High Prevalence of Silicosis Among Stone Carvers in Brazil

Vinícius Cavalcanti dos Santos Antão, MD, MSc, PhD,[1,3]*
Germania Araujo Pinheiro, MD, MSc, PhD,[1,3] **Jorge Kavakama,** MD,[2]
and Mário Terra-Filho, MD, PhD[3]

Background *In the city of Petrópolis, Brazil, artisans carve souvenirs from a variety of silica-containing minerals. The finding of pulmonary massive fibrosis in one of the workers motivated an investigation of the prevalence of silicosis in this group.*
Methods *Between January 2000 and June 2002, a cross-sectional study was performed. We obtained clinical and occupational histories, spirometry, lung volumes, and carbon monoxide diffusion capacity measurements. Chest radiographs and high-resolution computed tomographies (HRCT) were evaluated. Personal air samples were analyzed.*
Results *Forty-two stone carvers were examined. The prevalence of silicosis was 53.7%. HRCT better characterized silicotic lesions compared to chest radiographs. Early coalescence of small opacities was associated with lung function impairment. The concentration of dust exceeded permissible limits in 91% of the workplaces.*
Conclusions *Exposure to high levels of silica dust was associated with an increased prevalence of silicosis among stone carvers.* Am. J. Ind. Med. 45:194–201, 2004.

KEY WORDS: silicosis; Brazil; stone carving; HRCT; ILO reading; lung function; air sampling

INTRODUCTION

Silicosis can occur when workers are exposed to quartz-containing dust, such as in tunneling, quarrying, mining, and foundry work. In Brazil, where epidemiological data are scarce, silicosis is also related to sandblasting [COTEPO—Rio de Janeiro State Technical Comission on Occupational Lung Diseases, 1995], pit digging in the Northeast region of the country [Holanda et al., 1995], and the ceramics industry [Bagatin et al., 1995].

Few reports have addressed the occurrence of silicosis among lapidary workers. In South Africa [White et al., 1991] and Lesotho [Chapman and Tracey, 1989], gemstone processing, using mainly tiger's-eye (a type of quartz), is related to severe cases of silicosis, as well as the work with agate in India [Rastogi et al., 1991] and China [Jiang et al., 2001]. The manufacturing of jade ornaments has also been associated with silicosis in Hong Kong, but the disease was attributed to the use of silica flour as an abrasive, rather than stone cutting or grinding [Ng et al., 1985, 1987]. Recently, silicosis in stone carvers has been described in Thailand [Yingratanasuk et al., 2002].

In the city of Petrópolis (population 300,000), located in the mountains of the State of Rio de Janeiro, various minerals

[1]Reference Center for Occupational Lung Diseases, Faculty of Medical Sciences, Rio de Janeiro State University, Rio de Janeiro, Brazil
[2]Division of Radiology, Heart Institute (InCor), University of São Paulo Medical School, São Paulo, Brazil
[3]Division of Respiratory Diseases, Heart Institute (InCor), University of São Paulo Medical School, São Paulo, Brazil
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*Correspondence to: Vinícius C.S. Antão, 4008 Cedar Court, Morgantown, WV, 26505. E-mail: vfc1@cdc.gov

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FIGURE 1. Brazilian parrots carved in rose quartz by artisans from Petrópolis, Brazil. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

are crafted to produce souvenirs, frequently for export. Usually, birds from the Amazon forest are sculpted in quartz, agate, dolomite, calcite, and fluorite (Fig. 1). This activity involves at about 40 workers, who are grouped in small industries or home workshops.

The work process begins with the cutting of raw stones employing circular saws and is followed by shaping into desired formats, carving with diamond discs, and grinding. Sometimes the pieces are also polished with emery powder. Water is used in all processes, to prevent overheating of the machines and fracture of the stone carvings themselves. However, the water sprays aerosolize freshly fractured silica, generating a mist in the breathing zones of the artisans, because they work very close to the machinery.

After massive pulmonary fibrosis was detected in a stone carver from Petrópolis, Brazil, we organized a survey designed to establish the prevalence of silicosis, and to study the radiographic and functional changes associated with the disease among these workers.

