Investigation of the Health Effects of Workers Exposed to Respirable Crystalline Silica During Outdoor and Underground Construction Projects in Greece

Dimitrios Keramydas [1], Petros Bakakos [2], Manos Alchanatis [2], Ioannis Konstantakopoulos [3], Petros Papalexis [1], Kyriaki Tavernaraki [4], Vasileios Dracopoulos [5], Antonios Papadakis [6,11], Eugenia Pantazi [7], Nektaria Sidiropoulou [4] , Georgios Chelidonis [8], Elias Chaidoutis [9], Theodoros C. Constantinidis [10], Dimosthenis Chochlakis[11], Nikolaos Kavantzas [1], Efstratios Patsouris [1] and Andreas Ch. Lazaris [1,]

[1] 1st Department of Pathology, School of Medicine, National and Kapodistrian University of Athens, Athens, Greece; dkeramydas@med.uoa.gr (D.K.); alazaris@med.uoa.gr (A.L.); ppapalek@med.uoa.gr (P.P.); nkavantz@med.uoa.gr (N.K.); epatsour@med.uoa.gr (E.P.)

[2] 1st Department of Pneumonology, Medical School, National and Kapodistrian University of Athens, Athens, Greece; petros44@hotmail.com (PB); nalxanat@gmail.com (MA)

[3] Ministry of Labour and Social Affairs, National Focal Point of the European Agency for Safety and Health at Work (EU-OSHA), Athens, Greece, ioankons@yahoo.com (I.K.)

[4] Department of Imaging and Interventional Radiology, "Sotiria" Hospital, Athens, Greece; nektarsidiro@hotmail.com (N.S.); sandytavernaraki@hotmail.com (K.T.)

[5] Hellenic Institute for Occupational Health and Safety (ELINYAE), Athens, Greece; d@elinyae.gr (V.D.)

[6] Directorate of Public Health, Region of Crete, Heraklion, Greece; apapadakis@crete.gov.gr (A.P.)

[7] Department of Hygiene, Epidemiology and Medical Statistics, Medical School, National and Kapodistrian University of Athens, Athens, Greece; pantazimed@yahoo.gr (E.P.)

[8] National Actuarial Authority, Athens, Greece; g.chelidonis@eaa.gr (G.CH.)

[9] Ministry of Interior, Athens, Greece; echaidoutis@gmail.com (E.C.)

[10] Laboratory of Hygiene and Environmental Protection Democritus University of Thrace, School of Health Sciences, Faculty of Medicine, Alexandroupolis, Greece; tconstan@med.duth.gr (T.C.)

[11] Laboratory of Clinical Microbiology and Microbial Pathogenesis, School of Medicine, University of Crete, Heraklion, Crete, Greece; surreydimos@hotmail.com (D.C.); apapadakis@crete.gov.gr (A.P.)

* Correspondence: apapadakis@crete.gov.gr; Tel.: +306973479792

Abstract: Chronic exposure of workers to powder containing crystalline silica (SiO_2) can lead to chronic lung diseases (lung cancer, silicosis, etc.). The aim of the study was to evaluate the exposure of Greek construction workers to SiO_2 and describe their pulmonary function. The study involved 86 outdoor and underground workers. Medical and professional history was obtained, and breath samples were collected at morning hours through a mask for the determination of SiO_2 levels. Pulmonary function tests, radiological examination and evaluation of radiographs were, also performed. During the examination of the pulmonary function, the majority of the workers were within normal range (61.4%) while the rest were diagnosed with mild (26.5%) and more severe impairment (7.2%). Working conditions (underground-outdoor) were statistically significantly related to the categorization of pulmonary function (p = 0.038). During radiological examination, the type of working conditions (underground-outdoor) were statistically significantly related to the categorization of these findings (p = 0.044). Of the 69 employees, 52 did not present findings (75.4%) and five (5) were diagnosed with findings specific to occupational diseases (7.2%). The environmental exposure to RCS (Respirable crystalline silica) was detected at 0,0125 mg/ m³ in the workplace, which is not beyond the legal limits. Underground workers with more than 15 years of

exposure to SiO_2 are more likely to present chronic silicosis compared to the workers of outdoor activities.

Keywords: Silicosis; silicon powder; crystalline silica (SiO_2); construction workers; occupational exposure; occupational exposure limit; occupational hygiene.

1. Introduction

The working environment of industries in the construction branch, both in underground and in outdoor activities, is by its nature burdened with particulate dust [1,2]. This dust is a threat to the health and safety of workers since chronic exposure can lead to serious respiratory diseases. In particular, when the dust contains free crystalline silicon dioxide special measures and precautions are required since once inhaled, the dust ceases to be inert and can cause chronic lung diseases such as silicosis, chronic obstructive pulmonary disease (emphysema) and lung cancer [1–3].

