fracking procedure is very common, making hydraulic fracking workers a vulnerable group for developing diseases related to respirable crystalline silica. From 2000 to 2005, 162 deaths were from occupationally-induced silicosis (Rosenman et al., 2003). To ensure safer workplaces, the use of proppants containing less silica is preferential. The use of non-silica ceramic proppants are under examination to determine its feasibility as a sand replacement (Wu and Wu., 2012).

1.2.2 Ceramic Proppant

Ceramic proppant is considered as a safer choice of proppant in structure in comparison to sand proppant and other available proppants such as aluminum, and resin proppant (Wu and Wu., 2012). The production method of ceramic proppant includes the removal of silica from the proppant. Ceramic proppant was tested against acid resistance, corrosion, strength, conductivity, crush test, heat test against other types of proppants. The results showed that ceramic proppant has better acid resistance, heat resistance, and less production of residual product (by crush test) in comparison to other types of proppants. Because of its long durability, ceramic proppant remains inside shale rock fissure for many years and can therefore increase the production of oil and gas.(Fuss-Dezelic., 2014; Wu and Wu, 2012; Carbo Ceramics Inc, 2015).

1.3 Purpose of the Study

The purpose of this study is do determine whether exposure to ceramic proppant in an industrial setting poses a pulmonary health threat to hydraulic fracking workers. As the particulate matter produced by ceramic proppant contain little to no silica, the expectation is that ceramic proppant can become the preferred choice of proppant for health reasons. Up to this point, very few studies have been conducted on this issue; thus this study can certainly provide novel information.

The research questions of the study are as follows:

- Do workers who are manufacturing ceramic proppant and exposed to ceramic proppant have decreased pulmonary function as compared to general population?
- Is ceramic proppant an additional hazard in hydraulic fracturing or fracking procedure?

1.4 Hypothesis

The null hypothesis for this study is that there is no difference in pulmonary function in ceramic proppant workers and the general population.

CHAPTER TWO:

LITERATURE REVIEW

2.1 Hydraulic Fracturing

The worldwide need for energy in increasing. The highest energy consumer in the world is China, followed by the United States; Japan, Russia, and India are the other major consumers of energy (Enerdata.,2012).There is a continuous search for alternative energy which is environmental friendly, cost efficient, and safe for the countries as well as the industries. Cleaner energy alternatives include natural gas, hydropower, and nuclear energy. The higher proportion, around 24% of world's energy, is achieved from natural gas while hydropower and nuclear energy provides 6% and 5% of world's cleaner energy, respectively (EIA.,2012). Natural gas is considered to be an alternative source for cleaner energy as compared to fossil fuels. Unlike other fossil fuels, natural gas burns in the absence of unwanted by-products, emitting less carbon dioxide than coal or oil during combustion. Over the years, natural gas has emerged as a vital energy source (Finkel and Hays., 2013).

2.1.1 Unconventional and Conventional Gas

Unconventional and conventional gas, both forms of natural gas, are differentiated by their geophysical locations and extraction method. Presently, the major portion of natural gas is collected from conventional deposits. In conventional deposits, natural gas is trapped in porous rocks like sandstone and is released spontaneously after drilling. However, unconventional gas cannot be extracted freely when drilled like conventional gas. To collect unconventional gas, it is necessary to break open ("fracture") the rocks containing unconventional gas. Hydraulic fracking is currently the principle industrial method by which unconventional gas can be collected from less permeable rock sources, such as from coal beds, tight sands and shale (IEA., 2012, Finkel and Hays., 2013). Enough unconventional gas exists to increase gas resources from 13% of the 2009 global energy base to 25% worldwide by 2035, indicating it's potential as a viable alternative fuel source (IEA, 2011). Figure 2.1 shows the recoverable unconventional gas distribution in the world.

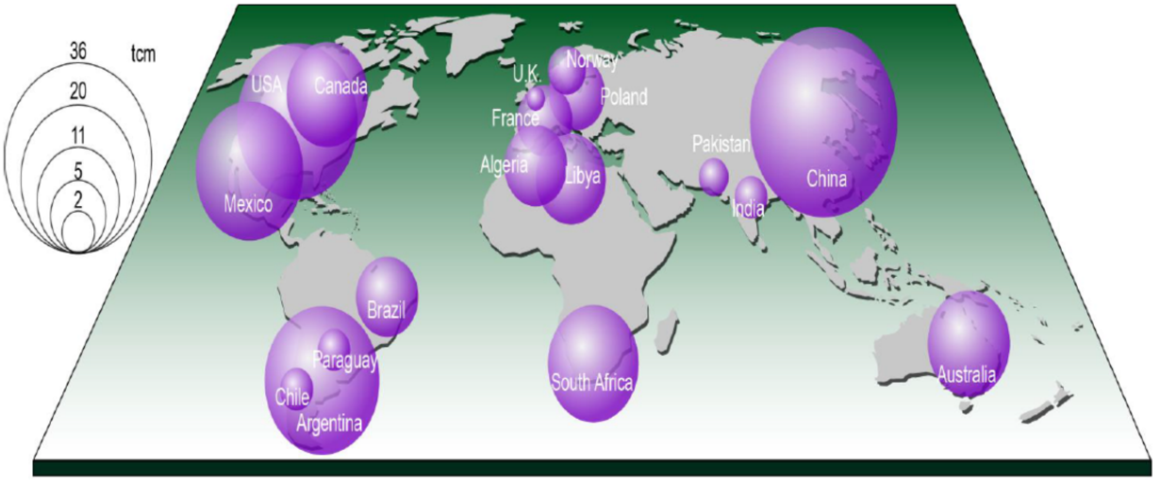

Figure 2.1: Worldwide recoverable deposit of unconventional gas in trillion per cubic meter. Reproduced with permission of the UNEP Global Environmental Alert Service (GEAS). Data source: Royal Society, 2012, cartography by UNEP/GRID-Geneva.

2.1.2 Hydraulic Fracking Procedure

As stated previously, hydraulic fracturing is performed by injecting large volumes of fluids of various viscosities and chemical makeup, combined with proppant, at high pressure and sufficient rates that break impermeable rock in two wings. To collect conventional gas or oil from permeable source, a vertical drilling of nearly 5000 to 7000 feet is needed (US EIA., 2012:PIOGA., 2013).

The amount of shale gas trapped inside the US shale presently is approximately 750 trillion ft^3 (IEA., 2011). Hydraulic fracking require horizontal drilling to collect unconventional gas. To collect unconventional gas both vertical and horizontal drilling are necessary. The deepness of vertical drilling well for hydraulic fracking is nearly 5,000 to 12,000 feet, which is approximately twice the deepness compared to conventional well (Zoback et al.,2010).When the desired depth is reached, water, sand and chemicals are added to the well under high pressure. This process fractures the concrete casing and nearby rock, allowing oil and gas to flow into the wellbore (PIOGA, 2013).Horizontal drilling need to be continued for several hundred feet to reach the gas or oil deposit. Horizontal wellbore depth can be 1,000 feet to 10,000 feet. (Zoback et al., 2010). Oil and gas comes out to the external surface due to the natural pressure.

Fissures which occur naturally are also essential to collect gas and oil from less porous or impermeable shale. These naturally occurring fissures expand during hydraulic fracking process. In addition, new fissures ("hydro fractures") are created under the increasing hydraulic pressure within the wellbores. A typical hydraulic fracking well may have such hydro fractures ranging from 10-20 in number (Zoback et al., 2010).

Chemicals used for the hydraulic fracking are mixed on the top of wellbore, just before or during insertion or injection into the well. The chemicals include gelling and foaming agents, friction reducers, crosslinkers, breakers, pH adjusters, biocides, corrosion inhibitors, scale inhibitors, iron control chemicals, clay stabilizers and surfactants (King., 2012; NYS DEC., 2011; API., 2010; Stringfellow et al., 2014). These chemicals play important roles such as bacterial growth prevention, reduction in well mineral scaling and ease of pumping proppant deep inside the well as well as inside the fissures formed due to fracture (King., 2012; NYS DEC, 2011; API., 2010).

Other than water and chemicals, the other major component to hydraulic fracking is proppant. Proppant prevents the hydro fractures from closing once well pressure is released. Figure 2.2 shows the creation of fissures formed by the hydraulic fracking procedure.

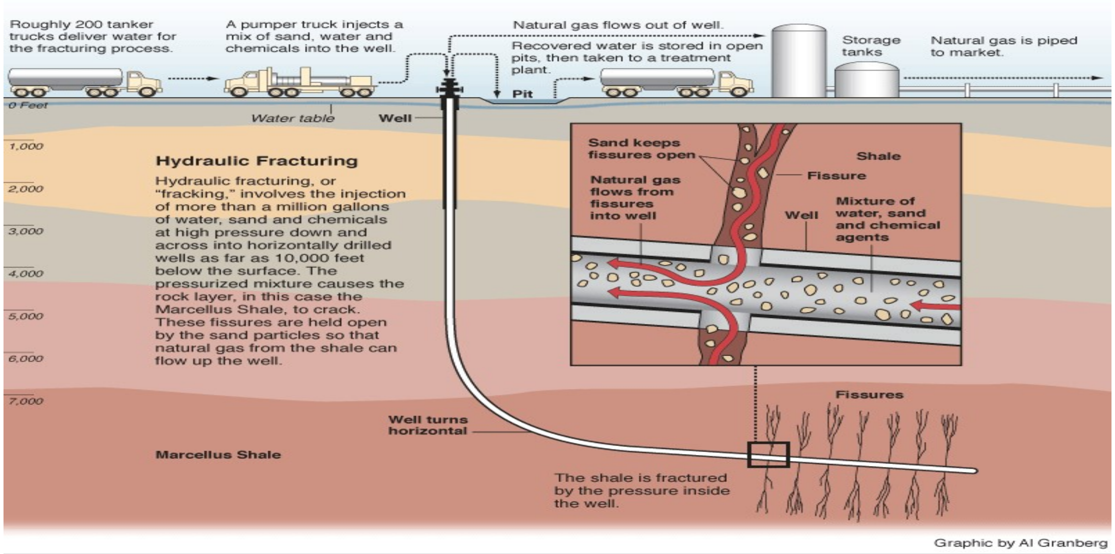

Figure 2.2: Hydraulic fracking procedure. (Propublica, 2015).Reproduced with the permission from propublica.org.

2.2 Proppant

Proppants are necessary contents of hydraulic fluid as it keeps the created fractures open and through that opening trapped gas and oil flows from the less permeable rock. Proppant use in hydraulic fracking has been continually increasing, with 10 times more proppant in use in 2013 than in 2004 (Fuss-Dezelic., 2014). Sand or other synthetic proppant are used to keep the fissures open in hydraulic fracking treatment (Weaver et al., 2005).

For a proppant to be effective, certain characteristics are required. Proppant is subjected to compressive forces from the rock and from transverse shear forces along with the fracture length including from the drag force exerted by the flowing fluid. The transverse forces may remove the proppants from the pack which may result in the impacting surface facilities well erosion and hinder production (Parker et al., 1999; Asgian and Cundall., 1995; Milton-Tayler., 1992).

Testing of proppants for suitability involves various tests like single particle compression, crush, particle settlement and conductivity tests (Kaufman et al., 2007). Currently ultra-light weight materials have been considered as a single material type or as a mix of hard-soft materials (Rickards et al., 2006; Card et al., 1995). The mixtures also have different particle shapes such as prismatic, rounded ceramic or walnut shell (Kulkarni and Ochoa.,2012).

Synthesized proppants are complex mixtures of ceramic phases produced by processing kaolin or bauxite at high temperature over 1000°C. Each proppant is manufactured specifically for desired mechanical strength and durability to withstand ambient stresses. Some other factors include desired temperatures and chemical properties of the fluid (Raysoni and Weaver.,2012).

2.2.1 Sand Proppant

In a patent application by O'Brian (2014), sand was stated to be cheaper and a more easily available type of proppant, but it cannot hold the fissures open for long time because of low closure forces (4,000 pounds per square inch or less). He stated that the strength of sand proppant can be increased to 8,000 pounds per square inch (psi) to hold the fissures open inside rock. The lowered ability of sand proppant to keep the fissures stay open for long time is a major disadvantage. Also, sand proppant does not have the ability to hold the fissures open in high pressure situation inside the rock. Nonporous characteristic is another disadvantage that prevent desired flow of oil and gas in the well created by hydraulic fracking process. Cost effectiveness of sand proppant is a desirable feature during hydraulic fracking procedure but above mentioned disadvantages may lower its significance to be used as an ideal proppant for hydraulic fracking procedure

Silica contains respirable crystalline fiber which cause occupational lung diseases. Sand which is a form of quartz mainly contains silica in the form of silicon dioxide (SiO2). Ceramic proppants are manufactured from bauxite or kaolin minerals. When kaolin and bauxite materials undergo high temperature condition, the process is known as "sintering". By using sintering, kaolin and bauxite materials are changed to crystalline forms. High temperature converts kaolin to cristobalite. Cristobalite compound is a type of crystalline silica which is hazardous while kaolin causes less health hazards (Fuss-Dezelic., 2014).

2.2.2 Aluminum Proppant

Certain properties such as ability to keep the newly formed and old fissures open for long time makes an ideal proppant. Various types of aluminum proppant such as high density, intermediate density and lower density aluminum proppant are also used as proppant in hydraulic fracking procedure. Adding aluminum in proppant or aluminum type of proppant makes it stronger as compared to sand. High density aluminum with bauxite type of proppant gives higher strength (75% to 90%) inside fissure in comparison to sand type of proppant. The amount of silica in the lightweight sintered aluminum proppant is still a health hazards that may occur due to silica exposure. The specific gravity of high density proppant is approximately 3.5gm/cc (gram per cubic centimeter) or more. The specific gravity of intermediate density aluminum proppant is 3.1 to 3.4gm/cc and 2.20 to 2.60 gm/cc, respectively. In intermediate and lower density proppant the density is reduced by decreasing aluminum content from the proppant. In higher density proppant aluminum content is approximately 75% to 90%. Intermediate and low density aluminum proppant contains 50% to 75% and 25% to 40% of aluminum, respectively. In intermediate density aluminum proppant, kaolin clay is added to decrease the aluminum density up to 50% (Weaver et al., 2005).

More pumping fluid with high viscosity characteristics and increased rate of pumping is required to pump high density aluminum type proppant inside well during hydraulic fracking process. Pumping high viscosity fluid with faster rate prevents required deposition of aluminum proppant in fissures inside the rock. The entire process with aluminum proppant is more labor intensive and costly. In addition, high density aluminum proppant can cause more abrasion and hence can damage the hydraulic fracking fluid and the working equipment (Weaver et al., 2005).

Low density aluminum proppant is considered as a better type of proppant than high density and intermediate density proppant. This is due to the fact that it does not require more viscous fluid to pump and it needs less pumping fluid rate as compared to high viscosity and intermediate viscosity fluid. Less viscous fluid and less pumping rate criteria are cost effective for low density proppant as well as no damage occurs into the instruments used from low density. Decreasing aluminum content also reduces strength of proppant. The increased amount of use of silica is responsible for lower strength in low density aluminum proppant. For the above reasons, scientists are continuously researching for ideal proppant with low density, higher strength, cost effective, and that can sustain for long time in hydraulic fracking procedure (Weaver et al., 2005).

The oil and gas industries try to keep the fractured channel open for longer times (lifetime) because of the high cost involved in the entire procedure. Recently, it has been noticed that these types of fractured channels may degrade because of the gel damage, proppant pack damage due to fracture fluid, back-flow of proppant, proppant crushing, and fines interruption (Weaver et al., 2005). In addition, the fracture flow is regulated by the inner effect of the proppant used, including proppant concentration and kind of proppant (Barree et al., 2003). All the above factors may change the total effectiveness of the hydraulic fracture procedure (Lee at al., 2010).

2.2.3 Resin Proppant

Resin coated proppant is another type of proppant used in hydraulic fracking beside sand, aluminum, and ceramic proppant. Hussian et al. (2003) stated that resin coated proppant helps to keep the fissure open and prevent sand exposure by covering as filter. Precured and curable are two kind of resin coated proppant. Resin coated precured proppant is a crosslinked substrate. Resin coating provides crush resistance characteristics by the coating method. Curable type of resin coated proppant is better choice as it is already cured and do not form mass in comparison to precured resin coated proppant under pressure and high temperature. The disadvantage of resin coated proppant is the flow back of proppant material during cleaning the wellbore (Hussain et al., 2003). Resin coated proppant works cannot work efficiently in higher temperature and may collapse when inner temperature is more than 130°F (Armbruster et al., 1988).

2.2.4 Ultralight Proppant

Ideal proppant should not be heavy in weight. Heavy weight proppant need more viscosity of proppant fluid and faster rate to pump the proppant. Ultralight proppant is the most widely used proppant that is composed of ceramic and resin and utilized for a broad range of applications, especially suited for moderate depth natural gas and oil (Gaurav et al., 2012). There are three types of ultralight proppants: ultralight proppant 1 (ULW 1), ultralight proppant 2 (ULW 2), and ultralight proppant 3 (ULW 3). ULW 1 (ceramic) type of proppant is the lightest proppant in comparison to ULW 2 and ULW 3. ULW 2 type of proppant is coated by resin and it contains ground walnut inside. Ground walnut hull is porous and weak in character. When walnut is coated with resin, the strength of resin coated walnut type of proppant (ULW 2) increase significantly. The resin coating is also used with sand that lowers silica exposure. The ULW 3 is a porous type of ceramic proppant. ULW 3 type of proppant is coated by resin. ULW 3 does not have impregnated characteristic which is present in ULW 1 type of proppant. In ULW 3 type of proppant, due to porous characteristics, air can be trapped in the resin covering (Gaurav et al., 2012).

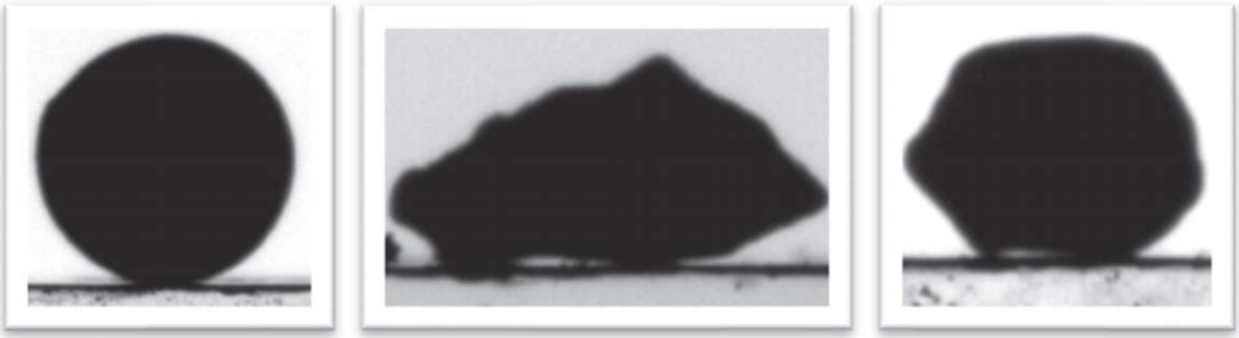

Figure 2.3: Three types of proppants: ULW 1, ULW 2, and ULW 3. Reproduced with the permission. Source: Gaurav et al., 2012.

With increase in stress, the proppant conductivity increases. The increased conductivity may range from 1 to 500 mD-ft (fracture conductivity). It decreases and later increases when proppant concentration increases for ULW1 and ULW2 types of proppant. In ULW3, the conductivity increases with the increase in concentration. ULW 1 type of proppant is considered as a better proppant in comparison to ULW 2, and ULW 3 (Gaurav et al., 2012). Table 2.1 shows bulk density, Nominal density and bulk porosity, bulk sphericity, sizes, and porosity of proppant.

Table 2.1: Different criteria of ULW1, ULW2, and ULW3 type of proppants

Criteria	**ULW1**	**ULW2**	**ULW3**
Bulk Density	0.6	0.77	1.19
Nominal Density	1.08	1.25	1.75
Sphericity	1	0.62±0.7	0.78±0.1
Proppant porosity (%)	44	36	31
Size	Spherical/round	Angular	Roughly Rounded
Porosity	High	Low	Low

The ceramic proppant produced is known for better performance and better quality that may keep required balance of contact as well as conductivity of life of the well. The ceramic proppants increases the oil and gas flow by overcoming the issues produced by sand proppant. Ceramic proppant is less expensive in comparison to aluminum proppant. In addition, because of long sustainability character ceramic proppant is considered as a better choice in terms of cost. Wu et al, (2013) conducted their experiment on ceramic proppant provided by CARBO Ceramic Inc. Use of ceramic proppant also decreases oil and gas finding and developments and expenses per barrel of oil. The ceramic proppant is considered as an ideal ceramic proppant according to world ceramic proppant standards provided by the company for the experiment (Wu et al., 2013; Carbo Ceramics Inc., 2015).