MATERIALS AND METHODS

A cross-sectional study was conducted to evaluate all current stone carvers in Petrópolis, between January 2000 and June 2002. The workers were found through data provided by the labor union, visits to the worksites, and personal contact with lapidary workers.

Stone carvers employed for at least 1 year were included in the study, and we excluded any worker who had worked with silica in a previous occupation or reported prior exposure to other mineral dusts, such as coal, iron, or graphite.

Environmental Assessment

All the workplaces were inspected by a physician (VCSA), an engineer, and an industrial hygienist. Personal samples of respirable dust were collected from the breathing zones of selected workers and analyzed according to NIOSH 7602 method [Cassinelli and O'Connor, 1994] to establish the percentage of silica.

For each workplace, we assigned personal samplers for workers who were performing different tasks from each other, or were working in distinct rooms, to assure that the samples were representative of the whole working group, and would reflect the variety of processes.

The permissible exposure limit (PEL) for dusts containing respirable silica (8 hr time-weighted average), set by the Brazilian Ministry of Labor [Ministério do Trabalho, 1998], was determined by the equation: 8/(% quartz) + 2, expressed in milligrams per cubic meters (mg/m^3).

Questionnaires

All workers provided informed consent for the study and were interviewed with Medical Research Council [1976] questionnaires and detailed occupational history, including questions about routine activities, types of stone employed, use of respiratory protection, and presence of ventilation/exhaust devices.

Radiological Investigation

Posteroanterior chest radiographs were taken with Siemens Polidoros LX30 equipment (Siemens Ltd., Erlamgem, Germany). Three "A" readers interpreted the films, in independent sessions, according to International Labour Office (ILO) [1980] rules. Nine films from normal nonsmoker subjects were included in the reading as negative controls. The median of the three readings was used to represent the results and a profusion of 1/0 or higher was considered as pneumoconiosis.

High-resolution computed tomography (HRCT) was performed with a GE Sytec Synergy scanner (General Electric Co., Milwaukee, WI) at 1 cm intervals with 1 mm collimation from the apex to the base of the diaphragm, 1 to 3 s scanning time, 150 mAs, 120 kV, with a 512×512 reconstruction matrix. Patients were examined during breath holding after deep inspiration, in prone and supine positions [Bégin et al., 1991]. Scans were photographed at a window of 1,000–1,500 Hounsfield units (HU) and a level of -700 to -800 HU, for pulmonary parenchyma and width 500–800 HU and level of 20–60 for mediastinum.

Three experienced radiologists, blinded for the exposure history, independently examined HRCT scans from the workers and nine controls, using a systematic protocol for grading silicosis and emphysema, modified from Bégin et al. [1991] and Bergin et al. [1986]. The scores of profusion, conglomeration and emphysema were expressed as the median of the readings.

Pulmonary Function Testing

The workers were evaluated with spirometry and flow-volume curves according to American Thoracic Society [1995] guidelines and reference values from Knudson et al. [1983]. Lung volumes were determined with body pletismography, and equations from Goldman and Becklake [1959]. Single-breath carbon monoxide diffusion capacity was calculated based on reference equations from Gaensler and Smith [1973]. All tests were performed on a Collins GS apparatus (Warren E. Collins, Inc., Braintree, MA). The prediction equations were suitable for the ethnic background of the study population.

Statistical Analyses

Means (X) and standard deviations (SD) were calculated for continuous variables. Shapiro-Wilks' W was used to check if variables had a normal distribution. Differences between the means were estimated, according to their distributions, with Student's *t* and Mann–Whitney's *U* tests. Spearman's correlation coefficient was used to test the relationship between pulmonary function and categorical variables, such as categories of profusion. Annual decline of FEV_1 and FVC was estimated for the group of workers as the slope of fitted linear regressions. A P value < 0.05 was considered to be statistically significant. All data were analyzed using Statistica 5.01b (StatSoft, Inc., Tulsa, OK), EPIDAT 2.1 (Servicio de Información sobre Saúde Pública, Xunta de Galícia, Spain), and EPI-INFO 6.04d (Centers of Disease Control and Prevention, Atlanta, GA).

