ORIGINAL CONTRIBUTION

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The effects of silica exposure on upper airways and eyes in denim sandblasters*

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SUMMARY

Objective: *Silicosis due to denim (or jean) sandblasters is newly described cause of silicosis. In such cases lungs are severely affected due to heavy exposure to silica without serious protection. We aimed to investigate whether silica had an effect on the upper airways and eyes.*

Methods: *The study included the patients recently diagnosed with silicosis. For comparisons, a control group was constituted. Firstly, a questionnaire was performed to obtain demographic and exposure characteristics of the cases. Later, routine nasal examination by endoscope and routine eye examination by slit-lamp microscope were performed to investigate presence of rhinitis and/or adenoid vegetation and eye findings associated with dust exposure, respectively, in both patient and control groups. Punch biopsies of the adenoid tissue were obtained using an endoscopic telescope with the patient under local anesthesia and sent for histopatologic examination. In addition, nasal pH and mucociliary clearance were investigated. Both pH and saccharin nasal transport time (SNTT) measurements were performed by two physicians, who reached a final consensus.*

Results: *The study group consisted of 83 male silicotics with an average age of 23 ± 6 years, and the control group consisted of 84 age and gender matched healthy individuals. Their mean exposure time was 40 ± 26 months. On routine nasal examination, silicotics had higher rates of rhinitis (28.9% versus 16.7%) mostly ipsilaterally ($p = 0.01$), adenoid vegetation (32.5% versus 13.3%, $p < 0.05$), conjunctival hyperaemia (70% versus 45%, $p < 0.001$), pingueculae (68% versus 23%, $p < 0.01$), papillar formation (40% versus 28%), and higher nasal pH values (7.9 ± 0.7 versus 6.9 ± 0.6, $p < 0,001$), higher SNTT values (19.9 ± 2.9 versus 10.9 ± 1.9, $p < 0,001$) compared with the controls.*

Conclusion: *The results of our study suggest that upper airways and eyes are considerably affected in the patients with silicosis. Thus, appropriate protection is required to prevent the development of such problems in denim sandblasters.*

Key words: Silicosis, sandblasting, nasal, upper airway, eye

INTRODUCTION

Silicosis is a fibrotic disease of the lungs caused by inhalation and retention of as well as pulmonary reaction to crystaline silica. Although it is a well–known occupational disease, new occupational causes of silicosis continue to be reported. Recently, silicosis in Turkish denim sandblasters has been reported as the newest cause of silicosis [(1)]. New cases with fatal outcomes due to denim sandblasting have also been reported [(2, 3)].

In denim sandblasting, workers are exposed to silica because they project silica-containing sand, as an abrasive, onto denim (or jeans) surfaces to produce a “worn-out” appearance. Because of a very intense exposure during long hours of work under very poor hygiene conditions without adequate respiratory protection, this kind of exposure seems to be more hazardous than the exposure from previously known sources.

It is highly possible that not only lungs but also other parts of the body such as the skin, eyes, and upper airways will be affected in people who are exposed to silica, especially due to sandblasting, if inadequate protection is implemented. However, to our best knowledge, there have been no reports of the

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effects of silica exposure on the upper airways and eyes, in English literature, possibly because of underestimation of such findings due to predominancy of lung involvement and respiratory complaints.

Besides respiratory complaints, non-respiratory ones including nasal and eye complaints in some patients with silicosis struck our attention in the evaluation of some cases, who were diagnosed in the outpatient clinic of chest diseases. Thus, in this study, we aimed to examine whether nasal and eyes involvement occurred due to silica exposure in the textile workers who had worked in a unique work area, denim sandblasting.

METHODS

Study population

Eighty-three male patients with silicosis among the cases who were previously diagnosed as silicosis in the outpatient clinic of chest diseases between 2005 and 2007 years (n=32) or among the cases of another study (unpublished data) on former denim sandblasters that was performed between May and June 2007 (n=51) were included in the study. The control group consisted of 84 healthy individuals of similar sex, age, and geographic region.