Use of ceramic proppant may result in higher gas and oil production when combined with an optimal fracture design. This may be achieved with no further increase in expenses and additional investment (Carbo Ceramics Inc., 2015). The rounded or spherical shape, uniform size, and strength of ceramic proppant characteristics were studied by Society of Petroleum Engineers. The study showed that these characteristics of ceramic proppant were responsible for more production in comparison to other types of proppants such as resin or sand. The other benefits of using ceramic proppant includes more production, more estimated recovery, increase return rate, with higher results on initial investment, along with better recovery times (Carbo Ceramics Inc, 2015).

2.2.5 Ceramic Proppant

Proper proppant selection requires crush, conductivity, compression, and settlement tests. Ceramic and resin coated proppant are resistant to high closure pressure inside the rock, up to 20 kilogram per square inch (ksi) without showing any sign of fracture of proppants. High density of ceramic and resin coated proppant transportation and placement are not cost effective. For this reason, ultra-light proppant such as ceramic or sand, aluminum, nut shell is preferred either as mixed form or as single form (Rickards et al., 2006; Card et al., 1995). Light weight proppant with sintered procedure that contains ceramic material may be an ideal proppant to keep the fissures open for continuous flow of oil and gas. Ceramic proppant with low aluminum content is considered as a better type of proppant. The main characteristics of light weight ceramic proppants are: specific gravity 2.61 to 2.69, density approximately 1.41 to 1.65 gm/cc, aluminum content is 32 to 39 weight percentage and silica content is nearly 52 % to 58%. Proppant size and shape is also important in hydraulic fracking procedure to keep the fissures open. Common shapes and sizes that are available are round or spherical ceramic, walnut or prismatic aluminum (Kulkarni and Ochoa.,2012). Figure 2.4 shows why ceramic proppant is considered as a better choice in comparison to sand and resin coated proppant.

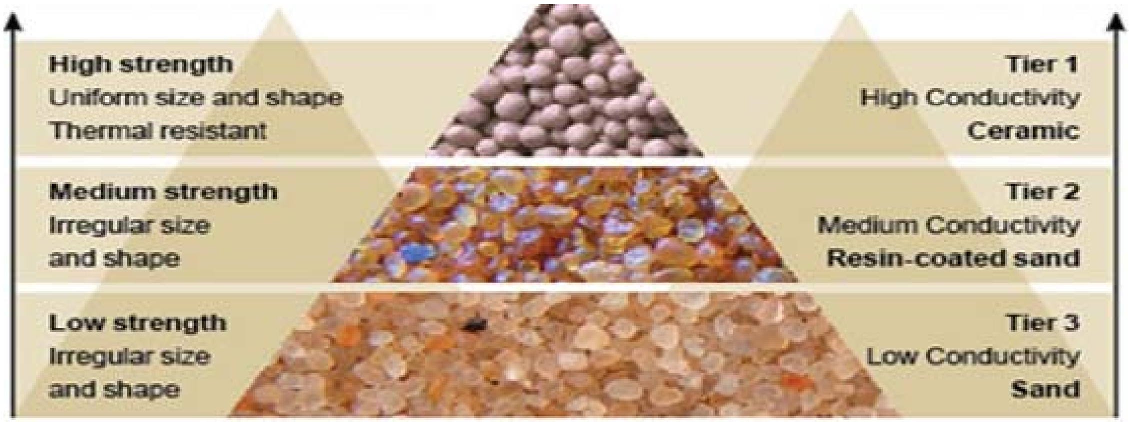

Figure 2.4: Comparison of ceramic proppant. Reproduced with the permission from CARBO Ceramic Inc.

Pure ceramic which is manmade is considered as an alternative proppant which is considered as a safer proppant since it decrease silica exposure (Fuss-Dezelic., 2014). The figure 2.5 shows the comparison of ceramics against the other types of proppant.

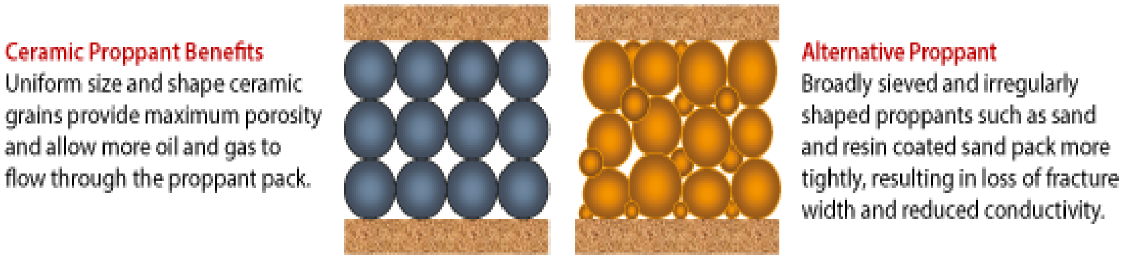

Figure 2.5: Advantage of Ceramic Proppant. Reproduced with the permission from CARBO ceramic Inc.

Fuss-Dezelic ,(2014), showed the crystalline silica contents in different types of proppants. The experiment was conducted by “Saint-Gobatin Proppants” ceramic industry. The industry measured different kinds of proppants ability to generate respirable crystalline silica in the laboratory. This multistage experiment included quantitative and qualitative measurement of crystalline silica present in dust. The crystalline silica particle was collected from dust and analyzed under microscope by X-ray (XRD) procedure to confirm whether the crystalline silica particles are respirable or safe for workers. According to NIOSH, respirable crystalline silica are defined as dust that enter the lung’s gas exchange area. Crystalline silica lees than 10µm (micro meter) in diameter can enter the lung. The research examined the collected crystalline silica under electron microscope to determine the particles size and to estimate the measurement of crystalline silica particles if they the meet the NIOSH criteria of “respirable crystalline silica”. The experiment included light weight ceramic proppant (economy), bauxite based intermediate proppant (intermediate), bauxite based ceramic proppants (lightweight), sand, and clay based proppant.

The experiment showed that sand and clay based proppants generates respirable crystalline silica which is more than 10µm in diameter. Thus, ceramic proppant that contains clay and sand should not be used in hydraulic fracking procedure due to high generation of respirable crystalline silica which can cause occupational lung diseases. Intermediate and light weight bauxite based ceramic proppant showed respirable crystalline silica from the dust samples and is thus considered as a safer proppant in workplaces. Ceramic proppant such as intermediate and light weight type bauxite type ceramic proppant can be an alternative and safe option for proppants for worker safety as well as it may increase production of oil and gas from hydraulic fracking procedure.

Wu et al. (2013) conducted a study on acid resistance of ceramic proppant in their laboratory. They stated that the reduced acid resistance is dependent on silica materials in the raw products. Silica can reduce acid resistance of proppant. The researcher concluded that by removing silica, acid resistance of ceramic proppant can be increased. Silica free proppant have the special characteristics of resistance to HCL-HF (Hydrochloride-Hydrofluoric) acid . If silica free ceramic proppant are used in solution for fracking, acid causes less destruction on the outer surface of proppant and the inner material do not show any kind of corrosion. The experiment showed that silicon-free outer layer is useful to protect inner layer for silica free ceramic proppant and the dense inner structure plays a vital role to resist proppant from acid corrosion. XRD (X ray powder diffraction) test was conducted with mixture with Al2O3, BaO, CaO and MgO (ABCM) system to compare the acid resistance in silica free ceramic proppants production. The test showed that silica free ceramic proppants can resist from solubility in HCL-HF mixture under SEM (Scanning Electron Microscopy). This study conducted on production of ceramic proppant showed that silica free by ABCM system has good resistance and the acid solubility is 0.73 wt%. Thus, ceramic proppant is not only useful to prevent acid corrosion, it also reduces silica exposure which cause various occupational lung diseases in dusty occupational settings.

Ceramic proppant is resistant to HCl acid but it can be corroded by HCL-HF acid mixture. Corrosion by HCL-HF acid mixture can cause less acid resistance and reduce use of ceramic proppant by the oil and gas industries. Natural quartz and ceramic particles are the common types of proppant that are in use for hydraulic fracking process. Quartz sand proppant have the properties to acid resistance. However, quartz sand proppant decreases the conductivity because of low strength and poor spherical characteristics. Ceramic proppant is a better choice in comparison to quartz sand proppant due to its better erosion, high acid resistance, high melting temperature and increased strength, and increase level of chemical inertness in harsh environment (Fang et al., 1997). Wu et al. (2012) conducted research on ceramic proppant characteristics on acid resistance and stated that acid resistance depends on silica in proppants raw materials. Silica is an amorphous material in ceramic compounds and HCL-HF acid mixture.

A study done by Schacht et al. (2000) showed that material safety influences the aluminum ceramic resistance. This is due to the sintering process that segregate the impurities. When barium carbonate reacts with aluminum oxide inside the raw material of proppant, it can increase the acid resistance of ceramic proppant. The chemical reaction of barium carbonate (BaCO3), aluminum oxide (Al2O3) and silicon di oxide (SiO2) form a complex compound BaAl2Si2O8. This complex compound have the ability to resist ceramic proppant from acid corrosion. The research found that if SiO2 can be removed it can increase the stronger acid resistance phase created by the reaction of BaCO3 and Al2O3. However the reaction of BaCO3 and Al2O3 requires very high temperature (1600 degree Celsius) to form acid resistance characteristics in ceramic proppants. By adding phosphorous pentoxide (P2O5) it is possible to create acid resistance ceramic proppant in 1,450 degree Celsius in combination with BaCO3 and Al2O3. The research showed that removing silicon product from raw materials and adding barium carbonate helps to increase the acid resistance in proppant industries (Wu and Wu.,2012).

2.3 Occupational Exposure

The National Institute for Occupational Safety and Health (NIOSH) conducted recent studies on hydraulic fracking sites and concluded that employees who are involved in fracking process may have higher risk of exposure to respirable crystalline silica. Respirable silica is the part of crystalline silica with less than 10 micrometer (µm) in diameter that have the ability to go inside the lung during inspiration (NIOSH.,2012a). The employees are exposed to respirable crystalline silica mainly from breathing air during hydraulic fracking process (NIOSH., 2012b).

2.3.1 Exposure to Silica and Health Hazard

In occupational settings, silicosis is known as one of the most common lung disease and occurs due to inhalation of silica or free crystalline silicon dioxide. Lysosomal damage occurs due to phagocytosis of silica which causes inflammatory changes and leads to fibrosis of lungs. Lung function impairment occurs with progression of disease, even after the patient is no longer exposed (Leung et al., 2012). Exposure to silica and dusts contains silica particle may alter normal histopathological characteristics of the lungs and pleura and can cause formation of pulmonary silicotic nodules, fibrosis, interstitial infiltrate, and pleural thickening. With the progression of silicosis, progressive multifocal fibrosis, pleural thickening, associated pleural invaginations are common complication occurs due to silica exposure (Salih et al., 2015). Lung cancer, COPD, and Tuberculosis can also developed due to silica exposure. There is no curative treatment for silicosis and progression of lung cancer is very poor in patients (Leung et al., 2012).

Workers with radiological presentation of silicosis scarring in lung tissue are at most risk for developing other silica-related diseases. The signs and symptoms due to silica-related diseases may have long latency periods. The approximate time to develop adverse effects due to silica-related disease is more than 20 years after the initial exposure. However, acute onset of silica related diseases may occur within a month and silicosis may develop after one year of exposure. Connective tissue disorder and tuberculosis develop sooner than other silica related diseases which have longer latency periods in persons exposed to silica. The disease with long latency periods include lung cancer, COPD and renal disease (Rosenman, 2014). Leung et al. (2012) also stated that it is important to ensure the workplace safe for workers from silica exposure and early detection of silica exposure as well as control silica in workplaces to protect the workers. Proper documentation of workers is necessary for future prevention and early detection of silicosis in workers.

Worldwide, silicosis is known as the most common occupational disease. Workers who are involved in mining, sand blasting, and construction work are at higher risk group to develop silicosis (Leung et al., 2012). Workers who are exposed to silica in workplace are at risk of many other diseases as well. Fibrotic lung related to silica exposure are: silicosis, COPD, tuberculosis, lung cancer, renal disease, connective tissue disease such as rheumatoid arthritis and scleroderma (Davis., 1996; Castranova and Vallyathan, 2000; Castranova., 2000; Castranova et al., 2002).

2.3.2 Silica Exposure of Workers in Hydraulic Fracking

The sand use in hydraulic fracking contains nearly 99% silica (NIOSH.,2012). There are 10 to 12 stages needed for a typical unconventional gas or oil extraction by hydraulic fracking process. Sometimes 40 or more stages may be needed to extract gas and oil. When stages increase for hydraulic fracking, amount of water, sand or proppant and chemicals requirement also increases. Processes that involve moving proppant along transfer belts and pneumatically filling such as displacement of many pounds of sand per stage may produce airborne dusts at the work site (Esswein et al., 2013).

Depending on the number of stages to be completed, delivery may consist of a single or multiple proppant deliveries in a single day of functioning. Sand truck transports sand or proppant in the well spot and is offloaded by operators who connect the sand delivery truck with a sand transport or sand holdings. Named as sand mover, it utilizes compacted air to pump sand over fill ports on sand move sides. A typical offloading takes average 30 to 45 minutes (Esswein et al., 2013). Sand movers deliver sand to blend truck through a motor belt assembly situated under the mover. The assembly known as dragon tail does retraction and extension, elevates, and swings. Sand mover stations are situated on the top rear and side rear of the movers that are above and side of the tail. Larger proppant loads are becoming common that require movers and a transfer (T-belt) between the sand mover and the blender truck. Sand Mover Operators generally control delivery of sand by hydraulically controlling gates that are located on the bottom of the sand mover. Sand mover operators oversee proppant that is delivered into the blender hopper or onto the T-belt and further maintain contact with blender operators and personnel in data monitoring vehicles. This is done so as to keep the proppant dry until it enters the wet section of the blender. This is done before the proppant is pumped via a manifold, piping, and finally into the bore (Esswein et al., 2013).

Various types of sand are used for the purpose of hydraulic fracking process. In spite of difference in color, shape, size and quality of sand, all types of sand contains silica, which is one of the most common earth’s crust elements and contain 99% quartz. Silica sand is the most common type of proppant used in hydraulic fracking process (Nebergal et al., 1972).

According to NIOSH there are various sources of silica dust exposures during hydraulic fracturing operations. These include dust ejected from thief hatches (access ports) on top of the sand movers during refilling operations and pulsed through open side fill ports on the sand movers. Dust may be produced by on site traffic activity or that released from the transfer belt. Other sources include dust containing silica released from operations of transfer belts between the sand mover and the blender; and that produced from the top of the sand transfer belt (NIOSH, 2012a).

One study was found that is conducted by NIOSH researcher to identify the workers who are at risk to exposure to silica. NIOSH conducted a study on workers who were involved in fracking procedure from 2010 to 2011 in Texas, Colorado, Pennsylvania, North Dakota and Arkansas to measure the exposure to silica in 11 hydraulic fracking areas. Workers were selected from 15 job titles and participations were completely voluntary. The aim of the study was to collect samples from personal breathing zone in hydraulic fracking work zone. 12 hours personalize breathing zone samples were collected for silica and other inhalable particulates. To measure humidity, temperature, and wind speed, portable weather station were used in well locations. The job titles studied for silica and other dust exposures were: T- belt operator, Sand mover operator, sand coordinator, pump truck operator, roving operator, blender operator, hydration unit operator, chemical truck operator, wireline operator, water tank operator, fueler mechanic, QC tech, Operator Data Van, and Sand truck driver (Esswein et al., 2013). Total 111 samples were collected in the study and analyzed for silica and dust containing silica. Out of 111 samples, 83.3% (93) of the samples exceeded ACGIH TLV (threshold limit value) limit, 86.5% (76) exceeded level of the NIOSH REL and 51.4% (57) of the sample exceeded OSHA PEL values for inhalable silica dust. The study showed that T-belt operator, sand mover operator and hydration unit operator were the highest exposure group. In contrast, Fueler and Roving operators were least exposed to silica dust. The study showed that, sand mover operators, T- belt (transfer belt) operators and Hydration unit operators were exposed to silica containing dust in hydraulic fracking process, which was 10 times more than NIOSH REL (Esswein et al., 2013).

In addition to respirable crystalline silica, workers who are involved in hydraulic fracking are also at risk to volatile organic compounds (VOC), diesel, radon, and hydrogen sulfide that are responsible for different types of lung diseases (Esswein et al., 2013). Fracking workers are also at risk to radiation exposure. Drilling is the essential part of fracking procedure to make whole inside the rock that contains radioactive constituents like radon, uranium and thorium. Radon, uranium and thorium are considered as naturally occurring radioactive material (EPA., 2008a; EPA., 2008b). However, for the purposes of this study, these exposures were not considered in the evaluation of pulmonary function of workers exposed to ceramic proppant.

2.4 Occupational Lung Diseases

Workers who are exposed to various toxic material in their workplace may develop respiratory diseases. Occupational lung disease changes the integrity or diameter of airways that can cause increase secretions from lung tissue, mucosal edema and airflow resistance. One of the classic obstructive disease in workplace is emphysema. Forceful expiration or expiration by a workers with emphysema can increase further narrowness of airspaces or collapse of the airways. Chronic bronchitis, and asthma are also known as obstructive type of lung disease which are common in workplace. Long term exposure to airborne contaminants leads to sensitization and causes allergic response in occupational asthma. Chronic bronchitis occurs due to recurrent exposure to dust like mineral fiber and wood dust and fumes. Ozone, nitrogen dioxide, oil aerosol. Exposure to cigarette smoking or for smoke may also lead to development of chronic bronchitis. Exposure to cigarette and other irritant substances may also develop emphysema which is a progressive disease and cause hear damage too. One of the characteristic feature of emphysema patient’s barrel shape chest of the patients (NIOSH.,2003).

Pneumoconiosis is the common restrictive lung disease in workers in dusty workplaces. Silicosis, asbestosis and black lung disease (coal worker’s pneumoconiosis) are examples of other restrictive lung diseases. Respirable dusts (inorganic) or fibers which are < 5 μm in size may develop pneumoconiosis in workers. Hypersensitive Pneumonitis is another example of restrictive lung disease also known as extrinsic allergic alveolitis. Hypersensitive Pneumonitis occurs due to exposure to organic dust which affects the alveoli and terminal bronchi. Granulomatous diseases developed restrictive lung disease due to reaction to toxin or infection. Berylliosis is the most common example for Hypersensitive Pneumonitis in workers. Other health conditions with preexisting condition may also develop restrictive lung disease in workers in workplace. Pneumoconiosis and pneumonias may show both restrictive and obstructive pattern in spirometry test in workers (NIOSH, 2003).

2.5 Spirometry Overview

In occupational settings, spirometry plays a vital role in workers surveillance respiratory health system. Spirometry play an important role in primary prevention in workplace settings where workers are exposed to dust or chemicals which can harm their respiratory health. By using spirometry results, health care expert can determine type of respiratory impairment as well as measure the effectiveness in the hazardous workplace settings. If pulmonary function test results shows an abnormality, the employee needs to be further assessed. Further assessment of respiratory function is also advised for severe decline in respiratory test as compared to previous test for the same worker (CDC.,2011a; Townsend et al., 2000). Table 2.2 shows usefulness of spirometry in the workplace settings (Miller et al., 2005).

Table 2.2: Indications for Spirometry. (Miller et al, 2005) .Reproduced with permission of the European Respiratory Society ©.

Diagnostic	To evaluate symptoms signs or abnormal laboratory test To measure the effect of disease on pulmonary function To screen individuals at risk of having pulmonary disease To assess pre-operative risk To assess prognosis To assess health status before beginning strenuous physical activity program
Monitoring	To assess therapeutic intervention To describe the course of disease that lung function To monitor people exposed to injurious agents To monitor for adverse reactions to drugs with known pulmonary toxicity
Disability/ Impairment Evaluations	To assess patients as part of a rehabilitation program To assess risks as part of an insurance evaluation To assess individuals for legal resource
Public Health	Epidemiological surveys Derivation of reference equations Clinical research

Spirometry can be undertaken with many different types of equipment's and requires cooperation between the subject and the examiner. Technical as well as personal factors may also vary the results obtained from spirometry (Miller et al., 2005).The routine steps of spirometry standardization are shown in Figure 2.6.