Silicon dioxide is the second most abundant element (following oxygen) in the earth's crust, is a group IV metal oxide that occurs in nature in three (3) forms: crystalline, microcrystalline (or cryptocrystalline) and amorphous (non-crystalline) [4]. The term "crystalline" that is commonly used refers to the orientation of silicon molecules (SiO_2) in a fixed configuration against a non-periodic, random molecular arrangement, designated as amorphous. The three most common crystalline forms [3 main polymorphs] of silicon that occur in the working environment are quartz, cristobalite and tridymite [2,5,6]. Quartz is the second most common mineral in the world [5].

Inhalation of Respirable Crystalline Silica (RCS) can lead to serious health effects, such as silicosis, Chronic Obstructive Pulmonary Disease (COPD), tuberculosis and lung cancer [7–11]. Respiratory diseases often occur in construction workers operating in underground excavation and tunneling constructions [12–14], as well as in outdoor ones [15]. Studies have shown that the potential exposure of construction workers to RCS exceeds that of 3 million in the European Union, 1.7 million in the US and 350 000 in Canada [3].

Silicosis is a type of pneumoconiosis caused by exposure of workers to inhaled crystalline silica powder [16]. Crystalline silicon dioxide, in the form of quartz powder or "cristobalite" and tridymite, is responsible for causing silicosis that is categorized as an occupational disease [7,8]. It is characterized by the appearance of pulmonary fibrosis and silica nodules. The development - progression of the disease continues even after the interruption of the exposure [12,13]. There are three (3) forms of the disease: Chronic, acute and lightning stroke. The latter occurs after massive exposure to silica dust. It presents with shortness of breath, fever, cough and weight loss and soon progresses to respiratory failure not responding to costicosteroids [17,18].

Cancer is the first cause of work-related deaths in the EU [6]. The International Cancer Research Organization (IARC) stated in its 100C monograph that "silica or inhalation of quartz or cristobalite powder is carcinogenic to humans (Group 1 of carcinogens for humans)" [12,14].

The European Union Scientific Committee on Occupational Exposure Limits (SCOEL) has assessed the impact of crystalline silica (respiratory dust) on employee health, and has proposed a limit value of 0.1 mg / m^3 which would mean avoiding 99,000 cancer cases by 2069 with total health benefits valued at between 34 billion and 89 billion euros [6]. The above proposal by SCOEL has led to the adoption of the European Union Directive 2017/2398 L 345/87 that aims at improving the prevention of occupational cancer cases that can be avoided [6].

Given the nature of the materials used in the construction industry, the powder may contain significant amounts of SiO_2 [1,15,21]. According to the International Labor Organization (ILO), silicosis, an incurable disease, requires quantitative and qualitative control of respiratory crystalline silica and the development of appropriate control measures [22].

The importance of the current study is based on the fact that we need to take under consideration the high occupational exposure to airborne powders of people working at underground and outdoor construction, drilling, concrete launching and machinery movement together with the absence of relevant studies in Greece. The purpose of the study herein was to evaluate the exposure of workers to respiratory crystalline silica (SiO_2) and to examine the condition of workers' pulmonary function.

2. Materials and Methods

2.1 Patients

The study involved 59 employees from one construction company mainly engaged in outdoor construction and 27 employees from a second construction company working exclusively at underground projects with their main activity being tunneling. A total of 86 employees participated all of which, suffered from active exposure to inhalable crystalline silicon dioxide. The construction workers who participated were categorized as artisans - builders, machine operators, builders - contractors, blasters, electricians, sorting and packaging workers.

The clinical/epidemiological history included both the medical and the professional one, in order to determine the relationship between exposure to a substance and the development of respiratory disease. The relevant information included the aggravating factors, the appearance and progression of the disease, the family and medical history of each exposed worker. Other medical allergic or respiratory disorders in childhood were, also reported in the medical history together with the smoking habits of each participant [23]. Certain characteristics (height, weight, age, years of work) of the exposed workers were, also, recorded.

2.2 Statistical analysis

Statistical analysis was performed with IBM-SPSS v.21. The level of statistical significance was set at 5% (p=0,05). The detection of any possible correlation between the type of construction and the radiological findings was performed using Pearson's χ^2 test.

2.3 Environmental measurements

In the present study samplings took place during the year of 2015. To test for dust at the workplace (solid particles or mixtures suspended in the air), environmental measurements - samplings were performed to ensure compliance with national and European legislation on industrial hygiene. In the above measurements, the sampling time corresponded to at least four (4) hours and the analysis technique for determining the content of SiO_2 (mainly quartz and cristobalite) was carried out by various methods such as X-ray diffraction (XRD), NMAM 7500 method, or by infrared spectroscopy via Fourier (Fourier Transform Infrared Spectroscopy) NIOSH 7602, or by visible VIS spectroscopy with the NIOSH 7601 method [1,23].

According to the National legislation for the protection of workers from natural, chemical and biological factors, when there is a group of workers who perform the same or similar tasks in the same place and under the same conditions, in way that they can reasonably be considered to be subjected to approximately the same degree of exposure to this particular chemical agent, in that case the testing may take place in groups and in a way that gives representative results. In our work, an individual testing was performed on one (1) for every ten (10) employees in the same job. In particular, individual sampling was performed on three (3) employees in a total of 27 in the underground construction projects where the sampling equipment was placed [24].