The subjects with a gross septal deviation causing a decrease in the area of the anterior nasal fossa at the valve by >50%, with a history of infection of either the upper respiratory tract or eyes within the past 3 weeks, and/or taking any topical nasal or eye medication, undergone previous nasal or ophthalmic surgery or attacks of allergic rhinitis were excluded from the study.

The written informed consents of all the participants were obtained, and the study protocol was approved by the local ethics committee.

Study procedures

Firstly, a questionnaire was used to obtain demographic and exposure characteristics of the cases. Then, routine nasal examination by endoscopy and routine eye examination by slit-lamp microscope were performed to detect rhinitis, adenoid vegetation and/or eye findings respectively, associated with dust exposure, in both the patient and control groups. Rhinitis was defined according to the criteria of previously published guidelines [10]. Adenoids occupying more than one third of the cross-sectional area of the choanae were accepted as adenoid hypertrophy [11]. Prick-test and RAST were used to evaluate allergic rhinitis for all cases. Punch biopsies of the adenoid tissue were obtained by the use of an endoscope under local anesthesia and the biopsies were sent for histopatologic examination. The nasopharyngoscopic findings were confirmed by computed tomography scan.

In addition, nasal pH and mucociliary clearance were investigated. Nasal mucosal pH was measured using a Macherey-Nagel 100 colour-fixed indicator sticks. The contact with the nasal mucosa provided an immediate reading. The measurements were taken 1cm along the medial aspect of inferior turbinates and 1 cm on the posterior of the maxillary spine on both sides of the nasal septum. All the readings were taken at the same time of the day. Each reading was repeated two times at 5-min intervals. The test was repeated on each side and the average of two readings was taken as the nasal mucosal pH.

Nasal mucociliary clearance was assessed via saccharin nasal transit time (SNTT) and evaluated by means of Andersen's saccharin test [4]. A saccharin particle (1.5-mm diameter) was carefully placed on the floor of the nasal cavity about 1 cm behind the anterior end of the inferior turbinate. Placement was achieved under direct vision using a standard nasal speculum and a head light. The exact time of saccharin placement was recorded. The subjects were asked not to sniff, sneeze, smoke, eat or drink during the test, and avoid deep breathing. They were asked to swallow every 30 s and to report the first change in their sensation of taste. The time taken by the subjects to perceive sweet taste in the pharynx was taken as mucociliary clearance time. The test was repeated on each side and the average of two was taken as the nasal mucociliary clearance time. This was done to exclude the effect of nasal cycle on mucociliary time.

Both pH measurement and SNTT were performed by two physicians and final consensus of them was reached.

Statistical analysis

The data were analyzed using the SPSS version 11 statistical software (SPSS Inc., Chicago, IL). Pearson Chi-square and Student t tests were used to compare categorical (presence of smoking history, allergic rhinitis, rhinitis on nasal examination, bilateral rhinitis, rhinitis in ipsilateral location of septum deviation, pingueculeae and conjunctival hyperemia) and continuous variables (age, nasal pH values, SNTT values), respectively. The value of $p < 0.05$ was considered statistically significant.

RESULTS

The mean age of the patients with silicosis was 23 ± 6 years (range 16 - 44), whereas the mean age of the control group was 23 ± 5 years (range 16 – 38). All the patients had a history of

Table 1. Summary of some demographic data and the results.

	Cases with silicosis (n=83)	Healthy controls (n=84)	p value
Ages (yrs ± SD)	23 ± 6	23 ± 5	0.98
Smoking history	57 (69%)	52 (62%)	0.36
Allergic rhinitis	16 (%)	13 (%)	0.52
Rhinitis on nasal examination	24 (29%)	14 (17%)	0.06
Bilateral rhinitis	3 (4%)	1 (1%)	0.31
Rhinitis in ipsilateral location of septum deviation	17 (20%)	1 (1%)	< 0.001
Adenoid vegetation	27 (33%)	4 (13%)	< 0.05
Nasal pH values	7.9 ± 0.7	6.9 ± 0.6	< 0.001
SNTT values	19.9 ± 2.9	10.9 ± 1.9	< 0.001
Pingueculae	57 (68%)	19 (23%)	< 0.001
Conjunctival hyperemia	59 (70%)	38 (45%)	< 0.01

