

ASSESSMENT OF LUNG PARTICLE ACCUMULATION IN FACTORY WORKERS BY MAGNETIC FIELD MEASUREMENT

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Abstract

Objectives: In industrial settings, minute particles of industrial substances lodge in the lungs and accumulate over decades, often leading to pneumoconiosis. Although these particles have been almost impossible to detect with x-rays, especially initially, we still rely upon them for detection of such deposits. As a result, particle accumulation is not detected early enough, and eventually diagnosed pneumoconiosis is typically irreversible. Accordingly, we investigated an alternative detection method that utilizes the magnetic characteristics of the particles after they are excited by an external magnetic field. Using accumulation of magnetic particles as a surrogate marker for total particle accumulation, our goal was to develop a method that can determine particle quantity and distribution in the lungs of individuals in different types of industrial situations. This method would allow us to identify factors that affect particle accumulation and to detect early such accumulations, before the pneumoconiosis stage. The pilot study reported herein represents proof of principle that such a method is feasible. **Materials and Methods:** After a magnetic field generated by a strong direct current is applied to particles, they continue to generate a weak magnetic field even after the external field is removed (relaxation). We measured relaxation using an external detector (scanning a flux-gate magnetometer, Helmholtz coil). To field test this method, we studied 150 subjects in various industrial settings. We studied a variety of factory workers, including those involved in welding and cutting for different employment durations. A static magnetic field of 50mT to the chest, and the residual magnetic field distribution were measured by scanning a flux-gate magnetometer in a 2-dimensional region covering the whole chest. **Results:** The strength of the magnetic field from the lungs of our subjects generally increased with the length of employment, particularly after 11-20 years. Welders showed higher particle accumulation than the others. Across all types of jobs, and work durations, smokers had lung particle accumulations substantially higher than non-smokers. **Conclusions:** 1. In the study reported herein, we describe application of a novel, portable device for measuring the accumulation of magnetizable particles in the lungs of factory workers. These particles are viewed as a surrogate for determining the extent and distribution of total particles in the lung. This is based on the detection of signal emanating from para- and ferromagnetic particles when they relax after an external magnetic field is switched off. 2. Particle accumulation increases proportionally to employment duration in welders, but may be less severe in other types of workers within the same company. 3. Smoking greatly increases the extent of particle accumulation. 4. Additional studies are now necessary to correlate signal with: (a) particle density at various sites, (b) total particle accumulation in the lungs, (c) lung function, and (d) the severity of lung fibrosis and pneumoconiosis. If correlated, the method may be useful in the early detection of particle accumulation and may allow for the assessment of outcomes following interventions for the treatment and prevention of pneumoconiosis.

Key words:

Biomagnetic fields, Lung particle accumulation, Industrial toxins, Pneumoconiosis, Magnetic field, Magnetization

INTRODUCTION

Pneumoconiosis is a disease that is induced by the sedimentation of particles in the lungs, making them fibroid.

In Japan, it is currently estimated that 650 000 people work in particle-rich environments. Of these, many long-term workers have developed pneumoconiosis, creating

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nowadays a large-scale problem in the Japanese society. Bearing this in mind, regulations governing particle exposure in the workplace were made into law in Japan, in 1960, and then further strengthened and revised in 1978 [1]. Apparently, this has little contributed to diminishing the number of patients with particle-related lung conditions. Pneumoconiosis is also a problem in various other countries, especially those with rich mining resources.

In Japan, pneumoconiosis is defined as “a disease resulting from an increase in lung fiber caused by the inhalation of ore particles”. This definition may not exactly correspond with definitions used in the USA and in the majority of European countries.

In its most common form, the disease is caused by the inhalation of a large number of particles over a long period of time, the seriousness of which varies depending on the type, size, and shape of the particles inhaled [1,2]. It is easiest for particles of roughly 1 micron in size to sediment in the lungs, while it is thought that particles over 5 microns in size cannot pass through the alveoli and are either coughed up or otherwise expelled from the body. Inorganic pneumoconiosis can result from the inhalation of particles from materials, such as free silica, cement, aluminum, iron, limestone, and gypsum. While most particles are non-magnetic, it is expected that ferromagnetic particles will in many situations accompany those directly responsible (free silica) for the development of pneumoconiosis. A chemical analysis of dust at the workplace may provide the required information in this respect. Even if long-term accumulation of various dust components may not be directly proportional to their quantitative participation in the dust found at the workplace, the presence of ferromagnetic particles retained in the respiratory system of exposed workers could provide a semi-quantitative indication of the past exposure. It should also be emphasized that tobacco smoke inhalation may play a role in retention of dust, and therefore indirectly influence the development of pneumoconiosis. The direct effects of this factor should not be neglected.