We followed the method of Fourier transform infrared spectroscopy (FTIR) that uses three (3) sampling filters in underground projects in order to calculate the individual exposure of respiratory SiO_2 in workers. A breathing zone was considered as an imaginary hemisphere with a radius of 30 cm extending in front of the employee's face and centered on the middle of the imaginary line connecting his ears. Sampling was performed on workers in workplaces with high exposure to dust and on sprayed concrete operators, builders, machine operators, engineers, blasters and materials sorters. The sampling time was eight (8) hours for each sample taken.

During the period of the environmental tests and of the individual sampling from underground workers at all jobs, a high accumulation of dust was recorded because of the use of GUNITE spray concrete. This concrete contains chemical agents such as sodium silicate, (Na_2SiO_3; chemical compound with cement that dries it immediately). In cases where cement contains >2% of quartz, workers are likely to present radiological findings of silicification several years after exposure [37].

Individual sampling was performed with a SKC (USA) 224-PCTX Respiratory Dust Sampling Pump. The device was intended for the detection and measurement of particles (inert dust, toxic dust, etc.) in the work environment. The above device is a pump with a flow rate of 750-4000 ml / min with a built-in battery.

Samples were collected on a filter which was weighed before and after sampling and analyzed for the detection of crystalline silica. For the current samplings, a Dorr Oliver type head with a flow of 2 l / min was used to collect samples of 960 liters of air each, on a 37mm cellulose ester filter. Flow was checked before and after sampling.

The analysis procedure using the IR technique follows these steps: a known amount of 1,3-butanediol was added at the sampling filter on which the powder was collected, and incubation at 600 ºC followed. The residue was then mixed with a given amount of potassium bromide (KBr), triturated and homogenized in a vibrating mill. Part of this mixture was used to produce a KBr tablet, which was placed as a cell in the infrared spectroscope. Absorption was performed on an FTIR spectrometer (model WQF - 510A) at wavelengths 779/798 cm^{-1} to identify and quantify quartz.

2.4 Lung function

Pulmonary function tests (PFTs) in our study were performed at the 1st Academic Department of Pneumonology of the General Hospital of Thoracic Diseases of Athens "Sotiria" using a spirometer (Cosmed, Quark PFT Pulmonary Function Testing and SensorMedics ™ Erich Jaeger).

Pulmonary functional test results were categorized as within normal limits, mild obstructive syndrome, mild decrease in diffusion capacity, small airway dysfunction, moderate restrictive syndrome, and upper thoracic airway dysfunction.

PFTs were performed using a commercially available system (Master Screen, Erich Jaeger GmbH, Wuerzburg, Germany). Forced expiratory volume in one second (FEV$_1$), forced vital capacity (FVC), FEV$_1$/FVC ratio, forced expiratory flow in the middle 50% of FVC (FEF$_{25-75}$), Total Pulmonary Capacity (TLC) - Total Lung Capacity, Peripheral Capacity (DLco), and the Special Rate Di [Kco (DLco)] were recorded. Post-bronchodilator values were obtained 20 minutes after the administration of 400 mg salbutamol via a spacer. Diffusing capacity for carbon monoxide (DL$_{CO}$) and diffusing capacity for carbon monoxide adjusted for alveolar volume (DL$_{CO}$/V$_A$) were assessed by means of the single breath method with the patient in the sitting position [25]. Lung function measurements were expressed as percentages of predicted values [17]. The results were interpreted in accordance with the guidelines of the American Thoracic Society [26–28].

2.5 Radiology

The chest x-rays of the participants were performed at the Department of Imaging and Interventional Radiology of the above-mentioned hospital; the Siemens X-RAY Diagnostics Axiom Vertix Solitaire M. radiograph was used.

To perform the chest high resolution computed tomography (HRCT), the INGENUITY CORE 64 system (Philips) was used.

The radiographs were evaluated according to the system developed by the International Labor Office Classification System in 1980 [29,30].

Written consent was obtained from each employee who participated in the study. This research has been approved by the bioethics and ethics committee of the National and Kapodistrian University of Athens under the decision 6323 received on the 06th of March of 2013.

3. Results

All workers belonged to the same socioeconomic class, with an average age of 41.04 years (standard deviation of 9.68) and an average of 15.69 years of work (SD 10.30); most were former and current smokers and did not use prescription drugs. In more detail, underground construction workers had an average age of 41.26 years (SD 9.67) and an average of 18.70 (SD 11.32) working years.

Outdoor construction workers had an average age of 40.93 years (SD 9.76) and an average of 14.31 (SD 9.59) working years.

3.1. Environmental SiO₂ measurements

The period when samples were received was the one in which at the tunneling process a spray gun, also known as GUNITE was extensively used; GUNITE contains Na_2SiO_3 and was present at all the working positions. Moreover, splashed concrete contains components such as cement (containing 5% silica - SiO_2), additives, aggregates, coagulation accelerators and silica foam. It is often used in tunnels, underground works to stabilize slopes and excavations. Low exposure to respiratory crystalline silica powder was observed among workers in underground excavation and tunneling. In particular, the concentration of SiO_2 in underground construction was 0,0125 mg/m³ at all the working positions from which samples were drawn (Table 1).