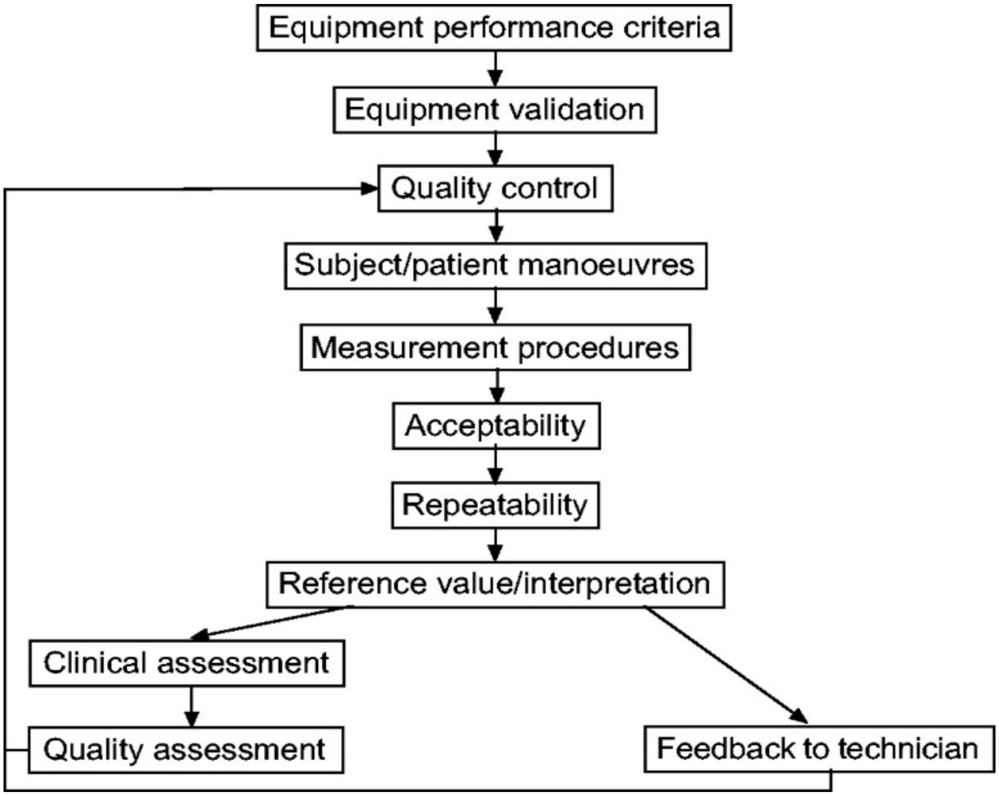

Figure 2.6: Steps of spirometry standardization. (Miller et al, 2005).Reproduced with permission of the European Respiratory Society ©.

2.5.1 Subject Consideration for Pulmonary Function Tests

Patient cooperation and any pathological condition may alter spirometry results. Patient with a history of myocardial infraction within 1 month are contraindicated for lung pulmonary function test. The other conditions pulmonary function tests should not be performed include abdominal pain or chest pain due to any cause, facial pain oral pain increased because of mouthpiece use, dementia, and stress incontinence (Miller et al., 2005).

Subjects should be in standing or sitting while performing pulmonary function test. The position of the subject during the test must be noted on the record (ATS., 1979; Townsend., 1984). Sitting position is more convenient during the test procedure, and it may help to prevent injuries from syncope-induced falling.

Subjects who are obese take deeper inspirations frequently during the standing position at the time of test. Subjects with normal weight generally provide same result with sitting or standing position. However, same position is suggested for longitudinal studies during the test procedure (Miller et al., 2005a).

Subject's weight and height needs to be recorded before the test procedure for the purpose of reference value calculation. Height is noted without shoe in standing position by using appropriate measuring instrument. Height and weight should be noted according to the respected countries measuring unit. About 87% of variance in standing height was observed in a regression equation that used age, sexual preference, race and arm length. Standard error of the estimate for height was observed from 3.0 to 3.7 cm (Parker et al., 1996; Miller et al., 2005a).

2.5.2 Laboratory Environment and Reference Values

Barometric pressure, ambient temperature and time of the day must be recorded by the recorder (Miller et al., 2005a). Barometric pressure is important as the reading by spirometer can change in different altitude, with FVC inversely proportional to altitude (Pollard et al., 1996).

Temperature plays an important role in lung function test and it is recorded directly by the preferable device. Lower temperatures are related to the exacerbation of COPD symptoms. Low temperature also decrease FEV1 and FVC readings (Donaldson et al., 1999). Temperature can be measured by typical thermometer or internal thermistor. The NIOSH software used to measure spirometry generate a warning message when difference among room temperature and spirometer's temperature is more than 3°C difference.

When subjects come in for repeat tests, the instrument and operator should be the same and the time of the test should be within 2 hours of last test. (Miller et al., 2005a). Chronic cough production and breathlessness are common symptoms that may obstruct airways at morning in obstructive diseases. Both FEV1 and FVC decrease at morning in obstructive diseases (Lewinsohn et al., 1960).

Proper hygiene and infection control procedure is mandatory during the test procedure. Selecting ideal reference value plays a vital part in pulmonary function test in lung function test interpretation. Reference values should be utilized from the same sources. American Thoracic Society (ATS) and European Respiratory Society (ERS) has created and stated the selection of reference values as well as pulmonary function interpretation in published format (Stocks and Quanjer., 1995; Quanjer et al., 1993; Cotes et al., 1993; Miller et al., 2005a).

Spirometers produce reports and printouts indicating accurate and inaccurate readings. Thus proper knowledge, spirometry pitfall understanding and adequate training is extremely important to report accurate pulmonary function test for workers. In occupational settings, both physician and other licensed Health Care Professional and technicians conduct spirometry test. Health care professionals and technician must be able to direct patient during the spirometry procedure while conducting the spirometry procedure (OSHA, 2013a).

Technicians or health care professionals who perform spirometry test should have proper knowledge to differentiate between invalid and valid results and recognize flawed curves. The National Institute for Occupational Safety and Health (NIOSH) created courses to train the individuals who perform pulmonary function tests. The course helps to prepare the participant to understand how to perform an ideal spirometry test and also provide knowledge of unacceptable maneuvers (Miller et al, 2005a).

2.5.3 Types of Spirometer

Volume spirometer and flow spirometer are the two types of spirometers commonly used to measure lung function test. Volume spirometer measures exhaled air from workers lung and flow type spirometer measures exhaled air speed and add the speeds of exhaled air to acquire exhaled air volumes. Volume time and flow volume curves can be obtained from both volume spirometer (Miller et al., 2005). Figure 2.7 provides examples of a volume-time curve for the expiration time curve, and a flow volume curve for the expiration time course (OSHA, 2013a).

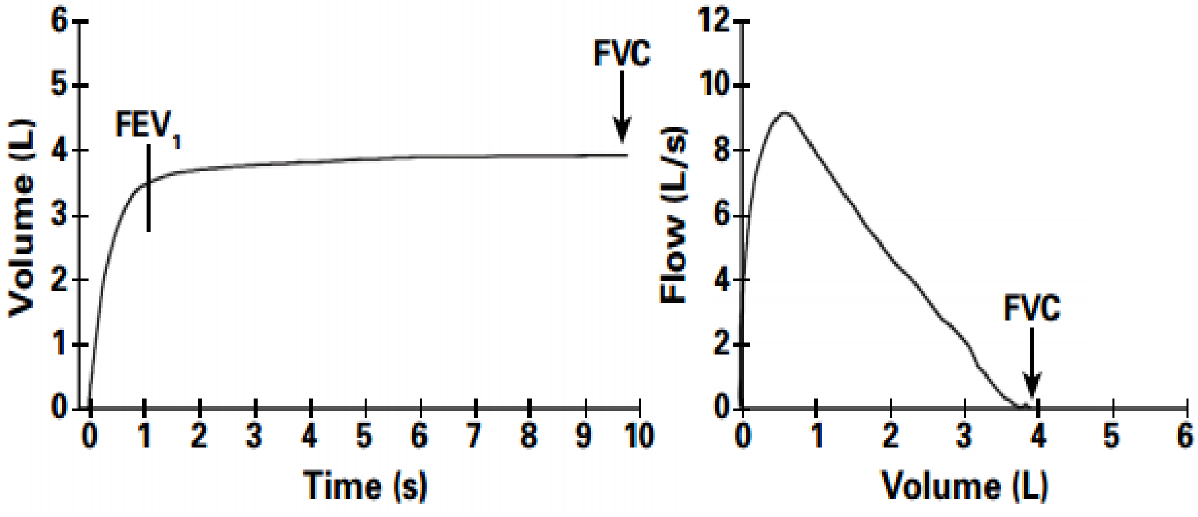

Figure 2.7: Volume-time curve in left volume flow curve in right. (Source: OSHA, 2013a).

2.6 Pulmonary Function Testing

Pulmonary Function Tests (PFT) are noninvasive diagnostic procedures. Spirometry is used to measure pulmonary function in individuals, although some PFT cannot be measured by spirometry process. Spirometry is also commonly used as lung function screening study.

Spirometer helps to measure the amount of air inhaled in and/or out and how fast the air is inhaled and expelled form lungs while breathing through lungs. Evaluation of PFT requires knowledge of personal characteristics such as age, sex, height, and ethnicity.

Changes in lung volume are measurable by spirometry. For this reason TLC and FRC cannot be measured by spirometry. Indirect methods like plethysmography or helium-dilution can be used to measure TLC, RV or FRC.

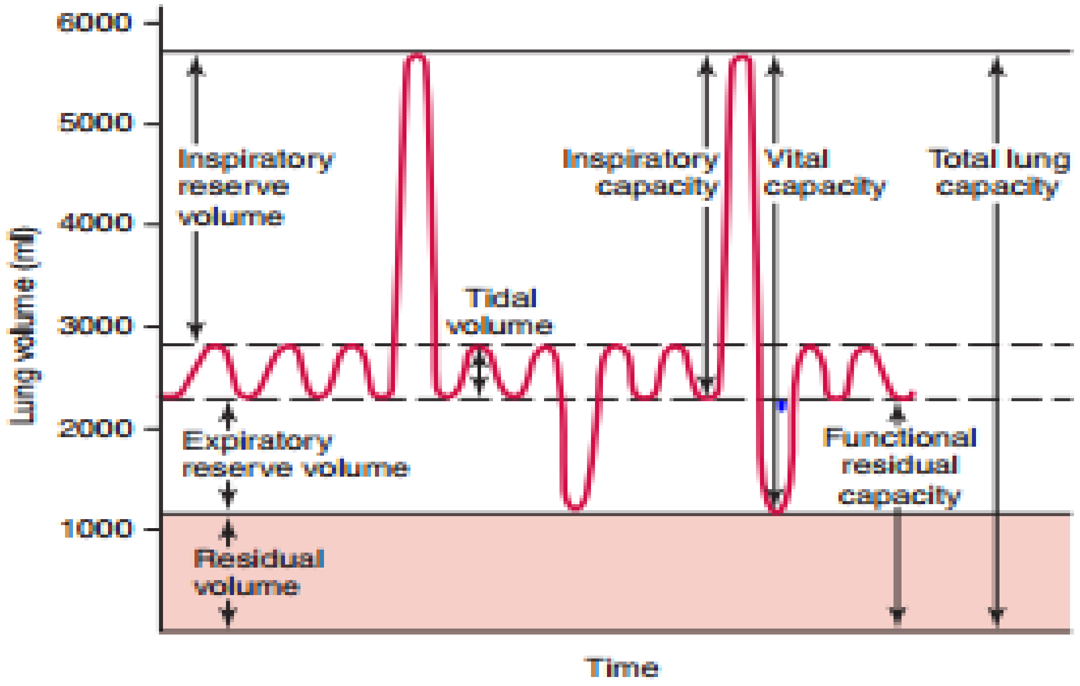

Figure 2.8: Lung Values and Capacities. Source: Pocket companion to Guyton and Hall Textbook of Medical Physiology. Hall, John.12th Edition E-ISBN:0781455711949;24 October 2014.Page no: 314.

2.6.1 Common Terms, Acronyms, and Definitions

A) Tidal Volume (TV): The amount of air inspired and expired normally in breathing. It is also referred to as minute volume or minute ventilation (Ahmed et al., 2012). Normal resting Tidal Volume is around 500 ml.

B) Residual Volume (RV): The amount of air inside the lung after a maximum expiration. The normal RV in an adult is approximately 1,200 ml (Sly et al., 2008, Wanger et al., 2005).

C) Inspiratory Reserve Volume (IRV): The additional amount of air which can be inhaled after a normal inspiration. The value of IRV in a normal person is nearly 3,500 ml (Schivo.,2012).

D) Expiratory Reserve Volume (ERV): The additional volume that can be expired after a passive expiration. Normal ERV is around 1,500 mL for a normal person (Schivo.,2012).

E) Functional Residual Capacity (FRC): The amount of air left in the lungs after a passive expiration; the neutral or equilibrium point for the respiratory system (Ahmed et al., 2012). FRC is also described as the amount of gas in lungs at the tidal position. (FRC=ERV+RV). Normal FRC is 2,700 ml (Wanger et al., 2005).

F) Inspiratory Capacity (IC): The maximum volume of air than can be inspired from FRC (IC=TV+IRV) (Wanger et al., 2005). Normal IC is 4,000 ml

G) Vital Capacity (VC): The maximum volume that can be expired after maximum inspiration (Sly et al., 2008). The normal VC is approximately 5,500 mL for normal person. VC=ERV+TV+IRV.

H) Total Lung Capacity (TLC): The amount of air in the lung after maximum inhalation. Normal TLC is nearly 6,700 mL in a normal person. TLC=RV+ERV+Vt+IRV (Ali et al, 2009).

I) Dynamic Lung Volume: To examine the dynamic ventilation function inhalation of TLC and followed by forced expiration of RV is necessary by a person. Performing a series of mentioned expiratory operation by increase strength of respiratory muscle, increase expiratory flow rate will reach to a certain level of effort. Outside this level, patient effort will not increase the forced expiratory flow rate. This procedure is known as forced the effort independence of forced expiratory flow. Elastic recoil of lungs determines the air flow rates at the time of effort independence phase of the expired flow rates. In pathological conditions, a rise of airflow resistance or increase airway wall compliance reduces the airflow rate inside lung that can be achieved in any lung volume. In contrast, increase in elastic recoil, decrease the resistance of the airway walls rise the air flow rate which can be achieved at any given lung volume. Spirometry is an important noninvasive screening tool in the PFT to measure dynamic lung volume. The important dynamic lung volumes are given below:

J) FVC (Forced Vital Capacity): The maximum volume of air can be exhaled forcefully by a person after a maximum inhalation. FVC is similar to VC (which is also known as slow vital capacity). In a normal person FVC is equal to VC. In obstructive lung disease VC is greater than FVC. In obstructive lung disorder, airways present the tendency to prematurely close along with collapse due to increased positive intrathoracic pressure at the time of forceful expiration. As a result air trapped inside the lung tissue (Ali et al., 2009).

K) FEV1 (Forced Expiratory Volume in 1 second): The amount of air that can be expired forcefully from the lung in one second after maximum inspiration. The normal range of FEV1 is approximately 80% of the FEV1 (Ali et al., 2009, Sly et al., 2008)).

L) FEV1/FVC Ratio: The ratio to observe the difference between obstructive and restrictive lung abnormalities. FEV1 decreased more significantly than FVC in obstructive lung disease and the ratio will be low. In restrictive lung disorders, FEV1/FVC ratio will be increased or normal due to the reduction of FVC (Ali et al., 2009). The normal ratio of FEV1/FVC is > 0.7 in a normal person. The changes in the older person represent the decrease elastic recoil in the lung and thus decrease FEV1/FVC ratio is common in elderly.

M) Instantaneous Forced Expiratory Flow (FEF25, FEF50, and FEF75) and the Maximum Mid Expiratory Flow (MMEF or FEF25-75): It is the flow of the expired air measured at various points of the FVC suck as 25, 50 and 75 % of the FVC. The maximum MMEF or FEF25-75 is the sum of average flow during middle half of the FVC (25% to 75% of the FVC). These measurements represent the effort independent FVC part (Ali et al., 2009). This are more sensitive but nonspecific in identifying early obstructive disease that occur that the lower lung volume.

N) Peak Expiratory Flow (PEF): The maximum amount of air at the time of forceful exhalation. PEF decrease in obstructive disease and with poor primary effort. A lesser drop in PEF is also seen in restrictive disease (Ali et al., 2009). The PEF test is use routinely at bedside to monitor asthmatic patients.

2.7 Spirometry, PFT and Lung Disease

Spirometer measure pulmonary function tests in individuals and measured the amount of air flow and volume rate in the lungs. Spirometry helps to identify obstructive, restrictive and mixed types of lung abnormalities.

2.7.1 Obstructive Lung Disease

Obstructive abnormality is defined as disproportionate decrease of maximum airflow from the lung in relation to the maximum air volume (e.g. VC) which can be moved from the lung. It causes narrowing of airway at the time of expiration and is defined by a decreased FEV1/VC ratio less than the 5th percentile of the predicted value. The common obstructive diseases are: asthma and Chronic Obstructive Pulmonary Disease (COPD). The primary alterations related with airflow obstruction in small airways are a decreasing in the terminal part of the spirogram, even though terminal part of the spirogram is rarely affected (Bates.,1989, Wilson., 1985; Pride et al., 1986; Pellegrino et al., 2005). This process slows down expiratory flow and is reflected as a concave shape on flow volume curve. The quantitative reflection displayed proportionate in greater decrease in the flow measured after 75% FVC has been breathe out (FEV75%) or in mean expiratory flow between 25% and 75% of FVC than in FEV1. These mid-range abnormalities flow measurement at the time of forced expiration are not specific for small airway disease in individual patients (Flenley., 1988).

With the progression of disease more airways are affected. In this situation, FEV1 will decreased out of proportion to the reduction in FVC (Pellegrino et al., 2005). Careful observation is necessary when FEV1 and FVC are concurrently reduced and the ratio of FEV1/FVC is normal or nearly normal. This characteristic is the parameter to measure the failure of patient to inspire or exhale air completely. FEV1/FVC ratio can be also be normal or nearly normal when patient cannot exhale properly to empty the lungs to RV. The flow volume curve will show concave towards the end of operation. In this situation, normal TLC and low FEV75 will be low. Decrease or slow VC (inspiratory or expiratory) measurement can provide a more accurate measurement of the FEV1/FVC or FEV1/VC ratio. Patchy collapse of small airways early in exhalation is other cause of this pattern (Quanjer et al., 1993; Olive and Hyatt,1972; Hyatt et al., 1973; Rodarte et al.,1975; Guerry-Forece et al.,1987). Normal TLC and increased RV can be observed in this situation. If this pattern exits, repeat spirometry is helpful after bronchodilator in a patient with a maximum and sustained strength. Major development in the FEV1, FVC or both suggests that the reversible obstruction of airflow is present (Pellegrino et al., 2005).

Apart from this uncommon situation, measurement of the volume of lung is not necessary to observe an obstructive defect. This observation may be useful to identify underlying diseases and its functional consequences. For example, increase RV/TLC ratio or increase in RV and TLC beyond upper limit of natural variability indicates the presence of bronchial asthma, emphysema or other obstructive diseases along with hyperinflation of lung (Pride and Macklem., 1986). Figure 2.9 shows different types of curves obtained from spirometry.