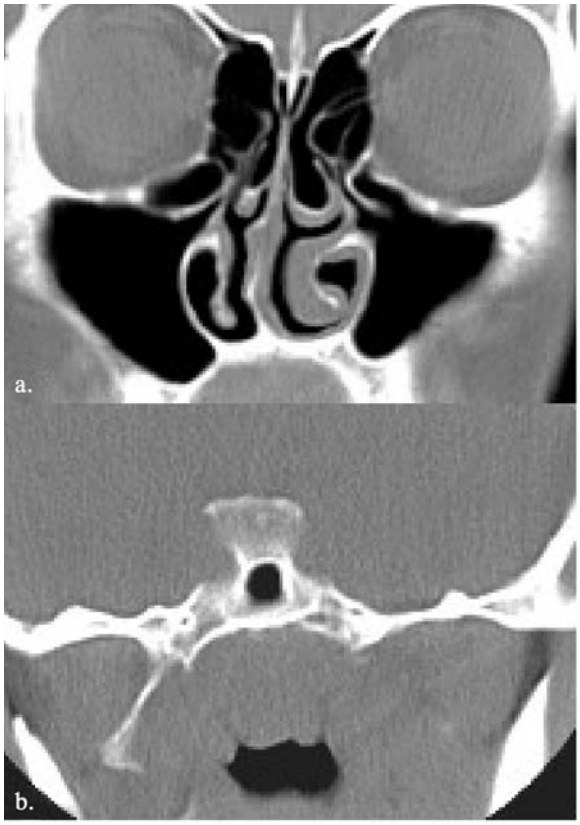

Figure 1. 1a) Coronal Paranasal CT image shows prominent nasal mucosal thickening and inferior turbinate hypertrophy located in the opposite side of the deviation without sinusitis.
1b) Coronal Paranasal CT image shows adenoid vegetation in the nasopharyngeal posterosuperior wall.

working in small workplaces sandblasting jeans but none of them was working at the time of admission to the study. Their primary work was to abrade jeans using silica. Their mean age at first exposure was 16 ± 6 years; the mean workdays per week was 6.0 ± 0.5 day/week (range 5 – 7), and the mean exposure time was 40 ± 26 months (range: 3-120 months). Latency period (time between first exposure and admission) was 7 ± 3 years (range 2-16 yrs). Although most of the patients were symptomatic, only 11 had nasal (n=7) or eye (n=4) complaints. Some demographic characteristics and results were summarized in Table 1. There was smoking history in 57 of silicosis cases and 52 of controls. Smokers had a 17 ± 4 versus 16 ± 5 pack/yrs smoking history in the cases with silicosis and controls, respectively. Allergic rhinitis was determined 16 of the cases and 13 of controls. But the difference between the groups for smoking and allergic rhinitis was not different statistically.
On routine nasal examination, 24 of the patients (29%) and 14 of the controls (17%) had rhinitis. However, the difference was not statistically significant. Of the cases, four (3 patients and 1 control) had bilateral rhinitis. Rhinitis was found to be more pronounced in the concave side of the septum deviation in 17 patients and in one control. There were no significant differences in the location of rhinitis between the patients and controls when all the patients were evaluated, including the ones with bilateral rhinitis ($p = 0.06$). However, rhinitis was more often located in the concave side of the deviation in the patients with silicosis compared with controls when only the cases with unilateral rhinitis were evaluated ($p < 0.01$) (Figure 1a).