RESULTS

Study Population

Eleven workshops are currently active in Petrópolis, employing 44 stone sculptors. Only the two largest were registered at the labor union, comprising 16 workers. The remaining workplaces were found by extensive search and contact with workers, since there are no official registries of the activity in the city. One worker was excluded from the analysis based on his past exposure to silica as a sandblaster, and another because of tenure of only 4 months in the stone carving industry.

Occupational Aspects

Only one of the factories showed adequate hygiene conditions. The mean ($\pm$SD) employment duration of the artisans was 15.5 ± 8.3 years. Cutting of raw stones (76%), shaping (71%), carving (62%), and polishing (17%), are the most frequent activities carried out by the workers. Several types of minerals are used, such as rock crystal, rose quartz, sodalite, amethyst, fluorite, calcite, serpentinite, smoky quartz, agate, dolomite, azurite, tiger's eye, and jasper. The most used stones are rock crystal and rose quartz, both composed of silicon dioxide. Twenty workers (48%) reported some type of exhaust or ventilation system at work. Only five artisans reported the use of respiratory protective equipment prior to the beginning of this study.

Twenty-three personal air samples were collected from the 11 worksites. The mean concentration of respirable dust was 1.5 ± 1.2 mg/m^3, and the mean percentage of silica, $18.1 \pm 15.2\%$. The ratio between respirable dust and the PEL (DUST/PEL) was 4.36, ranging from 0.7 to 19.6 (Table I). Ninety-one percent of the workshops had dust concentrations above the PEL. The operations responsible for the highest amounts of dust were cutting and shaping (Table II). The DUST/PEL ratio from samples collected in places where some kind of exhaust system was present ($n = 5$; 0.7 ± 0.6) was lower than the ratio observed in sites without exhaust/ventilation ($n = 18$; 5.4 ± 6.1) ($P < 0.01$). The same difference was true for the presence of windows when compared to closed rooms, with values of 3.0 ± 4.2 ($n = 19$) and 10.8 ± 8.4 ($n = 4$), respectively ($P < 0.06$) (Fig. 2a,b).

Clinical Characteristics

All workers answered the symptoms questionnaire. The characteristics of the population are shown in Table III. Five (12%) and eight (19%) patients reported cough or sputum production, respectively. Productive cough for more than 3 years consecutively, was reported by three patients, two of them current smokers. Eleven workers (26%) had dyspnea. One patient with severe disease required oxygen supplementation and referral for a lung transplant. A history of pneumonia was reported by 19% of the stone carvers. Pulmonary tuberculosis was newly diagnosed in two patients.

Chest Radiographs

Forty-one workers were examined with chest radiographs, which were interpreted as quality "2" (acceptable) by the three readers, in 61% of the cases. All radiographs from the controls were read as profusion 0/0, except by one film that was classified as 0/1 by one of the readers. In the workers group, 15 radiographs (36.6%) were considered as normal, four (9.7%) as suspect, and 22 (53.7%) were compatible with pneumoconiosis (profusion of small opacities of 1/0 or greater) (Table IV). The frequency of shape and size of small opacities was as follows: "qp" = 10; "qq" = 5; "qr" = 7; and "rq" = 4. Large opacities were found on three patients: one was classified as category "B" and the other two as "C." The most frequently mentioned symbols were: AX (five cases), OD (three cases), ID, EM, IH, and BU (one case each). Symbols OD referred to calcified nodules on two radiographs and pleural adherences in one case.

High-Resolution Computed Tomography

All 42 workers were evaluated with HRCT. Twenty-three cases (54.8%) were classified as abnormal, due to the presence of nodules suggestive of silicosis. The exams showed confluence or large opacities on 16 patients (38.1%), and these images were generally present on patients with higher profusion, as shown in Table V. Lesions suggesting paraseptal emphysema were seen in three workers (one without pneumoconiosis and two with large opacities "A"). Irregular emphysema was present on two patients, both with large opacities "C."