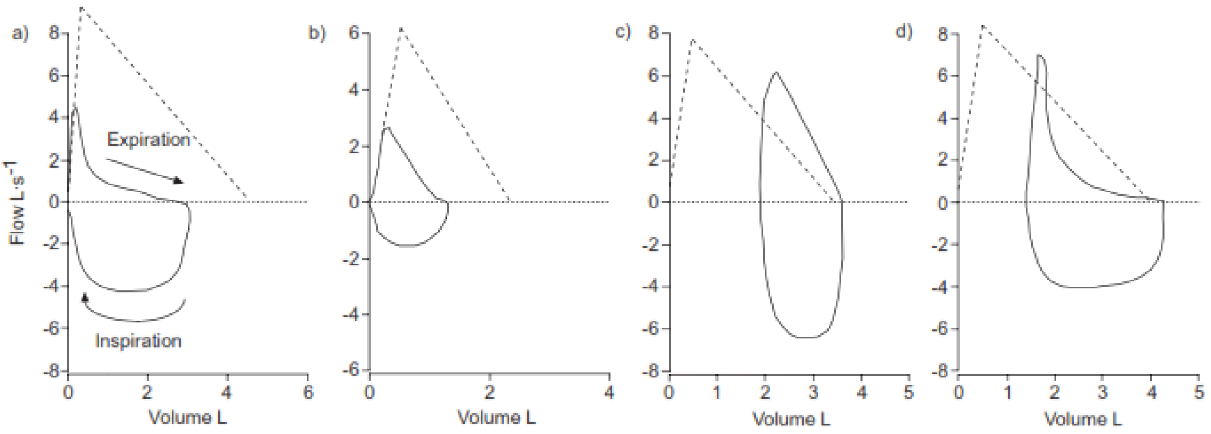

FIGURE 1. a, b) Examples of obstructive pulmonary defects with a low (a; forced expiratory volume in one second (FEV1) 38%; FEV1/vital capacity (VC) 46%; peak expiratory flow (PEF) 48%; total lung capacity (TLC) 101%) or normal (b; FEV1 57%; FEV1/VC 73%; PEF 43%; TLC 96%) ratio of FEV1/VC. In both cases, TLC is normal, and flows are less than expected over the entire volume range. c) Example of a typical restrictive defect (FEV1 66%; FEV1/VC 80%; PEF 79%; TLC 62%). The TLC is low and flow is higher than expected at a given lung volume. d) Example of a typical mixed defect characterised by a low TLC and a low FEV1/VC ratio (FEV1 64%; FEV1/VC 64%; PEF 82%; TLC 72%). – – – –: predicted flow–volume curves; ——: observed inspiratory and expiratory flow–volume curves (as indicated in a).

Figure 2.9: Examples of Different Types Curve Produced by Spirometer. Reproduced with permission of the European Respiratory Society ©. European Respiratory Journal Nov 2005, 26 (5) 948-968,DOI: 10.1183/09031936.05.00035205 Published 1 November 2005.

2.7.2 Restrictive Pulmonary Disease

Restrictive pulmonary disease is characterized by an increase in elastic recoil- a decrease in lung compliance which is measured as a decrease in all lung volumes. Decreased VC along with low lung volumes are characteristic features of restrictive lung disease. In restrictive disease, the TLC reduction goes below the 5th percentile of the predicted value with FEV1/VC in normal range. The restrictive ventilatory pattern presentation can be identified when VC is decreased, and the FEV1/VC is >85% to 90%. Convex pattern in flow volume chart will appear in this case. However, a decreased VC and normal or slightly increased FEV1/VC sometimes occur by submaximal inspiratory or expiratory efforts and/or patchy airflow obstruction in peripheral part, as well as decreased VC by itself do not prove a respiratory restrictive defect. This is related with a decreased TLC not more than half the time (Aaron et al., 1999; Glady et al., 2003).

2.7.3 Mixed Pulmonary Abnormalities

A mixed abnormality in ventilatory defect is characterized by mixture of both obstructive and restrictive pattern. Mixed abnormalities are defined as when TLC and FEV1/VC are below 5th percentile of their relevant predicted values. As because VC can be likewise reduce in restrictive and obstructive disease, the appearance of restrictive pattern in obstructive case cannot be inferred from general measurement of VC and FEV1 (Aaron et al., 1999; Glady et al.,2003; Dykstra et al., 1999).

2.8 NHANES for Use in Population Studies

The National Health and Nutrition Examination Survey (NHANES) was started in the US to evaluate nutrition and health condition of children and adult. It is an exclusive survey that merges physical examination and interviews and it is considered as one of the most important database for the National Center for Health Statistics (NCHS). NHANES data has a unique advantage that it can be used in epidemiological studies that may help in guiding policies, initiating and maintaining health programs and expand health and nutrition knowledge. The NHANES III survey was conducted from 1985 to 1994 that included people from different institutions. Nearly 20 institutions or organizations collaborated with NHANES III study. It is the seventh study in a series conducted on the national level since NHANES was started in 1960.

The first 3 studies were conducted under the name of National Health Examination Surveys (NHES), in 1960. (NCHS., 1965; NCHS., 1967; NCHS., 1969). In 1970 the name has been changed to NHANES (Miller., 1973, Engel et al., 1978, McDowell et al., 1981). NHANES surveys play a vital role in public health and help to develop public health policy accordingly in the US (NCHS., 1994).Since, 1999, NHANES became a continuous survey, and approximately 5,000 peoples are examined by the NHANES program each year. Multiple counties account for these 5,000 people with 15 of them being surveyed each year. Due to national coverage it became a nationally representative sample (NCHS., 2015). For our study, the primary population from NHANES III group was 130,691. NHANES III population was merged with raw spirometry data after excluding participants < 18 years and females, the final population was 45,569. After excluding multiple observation per subjects the total population was 8,701. In NHANES III total population after excluding people less than 61 inch and greater than 76 inch, the population chosen was 8039. After deducting weight, and due to missing data in NHANES III population final sample size was reduced.

Comparison to NHANES III data with other health related study population plays a vital role to measure in different disease as well as occupational surveillance. NHANES III data was used as comparison group for different studies related to various health issues including respiratory health. NHANES III data is not only used in the US, it is also used by other countries because of the reliability and accuracy of the NHANES III data collection, strength, storage, and availability.

Various studies have included NHANES and NHANES III population as their comparison group. The study by Schwartz. (1989) studied the NHANES III data to evaluate the relationship of lung function with air pollution exposure. The study used the NHANES data since it is drawn from multiple locations of US and from varied sample of population. Another study by Hu and Cassano. (1998) studied the effect of vitamins C and E along with selenium on the lung function. The data was collected from NHANES III because it represented the vast array of population from multiple cities and thus was a good representative of US population. Another study done by Brown et al. (2005) studied the effect of smoking on the incidence of asthma and lung cancer. They used NHANES II population as the reference group to estimate the relative risk ratios. NHANES data is a reliable sample since it had a huge number (9087) of adults that were representative of the population studied.

Schols et al. (2005) conducted a study on mortality of underweight cohort who were suffering from chronic obstructive pulmonary disease (COPD). The study population was selected with patients suffering from moderate to severe COPD. These patients were selected from pulmonary rehabilitation center while screening since 1988 to 1999. The study group was selected from Netherlands and one of the reason was to select the population that the group was stable and did not go through any intervention that could change body composition such as: vigorous exercise or nutritional intervention in between follow up period (5 years) and during the screening time. Low fat mass and functionally active fat free mass was compared with NHANES III population from US. Physical disability risk for the subjects were also used from NHANES III disable population's cut off point that was set by Janssen et al. (2000). NHANES sample provided a reliable data to compare the study population. The study concluded that body fat is an important biomarker for COPD to measure patients staging and severity of the disease.

Hnizdo et al. (2002) conducted a study on occupational group employed in various industries in the US. The main objective of the study was to measure the magnitude of COPD in occupational exposure in the US population. Researchers used 9,823 subjects from NHANES

III. COPD was expressed as FEV1 <80% and FEV1/FVC <70% predicted value. The odds was noticed to increase in certain occupations such as plastic, rubber, leather, textile mill, gas station, office building factories, agriculture, construction, transportation, health care and armed forces industries. About 9,000 sample population for comparison from NHANES III provided a suitable match to compare with the study population.

Studies also included NHANES population as comparison group for non-pulmonary purpose. Tinggaard et al. (2012) conducted a study on male puberty markers. In 2005 American puberty data was collected for boys and was reviewed by an expert panel. The expert panel could not established any time trend for the puberty timing in boys from the existing data. The NHANES III data and the findings were used for the study. The study concluded by using NHANES III population that testicular volume is the potential markers in evaluating onset of male puberty.

Wade et al. (2014) performed a research on prevalence of osteoporosis estimation in developed countries. The countries included in the study were: UK, Germany, France, Spain, Italy, USA, Canada, Japan, and Australia. The study included male and female more than 50 years old and used BMD (bone mineral density) of spine/spine or total hip. The NHANES III age and BMD reference group data was used. NHANES III relevant ratios were used for missing data from other countries. Population estimation was conducted for the year 2010 and data was collected from published sources, US census, NHANES III and from United Nations. The study observed that NHASES III in USA had completed BMD data as compared to other countries. NHANES III contained BMD measurement for 14,646 males and females. The study concluded that approximately 49 million people form industrialized countries who are suffering from osteoporosis, met the disease criteria published by WHO. The study suggested that the NHANES

III population was most reliable data to compare countries so as to measure prevalence of osteoporosis.

Goff et al. (2005) conducted a research on schizophrenic patients. 689 patients who had 10 years risk for CHD were selected for the study and the subjects were selected from the CATIE (Clinical Trials of Antipsychotic Treatment Effectiveness) program. The comparison group was selected from NHANES III study by matching age, sex, and ethnicity or race. Total of 687 subjects were selected from NHANES III for comparison purpose. The study result showed that 10-year CHD was higher in female and male schizophrenic patients than the NHANES III control group. Lamberti et al. (2006), conducted a research on comparing the prevalence of metabolic disorders in outdoor patients who were suffering from schizophrenic disease and those on clozapine medication for treatment. The diseased group were compared with NHANES III matched group for assessment. 93 outdoor patients were compared with 2,701 persons and matched by body mass index, age, and, ethnicity. The study finding showed that metabolic syndrome prevalence was higher in the patients who were on clonazepam as compared to NHANES III sample.

CHAPTER THREE:

METHODOLOGY

3.1 Overall Design

The study population was selected from CARBO Ceramic Inc. (CARBO). Inclusion criteria for the CARBO workers was being of age 18 years and older, and having undergone spirometry testing. Age, sex, race, weight, smoking history and height information were recorded for each subject to identify possible confounders that may have had an effect on pulmonary function. FEV1, FVC, and FEV1/FVC data for the CARBO workers was selected from spirometry records provided by the Occupational Health and Surveillance System (OHSS), a medical care company that specializes in providing medical support personal for testing and compliance needs. NHANES III comprised the control population, and the same inclusion criteria and personal information were selected as was for the CARBO workers. Similarly, FEV1, FVC, and FEV1/FVC were taken from the raw spirometry data publicly available for NHANES III population. The study was approved by the University Of South Florida Institutional Review Board (IRB). The IRB number of the research was 000001348.

3.2 CARBO Population

For the study sample CARBO workers were selected as our research was on ceramic proppant. CARBO Ceramic Inc., located in Georgia, is one of the largest ceramic companies producing ceramic proppant for worldwide use (Wu et al., 2013). CARBO workers wear respirators because of their occupational exposure to ceramic proppant, and are also subject to periodic spirometry testing to monitor any changes in their pulmonary functions (CDC 2011a). Spirometry records for 316 CARBO workers were made available for the study through OHSS. After assessing the records for inclusion criteria, agreement with ATS spirometry criteria and the removal of duplicate entries, 101 subjects remained for statistical analysis: 100 male workers and 1 female worker. The female worker was culled from the dataset because of the limited statistical power for categorization by gender, leaving a final dataset of 100 male workers

3.3 NHANES III Population

The comparison group was selected from the NHANES III Raw Spirometry group, which included pulmonary function tests for 130,691 people. The file of raw spirometry data was merged with the Adult Household file from NHANES III record to obtain the same behavior and demographic as was available for the CARBO workers. The comparison group from NHANES III was restricted by age in the same manner as the CARBO workers. Pulmonary function tests that were acceptable by ATS criteria were taken for the statistical analysis; those not acceptable were removed from the data set. Because in NHANES III data, FEV1 and FVC values were measured in milliliters, the values were multiplied by 1000 to allow unit-appropriate comparisons with the CARBO spirometry results.

3.4 Measurements by Spirometry

The Spirometry testing for all subjects was conducted according to the guidelines from ATS. NIOSH trained the technicians and supplied equipment to the site. NIOSH was also responsible for collecting raw spirometry data from the pulmonary function test. Questionnaires were also used to collect data on individual's respiratory health.

Koko spirometry protocol was used for the pulmonary function testing of the CARBO workers. Minimum 3 attempts were performed by the subjects for spirometry and the best attempt was taken and were compared with the comparison group for statistical analysis.

Subjects were asked to breathe normally with a resting tidal pattern followed by maximal inspiration. Participants performed the 5 to 8 "blows" according to the spirometry protocol. The spirometry results that did not met the ATS inclusion and exclusion criteria were further reviewed with a physician before a final decision to exclude was made.

The acceptability for a good spirometry requires a good start of the procedure whereby a person takes a full inspiration at the start of the test. The end of test criteria helps to determine an acceptable FVC effort. The two recommendation for end of test criteria are given as follows (Miller et al., 2005): "The subject cannot or should not continue further exhalation. Although subjects should be encouraged to achieve their maximal effort, they should be allowed to terminate the maneuver on their own at any time, especially if they are experiencing discomfort. The technician should also be alert to any indication that the patient is experiencing discomfort, and should terminate the test if a patient is becoming uncomfortable or is approaching syncope. The volume–time curve shows no change in volume (<0.025 L) for ≥ 1 s, and the subject has tried to exhale for ≥ 3 s in children aged <10 yrs and for ≥ 6 s in subjects aged >10 yrs." (Miller et al., 2005).

The standard acceptability criteria for spirometry tests should include:

1. Person at full inspiration at the start of the test (a "good start")
2. Continuous exhalation without hesitation

3. Maximum effort during the test
4. No unsatisfactory start like start with hesitation or false start
5. EV (Extrapolated volume) is <5% of FVC or 0.150L, whichever value is more or greater
6. No coughing between 1st second of maneuver that may affect FEV1
7. No early cessation of exhalation
8. No closure of glottis or hesitation during the test that may obstruct the airflow, it prevents to achieve accurate FEV1 or FVC
9. No leak and obstruction in the mouthpiece
10. No extra breathing during the test

The duration of the test should be 6 seconds for an adult, or until there is a plateau in the volume time curve or the individual is not able or should not exhale further (Miller et al., 2005).

Usually the spirometry curve must meet numbers 1, 5 and 6 above for acceptable result; however an acceptable curve required to meet all the above criteria (Miller at al., 2005, ATS., 1995). The repeatability criteria are required to decide if > 3 acceptable procedures are needed to achieve an acceptable FVC. Acceptable repeatability is met when the largest and the next largest FVC difference is ≤ 0.15 L and between the largest and next to largest FEV1 difference ≤ 0.15 L. In total, 8 manoeuvers can be performed by a participant for an acceptable and reliable test. (Hankinson and Bang., 1991; Miller et al., 2005).

3.5 Lung Function Tests

Spirometry measures FEV1, FVC, and FEV1/FVC ratio and helps physician determine normal or abnormal condition of respiratory health. Table 3.1 shows the definition, unit of measurement, and normal range of FVC, FEV1, and FEV1/FVC ratio.

Table 3.1. Overview of FVC, FEV1, FEV1/FVC ratio

Measured Feature	Definition	Unit of Measure	Normal Results
FVC (Forced Vital Capacity)	The maximum volume of air can be expired forcefully by an individual after a maximum inspiration.	Liters (l)	Approximately 80%
FEV1 (Forced Expiratory Volume in 1 second)	The amount of air that can be expired forcefully from the lung in one second after maximum inspiration.	Liters (l)	Approximately 80%
FEV1/FVC Ratio	A comparison value used to identify the difference among obstructive and restrictive lung abnormalities.	N/A	70% or greater

The Spirometry test was conducted according to the guidelines from American Thoracic Society (ATS). Participants performed the blows (5 to 8) according to the spirometry protocol. NIOSH trained the technicians and supplied equipment to the site. NIOSH was also responsible for collecting raw spirometry data from the pulmonary function test. A questionnaires were also used to collect data on individual's respiratory health. The age of all the participants who went for spirometry were from 8 years and over (ATS.,1987). For our study we selected participants who were equal or more than 18 years and underwent spirometry tests.

3. 6 Data Analyses

The primary variables measured were: age, height, weight, smoking status, and race. Since weight has no known impact on pulmonary function so weight variable was removed. After excluding weight variable the final data set used for NHANES III population was 6662 people and 100 people were from CARBO workers group. In addition, the missing data from NHANES III that did not correspond with our CARBO data was removed, resulting in decrease of population from 8039 to 6662. For primary analysis weight variable was included to see any role of weight in workers pulmonary function. Since weight did not have any significant impact on workers pulmonary function, for our final data set weight variable was removed. Thus, our total sample decreased from 8039 to 6662 for NHANES III population for missing data as well as weight variable was removed. All the information was recorded from the data provided by OHSS for CARBO workers. 316 workers data were recorded at first with spirometry and demographic information. ATS guideline were followed for acceptable pulmonary function test. The best values of FEV1, FVC, and FEV1/FVC ratio were taken from the spirometry record.

After merging variables name was made similar for both NHANES III and CARBO workers. NHANES III codes were renamed for the purpose of similar names for data analysis. The table 3.2 shows the variable codes renamed from NAHNES III for data analysis purpose.

Table 3.2 Code for NAHNES III Variables

Variable	Code
Age	HASGEIR
Weight	HAM6S
Height	HAM5S
Smoke (pack-years)	HAR1
Race	DMARACER=1, Then white DMARACER=2, Then black

3.7 Statistical Analyses

The student’s t-test was used to compare lung function in CARBO workers group. With the NHANES III (standard population) group by using mean values were generated for FVC and FEV1 as well as the significant differences were measured. Further analysis was conducted by stratification of median height, median age, and smoking status. Multivariate linear analysis was conducted to estimate which factors are the most predictive of lung function for FEV1 and FVC outcomes. Multivariate analysis was evaluated for the variable as predictors of lung function outcomes. The variable evaluated included: age, height, smoking history (pack years) and race was analyzed by multivariate analysis. To evaluate lung obstruction, studying a preclinical FEV1/FVC ratio was done by logistic regression. In clinical practice, FEV1/FVC ratio is in use to determine the obstructive diseases. We took FEV1/FVC ratio < 0.8 rather than 0.7 which is considered as a preclinical precursor since <0.7 value indicates abnormal lung function in pulmonary impairment. Our study evaluated the worker population for lung function deficits at the higher end of the normal FEV1/FVC of 0.80.

Along with lung function ratio, odds ratios was estimated for each of the independent variables in the data set. Categories for independent variables were defined as above and below median height and median age, nonsmokers vs those with a smoking history. The cut off point for p-value for statistical significant were set at <0.05 for all analysis. SAS version 9.4 was used for statistical analysis.

CHAPTER FOUR:

RESULTS

4.1 Final Sample Population

As stated in the methods sections, the original data set for the CARBO workers included 316 subjects. After excluding those without adequate spirometry results, the sample set was reduced to 101. As there was only a single female, the decision was made to exclude her data to prevent any skew resulting from gender effects unequally represented. The final sample set for CARBO was therefore 100 subjects.

The original NHANES III data included 8039 subjects. A preliminary analysis was performed using weight as a variable, but no effects were noted. Therefore, subjects who met only the inclusion criteria for weight were excluded. Females were excluded as well to match the gender makeup of the CARBO population. Finally, subjects who were missing values for the age, height, race, and smoking history were excluded. The final sample set for NHANES III used for this analysis was therefore 6662 subjects.

4.2 Univariate Analysis

For our study the study group was CARBO population with PFT data. The study population included workers ≥18 years old with maximum and minimum heights of ≤76 and ≥ 61 inches respectively.

4.2.1 CARBO Workers

Table 4.1 shows the smoking status in percentage of CARBO workers who answered "yes" or "no" to the smoking question. Those answering "no" were in the majority, showing over 2:1. Table 4.1 also shows that the majority of the CARBO worker population identified themselves as "white" while rest identified themselves as "black", and none identified themselves as "other".

Table 4.1: Smoking History and Race in CARBO Workers Sample (N=100)

Smoking		Race	
Yes (%)	31	White (%)	85
No (%)	69	Black (%)	15

Table 4.2 shows the mean, standard deviation, median, minimum and maximum values of age, height, and weight of the CARBO population.

Table 4.2: Mean, Standard Deviation. Median, Minimum and Maximum value of Age, Height and Weight of CARBO workers (N = 100)

CARBO workers	Mean	Std. deviation	Median	Minimum	Maximum
Age (in years)	40.0	8.6	39.0	24.0	64.0
Height (in inches)	70.2	2.5	70.0	61.0	76.0
Weight (in pounds)	197.4	29.4	195.0	145.0	275.0

4.2.2 NHANES III Population

For this study the comparison group was NHANES III population with PFT data.