In the analysis of the cases, 27 patients (33%) and 4 controls (13%) had adenoid hypertrophy. The rate of adenoid hypertrophy (Figure 1b) was significantly higher in the patients with silicosis ($p < 0.05$). The results of histopathological examination of adenoid vegetation biopsy specimens were shown in Figure 2. On histologic examination of adenoidal vegetation biopsy specimens, mostly normal ciliated respiratory epithelium and sometimes squamous metaplasia of goblet cells were determined. The submucosa contained lymphoid follicles with prominent germinal centers. Plasma cells, macrophages, and sometimes neutrophils or eosinophils found in the parafollicular regions, and there is often striking hyperplasia of the

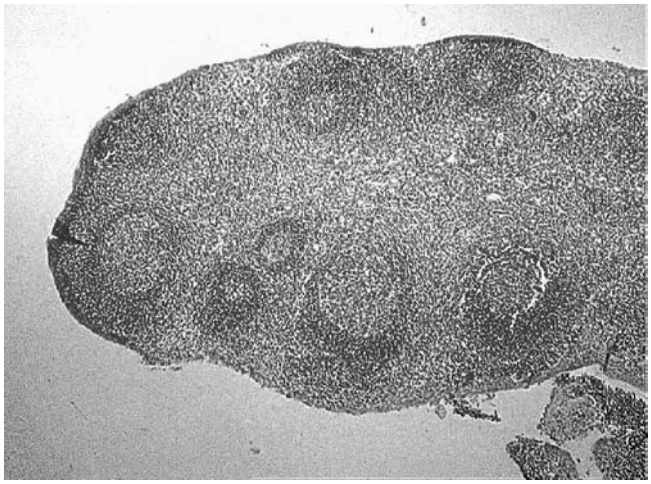

Figure 2. On histological examination of adenoidal vegetation biopsy specimens, lymphoid tissue with prominent germinal centers, which were similar to the regular adenoidal tissue were detected.

Figure 3. Pingueculae and conjonctival hyperemia in a case with silicosis. The condition was diagnosed with a slit lamp microscope.

mononuclear phagocytic cells linning the lymphatic sinuses. In all the adenoid vegetation biopsies, reactive changes in the lymphoid tissue, predominantly follicular hyperplasia similar to that seen in the regular adenoidal tissue were noted (HE X 20). In addition, compared to the subjects without silicosis, those with silicosis had significantly higher nasal pH values (7.9 ± 0.7 versus 6.9 ± 0.6, $p < 0.001$) and higher SNTT values (19.9 ± 2.9 versus 10.9 ± 1.9, $p < 0.001$).

On routine eye examination, there was conjunctival hyperaemia, pingueculae (Figure 3) and papillar formation on the conjunctiva in both eyes of 59 (70%), 57 (68%) and 34 (40%) of the patients with silicosis, respectively. On the other hand, there was conjunctival hyperaemia, pingueculae and papillar formation on the conjunctiva in both eyes of 38 (45%), 19 (23%) and 23 (28%) of the controls, respectively. Pingueculae in the nasal conjunctiva and conjunctival hyperaemia were significantly more common in the patients with silicosis ($p < 0.001$ and $p < 0.01$, respectively) compared to controls. Although papillar formation was also commoner in the patients with silicosis, the difference was not statistically significant ($p = 0.12$).

DISCUSSION

Present study showed that denim sandblasters who were exposed to crystalline silica had considerable upper airway and eye complaints in addition to pulmonary ones. The findings on the upper airway and eye of the patients with silicosis were a higher rate of rhinitis in the opposite side of deviation, a higher rate of adenoid vegetation, increased pH value, increased time of mucociliary clearance and higher rates of pinguecula and conjunctival hyperemia. These findings demonstrate the non-pulmonary effects of silica exposure, especially considering the relatively short exposure duration.

The occupation of sandblasting denim jeans is relatively new and has developed as a result of changes in fashion in developed countries and the demand for worn-looking jeans. Tragically, this condition has occurred in very young men with an average of only 3 years in this particular occupation. Lack of awareness of the condition and the dangers of silica and inadequate protective measures have already had fatal results (2, 3). Silicosis is a well-known disease and its clinical forms have been well characterized. The classical form of silicosis usually follows one or more decades of exposure. However, in contrast to the chronic or classical form of silicosis, the accelerated and acute forms result from intense exposure to high levels of respirable dust that contains a significant proportion of silica, and these develop after much shorter duration [5]. However, there is limited information on the non-pulmonary effects of silica in both classical and acute/accelerated cases with silicosis.