TABLE I. Mean and Standard Deviations (SD) of the Amount of Respirable Dust, Concentration of Silica, and Ratio Dust/Permissible Exposure Limit (DUST/PEL), by Workplace; Stone Carvers in Petrópolis, Brazil

Workplace	Number of workers	Number of samples	Dust (mg/m^3)		% Silica		DUST/PEL	
			Mean	SD	Mean	SD	Mean	SD
A	3	2	0.61	0.30	36.69	10.03	3.11	2.23
B	4	2	2.01	1.74	23.91	24.08	9.13	11.68
C	7	3	2.50	1.48	5.22	6.80	3.04	4.24
D	4	4	0.90	0.58	29.02	7.88	3.67	3.00
E	5	2	2.02	1.84	4.93	3.38	1.36	0.74
F	1	1	4.16	—	35.76	—	19.64	—
G	3	1	3.16	—	37.53	—	15.61	—
H	1	1	1.06	—	17.29	—	2.56	—
I	2	1	1.46	—	33.45	—	6.47	—
J	3	1	1.24	—	6.57	—	1.33	—
K	9	5	0.76	0.21	4.72	3.98	0.71	0.62

TABLE II. Mean and SD of the Amount of Respirable Dust, Concentration of Silica, and DUST/PEL, by Operation; Stone Carvers in Petrópolis, Brazil

	Dust (mg/m^3)		% Silica		DUST/PEL	
Operation	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Cutting	2.18	1.40	23.82	14.92	6.90	6.30
Shaping	1.84	1.36	26.14	21.35	6.89	9.13
Carving	0.79	0.36	10.95	1.63	1.11	0.99
Polishing	0.82	0.05	6.38	0.71	0.86	0.02

Workers exposed for 15 years or more showed a 2.7 times higher prevalence of silicotic lesions on HRCTs (category 1, 2, or 3) when compared with stone carvers who had shorter tenures (see Table VI for details). These differences were consistently seen with each category of profusion, as demonstrated on Figure 3.

Pulmonary Function Tests

Pulmonary function tests were performed in 41 stone carvers. The worker who was not tested had normal radiographs. One of the subjects did not perform lung function measurements because of technical difficulties. The workers' lung function was compared in respect of their smoking habits, but no statistically significant differences were present in spirometry, lung volumes, or diffusing capacity (Table VII). Therefore, data from smokers and nonsmokers were evaluated together.

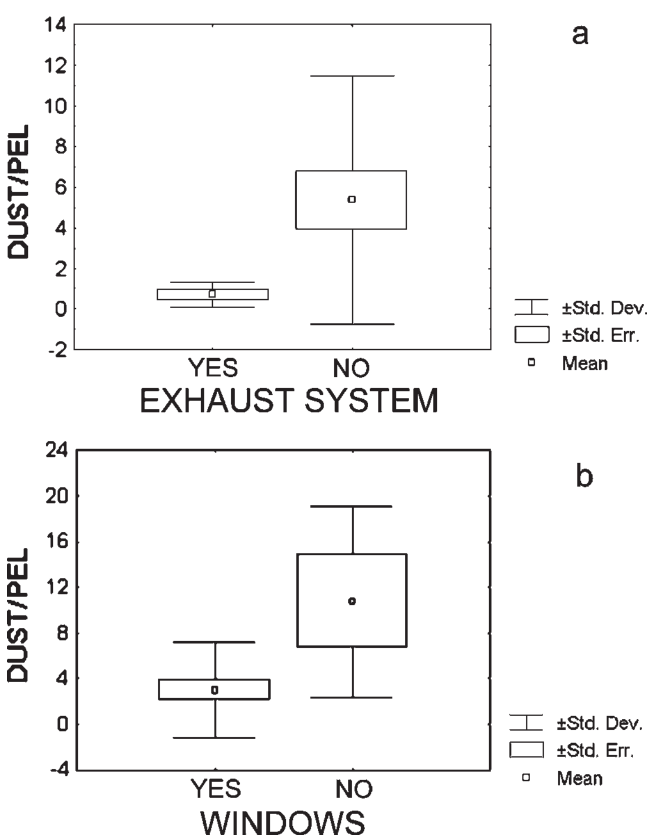

FIGURE 2. Box plots of mean, standard deviation (SD), and standard error of the ratio dust/permissible exposure limit (DUST/PEL), according to the presence of (**a**) exhaust system and (**b**) windows, in the stone carving industry in Petrópolis, Brazil.