Tobacco smoke inhalation is a common cause of organic pneumoconiosis. Both types of pneumoconiosis start gradually and progress slowly. Often, there are no obvi-

ous symptoms at the advent of lung disease. The main signs are: accelerated respiration when exercising, heart palpitations, and an enhanced susceptibility to colds, being together with pulmonary emphysema a next stage of the disease [3]. Damage to the respiratory system is manifested by reduced lung activity, lung capacity, and lung activity over time, as well as by reduced lung surface area being used for respiration, loss of lung elasticity, and stricture of the air passages. Diagnosis is made by comparing work history with x-ray pictures and symptoms.

In general, pneumoconiosis is not diagnosed at an early stage because it is extremely difficult to detect with x-rays particles of less than several microns in size, and thus early detection of pneumoconiosis using current techniques for examining lung function is nearly impossible [4]. Indeed, by the time an abnormal shadowing caused by particle accumulation or by lung tissue fibrosis can be detected by x-ray, pneumoconiosis is already in an advanced stage, and the patient begin to experience symptoms related to the condition.

Because pneumoconiosis is typically irreversible, its prevention is of paramount significance. Currently, the research is carried out in various countries to find out new methods for treating this disease and analyzing disease-related lung dysfunction [5]. Some of this research involves measurements of magnetic fields generated by living bodies. It has long been hypothesized that the heart, brain, lungs, and other organs all generate a weak magnetic field because of the electrical current running through the body and the accumulated magnetic particles in various organs. Numerous methods of measuring these fields have been attempted, but their measurement has thus far been difficult due to their extremely weak nature.

Somewhat more progress has been achieved using magnetic field measurement on the lungs. A new examination method may really be possible. Over a decade ago, Kotani et al. [6] developed and produced a basic model for a magnetized lung particle measurement device, using a method that succeeded in diagnosing pneumoconiosis impossible to be detected with x-ray, by magnetizing inhaled particles from outside the body, and then measuring the residual magnetism of the particles. Since then, many advances in

measuring pulmonary magnetic fields have been made, and it is now possible to accurately measure the volume and distribution of minute accumulations in the lungs using the characteristics of pulmonary sediments [7]. Recognizing the need for an inexpensive technique for performing these measurements, we developed a simple device able to perform regular lung examinations of workers. As an initial field test of our portable device, our objective was to determine how the type of work, length of exposure, and smoking history affect the magnitude of particle accumulation in the lungs [8].

MATERIALS AND METHODS

In this pilot study, we examined 23 smokers and 21 non-smokers. There were 3–5 subjects in each category of employment duration.

To measure particle accumulation in the lungs, we first applied an external direct current magnetic field at a constant strength to the entire lung, thereby magnetizing all susceptible particles. Because the residual magnetic fields of the particles magnetized in this way are all aligned in the same direction, it is possible to measure the magnetic field of the magnetized particles from outside the body. We used a portable Helmholtz coil [1] to generate the necessary constant magnetic field. By applying a direct electrical current, we were able to create parallel magnetic fields.

To measure the lung's magnetic fields and the volume and distribution of particle contaminants in the lungs, we used circuits that have been previously described [1]. In our instrumentation, components can be disassembled and moved as separate units. An electric magnet is capable of generating a magnetic flux density of 50 milliteslas (mT, the equivalent of 500 gauss in the CGS scale) in the entire lungs. An ultrasensitive monitor capable of recording this very weak magnetic field produced by the lungs was used [2]. A movable bed made with non-magnetic materials was used for taking readings at 10 measurement sites.