Table 1. Environmental testing of employees working in underground construction projects

Job position	Dust quantity (mg)	Quantity of SiO2 at the filter (µg)	Quantity of SiO2 in the air (mg/m3)	Limit according to the EU 2398/2017
GUNITE launcher concrete operator	2,59	12	0,0125	0,1 mg/m³
Craftsman builder	4,50	12	0,0125	0,1 mg/m³
Machine operator	4,70	12	0,0125	0,1 mg/m³

3.2. Pulmonary function tests

The results of the PFTs performed are shown in Table 2.

Table 2. Pulmonary function test results

Test	Results	Frequency	%
RX % PRED FVC (Liters)	Not normal	3	3,7
	Normal	79	96,3
	Total	82	100
RX % PRED FEV 1 (Liters)	Not normal	4	4,9
	Normal	78	95,1
	Total	82	100
RX BEST FEV 1 / FVC %	Not normal	6	7,4
	Normal	75	92,6
	Total	81	100
RX FEF 25-75% PRED L / SEC	Not normal	9	11,0
	Normal	73	89,0
	Total	82	100
TLC % PRED PRE - RX	Not normal	8	9,6
	Normal	75	90,4
	Total	83	100
DLCO (mmol/k.Pa.min)	Not normal	9	10,7
	Normal	75	89,3
	Total	84	100
KCO (DLCO/ VA)	Not normal	2	2,4
	Normal	82	97,6
	Total	84	100

According to the analysis of the results, 51 employees (61.4%) were within normal limits, 22 (26.5%) were diagnosed with mild obstructive syndrome, four (4.7%) were diagnosed with mild impairment of diffusing capacity and two (2.4%) were diagnosed with moderate restrictive syndrome. However, the above results were not statistically significant.

The project type (underground-outdoor) was significantly associated with categorization of pulmonary function test (p = 0.038). When comparing underground and outdoor construction workers (Figure 1) we revealed that underground workers were less likely to lie within normal limits compared to those working outdoors (53.8% vs 64.9% respectively). Moderate restrictive was defined as TLC 60-79% predictive, small airway dysfunction was defined as FEF25-75 <65% predictive with FVC and FEV1 >80% predictive, mild decrease in diffusion capacity as DLCO 60-79% predictive and mild obstructive was defined as FEV1/FVC <75% and FEV1>80% predictive.
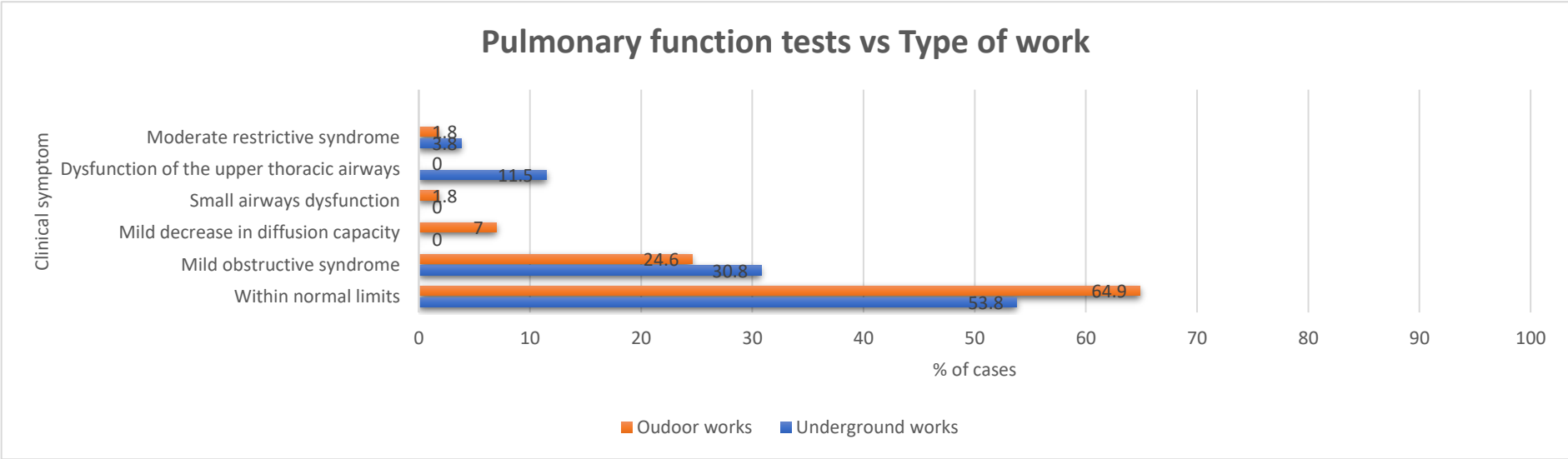
Figure 1. Comparison of results of functional respiratory testing by job type (underground and outdoor construction projects)
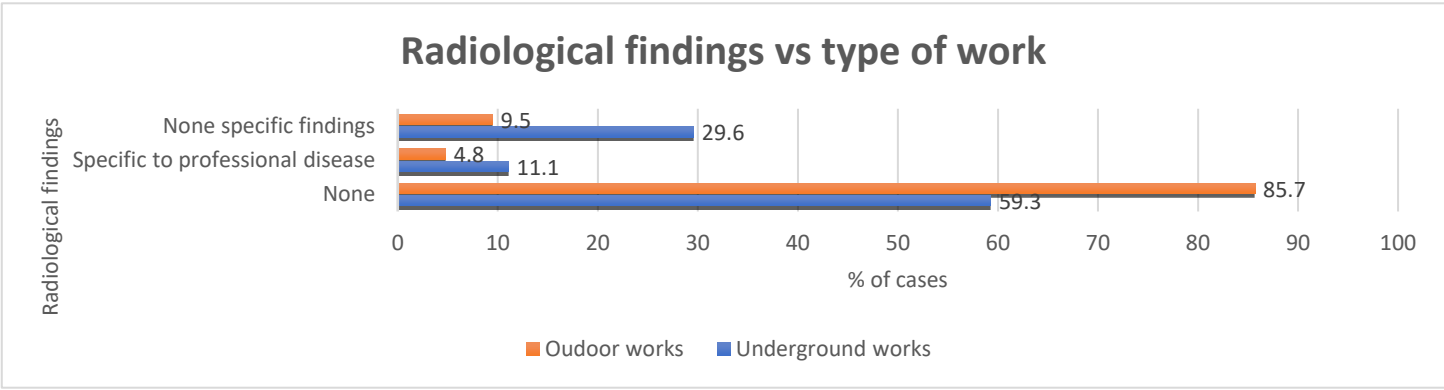
Figure 2. Categorization of radiology findings vs work type