TABLE III. Demographic Characteristics, Smoking Habits, and Tenure of the Stone Carvers in Petrópolis, Brazil

Characteristic
- Gender
  - Male: 41 (98%)
  - Female: 1 (2%)
- Age (mean ± SD): 36.2 ± 8.8 years old
- Height (mean ± SD): 170.3 ± 5.3 cm
- Weight (mean ± SD): 68.3 ± 11.3 kg

Smoking status
- Nonsmokers: 27 (64.4%)
- Ex-smokers 7 (16.6%)
- Current smokers: 8 (19.0%)

Pack-years (mean ± SD)
- Ex-smokers: 10.6 ± 9.8
- Current smokers: 13.6 ± 16.0

Tenure (mean ± SD): 15.9 ± 8.2 years

Total lung capacity (TLC), percent predicted forced vital capacity (FVC%) and TLC% were inversely correlated with categories of profusion (0, 1, 2, and 3), with Spearman correlation coefficients (r_S) of −0.41, −0.40, and −0.47, respectively ($P < 0.01$). Mean values of FVC (%) and TLC (%) among silicotic patients were significantly lower when compared to workers without evidence of silicosis, but remained within the normal range. The age coefficient for FEV_1 was −28 ml/year for stone carvers with normal chest X-rays versus −128 ml/year for workers with pneumoconiosis. The FEV_1 age coefficients for each category of profusion were −28, −95, −74, and −122 ml/year, respectively. The age coefficients for FVC were also significantly different (−29 ml/year for workers without pneumoconiosis vs. −111 ml/year for those with radiographic evidence of the disease).

In patients without large opacities, the presence of early coalescence, as diagnosed by HRCT, was associated with a lower mean FVC (% predicted) In this group, we found a

TABLE IV. Median of Radiograph Readings for Profusion of Small Opacities, According to International Labour Office (ILO) [1980], in 41 Stone Carvers in Petrópolis, Brazil

Profusion	0/0	0/1	1/0	1/1	1/2	2/2	2/3	3/2	3/3
n	15	4	3	4	2	2	2	2	7
%	36.6	9.7	7.3	9.7	4.9	4.9	4.9	4.9	17.1

TABLE V. Frequency of Small Opacities, Confluence, and Large Opacities, Evaluated by HRCT, in 42 Stone Sculptors in Petrópolis, Brazil

Confluence/ large opacities	Small opacities 0	0/1	1	2	3	Total
0	15	4	4	3	0	26
1	0	0	0	5	2	7
A	0	0	0	2	4	6
B	0	0	0	0	1	1
C	0	0	0	0	2	2
Total	15	4	4	10	9	42

HRCT, high-resolution computed tomographies.

mean FVC of 107.3% predicted and in workers without confluence, 122.4% predicted ($P < 0.02$). The presence of large opacities was associated with significantly lower mean values for FVC, FEV_1, TLC, D_LCO, and D_LCO (% predicted) in the group of workers with silicosis. Four workers had airflow limitation (FEV_1 and $FEV_1/FVC <$ lower limit of normality (LLN)), three had restriction of lung volumes (TLC < 80% predicted) (one with a mixed pattern), and seven had a reduced D_LCO (<75% predicted) (Table VIII).

DISCUSSION

This is the first report describing silicosis in stone carvers in Brazil. The carving process in our country differs from that described on the few reports about silicosis among lapidary workers [Ng et al., 1985, 1987; Chapman and Tracey, 1989; Rastogi et al., 1991; White et al., 1991; Jiang et al., 2001; Yingratanasuk et al., 2002].