As we stated above, our results indicate that upper airway involvement such as adenoid hypertrophy, rhinitis particularly in the non-deviated side, SNTT, and nasal pH values are significantly higher in the patients with silicosis due to heavy silica exposure. Since respiration starts in the nose, it is naturally the place where the first deposition of foreign particles may take place. The nasal mucosa directly encounters these particles because workers do not use protective or proper masks and thus heavy exposure to the particles leads to the passage of silica particles, depending on their diameters, to the pharynx where the lymphoid tissue is dense and then to the lungs after passing through the nasal cavity.

Adenoid hypertrophy, one of our prominent findings, is commonly seen during childhood, between 3 and 7 years of age. Diet as well as endocrine and constitutional factors have also been held responsible in the etiology. It becomes atrophic or involutes gradually after puberty [6]. After adenoiditis attacks, adenoid hypertrophy may occur. General systemic infections and local causes like changes that occur in the mucosal barriers have also been reported as causative factors [7,8,9]. Finkelstein et al have evaluated the effects of smoking on the nasopharyngeal lymphoid tissue in heavy smokers under electron microscope and concluded that rapidly moving smoke particles might easily adhere to the nasopharyngeal mucosa and stimulate the lymphoid tissue in the nasopharyngeal posterosuperior wall [11]. Silica may have a direct effect upon the nasopharyngeal lymphoid tissue, which is part of the immune system. Adenoid vegetation in silicosis patients is likely to develop through similar mechanisms to those in heavy smokers. Further investigations are needed in order to determine the frequency of this phenomenon in sandblasters and its potential clinical implications. In addition, further investigations are required to determine whether the lymphatic tissue in the lung behaves in the same way as in the nasopharynx, and whether there is a link between adenoid vegetation and increased risk of silicosis or cancer.

Our findings suggest that adenoid hypertprophy should be added to the list of known airway manifestations of silica exposure and that nasopharyngoscopic examination of the nasopharynx is essential for all cases with silicosis, especially sandblasters. Clinical signs of obvious lymphoid hyperplasia as a distinct diagnostic entity should also be listed as an additional clinical manifestation of sandlasters.

Rhinitis is the inflammation of nasal mucosa due to infectious agents such as bacteria and viruses or environmental pollution and non-infectious causes such as allergies. In an experimental study, it was shown that intranasally inserted foreign body caused the development of sinusitis in rabbits [12]. In another study, the synthetic sponge itself had a major role in the manner of a foreign body in the development of sinusitis [13]. Silica particles might have induced intranasal mucosal inflammation acting as a foreign body. The particles might have rapidly hit the nasal mucosa due to intensive silica passage through the non-deviated side with high velocity air-flow and caused

inflammation associated with reactions to trauma and/or foreign bodies.

It has been proposed that nasal airflow have a 'physiological effect' on the nasal epithelium, with nasal airflow being necessary for the normal functioning of the nasal epithelium [14]. Although it is suggested that excessive nasal airflow causes drying of the nasal epithelium that leads to nasal disease as crusting and infection [15], inadequate nasal airflow associated with nasal septal deviation may also be an important causative factor of nasal and sinus infection [4].
Proetz comments that "cold, dry, contaminated, inspired air does not come in contact with the sinus ostia, at least not in any direct stream, but that "air currents reaching these openings are all expiratory and therefore moist, warm and clean."[16]. The ostia of the paranasal sinuses are protected from the damaging effects of inspiratory airflow. In our patients, rhinitis was more common in the side with no septum deviation, while the number of the patients with sinusitis on the same side was very low.

Normal saccharine clearance time is 7–15 minutes. When it is over 20 minutes, it is pathological [17]. The changes in the structure of the nasal epithelium caused by increases in nasal airflow are thought to be due to damage to ciliated cells [18]. It is suggested that over a period of 2–3 months the doubling of airflow on the open side causes a shift in the anterior part of the nose that is exposed to high velocity airflow both increasing the extent of the squamous epithelium and decreasing the number of ciliated cells and goblet cells. Histological studies on the closed side of the nose report there was an increase in the number of goblet cells and ciliated cells [19, 20]. Similarly, in our study, mucociliary clearance time determined in the patients with no septum deviation was parallel to the earlier reports.