3.3. Radiology testing

Of the 86 workers, 69 participated in the radiological examination. The remaining 17 employees from the company engaged in outdoor construction projects, refused to participate in the radiological examination because they stated that they had performed this test at the same year as part of their collaboration with the company.

Of the 69 employees, in 52 (75.4%) no findings were recorded and five (7.2%) were diagnosed with specific occupational disease findings while 12 (17.4%) presented non-specific findings. One out of the five (5) subjects with abnormal findings in chest x-ray was diagnosed with lung cancer three months later.

When comparing underground and outdoor construction workers (Table 3, Figure 2) we revealed that underground workers were less likely to lack any findings (59.3% compared to 85.7% for those working outdoors). Furthermore, underground jobs were more likely to be linked both to specific (11,1% vs 4,8% for outdoor workers) and non-specific (29,6% vs 9,5%) occupational radiological findings. The relationship between job type and categorization of radiological findings was significant (Pearsons's χ^2 test - p = 0.044).

Table 3. Radiological findings and type of job

Type of job	No findings	Specific to occupational disease	Non-specific
Underground	16 (59,30%)	3 (11,10%)	8 (29,6%)
Outdoor	36 (85,7%)	2 (4,80%)	4 (9,5%)

Corresponding radiological findings are shown in Figure 3. At one patient the chest x-ray revealed a suspicious right hilar enlargement, as an incidental finding. A subsequent CT scan of the chest confirmed the presence of a right hilar mass, consistent with lung cancer.
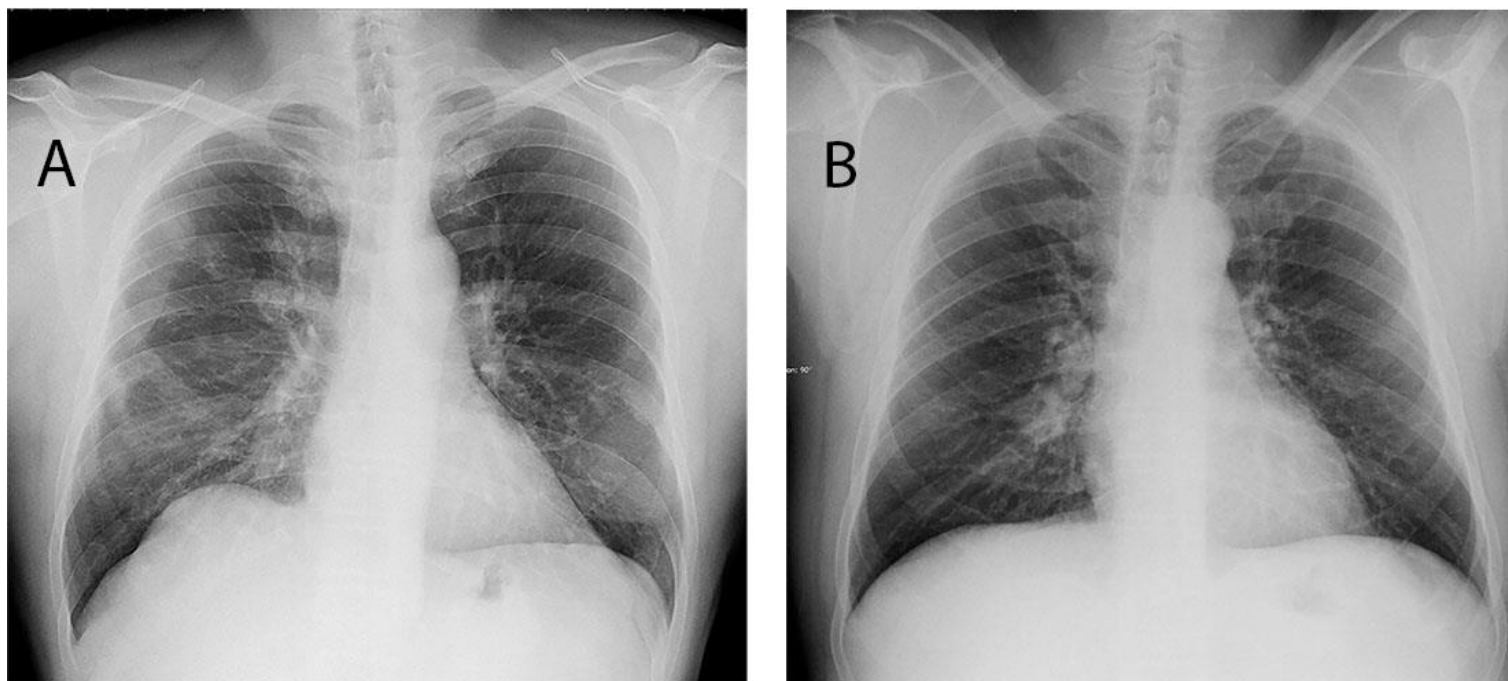
Figure 3. A: Chest x-ray showing right hilar enlargement. A subsequent CT scan confirmed a right hilar mass due to lung cancer. **B:** Chest X-ray showing bilateral calcified pleural plaques and linear opacities in the lower lung zones.

4. Discussion

Historically, silicosis is considered as a significant occupational disease and still is of interest [32]. During our study, environmental measurements were performed, samples were collected to detect breathable crystalline silica (SiO_2) in the workplace of outdoor and underground construction works, and medical tests of the pulmonary function tests of workers were carried out. Chest X-rays, as well as, High Definition Computed Tomography (HRCT) were also performed where deemed appropriate in order to obtain a better picture of the diagnosis.