Workers were carefully selected, and those who reported past exposures to mineral dusts in other jobs were excluded, because of the possible confounding factor of clinical or radiological findings due to other pneumoconioses. This resulted in a smaller sample, which better represents the occupational exposure to the dust derived from the craftwork. Possible confounding of the relationship between silica exposure and lung function was reduced due to the small number of smokers (19%).

TABLE VI. Number of Stone Carvers With Each Category of Silicosis (as Assessed by HRCT), by Duration of Exposure (Tenure), in Petrópolis, Brazil

Category	Tenure <15 years	≥15 years	Total
0	13	6	19
1	1	3	4
2	2	8	10
3	2	7	9
Total	18	24	42

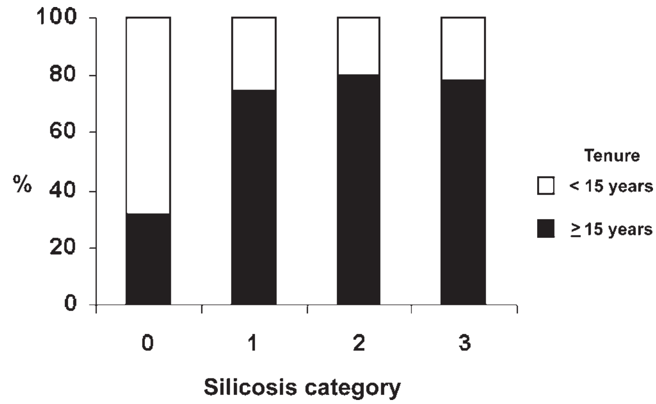

FIGURE 3. Stacked columns graph showing the proportion of workers with each category of silicosis (as assessed by high-resolution computed tomographies, HRCT), stratified by tenure; Petrópolis, Brazil.

The prevalence of silicosis in this sample (53.7%) is very high, when compared with other studies of silica-exposed workers in Brazil. Holanda et al. [1995], found a prevalence of 26.2% among pit-diggers. In Rio de Janeiro, silicosis was reported in 23.6% of 586 sandblasters [COTEPO—Rio de Janeiro State Technical Comission on Occupational Lung Diseases, 1995]. The occurrence of silicosis among gemstone workers in other countries is also variable. Jiang et al. [2001] described a prevalence of 47%, in workers exposed to agate dust and Rastogi et al. [1991] evaluated 342 subjects with similar exposure, finding 18.4%. In Hong Kong, 27.4% of the workers exposed to silica flour in the lapidary industry,

TABLE VII. Pulmonary Function Tests (Mean and SD) in Current Smokers and Nonsmokers ($P =$ NS) Stone Carvers, Petrópolis, Brazil

Parameter	Smokers ($n = 8$) Mean	SD	Nonsmokers ($n = 33$) Mean	SD
FVC (L)	4.93	1.06	4.78	0.79
FVC (%)	112.4	21.20	121.8	23.00
FEV_1 (L)	3.92	0.99	3.84	0.68
FEV_1 (%)	107.3	25.03	118.4	23.55
FEV_1/FVC (%)	78.5	9.80	80.4	6.02
TLC (L)	6.40	1.07	6.03	1.10
TLC (%)	104.1	17.39	110.1	21.59
RV (L)	1.35	0.75	1.35	0.50
RV (%)	79.6	46.10	81.4	29.81
RV/TLC (%)	22.0	12.54	22.0	8.26
D_LCO (ml/min/mmHg)	30.6	9.16	29.5	4.53
D_LCO (%)	100.7	27.93	100.3	15.22
D_L/VA	7.26	7.16	5.00	0.92
D_L/VA (%)	105.8	26.36	102.0	18.06

TABLE VIII. Number of Workers With Abnormalities on Pulmonary Function Tests, According to Category of Profusion Assessed by HRCT, in Stone Carvers, Petrópolis, Brazil

Category	n	FEV_1 and FEV_1/FVC < LLN	TLC < 80% predicted	D_LCO < 75% predicted
0	18	1	—	2
1	4	—	—	—
2	10	1	1	3
3	9	2	2	2
Total	41	4	3	7

had silicosis [Ng et al., 1987]. In a short report about lapidary work in Lesotho, 22 out of 24 workers had radiographic evidence of pneumoconiosis [Chapman and Tracey, 1989]. Recently, a prevalence of 2% was described among stone sculptors in Thailand, who were exposed to lower levels of dust, when compared to workers in our study [Yingratanasuk et al., 2002].