NHANES III Workers total population included workers ≥18 years old with maximum and minimum heights of ≤76 and ≥ 61 inches respectively.

Table 4.3 shows the percentage of smokers in the NHANES III population was greater (62.8%) in comparison to nonsmokers. Table 4.3 shows the percentage of race in NHANES III population. As with the CARBO worker population, the greatest percentage of subjects identified themselves as "white". The remaining NHANES III population had a higher percentage identifying themselves as "black", leaving only a comparatively small population in the "other" race category.

Table 4.3: Smoker/nonsmokers in NHANES III data (N=8039)

Smoking History		Race	
Yes (%)	62.8	White (%)	69.1
No (%)	37.2	Black (%)	27.6
		Others (%)	3.3

Table 4.4 shows the mean, standard deviation, median, minimum and maximum values of the age, height, and weight of the NHANES III population.

Table 4.4: Mean, Standard Deviation, Median, Minimum and Maximum value of Age, Height and Weight NHANES III sample

NHANES III	Mean	Std. deviation	Median	Minimum	Maximum
Age (in years)	49.3	28.0	46.0	19.0	90.0
Height (in inches)	68.9	2.9	69.0	61.0	76.0
Weight (in pounds)	177.5	33.0	175.0	85.0	450.0

4.3 Comparison of CARBO workers and NHANES III: Pulmonary Function Results

The comparison of the mean values of FEV1 and FVC in general and by stratification are shown in Figure 4.1 through Figure 4.18. Stratification by smoking status, median height, median age, and race was done to determine their association with the FEV1 and FVC measurements. The means of FEV1 and FVC for smoking, for above and below median height, of above and below median age, and by race for both NHANES III comparison group and CARBO study population were inconsistently statistically significant depending on the strata in question.

The mean values of FEV1 and FVC values were statistically significant between the study population (CARBO workers) and the comparison population (NHANES III). Both mean values of FEV1 and FVC for smoking, median heights of above and below 69 inches and median age less than 39 years were also statistically significant. The mean value of FVC when median age ≥ 39 was found statistically significant between the comparison and study group while the mean value of FEV1 was not. The mean value of FEV1 and FVC for black sample population as well as the white sample population had no statistically significant association between NHANES III and CARBO population.

Table 4.5 provides overall measurements for the FEV1 and FVC of both the NHANES III and the CARBO workers. Graphic results are shown in Figures 4.1 and 4.2. The means of the FEV1 and FVC were statistically significant (p value <0.05) for CARBO workers.

Table 4.5: Mean FEV1 (l), FVC (l) for NHANES III and CARBO Workers

Population	Total no.	Mean FEV1	FEV1 95% CI	P value	Mean FVC	FVC 95% CI	P value
NHANES III	6662	3.3	3.30-3.35	<0.0001	4.3	4.30-4.35	<0.0001
CARBO	100	3.8	3.66-3.92		4.8	4.63-4.94	

Figure 4.1 shows that the mean FEV1 of the NHANES III was 3.3 and of the CARBO workers was 3.8 with p <0.0001.This indicates that the mean difference of 0.5 between the FEV1of these two samples was statistically significant. The CI (Confidence Interval) of NHANES III was 3.30-3.35 which means that 95% of the time the mean 3.3 lies in the interval. The CI of CARBO workers was 3.66-3.92 which means that 95% of the time the mean 3.8 lies in the interval.

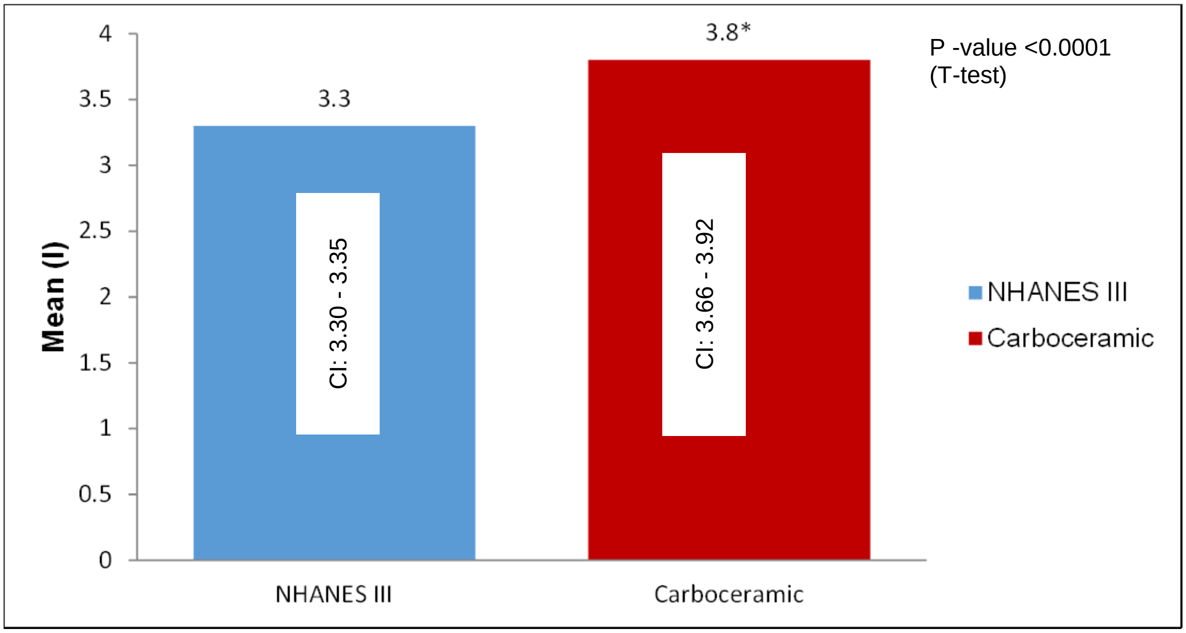

Figure 4.1: Mean FEV1 for NHANES III and CARBO Workers (*indicates that the value is statistically significant)

Figure 4.2 shows that the mean FVC of NHANES III was 4.3 and CARBO workers was 4.8 with a p value of <0.0001.This indicates that the mean FVC difference of 0.5 between CARBO workers' and NHANES III was statistically significant. The CI of the CARBO workers' mean FVC was 4.63-4.94, which means that 95% of the time the mean 4.8 lies in the interval. The CI of NHANES III FVC was 4.30-4.35, which means that 95% of the time the mean 4.3 lies in the interval.

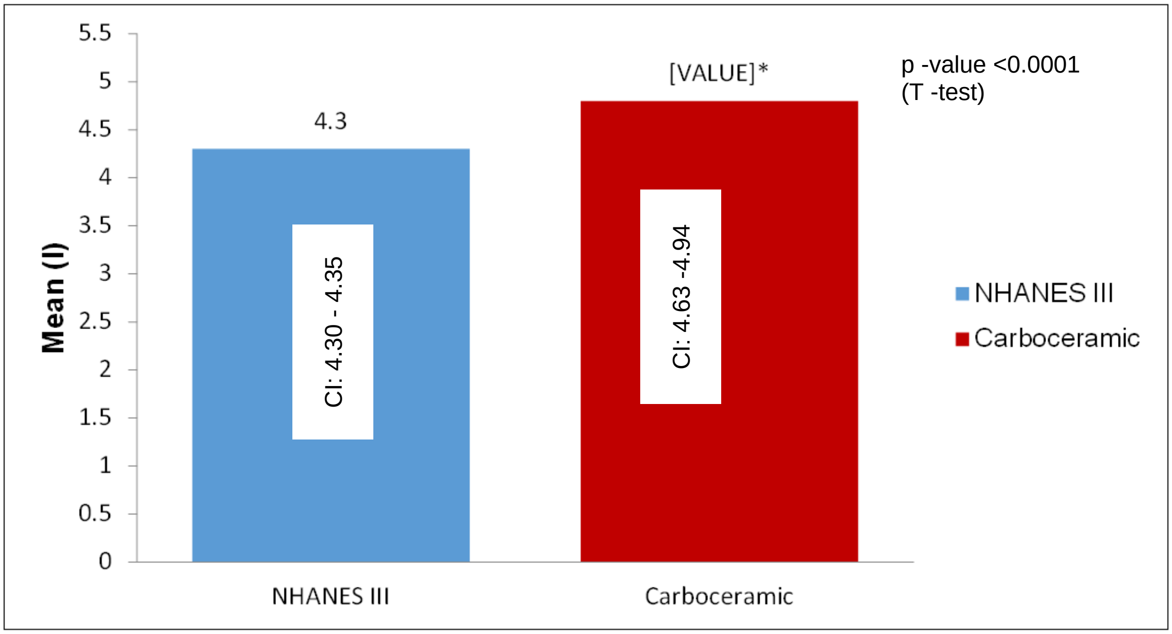

Figure 4.2: Mean FVC for NHANES III and CARBO Workers

Table 4.6 shows the comparisons of NHANES III and CARBO workers FEV1 and FVC for subject indicating that they were smokers. The means of the FEV1 and FVC were statistically significant (p value<0.05) for the CARBO workers who self-defined as smokers.

Table 4.6: FEV1 (l) and FVC (l) for NHEANES III and CARBO Workers for Smokers

Population	Total	Mean FEV1	FEV1 95% CI	P value	Mean FVC	FVC 95% CI	P value
NHANES III	4165	3.2	3.15-3.21	0.01	4.2	4.20-4.27	0.03
CARBO	31	3.5	3.26-3.82		4.6	4.28-4.87	

As seen in Figure 4.3, the mean FEV1 of the NHANES III smokers was 3.2 and of the CARBO workers was 3.5, with p value of 0.01. This indicates that the mean FEV1 difference of 0.3 was statistically significant. The CI of the mean FEV1 of the NHANES III for smokers was 3.15-3.21, which means that 95% of the time the mean 3.2 lies in the interval. The CI of mean FEV1 of the CARBO workers who were smokers was 3.26-3.82, which means that 95% of the time the mean 3.5 lies in the interval.

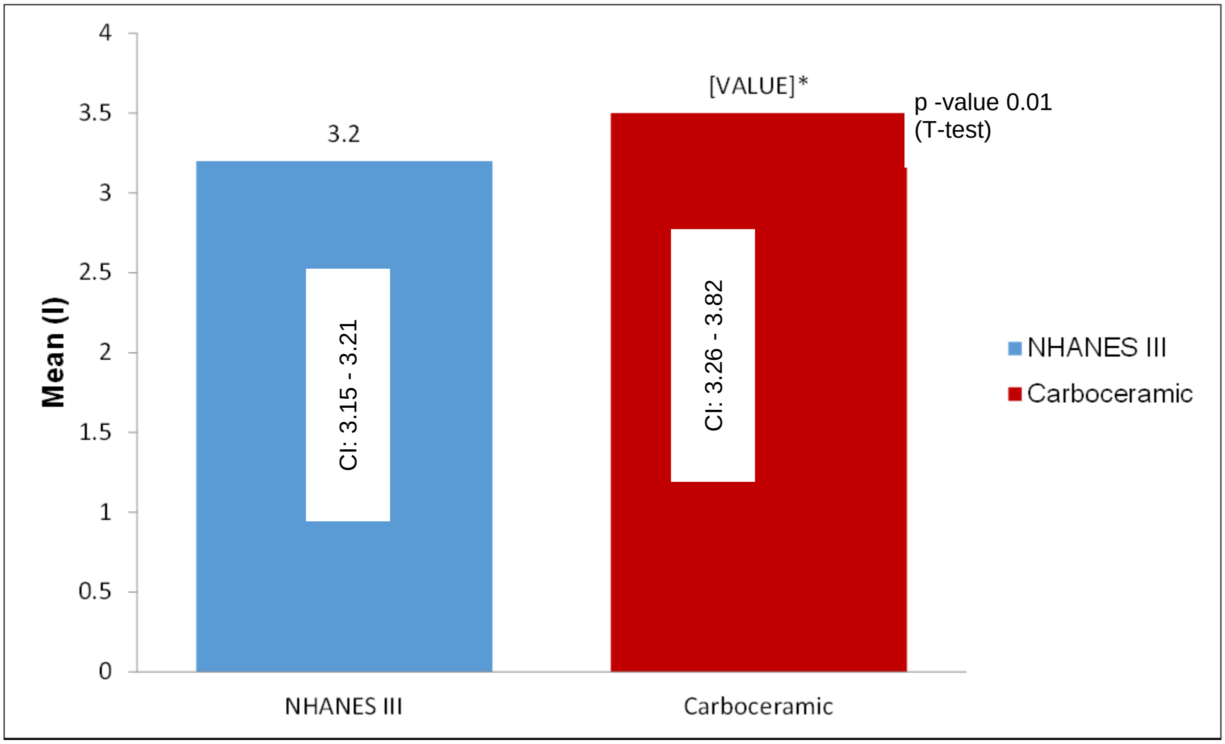

Figure 4.3: FEV1 Comparison for NHANES III and CARBO workers when Smoking=Yes

As seen in figure 4.4, the mean FVC of the NHANES III smokers was 4.2 and of the CARBO workers who were smokers was 4.6, with p value of 0.03.This indicates that the mean FVC difference of 0.4 was statistically significant. The CI of the mean FVC for the NHANES III smokers was 4.20-4.27, which means that 95% of the time the mean 4.2 lies in the interval. The CI of CARBO workers who were smoker was 4.28-4.87 which means that 95% of the time the mean 4.6 lies in the interval.

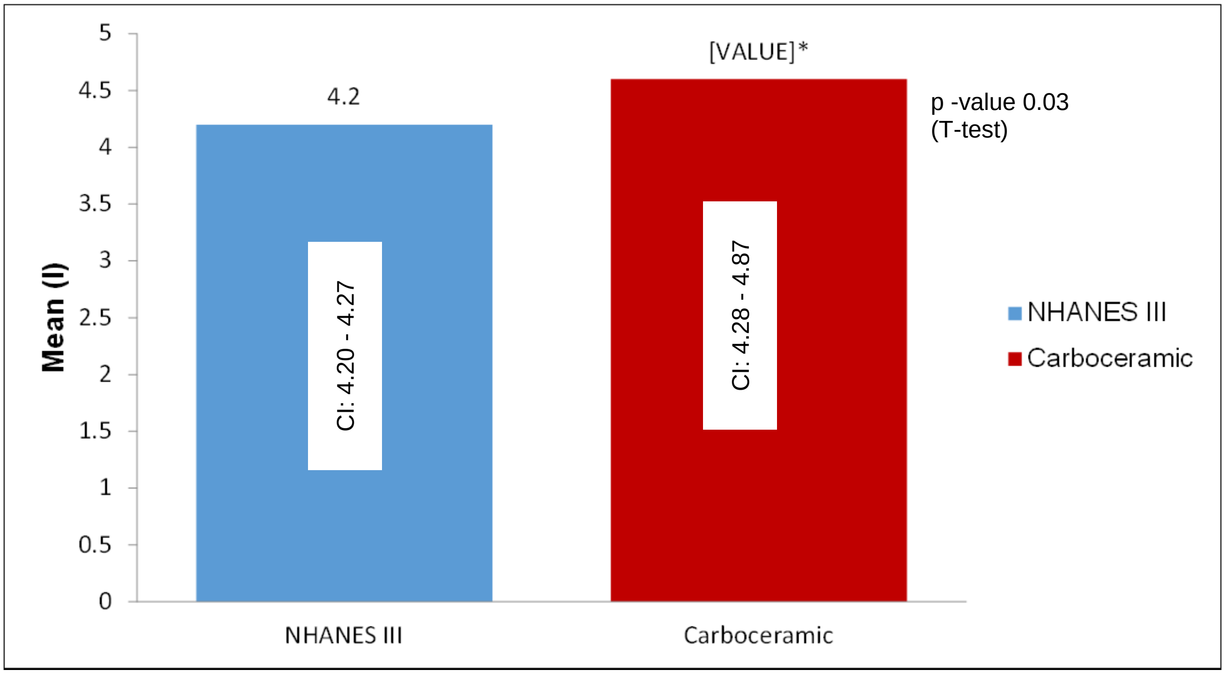

Figure 4.4: FVC Comparison for NHANES III population and CARBO Workers when Smoking=Yes

Table 4.7 shows the comparison of NHANES II and CARBO workers FEV1 and FVC for subjects indicating that they were non-smokers. The means of the FEV1 and FVC were statistically significant (p value <0.05) for the CARBO workers who self-identified as non-smokers.

Table 4.7: FEV1 (l) and FVC (l) in NHEANES III and CARBO Workers for Nonsmokers

Population	Total no.	Mean FEV1	FEV1 95% CI	P value	Mean FVC	FVC 95% CI	P value
NHANES III	2498	3.6	3.52-3.59	<0.001	4.5	4.42-4.50	<0.001
CARBO	69	3.9	3.76-4.04		4.9	4.69-5.06	

As seen in Figure 4.5, the mean FEV1 of the NHANES III non-smokers was 3.6 and of the CARBO workers who were smokers was 3.9, with p value <0.001.This indicates that the mean FEV1 difference of 0.3 was statistically significant. The CI of the mean FEV1 of the NHANES III for non-smokers was 3.52-3.59, which indicates that 95% of the time the mean 3.6 lies in the interval. The CI for the mean FEV1 for the CARBO workers who were smokers was 3.76-4.04, which means that 95% of the time the mean 3.9% lies in the interval.

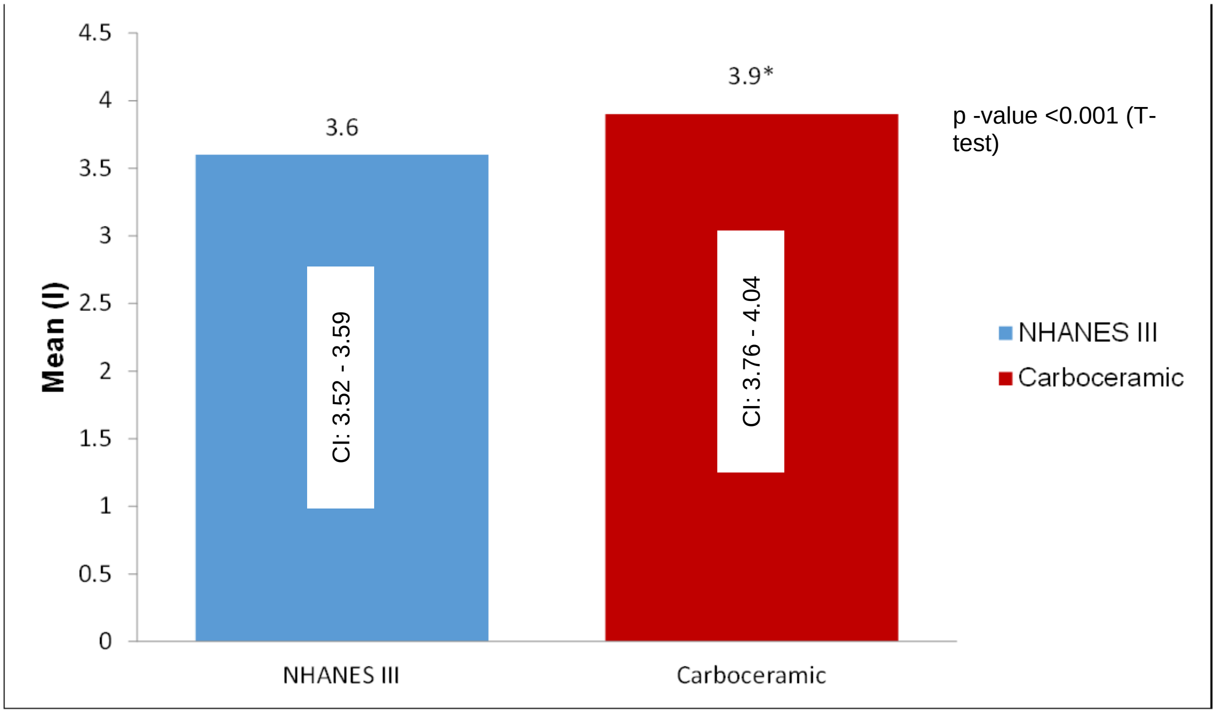

Figure 4.5: FEV1 Comparison for NHANES III and CARBO Workers when Smoking= No

As seen in Figure 4.6, the mean FVC of the NHANES III non-smokers was 4.5 and of the CARBO workers who were non-smokers was 4.9, with p<0.001. This indicates that the mean FVC difference of 0.4 was statistically significant. The CI of the mean FVC for the NHANES III smokers was 4.42-4.50, which means that 95% of the time the mean 4.5 lies in the interval. The CI for the mean FVC of the CARBO workers who were smokers was 4.28-4.87 which means that 95% of the time the mean 4.6 lies in the interval.