Low exposure to respiratory crystalline silica powder was observed among workers in underground excavation and tunneling. In particular, the concentration of SiO_2 in underground construction was 0,0125 mg/ m^3, according to the limit value of 0.1 mg / m^3 set by the European Union Directive 2017/2398 / L345 / 87. This limit value is also laid down in the National Mining and quarrying legislation [33]. The above concentration of SiO_2 in the dust generated in underground construction projects does not makes it detrimental to the health of workers in this area [31]. However, according to Chi Chiu Leung's study low environmental concentrations rarely pose any risk for silicosis [34].

Contrastively, at the study of the Tavakol et al. construction workers' exposure to respirable dust of crystalline silica dust exceeded the threshold limit value [15]. A similar conclusion on the exposure limit on respiratory SiO_2 in underground excavation works is presented at the Mazurek and Attfield's research [35]. An important factor about exposure is the production process carried out in underground excavation projects that involves the frequent use of sprayed concrete, also known as GUNITE.

Based on the results of the pulmonary function testing in the present study, underground workers were more likely to lie outside the normal limits compared to those working outdoors. In a study by Hochgatterer et al. (2013), occupational quartz exposure adversely affected lung function parameters [36].

The finding that five workers presented occupational disease-specific pathological findings can be considered serious especially since these workers had worked > 15 years in underground construction - excavation and tunneling projects. In our study, lung function and x-ray findings did not differ significantly between workers with more than 15 working years against those with less than 15 working years. This is further supported by the establishment of lung cancer diagnosis in one employee three months after the inclusion into the current study. This employee had a 30.5 year working history and was a current smoker (60 packs/year). He mentioned that he was exposed to Sodium silicate, (Na_2SiO_3; chemical compound with cement that dries it immediately), sprayed concrete, also known as GUNITE, dust from moving machinery, sand, while he also stated that his workplace did not have proper ventilation, while he was wearing Personal Protective Equipment (Gloves, Masks, Helmets, Glasses). Since smoking is a risk factor for lung cancer, the employee's lung cancer may be attributed both to environmental working exposure and smoking.

According to the conclusions of the study of Kachuri et al. [20], prolonging the activity of exposed workers for more than 30 years, that is, long exposure to crystalline SiO_2, is likely to increase the risk of developing lung cancer [9,20].

It is worth noting that people working in underground construction projects were fewer in number due to the financial crisis in Greece from 2010 to date. Underground and outdoor projects have been reduced in numbers throughout the country.