Data were fed into a computer system that automatically calculated the volume and distribution of magnetic particles within the lungs from the magnetic field values record-

ed at each measurement site. The individual components are the essential components comprising the assembled pulmonary biomagnetic field or magnetopneumogram [9]. The center of the magnetizing Helmholtz coil is aligned with the sternum, with the chest touching the device. Magnetization is at 500G for approximately 10 sec. The patient was asked to lie down, and a probe was placed 1–2 cm above the chest. The area measured was set at 38 cm horizontally across the chest wall, and 16 cm vertically, giving an area of $38 \cdot 16$ cm. For measurement, we used a single flux-gate fluxmeter, moving the bed so that the probe was positioned above the right chest wall. Then we moved the probe 38 cm to the left (on the horizontal x-axis) and back, giving two readings along one line. Next, we shifted the probe 4 cm downwards (on the vertical y-axis) and measured a new line, measuring it twice as we did before, repeating this process until we covered the entire lung. The second measurement line from the bottom was positioned to pass over the patient's sternum. We then recorded pulses from an optical sensor that measures body movement and the magnetic signals coming from the patient, entering these data into an X-T recorder, a data recorder, and a PC. Finally, we recorded the total time used for measurement. The sensitivity for this instrumentation was 5 μ G (50 nT).

RESULTS

Using patients' histories and the maximum values of pulmonary magnetic fields detected, we calculated average pulmonary magnetic fields for groups of patients performing different types of job. We chose a 10-year time span for our averages to show the trends in variations of particle accumulation (Fig. 1). In a planned comparison of patient data at all durations of employment for the three separate employment groups, that is, welders, cutters, and others (paint appliers, administrators, etc.), we found a significant difference across groups ($F(1, 123) = 6.69, p = 0.01$). Furthermore, for the largest group, the welders, the strength of the magnetic field increased in proportion to the length of employment (regression coefficient, $r = 0.29; F(1, 99) = 9.01, p < 0.0034$).

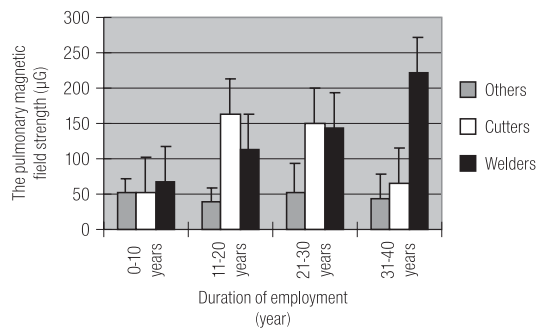


Fig. 1. The effect of job performed and employment duration on lung particle accumulation as measured by pulmonary magnetic field strength. At each employment duration the left bar represents other workers, the middle bar – cutters, and the right bar – welders.

We also asked the same patients about their smoking habits in an attempt to determine whether there might be a connection between smoking and pulmonary magnetic fields. Our findings plot magnetic field strength against length of employment (Fig. 2). Comparing smokers with non-smokers across all time points, smokers' lungs had higher remnant magnetic field strength than those of non-smokers (633 vs. 100 uG), $t(25) = 5.07$, $p < 0.00003$. In smokers, pulmonary magnetic field strength increased with duration of employment ($r = 0.48$, $F(1,20) = 6.1$, $p < 0.02$). In addition, an analysis with use of a multiple regression model with an interactive term revealed that for each year of added employment, the increase in pulmonary magnetic field strength was by 17.3 times higher in smokers than in non-smokers ($p < 0.02$).

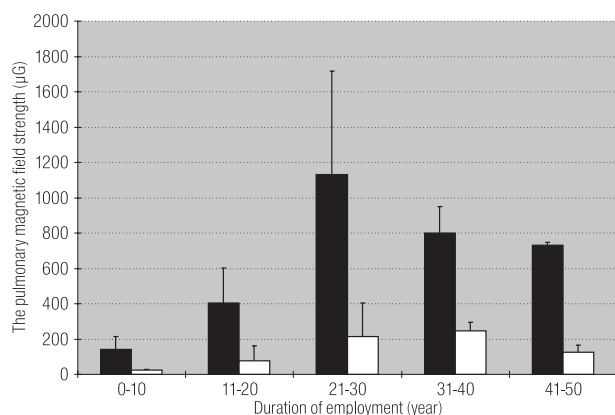


Fig. 2. The effect of smoking on lung particle accumulation as measured by pulmonary magnetic field strength. At each employment duration smokers are represented by the left bar and non-smokers by the right bar.