The high prevalence found in our population can be explained by several adverse work conditions. The absence of windows or exhaust systems was responsible for higher concentrations of dust. Ng et al. [1985] showed that the amount of respirable dust was reduced from 0.72 to 0.34 mg/m^3 when exhaust systems were turned on, as we could demonstrate in our study. As previously described by Ng et al. [1985] and White et al. [1991], we noticed that most of the stone sculptors work at home, in little workshops, without adequate engineering control. The variety of minerals used by the artisans also makes our study different from others that report the use of only one type of stone, such as jade [Ng et al., 1985], agate [Rastogi et al., 1991; Jiang et al., 2001], and tiger's eye [White et al., 1991]. However, most of the minerals used in Petrópolis are varieties of quartz. Furthermore, few workers use protective equipment, as reported in other studies about mineral craftwork [Ng et al., 1985, 1987; Chapman and Tracey, 1989; Rastogi et al., 1991; White et al., 1991; Jiang et al., 2001; Yingratanasuk et al., 2002].

Duration of exposure also played an important role in the occurrence of disease. The prevalence of silicosis was nearly three times higher in workers with tenures of 15 years or more, as compared to lower tenure workers. Rastogi et al. [1991] and Yingratanasuk et al. [2002] also showed that prevalence of silicosis was higher among workers exposed for longer periods of time.

The frequency of respiratory symptoms in this sample is similar to the findings of Ng et al. [1987] in lapidaries from Hong Kong. However, other studies found a higher number of symptomatic workers [Koskinen, 1985; Jiang et al., 2001]. This difference may be attributed to the higher proportion of smokers in those studies. Despite the high prevalence of tuberculosis in Brazil, only two cases were found, yielding a prevalence of 4.8% among exposed workers and 8.6% if only subjects with silicosis are considered. In China and India, the prevalence of tuberculosis in silica-exposed lapidaries was 12.5 and 15.5%, respectively [Rastogi et al., 1991; Jiang et al., 2001].

HRCT demonstrated silicosis in 23 cases, and identified more severe disease than the radiographs, by showing earlier coalescence and large opacities "A" with greater precision. Other reports have shown the superiority of HRCT in the evaluation of silicosis [Bergin et al., 1986; Bégin et al., 1991, 1995; Talini et al., 1995].

Reduced pulmonary volume was associated with the presence and severity of silicosis. This was also evident in silicotic patients whose normal values of FVC and TLC were in fact decreased in comparison to workers without pneumoconiosis, and in patients with coalescence of small opacities demonstrated by HRCT, confirming the findings of Bégin et al. [1988]. Another prominent indication of the deleterious effects of silicosis is excessive FEV_1 decline [Hnizdo, 1992; Malmberg et al., 1993; Graham et al., 1994; Cowie, 1998]. Even though we have the limitations of a cross-sectional study, reduced age coefficients of lung function were detected in all categories of silicosis. Similar to our findings, Cowie [1998] have also demonstrated losses of 37, 57, 100, and 128 ml/year in FEV_1, for categories 0, 1, 2, and 3, respectively.

In summary, exposure to high levels of silica dust was associated with a high prevalence of silicosis and lower lung function among stone carvers in Petrópolis, RJ, Brazil.

The implementation of measures of industrial hygiene aimed to reduce environmental risks in this group of workers is of paramount importance. In an attempt to increase worker awareness of occupational risks, we also developed an educational program. It consisted of interactive presentations with comprehensible terminology and slide projections, comprising topics of hygiene, prevention, discussion of real cases of silicosis, and practical notions of respiratory protection. It seemed to improve the commitment of the workers towards occupational health, given that in subsequent visits to the workplaces we noticed that the use of proper respiratory protection had increased to 75%. Nevertheless, measures of industrial hygiene regarding dust control in the source are needed to try to minimize the future burden of silicosis in this group of workers.

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