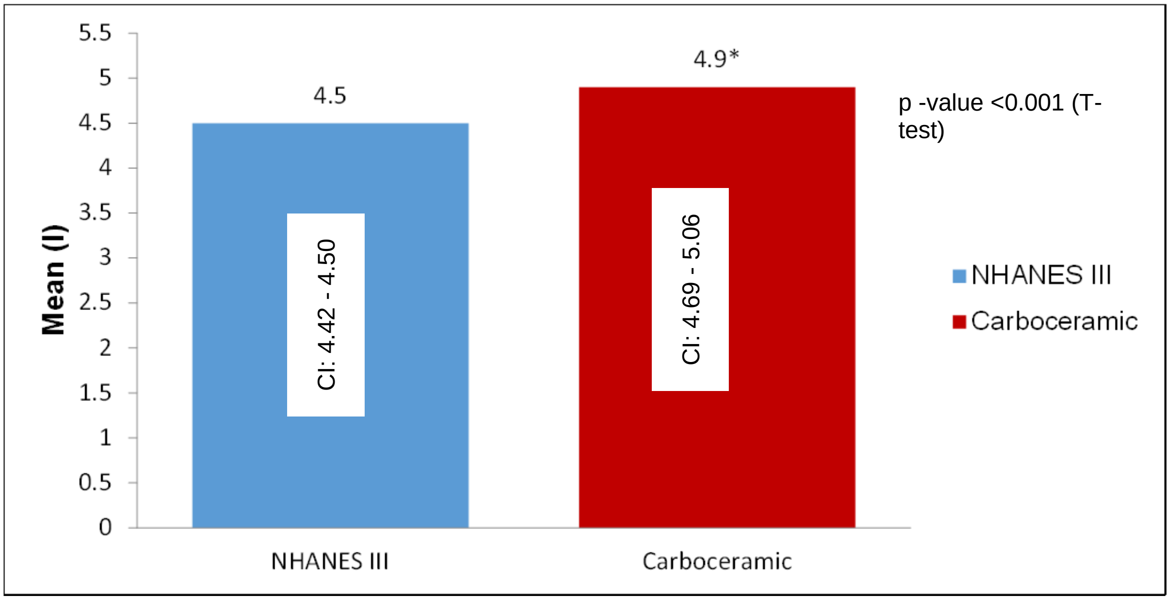

Figure 4.6: FVC mean comparison for NHANES III population and CARBO workers when Smoking= No

Table 4.8 shows the comparison of NHANES III and CARBO workers FEV1 and FVC for subjects with median heights ≥ 69 inches. The means of FEV1 and FVC were statistically significant (P value <0.05) for CARBO workers when compared with NHANES III.

Table 4.8: FEV1 (l) and FVC (l) in NHANES III population and CARBO Workers for Median Height ≥ 69 inches

Population	Total no.	Mean FEV1	FEV1 95% CI	P value	Mean FVC	FVC 95% CI	P value
NHANES III	3733	3.5	3.47-3.53	<0.001	4.6	4.55-4.61	0.02
CARBO	80	3.8	3.67-3.97		4.9	4.69-5.06	

Figure 4.7 shows that the mean FEV1 for the NHANES III with medium height ≥69 inches was 3.5 and the CARBO workers with median height ≥69 inches was 3.8, with p<0.001.This indicates that the mean FEV1 difference 0.3 was statistically significant. The CI of the mean FEV1 of the NHANES III subjects with median height ≥69 inches was 3.47-3.53, which means that 95% of the time the mean 3.5 lies in the interval. The CI for the mean FEV1 for the CARBO workers with median heights ≥69 inches was 3.67-3.97, which means that 95% of the time the mean 3.8 lies in the interval.

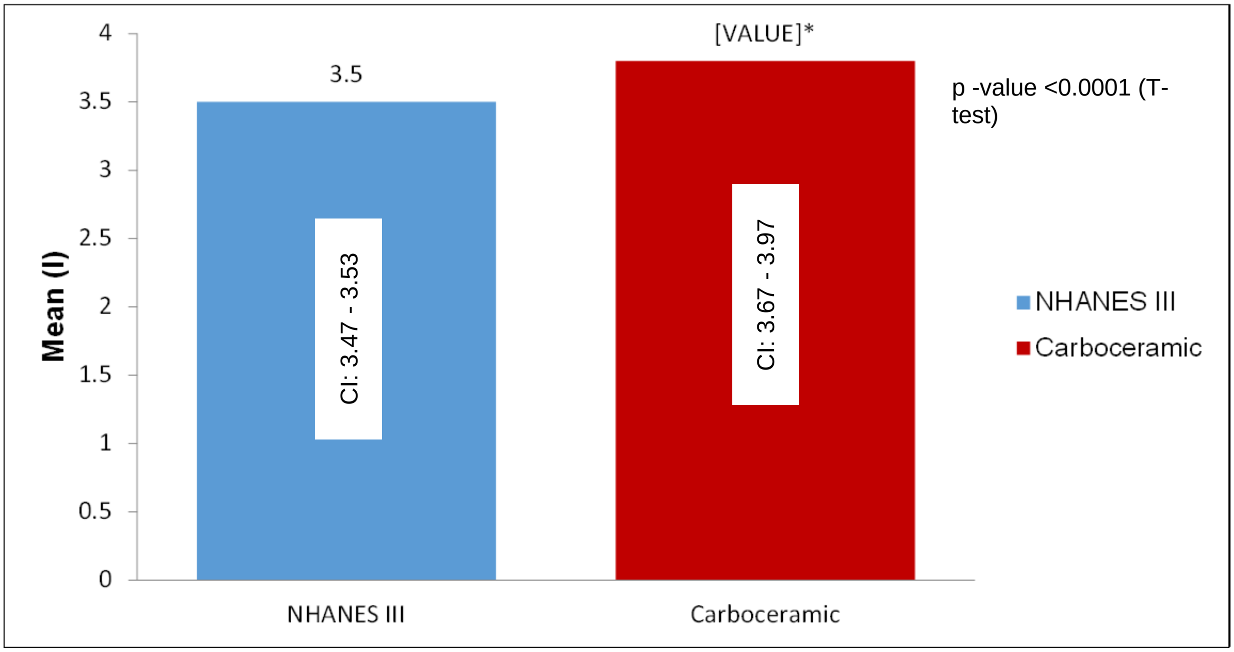

Figure 4.7: FEV1 for NHANES III and CARBO Workers when Median Height ≥ 69 inches

Figure 4.8 shows the mean FVC for the NHANES III subjects with median height ≥69 inches was 4.6 and of the CARBO workers with median heights ≥69 inches was 4.9 , with p=0.02. This indicates that the mean FVC difference of 0.3 was statistically significant. The CI of the mean FVC of the NHANES III subjects with median height ≥69 inches was 4.55-4.61, which means that 95% of the time the mean 4.6 lies in the interval. The CI for the mean FEV1 for the CARBO workers with median heights ≥69 inches was 4.69-5.04, which means that 95% of the time the mean 4.9 lies in the interval.

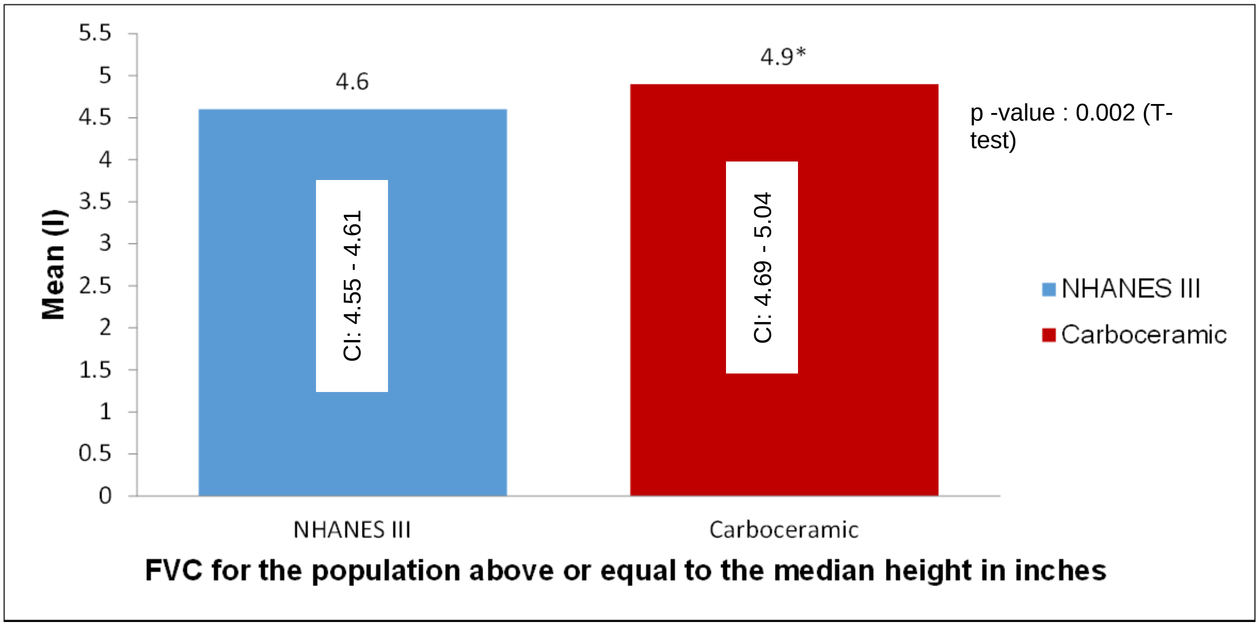

Figure 4.8: FVC for NHANES III and CARBO Workers when Median Height ≥ 69 inches

Table 4.9 shows the comparison of NHAES III and CARBO workers FEV1 and FVC for subjects with median heights <69inches. The mean of the FEV1 and FVC were statistically significant (P value <0.05) for the CARBO workers who had median height <69 inches.

Table 4.9: FEV1 (l) and FVC (l) in NHANES III population and CARBO Workers for Median Height < 69 inches

Population	Total no.	Mean FEV1	FEV1 95% CI	P value	Mean FVC	FVC 95% CI	P value
NHANES III	2929	3.1	3.06-3.13	0.0006	4.0	3.96-4.02	0.027
CARBO	20	3.7	3.37-3.95		4.5	4.11-4.80	

Figure 4.9 shows the mean FEV1 for the NHANES III subjects with median heights <69 inches was 3.1 and of the CARBO workers with median heights <69 inches was 3.7, with p=0.0006.This indicates that the mean FEV1 difference of 0.6 was statistically significant. The CI of the mean FEV1 of the NHANES III subjects with median difference of 0.6 was statistically significant. The CI of the mean FEV1 of the NHANES III subjects with median height <69 inches was 3.06-3.13, which means that 95% of the time the mean 3.1 lies in the interval. The CI interval for the mean FEV1 of the CARBO workers with median heights <69 inches, which means that 95% of the time the mean 3.7 lies in the interval.

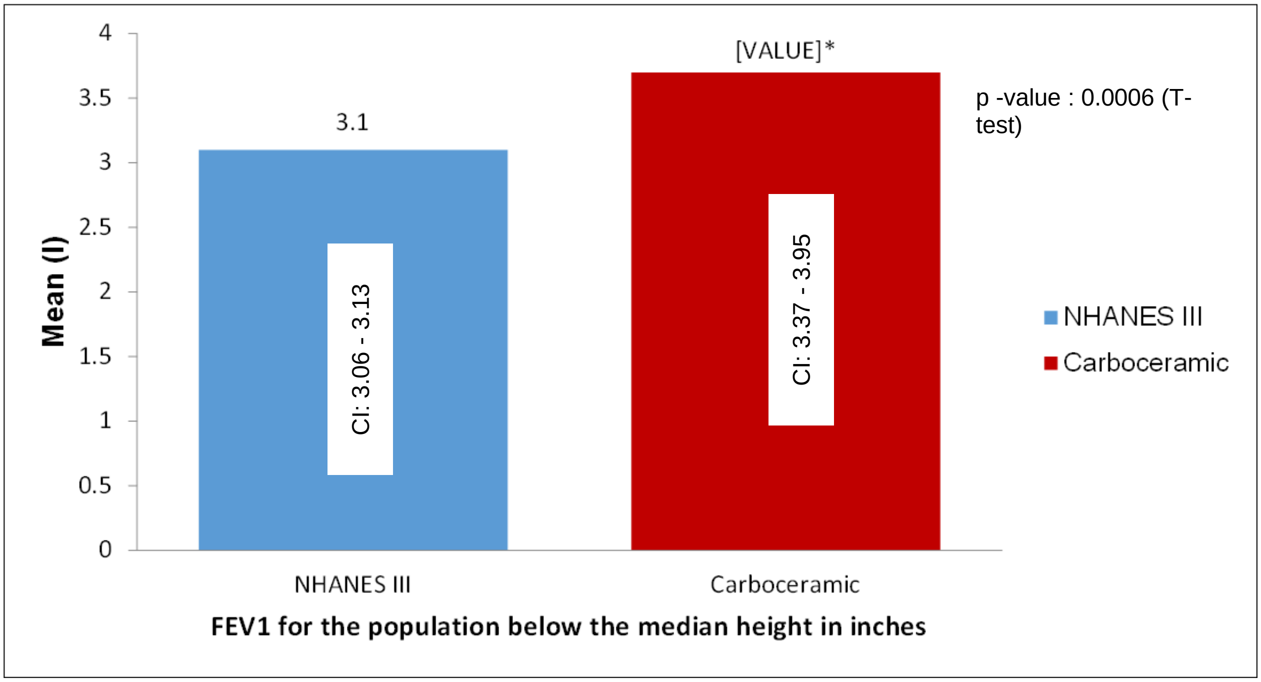

Figure 4.9: FEV1 for NHANES III and CARBO Workers when Median Height < 69 inches

Figure 4.10 shows the mean FVC for the NHANES II subjects with median height <69 inches was 4.0 and of the CARBO workers with median heights <69 inches was 4.5, with p=0.027. This indicates that the mean FVC difference of 0.5 was statistically significant. The CI of the mean FVC of the NHANES II subjects with median heights was <69 was 3.96-4.02, which means that 95% of the time the mean 4.0 lies in the interval. The CI for the mean FVC for the CARBO workers with median heights <69 was 4.11-4.80, which means that 95% of the time the mean 4.5 lies in the interval.

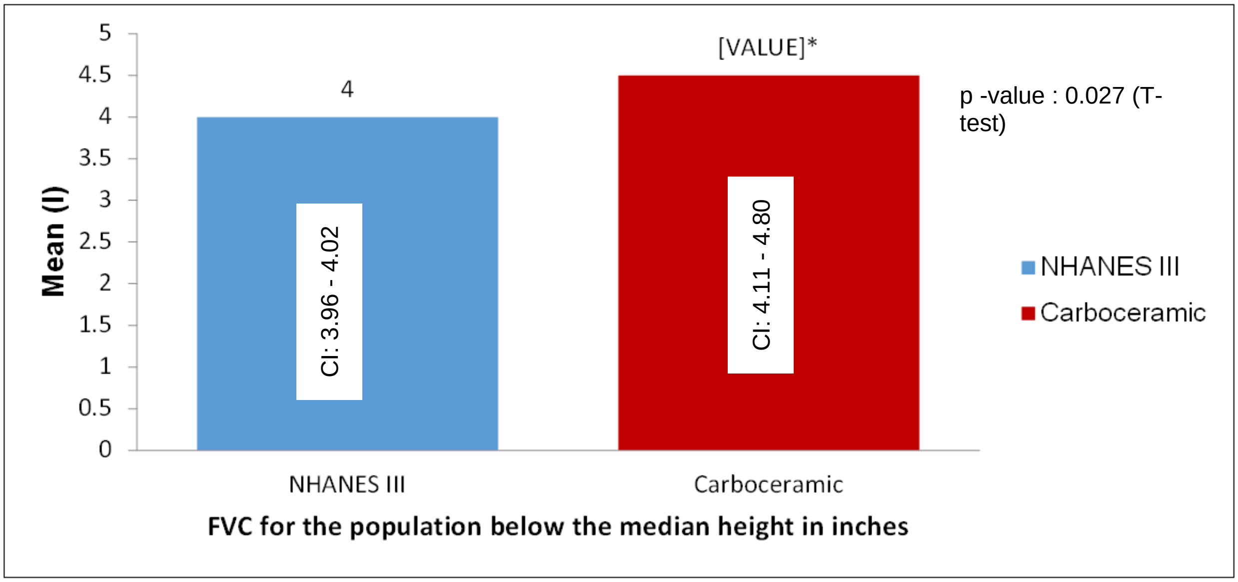

Figure 4.10: FVC for NHANES III and CARBO Workers when Median Height < 69 inches

Table 4.10 shows the comparison of NHANES III and CARBO workers FEV1 and FVC for subjects with median age ≥39 years. The means of the FVC were statistically significant (p value <0.05) for the CARBO workers who were of median age ≥39 years. On the other hand the means of the FEV1 were not statistically significant (p value >0.05) for the CARBO workers who were of median age ≥39 years.

Table 4.10: FEV1 (l) and FVC (l) for NHANES III and CARBO Worker when Median Age ≥ 39 year

Population	Total no.	Mean FEV1	FEV1 95% CI	P value	Mean FVC	FVC 95% CI	P value
NHANES III	2634	4.0	3.94-3.99	0.372	4.9	4.88-4.90	0.017
CARBO	46	4.0	3.90-4.16		5.1	4.90-5.20	

Figure 4.11 shows the mean for the NHANES III subjects with median age ≥39 years was 4.0 and of the CARBO workers median age ≥39 years was 4.0,with p=0.372.This indicates that the mean FEV1 difference of 0.0 was not statistically significant. The CI of the mean FEV1 of the NHANES III subjects with median age ≥39 years was 3.94-3.99, which means that 95% of the time the mean 4.0 lies in the interval. The CI for the mean FEV1 for the CARBO workers with median age ≥39 years was 3.90-4.16, which means that 95% of the time the mean 4.0 lies in the interval.

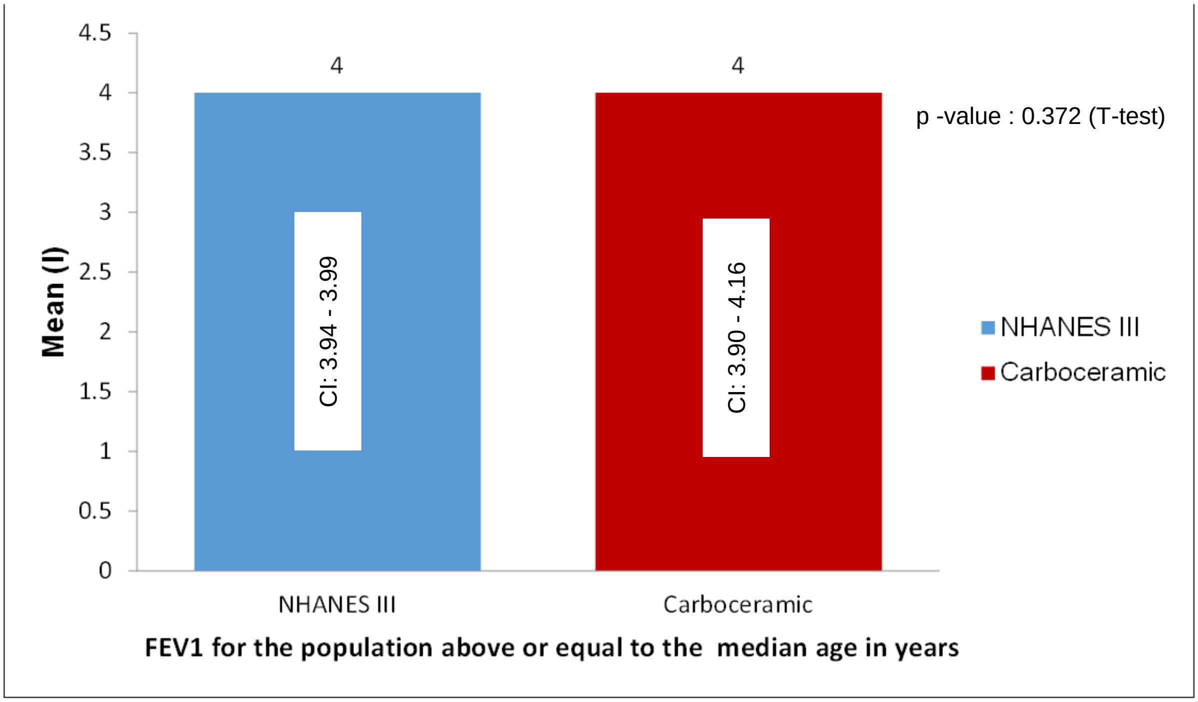

Figure 4.11: FEV1 for NHANES III and CARBO Workers when Median Age ≥ 39 years

Figure 4.12 shows that the mean FVC for the NHANES III subjects with median age ≥39 years was 4.9 and of the CARBO workers with median age ≥39 years was 5.1, with p=0.017.This indicates that the mean FVC difference of 0.2 was statistically significant. The CI of the mean FVC of the NHANES III subjects with median age ≥39 years was 4.83-4.90, which means that the 95% of the time the mean 4.9 lies in the interval. The CI for the mean FVC for the mean FVC for the CARBO workers with median age ≥39 years was 4.90-5.20, which means that 95% of the time the mean 5.1 lies in the interval.