5. Conclusions

People in the Greek construction industry were not exposed to crystalline silica powder that exceeded the limit value as laid down in the European legislation. Workers in underground tunneling projects with more than 15 years exposure to SiO_2 are more likely to develop silicosis in its chronic form [37]. Pulmonary function testing revealed that underground workers were less likely to lie within normal limits compared to those working outdoors. As a result, further precautionary measures are required for workers in the construction sector to promote their health and safety. In

particular, the following steps are suggested: a) a more frequent training in safe work practices [38,39], b) the use of appropriate respiratory protection devices in accordance with the requirements of European legislation [40], c) undertaking of workers to precautionary measures, d) undergoing of medical tests every year and e) periodic workplace sampling to perform respiratory crystalline silicon analyzes with the results being compulsory reported to the Competent Authority [31,41]. Finally, the establishment of a National Occupational Health and Safety System is needed to identify risk factors in the work environment in accordance with the National Occupational Health and Safety Strategy [42]**.**

Author Contributions: All authors have read and agree to the published version of the manuscript. **Dimitrios Keramydas:** Organization and performing of research, collecting and testing samples, writing of the research article, overall project management. **Manos Alchanatis, Kyriaki Tavernaraki, Nektaria Sidiropoulou:** Evaluation of radiological tests. **Petros Bakakos:** Evaluation of pulmonary tests. **Georgios Chelidonis:** Statistical analysis, data assessment. **Dimosthenis Chochlakis:** editing of manuscript. **Elias Chaidoutis:** Preparation and writing of the research article. **Ioannis Constantakopoulos, Vasileios Dracopoulos, Petros Papalexis, Antonios Papadakis, Eugenia Pantazi, T.C. Constantinidis, Nikolaos Kavantzas, Efstratios Patsouris and Andreas Ch. Lazaris:** Reviewing and plan assessment.

Funding: This research was funded by own revenue

Conflicts of Interest: The authors declare no conflict of interest.

References

1. NEPSI The European Network on Silica Agreement on Workers Health Protection through the Good Handling andUse of Crystalline Silica and Products containing it 2003.

2. European Commission Guidance for National Labour Inspectors on addressing risks from worker exposure to respirable crystalline silica (RCS) on construction sites 2016.

3. Silica Exposure During Construction Activities: Statistical Modeling of Task-Based Measurements from the Literature. *Ann. Occup. Hyg.* **2012**.

4. Steenland, K.; Ward, E. Silica: A lung carcinogen: Silica: A Lung Carcinogen. *CA. Cancer J. Clin.* **2014**, *64*, 63–69.

5. IARC Working Group on the Evaluation of Carcinogenic Risks to Humans: Silica, Some Silicates, Coal Dust and Para-Aramid Fibrils. Lyon, 15-22 October 1996. *IARC Monogr. Eval. Carcinog. Risks Hum.* **1997**, *68*, 1–475.

6. European Council 2016/0130 - Directive of the European parliament and of the council amending Directive 2004/37 / EC on the protection of workers from the risks associated with exposure to carcinogens; or mutagenic agents at work 2016.

7. European Comission 2003/670/EC - Commission Recommendation of 19 September 2003 concerning the European schedule of occupational diseases 2003.

8. Hellenic Republic Presidential Decree no 41/2012, National list of occupational diseases, in accordance with Commission Recommendation 2003/670 / EC 2012.

9. Rees, D.; Murray, J. Silica, silicosis and tuberculosis. *Int. J. Tuberc. Lung Dis. Off. J. Int. Union Tuberc. Lung Dis.* **2007**, *11*, 474–484.

10. Arndt, V. All-cause and cause specific mortality in a cohort of 20 000 construction workers; results from a 10 year follow up. *Occup. Environ. Med.* **2004**, *61*, 419–425.

11. Beaudry, C.; Lavoué, J.; Sauvé, J.-F.; Bégin, D.; Senhaji Rhazi, M.; Perrault, G.; Dion, C.; Gérin, M. Occupational Exposure to Silica in Construction Workers: A Literature-Based Exposure Database. *J. Occup. Environ. Hyg.* **2013**, *10*, 71–77.

12. Oliver, L.C.; Miracle-McMahill, H.; Littman, A.B.; Oakes, J.M.; Gaita, R.R. Respiratory symptoms and lung function in workers in heavy and highway construction: A cross-sectional study. *Am. J. Ind. Med.* **2001**, *40*, 73–86.

13. Arcangeli, G.; Cupelli, V.; Montalti, M.; Pristera, M.; Baldasseroni, A.; Giuliano, G. Respiratory Risks in Tunnel Construction Workers. *Int. J. Immunopathol. Pharmacol.* **2004**, *17*, 91–96.

14.   Ellingsen, D.G.; Ulvestad, B.; Bakke, B.; Seljeflot, I.; Barregard, L.; Thomassen, Y. Serum pneumoproteins in tunnel construction workers. *Int. Arch. Occup. Environ. Health* **2015**, *88*, 943–951.