DISCUSSION

In the pilot study reported herein, we showed proof of principle that it is possible to use a portable device to measure the accumulation of magnetizable particles in the lungs of factory workers to determine the extent and distribution of particles in the lung. Since this study was done at an industrial site and not in a laboratory, this suggests that the device can probably be used effectively in industrial settings.

The specific differences we found are in themselves interesting and suggestive. For example, it appeared that in workers at the iron factory, where the study was performed, particle accumulation increased with the increasing number of employment years and was higher as compared to cutters and other workers. Not surprisingly, welders showed higher accumulations, as they are expected to be exposed to dusts that contain relatively higher concentrations of para- or ferromagnetic particles.

During normal respiration, inhaled particles and other unwanted substances are expelled from the lungs by ciliary movement in the form of phlegm. In the case of welders and cutters who work in a particle-rich environment, one is led to conclude that even if the lungs purify themselves as just described, the intake of inhaled particles must be greater than the amount of particles expelled, thus leading to increasing particle accumulation in the lungs over decades of employment.

Unexpectedly, the workers' situation improved when the number of years of employment exceeded 30 years. This may be due to changes in the type of work done in the 4th and 5th decades of employment. Even if they take in a large amount of particles during their initial few decades on the job, after 20 years of employment they are often shifted to workposts where there is less or no direct contact with particle-rich environments. This shift would give their lungs a chance to expel previously inhaled particles, and could account for the weakening of the pulmonary magnetic field strength observed in later decades of employment [10]. The other workers are in environments with few aerial impurities, and thus tend to show lower magnitude and little variation.

We also found that smoking has a substantial effect on lung particle accumulation when added to workplace fac-

tors (Fig. 2). When compared to patients working under similar conditions, smokers show a dramatic increase in field strength, peaking after the period of 21–30 years. The increase in strength for non-smokers working in the same conditions is only slight, creating a large gap between them and smokers. Looking at a 31–40-year period, magnetic field strength drops for various reasons, including a change in work environment, yet the gap between smokers and non-smokers still remains. This suggests that the lungs of smokers working under the same conditions or in the same environment are more damaged than those of non-smokers. This may result from tar accumulation in the lungs, which restricts ciliary movement, reducing the lungs' ability to purify themselves by expelling foreign materials, and thus leads to the accumulation of particles in the lungs. That mechanism is supported by a study performed by Cohen et al. at the Massachusetts Institute of Technology (MIT) [9], in which the relative amounts of magnetizable material (Fe_3O_4) expelled from the lungs of smokers and non-smokers were analyzed in a laboratory setting. The study revealed that in one year, non-smokers expelled 90% of 1 mg of inhaled Fe_3O_4 , while smokers expelled only 50% of the inhaled Fe_3O_4 , retaining the remaining 50% in their lungs. Such a mechanism could account for a greater particle accumulation in the lungs of smokers. Moreover, our finding that particle accumulation is exacerbated by smoking (the degree of particle accumulation of smokers was 5 to 17-fold worse than for non-smokers, with tar-like substances being found in the trachea or the alveoli) agrees quantitatively with the data of Cohen et al. [9] who reported a 5-fold increase in particle accumulation in smokers compared to non-smokers. A limitation of our study is that we did not measure dust (particle) levels in the areas occupied by different types of workers. This information was not collected, in part because at the time of our study the accumulation of particles in the lungs of the subjects had occurred for over as much as 50 years. Thus, although current dust levels might explain differences between types of workers, and such findings would be very important, current dust levels would not explain long-term accumulation or exacerbation by smoking.

Our findings provide proof of principle that portable instrumentation can be used to measure particle accumulation in the lungs of workers at industrial sites. This provides a rationale for further studies that attempt to confirm and to improve on the current method for detecting particle accumulation over time. Studies will also need to be done to correlate signal with particle levels in different environments, with lung function, and with fibrosis and pneumoconiosis. If such correlations can be shown, our method might turn out to be useful for early detection of particle accumulation and/or of pulmonary disease as well as for monitoring effects of any treatments or preventive measures that might be developed.

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