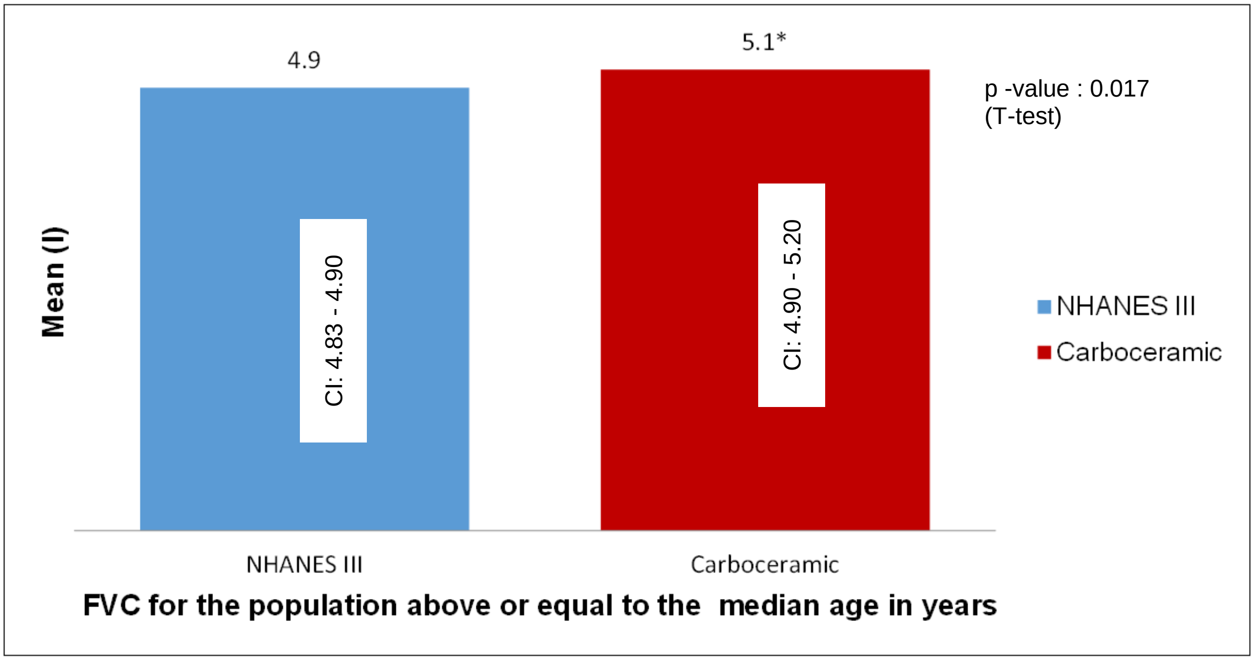

Figure 4.12: FVC for NHANES III and CARBO Workers when Median Age ≥ 39 years

Table 4.11 shows the comparison of NHANES III and CARBO workers FEV1 and FVC for subjects with median age <39 years. The means of the FEV1 and FVC were statistically significant (p value <0.05) for the CARBO workers with median ages <39 years.

Table 4.11: FEV1 (l) and FVC (l) in NHANES III and CARBO Workers When Median Age < 39 year

Population	Total no.	Mean FEV1	FEV1 95% CI	P value	Mean FVC	FVC 95% CI	P value
NHANES III	4028	2.9	2.87-2.93	<0.0001	4.0	3.93-3.99	<0.0001
CARBO	54	3.6	2.87-2.93		4.6	4.30-3.99	

Figure 4.13 shows that the mean FEV1 for the NHANES III subjects with median age <39 years was 2.9 and of the CARBO workers median age <39 years was 3.6, with p <0.0001. This indicates that the mean FEV1 difference of 0.7 was statistically significant. The CI of the mean FEV1 of the NHANES III subjects with median age <39 years was 2.87-2.93, which means that 95% of the time the mean 2.9 lies in the interval. The CI for the mean FEV1 for the CARBO workers with median age <39 years was 3.38-3.79, which means that 95% of the time the mean 3.6 lies in the interval.

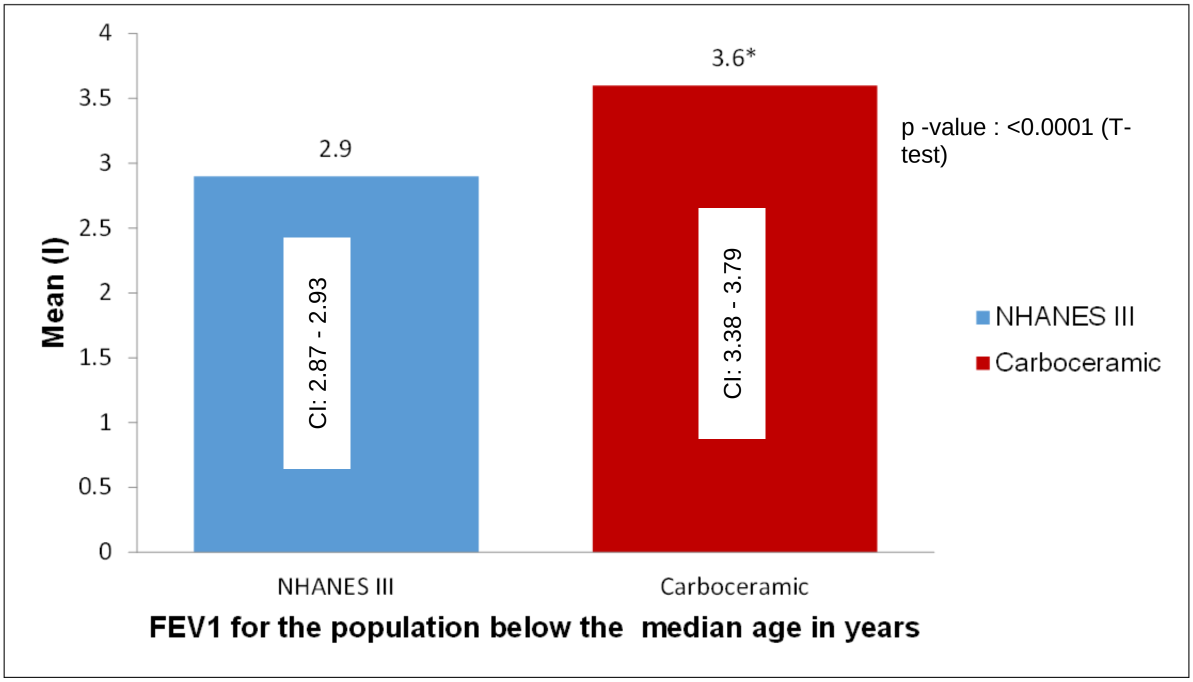

Figure 4.13: FEV1 for NHANES III and CARBO Workers when Median Age < 39 years

Figure 4.14 shows that the mean FVC for the NHANES III subjects with median age <39 years was 4.0 and of the CARBO workers with median age <39 years was 4.6, with p <0.0001. This indicates that the mean FVC difference of 0.6 was statistically significant. The CI of the mean FVC of the NHANES III subjects with median age <39 years was 3.93-3.99, which means that 95% of the time the mean 4.0 lies in the interval. The CI for the mean FVC for the CARBO workers with median age <39 years was 4.30-4.80, which means that 95% of the time the mean 4.6 lies in the interval.

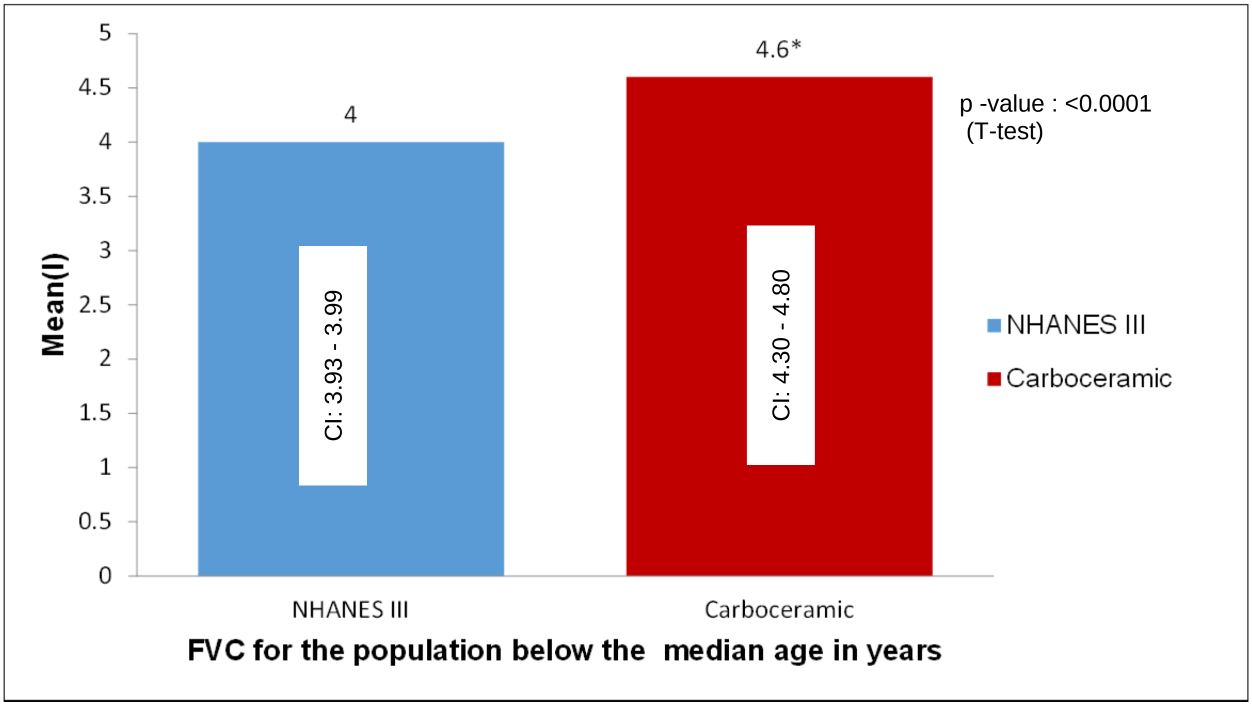

Figure 4.14: FVC for NHANES III and CARBO Workers when Median Age <39 years

Table 4.12 shows the comparison of NHANES III and CARBO workers FEV1 and FVC for subjects who indicates their race as white. The means of the FEV1 and FVC were statistically significant (p value <0.05) for the CARBO workers who indicated their race as white.

Table 4.12: FEV1 (l) and FVC (l) for NHANES III and CARBO Workers when Race=White

Population	Total no.	Mean FEV1	FEV1 95% CI	P value	Mean FVC	FVC 95% CI	P value
NHANES III	4562	3.4	3.36-3.41	<0.0001	4.4	4.41-4.48	<0.0001
CARBO	76	3.8	3.66-3.98		4.8	4.67-5.02	

Figure 4.15 shows that the mean FEV1 for the NHANES III subjects who indicated their race as white was 3.4 and of the CARBO workers who indicated their race as white was 3.8, with p <0.0001.This indicates that the mean FEV1 difference of 0.4 was statistically significant. The CI of the mean FEV1 of the NHANES III subjects who indicated their race as white was 3.36-3.41, which means that 95% of the time the mean 3.4 lies in the interval. The CI for the mean FEV1 for the CARBO workers who indicated their race as white was 3.66-3.98, which means that 95% of the time the mean 3.8 lies in the interval.

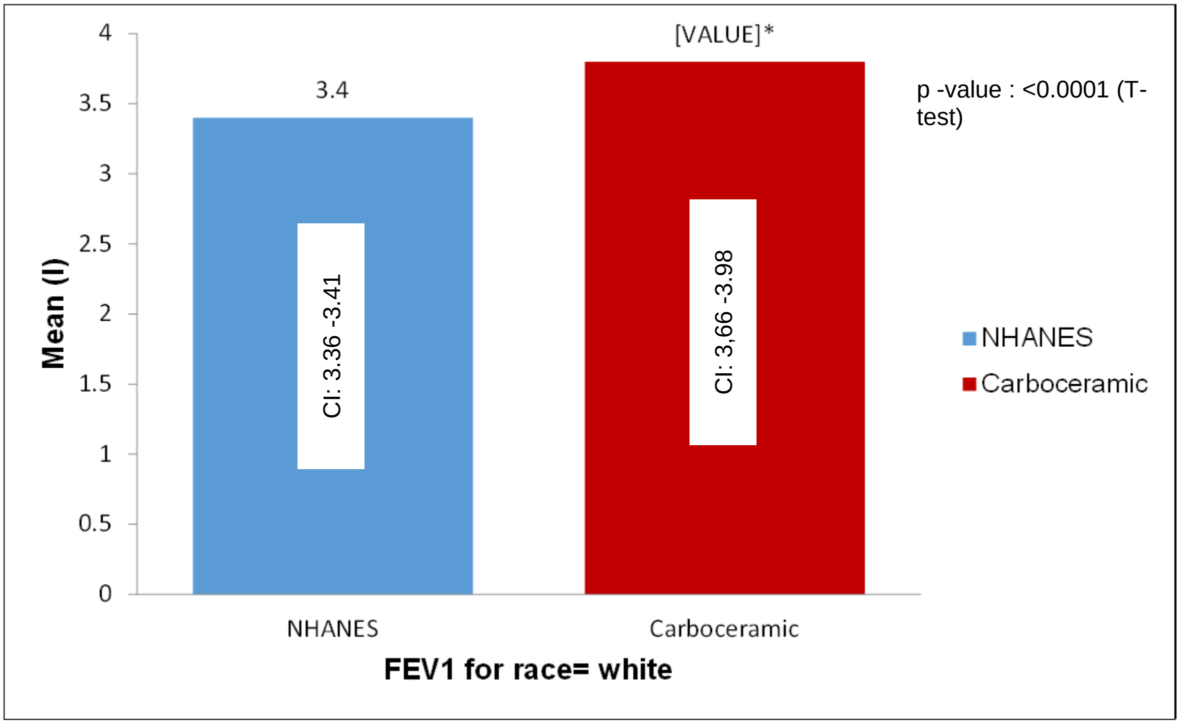

Figure 4.15: FEV1 for NHANES III and CARBO workers when race=white

Figure 4.16 shows the mean FVC for the NHANES III subjects who indicated their race as white was 4.4 and of the CARBO workers who indicated their race as white was 4.8, with p <0.0001.This indicates that the mean FVC difference of 0.4 was statistically significant. The CI of the mean FVC of the NHANES III subjects who indicated their race as white was 4.41-4.48, which means that 95% of the time the mean 4.4 lies in the interval. The CI for the mean FVC for the CARBO workers who indicated their race as white was 4.67-5.02, which means that 95% of the time the mean 4.8 lies in the interval.

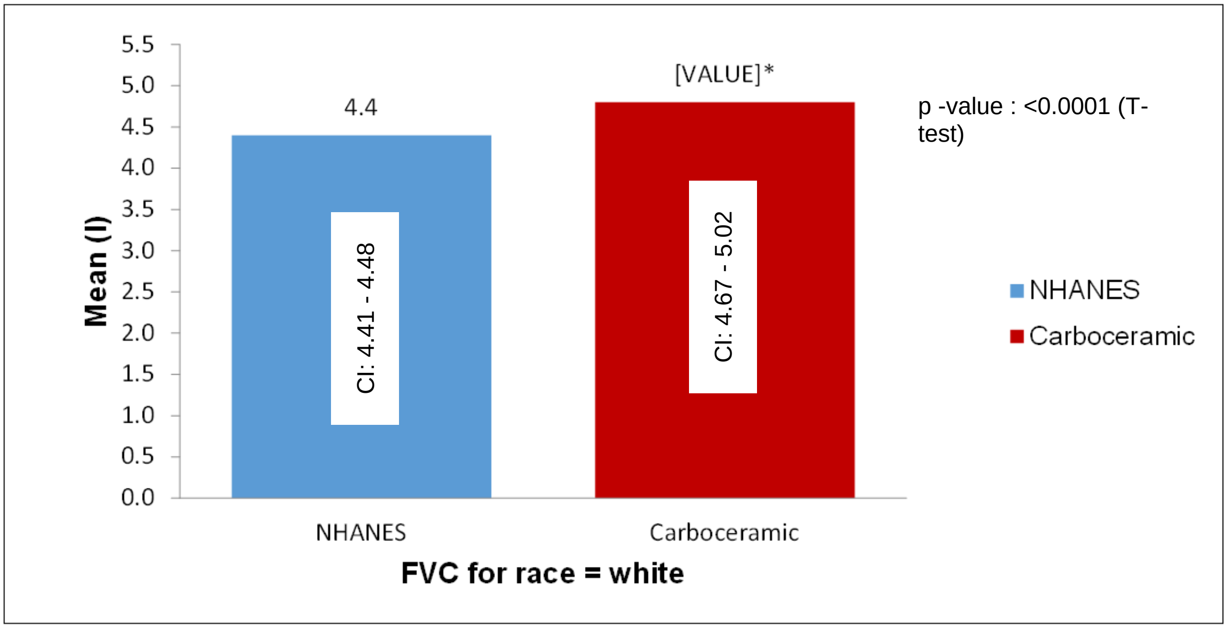

Figure 4.16: FVC for NHANES III and CARBO workers when Race=White

Table 4.13 shows the comparison of NHANES III and CARBO workers FEV1 and FVC values for subjects who indicated their race as black. The means of the FEV1 and FVC were not statistically significant (p value >0.05) for the CARBO workers who indicated their race as black.

Table 4.13: FEV1 (l) and FVC (l) for NHANES III and CARBO workers when Race=Black

Population	Total no.	Mean FEV1	FEV1 95% CI	P value	Mean FVC	FVC 95% CI	P value
NHANES III	1876	3.2	3.12-3.20	0.1232	4.0	3.97-4.06	0.9489
CARBO	14	3.3	3.10-3.58		4.0	3.66-4.40	

Figure 4.17 shows the mean FEV1 for the NHANES III subjects who indicated their race as black was 3.2 and of the CARBO workers who indicated their race as black was 3.3, with p=0.1232.This indicates that the mean FEV1 difference of 0.1 was not statistically significant. The CI of the mean FEV1 of the NHANES III subjects who indicated their race as black was 3.12-3.20, which means that 95% of the time the mean 3.2 lies in the interval. The CI for the mean FEV1 for the CARBO workers who indicated their race as black was 3.10-3.58, which means that 95% of the time the mean 3.3 lies in the interval.