15.   Tavakol, E.; Azari, M.; Zendehdel, R.; Salehpour, S.; Khodakrim, S.; Nikoo, S.; Saranjam, B. Risk Evaluation of Construction Workers' Exposure to Silica Dust and the Possible Lung Function Impairments. *Tanaffos* **2017**, *16*, 295–303.

16.   Khoza, N.N.; Grové, T.; Schutte, P.C. Worker exposure to silica dust in South African non-mining industries in Gauteng: an exploratory study. *Occup. Health South. Afr.* **2012**, *18*, 18–26.

17.   Hellenic Pulmonary Society Occupational and environmental lung diseases 2007.

18.   Hellenic Republic Joint Ministerial Decision F.80000/45219/1864/2017 Single Disability Identification Table. 2007.

19.   *IARC monographs on the evaluation of carcinogenic risks to humans, volume 100 C, arsenic, metals, fibres, and dusts: this publication represents the views and expert opinions of an IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, which met in Lyon, 17 - 24 March 2009*; International Agency for Research on Cancer, Weltgesundheitsorganisation, Eds.; IARC: Lyon, 2012; ISBN 978-92-832-1320-8.

20.   Kachuri, L.; Villeneuve, P.J.; Parent, M.-É.; Johnson, K.C.; Canadian Cancer Registries Epidemiology Group; Harris, S.A. Occupational exposure to crystalline silica and the risk of lung cancer in Canadian men. *Int. J. Cancer* **2014**, *135*, 138–148.

21.   Linch, K.D. Respirable concrete dust--silicosis hazard in the construction industry. *Appl. Occup. Environ. Hyg.* **2002**, *17*, 209–221.

22.   Tavakol E; Rezazadeh Azari M; Salehpour S.; Khodakarim S. Determination of Construction Workers' Exposure to Respirable Crystalline Silica and Respirable Dust. *Journal of safety promotion and injury prevention* **2016**, *3*, 263–70.

23.   European Commission Regulation (EC) no 1272/2008 of the European parliament and of the council on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006 2008.

24.   Hellenic Republic Presidential Decree 77/1993, For the protection of workers against physical, chemical and biological agents and amending and supplementing Presidential Decree 307/86 in accordance with its Directive Council Regulation 88/642 / EEC 1993.

25.   MacIntyre, N. Standardisation of the single-breath determination of carbon monoxide uptake in the lung. *Eur. Respir. J.* **2005**, *26*, 720–735.

26.   Miller, M.R. Standardisation of spirometry. *Eur. Respir. J.* **2005**, *26*, 319–338.

27.   Pellegrino, R. Interpretative strategies for lung function tests. *Eur. Respir. J.* **2005**, *26*, 948–968.

28.   Kreider, M.E.; Grippi, M.A. Impact of the new ATS/ERS pulmonary function test interpretation guidelines. *Respir. Med.* **2007**, *101*, 2336–2342.

29.   Webb, W.R.; Higgins, C.B. *Thoracic imaging: pulmonary and cardiovascular radiology*; 2017; ISBN 978-1-4963-2104-6.

30.   Cox, C.W.; Lynch, D.A. Medical imaging in occupational and environmental lung disease: *Curr. Opin. Pulm. Med.* **2015**, *21*, 163–170.

31.   European Parliament Directive (EU) 2017/2398 of the European Parliament and of the council amending Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work 2017.

32.   Greenberg, M.I.; Waksman, J.; Curtis, J. Silicosis: A Review. *Dis. Mon.* **2007**, *53*, 394–416.

33.   Hellenic Republic Ministerial Decision no. 12050/2223/2011 - National Regulation of mining and quarrying 2011.

34.   Leung, C.C.; Yu, I.T.S.; Chen, W. Silicosis. The Lancet 2012, 379, 2008–2018.

35.   Mazurek, J.M.; Attfield, M.D. Silicosis mortality among young adults in the United States, 1968–2004. *Am. J. Ind. Med.* **2008**, *51*, 568–578.

36.   Hochgatterer, K.; Moshammer, H.; Haluza, D. Dust Is in the Air: Effects of Occupational Exposure to Mineral Dust on Lung Function in a 9-year Study. *Lung* **2013**, *191*, 257–263.

37.   Patakas Dimitrios *Epithelial pulmonology*; 2nd ed.; University Studio Press: Thessaloniki, Greece, 2006; ISBN 13 978-960-12-1562-4.

38.   Council of the European Union Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work. 1989.

39.   Hellenic parliament Law no. 3850/2010 Ratification of the Code of Health and Safety of Workers. 2010.

40.   European Commission Regulation (EU) 2016/425 of the European Parliament and of the Council on personal protective equipment and repealing Council Directive 89/686/EEC. 2016.

41.   European Commission Directive 2004/37/EC of the European parliament and of the council on the protection of workers from the risks related to exposure to carcinogens or mutagens at work 2004.

42.   Hellenic Republic Ministerial Decision no 48416/2564/2017 - Adoption of National Strategy for Health and Safety at Work for the years 2016-2020. 2017.