Cinar et al. investigated the effects of coal dust particles on the nasal mucociliary function in coal mine workers and determined that the average SNTT in coal mine workers was longer than that of the control subjects [21]. We found significantly delayed SNTTs in sandblasters.
In many studies, it has been shown that dust particles have slowed down mucociliary transport or increased mucociliary transport time [22]. The determination of increased SNTT in silicosis patients have shown that silica dust particles decrease the nasal mucociliary function. It was also suggested that adenoidal hypertrophy reduced the nasal mucociliary functions [23]. In our study, the presence of statistically significant degree of adenoid vegetation might have been another reason for prolonged SNTT.

The pH of the nasal mucosa in normal people was reported to be within the range of 5.5 - 6.5 as far back as 1941 [24]. It is postulated that the maintenance of the pH of nasal secretions depends on intact nasal epithelium; nasal pH rises to more alkaline values where the epithelium is damaged by infective or allergic rhinitis. For mean pH values, it was suggested that gender was the only consistently significant variable but the variables of smoking, anatomical variation and the continuous covariate age were not consistently significant [25]. Furthermore, for cilia movements, the optimum pH level is 7.5. When nasal mucosa has a pH of 6.4-8.5, they are active. When pH is lower than 4.6 or is higher than 9, the motions of cilia go into recess. In our patients, the mean nasal pH values were 7.9 ± 0.7, which might have been an effective factor on the increased SNTT.

Considering factors such as allergies, vasomotor or infectious rhinitis, foreign bodies, nasal pH changes, and inhalation of polluted air, which affect the mucociliary clearance, increased SNTT may be highly significant in denim sandblasters.
In addition to upper airway findings, our results also indicate that eye findings such as pinguecula and conjunctival hyperemia are significantly more common in patients with silicosis due to heavy silica exposure. A pinguecula is a nonmalignant lump that develops on the conjunctiva next to the cornea, as in a similar condition known as pterygium. This condition may include other symptoms such as dry eyes, inflammation, and redness. It develops due to an alteration of normal tissue, where stromal collagen is replaced with thicker fibers [26, 27].

Pathogenesis and the causes of that disease have not been clearly understood. Long-term exposure to ultraviolet light, wind, dust and/or smoke are the most common among the known environmental factors causing this condition and can appear either on the temporal or nasal side (or both) of the cornea, but are more commonly found nasally. A routine eye examination is usually sufficient to diagnose this condition, but a slitlamp microscope examination can also be performed. Treatment of this condition is rarely required because of its benign nature. However, if the patient suffers from discomfort because of pingueculitis (acute inflammation), anti-inflammatory drops or artificial tears may be used. In addition to this, patients may also benefit from wearing good quality sunglasses to avoid exposure to ultraviolet radiation, dust, and wind. In extreme cases, such as corneal thinning, severe inflammation, and excessive growth or for cosmetic purposes, surgery may be required [28, 29].

To our best knowledge, there are no previous reports of such nasal or eye findings in cases with silicosis in literature. It is highly possible that nasal and eye findings as well as other respiratory complaints may be underestimated due to predominance of respiratory complaints. In our cases, there was a heavy exposure history to silica due to closed, poorly ventilated work areas, long daily working hours, and no effective protection for their mouths, noses, and eyes. The findings of our study suggest that in the cases with silicosis due to denim

sandblasting adenoid vegetation, rhinitis, increased nasal pH, decreased mucociliary clearance, pinguecula and conjunctival hyperemia were main non-pulmonary findings. A first approach to preventive medicine is to institute environmental control measures, such as providing adequate ventilation. Thus, to prevent the development of eye or upper airways complications, appropriate measures such as using equipment covering eyes, nose and mouth during sandblasting are required or other methods instead of sandblasting should be used. Another, even more important, option may be to use strict control measures for such workplaces or to completely ban sandblasting procedures as many European countries have done. However, it remains to be investigated whether these finding are seen in the classical cases and what will be the long-term outcomes of these findings.

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