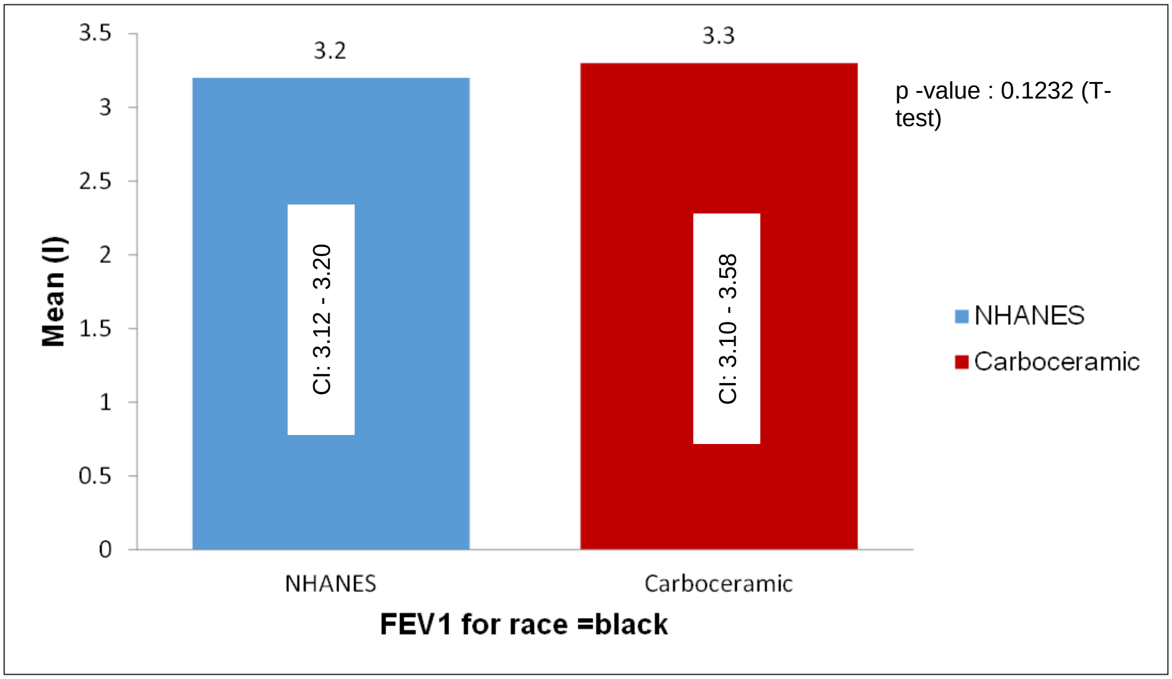

Figure 4.17: FEV1 for NHANES III and CARBO Workers when Race=Black

Figure 4.18 shows the mean FVC for the NHANES III subjects who indicated their race as black was 4.0 and of the CARBO workers who indicated their race as black was 4.0, with p=0.9489. This indicates that the mean FVC difference of 0.0 was not statistically significant. The CI of the mean FVC of the NHANES III subjects who indicated their race as black was 3.97-4.06, which means that 95% of the time the mean 4.0 lies in the interval. The CI for the mean FVC for the CARBO workers who indicated their race as black was 3.66-4.39, which means that 95% of the time the mean 4.0 lies in the interval.

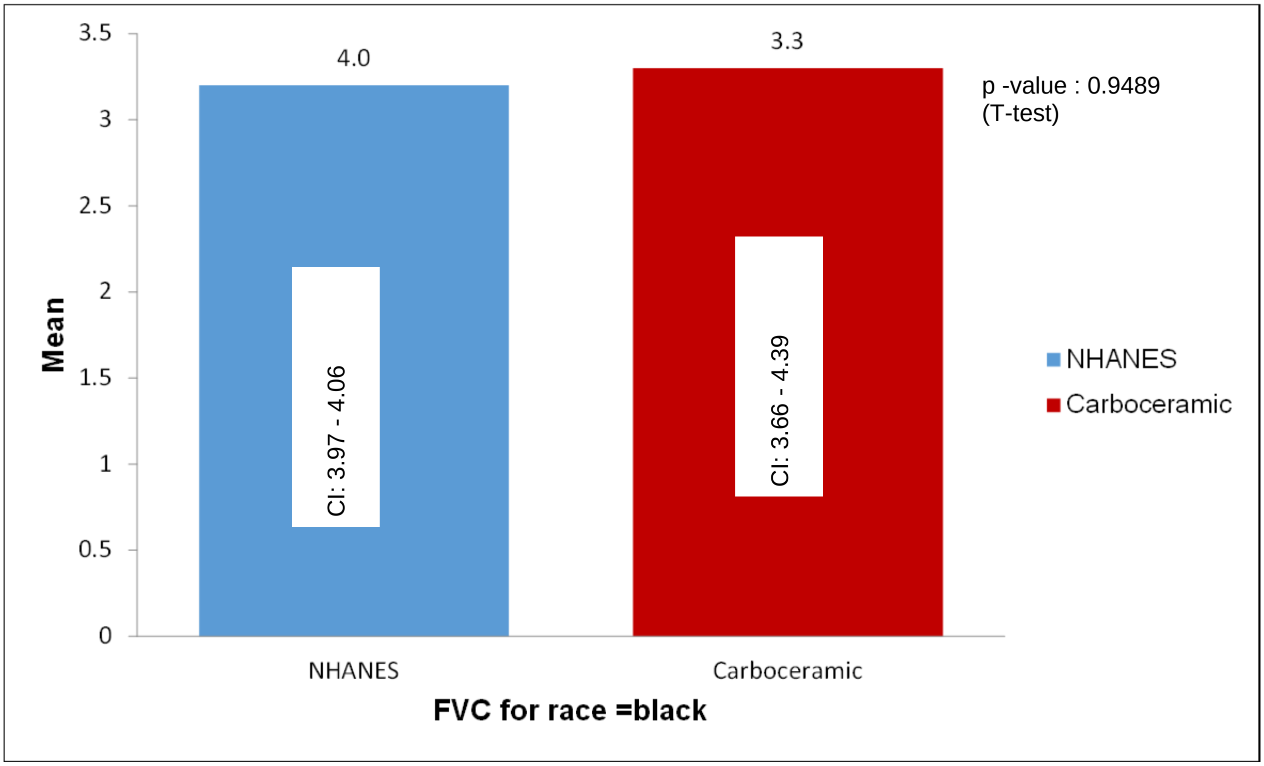

Figure 4.18: FVC for NHANES III and CARBO workers when Race=Black

4.4 Multivariate Analysis

Linear regression was performed for multivariate analysis study. Tables 4.14 and 4.15 shows the FEV1 and FVC values from multiple regression results. The multivariate analysis findings showed that median age, race, smoking history, and median height were statistically significant for CARBO workers in comparison to NHANES IIII. The analysis also showed that median age, race, smoking history, and height were statistically significant for CARBO workers when in comparison to NHANES III. The analysis also showed that median age race, smoking history, and height were statistically associated with FVC, however, the association was not statistically significant for CARBO workers when in comparison to NHANES III.

Table 4.14 shows the FEV1 multiple linear regression analysis for the median age (years), race (black vs white), smoking history (pack-years), and median height (inches) of CARBO workers and NHANES III. The analysis results demonstrated that each yearly increase in age was associated with 0.98 liter decrease in FEV1; this association was statistically significant ($p<0.0001$). Subjects identifying themselves as black had a 0.32 liter lower FEV1 as compared to subjects identifying themselves as white; this association was statistically significant ($P<0.0001$).Each unit increase in pack-years of smoking was associated with 0.01 liter decrease in FEV1; this association was statistically significant ($p<0.0001$).Each inch increase in height was associated with 0.41 liter increase in FEV1; this association was statistically significant ($p<0.0001$). Overall, the mean FEV1 value in CARBO workers was 0.11 liters greater than the value for NHANES III. However, this association was not statistically significant (p value >0.05).

Table 4.14: Variables of FEV1 (l) from Multiple Linear Regression

Variable	**Regression Coefficient**	**Standard Error**	**P value**
Medians Age (in years)	-0.98	0.0005	<0.0001
Race (Black vs White	-0.32	0.02	<0.0001
Smoking History (pk-yrs)	-0.01	0.0006	<0.0001
Median Height (in inches)	0.41	0.02	<0.0001
CARBO workers vs NHANES III	0.11	0.07	0.13

Table 4.15 shows the multiple regression analysis for the median age (years), race (black vs white), smoking history (pack-years), and median height (inches) of CARBO workers and NHANES III population. The analysis results demonstrated that each year increase in age was associated with 0.88 liter decrease in FVC; this association was statistically significant (p<0.0001). Subjects identifying themselves as black had a 0.46 liter lower FVC as compared to subjects identifying themselves as white; this association was statistically significant (p<0.0001). Each unit increase in pack-years of smoking was associated with 0.003 liter decrease in FVC; this association was statistically significant (p<0.0001).Overall, the mean FVC value in CARBO workers was 0.08 liter greater than the value for NHANES III. However, this association was not statistically significant (p value >0.05).

Table 4.15: FVC (l) from Multiple Linear Regression Analysis

Variable	Regression Coefficient	Standard Error	P value
Medians Age (in years)	-0.88	0.02	<0.0001
Race (Black vs White	-0.46	0.02	<0.0001
Smoking History (pk-yrs)	-0.003	0.0009	0.0001
Median Height (in inches)	0.56	0.02	<0.0001
CARBO workers vs NHANES III	0.08	0.08	0.32

4.5 Logistic Regression Analysis

Logistic regression analysis was conducted to identify the influence of variables on the FEV1/FVC ratio, since FEV1/FVC ratios less than 0.8 can be indicative of a preclinical loss of lung function. Table 4.16 shows the variables that may produce a change in pulmonary function: median age (in years), race (black vs white), smoking history (in pack-years), median height (in inches), and CARBO workers status (CARBO workers vs NHANES III population).

Smoking history and median height were not associated with FEV1/FVC <0.8. The odds ratio of race and carbo ceramic workers status was not more than 1 which indicate that these two variables do not have harmful impact on pulmonary function, when FEV1/FVC ratio is <0.8. The workers more than 39 years old (median age) have 3.6 times higher chance to generate FEV1/FVC ratio <0.8. The black population had 0.76 less chance to generate FEV1/FVC ratio <0.8. In addition, carbo ceramic workers were 0.44 less at risk to develop FEV1/FVC ratio of <0.8. The statistical analysis result from odds ratio and logistic regression showed that our workers population was not suffering from abnormal pulmonary functions.

Table 4.16: Odds Ratio Estimates of FEV1/FVC <0.8

Effect	**Odds Ratio**	**95% CI**
Median Age (≥39 years)	3.61	3.19-4.07
Race (Black vs White	0.76	0.69-0.85
Smoking History (pack years)	1.03	1.03-1.04
Median Height (≥69 inches)	1.12	0.99-1.26
CARBO workers vs NHANES III	0.44	0.28-0.67

CHAPTER FIVE:

DISCUSSION

5.1 Evaluation of Research Hypothesis

This study was done to assess the association of pulmonary function among workers at the CARBO Ceramic Inc. factory and who were exposed to proppant during their workday .A cross-sectional analysis was conducted of workers at the factory located in Georgia from the data collected by OHSS. For comparison, the NHANES III population was used since it represents a general population, with publically available data. The CARBO workers pulmonary function data allowed us to evaluate the lung health of a cross-section of a worker population involved in proppant production. The CARBO worker information, as well as the NHANES III data set included age, race, height, and smoking, status allowing us to assess these confounders in relation to pulmonary function. The statistical analysis of the spirometry readings did not showed statistically significant pulmonary impairment in the CARBO workers population, supporting our study hypothesis that there is no difference in pulmonary function in ceramic proppant workers and the general population.

Our study group were exposed to ceramic proppant during the manufacturing process. Any difference in variables normally associated with decrease lung function were not statistically different between the study group and the control population. Thus, using ceramic proppant to collect unconventional gas and oil by hydraulic fracking does not pose any increased risk to the pulmonary function of a hydraulic fracking proppant worker.

5.2 Comparison of Study to Other Research Findings

Chen et al. (2003) studied fur workers and PFT in China. 212 employees who were exposed to fur were selected as study group and 148 male employees were selected as control group. The study showed that the exposed fur workers group had lower FEV1 and FVC as compared to control. Multiple regression analysis showed that workers exposed to fur dust were experiencing in lower FEV1 and FVC in comparison to the unexposed group. Our study result varied from the above mentioned study and better protection of workers in US industries may be one of the reasons for different results.

Wang et al. (2015), conducted a study on exposure of manganese workers and its effect on pulmonary function in China. The research also studied the synergistic effect on smoking status and manganese exposure in manganese workers. 1658 workers were selected for form ferromanganese factory. Spirometry test was conducted for FEV1, FVC, and FEV1/FVC ratio. The result showed that workers smoked had decrease in PFT. The study also showed that male workers had lower FEV1 and FVC values and FEV1/FVC ratios than in female workers. Our study also showed that FEV1and FVC decreased in smoker in CARBO population.

Mandel & Majumder. (2013a), conducted study on paint workers in India to evaluate the respiratory status of the exposed group. The study was a cross-sectional study with 149 subjects as study group from paint factories and 141 controls. The study measured FEV1, FVC and other parameters related to PFT. A significant association for changes in PFT in the older workers was found in the exposed group, supporting our findings from multiple linear regression results for both FEV1 and FVC.

Abejie et al. (2010) conducted a study on exposure to asbestos and its effect on pulmonary function. The study selected 277 asbestos workers as exposed group, 22% of the group were nonsmokers. 177 people were selected as control with 50% of them were nonsmokers. Spirometry test was conducted to evaluate the PFT. The result showed that FEV1, FVC, and FEV1/FVC reduced in both smoker and nonsmoker groups, however, the study suggested that exposure to asbestos alone did not have significant impact on the FEV1/FVC ratio in exposed group. Our study also showed similar decreases, although the CARBO workers (who were respirators) had overall decreased risks in decreased FEV1/FVC ratios than the general population

Mandel & Majumder. (2013b) conducted a cross-sectional study on cement workers in West Bengal, India. The study evaluated pulmonary function among ninety male workers, compared with 141 office workers. Spirometry readings were evaluated along with smoking status, workers exposure status, and respiratory status. Multivariate regression analysis showed that there were significant association of age, height, cement exposure status, and smoking with the workers' FEV1, and FVC values. The study concluded that the workers group in cement industry were at high risk to develop pulmonary disease due to exposure to cement. In our study, we also found that multivariate regression showed that both FEV1 and FVC decreased with age and smoking status, and increased with height, but that the associated exposure to ceramic proppant had no statistically significant detrimental effect. However, our CARBO population also had access to respirators with increased occupational monitoring than those in Mandel and Majumder' study.

Chattopadhyay et al. (2006) conducted study on workers crushing stones in West Bengal, India. The researcher examined the respiratory function among stone crusher workers (272) and compared them with farming workers (120). Spirometry tests were conducted to determine the FVC, and FEV1 values. Their results indicated that FVC values were greater in the stone workers in comparison to the farming workers, which the authors found “unexpected”. In our study we also found that both FEV1 and FVC were better in CARBO workers as compared to NHANES III population. On possibility may be that the “healthy workers” phenomenon may play a role in both studies, as considerable physical ability would be required for both study groups.

5.3 Evaluation of Confounders

The student’s t-test was used to detect any difference in mean lung function in the CARBO workers in comparison with the NHANES III (standard population) group. Further analysis was conducted by stratification of median height, median age, smoking status and race. Of study population, 31% of them had positive history for smoking, 80% 69 inches (median height) or taller and 54% subjects were 39 years old (median age) or younger. Racially, 85% of the CARBO workers identified themselves as white.

5.3.1 Race

Research has shown that black populations to have lower PFT scores than white sample populations (Wang et al, 1993; Pellegrino et al., 2005). In our study, no significant difference in the mean values of FEV1 and FVC was observed between black and white CARBO workers, but increases in FEV1 and FVC were observed when compared with NHANES III population. The FEV1 and FVC values were statistically different from the black population after controlling for other variables such as age and smoking history, with white workers showing higher PFTs than black workers.

5.3.2 Age

When stratified by age, our study demonstrated that there was difference among study group and comparison group in the mean lung function (FEV1) when median age was equal to or greater than 39 years old, indicating that our worker population showed greater lung function (FEV1) values than NHANES III population. Research has suggested that lung function starts declining from 15 years to 25 years (Miller & Pincock, 1988). In contrast, other research has found that FEV1 appear to increase past 25 years of age, with increase up to age 40 (Knudson et al., 1983).

5.3.3 Height

Pellegrino et al. (2005) showed that height and lower age population have higher pulmonary function tests than corresponding population of lower height and higher age. Our study was not able to find a similar association of height with lung function.

5.3.4 Smoking

A cross-sectional study by Nemery et al. (1983) compared smoking and nonsmoking employees among 45-55 year-old workers in a steel factory. They found lower pulmonary functions, including lower FEV1/FVC ration, in smokers as compared to nonsmokers. The researchers also found that the weight of the smokers was significantly lower than that of the nonsmokers. The authors suggested that lower weight in smokers may have been due to the impairment of lung function. Our study similarly showed that differences in the mean FEV1 and FVC values for smoking and non-smoking were statistically significant, although we did not include analysis of weight as a factor.

5.4 Consideration of Multivariate Analyses

Multivariate linear regression analyses were conducted to determine the significant variables which may have impact on the CARBO workers' lung health.FEV1 analysis showed that median age (years), race (black versus white), and smoking history (in pack-years) affected the pulmonary function of CARBO workers either in increased or decreased direction. Each unit increase in median age, race, and smoking history decreased FEV1; each unit increased in height above 69 inches (median height) increased FEV1.

The effect of race on FEV1 was found to be statistically significant, with black study population showing a mean FEV1 value 0.32 liters lower than the mean FEV1 value of the white study population. Each unit increase in pack-years of smoking was associated with 0.01 liter decrease in FEV1, while each inch increase in height was associated with 0.41 liter increase in FEV1.Overall, the mean FEV1 in CARBO workers was found to be 0.11 liter more than NHANES III sample. However, this association was not statistically significant (P value >0.05).

Similar results were obtained from multiple linear regression analyses using FVC. Each unit increase in median age, race and smoking history demonstrated decreases in FVC. Increases in median height showed decreased results for FVC. Each yearly increase in age and smoking was significantly associated with an FVC decrease of 0.88 liters and 0.003 liters, respectively. Black study population were found to have 0.46 liter lower FVC than the white study population, which was statistically significant. As with FEV1, each inch increase in height was significantly associated with 0.56 liter increase in FVC. The mean FVC in CARBO workers was 0.08 liter more than the mean of the NHANES III sample. However, this association was not statistically significant (P value >0.05). The CARBO workers did not show any statistical association for FEV1 and FVC. The analysis of FEV1 as well as FVC validate that the variables like height, age, smoking history and race that are known to be associated with pulmonary impairment also have influence on lung function.

The logistic regression analysis was conducted for the FEV1/FVC ratio to determine the possibility of obstructive impairments in the CARBO workers in comparison with the NHANES III group. In the analysis, an FEV1/FVC ratio of <0.8 was used to define early stage obstructive lung disease, while an FEV1/FVC ratio of ≥0.8 was considered as having normal lung function. The logistic regression analysis showed that showed that there was no significant association of CARBO workers for FEV1/FVC ratio <0.8. The odds ratio estimate determined that the CARBO workers were at lesser risk to develop pulmonary function impairment when the FEV1/FEV ratio determined at <0.8 was compared with ≥0.8. The logistic regression analysis showed that the people more than 39 years or older had 3 times greater risk in developing obstructive type of lung impairment (FEV1/FVC ratio >0.8).

The positive association of FEV1 and FVC for CARBO workers was observed in our study. The association showed the possibility of the “healthy workers effect” in the workers group, in comparison to NHANES III sample population which may have sick people, sedentary life style or people out of work. The statistical analysis did not detect significant pulmonary impairment in the CARBO workers population. The study thus indicates that workers involved in ceramic proppant manufacturing had no greater risk for pulmonary function impairment than those in the general population.

5.5 Direction for Future Studies

Sriproed et al. (2013) conducted a research study on pulmonary dysfunction and related symptoms in a rubber industry in Thailand. The study included 89 rubber workers, with pulmonary function tests performed before and after work shifts. High dust levels (>1mg/m3) in the workplace were found to be associated with a decreased FEV1/FVC ratio. As we did not have access to have pre- and post-shift spirometry data, we could not perform similar comparison analyses. Future studies may benefit from incorporating this methodology.

5.6 Limitations

A major obstacle for conducting the research was in the collection of spirometry data. Recoding and reformatting were required to compare results between the study population and comparison population. A standardized coding and formatting system of spirometry records for use by OHSA,ATS, and any other federal, state or industrial agency would be very helpful in future research.

Another limitation of this study was the comparatively small sample set of CARBO worker data available for analysis. Likewise, more data on different forms of ceramic proppant produced and the specific durations of exposure would have allowed greater effect analysis. An additional limitation was a sample set that was exclusively male, preventing generalization to the females working in hydraulic fracking.

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