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# ASSESSMENT OF EXPOSURE AND RISK THROUGH USE OF A PERSONAL, CUMULATIVE ORGAN RISK INDEX

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**ABSTRACT**

In assessing levels of risk as a result of exposure to toxic materials in the workplace, many factors must be considered. These have usually included duration and intensity of exposure. The current practice of workers moving from job to job based on seniority and training has created difficulty in appropriately assessing risk. Additionally, the multiplicity of exposures, particularly when these have their major impact on the same target organs, further complicates the problem.

In carrying out a study of 1 242 aluminum smelter workers, a cumulative organ risk index was developed for each worker. Basically, it was an attempt to express, in quantitative terms, the duration, intensity, and multiplicity of an individual's exposure to toxic materials in the smelter. Using the combined estimates made by those who had worked and/or were currently working in the smelter, we obtained a "low", "medium", and "high" rating for exposure to each of twenty-six toxic materials for each job in the smelter. This accounted for the intensity and multiplicity of exposures for each job that an individual had had. Then each person's exposure to each material was summed over all jobs held and an exposure risk index for each of the twenty-six toxic materials was computed.

In order to use these indices in the most precise manner possible, twenty-six different toxic materials were rated on a scale of 0 to 3 for their potential ill health effects on two different organ systems. Then, the exposure risk index was multiplied by the toxicity rating, creating a risk index for each organ system.

Tests measuring functional abnormalities of each major organ system were then carried out and compared among those with high and low levels of risk.

Significant differences in rates of abnormalities were found between those at high and low risk for the pulmonary and musculoskeletal systems. It would appear that this method of examining dose-response relationships may be useful in assessing the true risk of combined occupational exposures to toxic materials.

Epidemiologic studies of the effect on health of exposure to toxic materials in the workplace demand an accurate assessment of exposure. The development of modern industrial technology has made this increasingly difficult to do for many reasons. Complex industrial operations in a single workplace have led to exposure of individual workers to multiple processes and materials in a single plant. Workers' skills are frequently no longer specific to an industry, enabling them to move from job to job and even from industry to industry. Job changes due to seniority also increase the number and kinds of exposure which workers may experience, a situation unlike that of years ago when workers remained at the same job for much of their working lifetime. Thus, workers are not only exposed to materials for varying periods of time, with varying intensity of exposure, but in addition, are exposed to multiple materials which may additively or synergistically affect a single target organ.

This paper represents an attempt to deal with these difficulties in a cross-sectional morbidity study and will discuss an approach to assessing risk through the development of a personal, organ-specific risk index.

## METHOD

In developing an accurate index of risk, it is necessary to take into account duration, intensity, and multiplicity of exposure, particularly in relation to impact on a single target organ. In a cross-sectional study of 1 242 aluminum smelter workers, this was done as follows.

Work histories for each participant were obtained, each job was given a code number, and the number of months that a given individual spent on each job was recorded. A complete list of all jobs in the plant, along with a description of the duties involved and materials handled, was obtained. "Old" or non-existent job titles were matched with current job titles, and where no match was possible, the "old" job was given a unique code number.

Based on the known hazards involved in the Söderberg vertical stud aluminum smelting process, in the production and maintenance of the anodes and cathodes, on emission data, and on past industrial hygiene reports, a list of 26 toxic materials to which workers in the plant might be exposed in significant quantities was drawn up (Table 1). Then, the relative intensity of exposure at each individual job in the smelter to each of the 26 toxic materials was estimated, using a 3 point scale where "0" equaled low or no exposure, "1" equaled moderate exposure, and "2" equaled high exposure. Thus, jobs were given an empirical rating of exposure intensity relative to other jobs in this smelter. Union members with experience on the Job Evaluation Committee reviewed each job and assigned a rating. This rating was also reviewed by scientific personnel, and a random sample of approximately 10% of the jobs were processed a second time to check for consistency. If a job was no longer in existence, or if there was doubt as to the exposure, the Environmental Control Department at the smelter was asked to provide information which was supplied as available.

Based on the known biologically toxic effects of each to the 26 materials on the pulmonary and musculoskeletal systems, an intrinsic toxicity rating was assigned to each material using a "0, 1, 2, 3" scale representing "none," "slight," "moderate," and "severe" toxicity, respectively (see Table 1).

TABLE 1
Toxicity rating of materials used in aluminum smelter by severity of impact on pulmonary and musculoskeletal systems, Kitimat Study – 1977.

| Substance | Target organ system | |
|---|---|---|
| | Pulmonary | Musculoskeletal |
| 1. Hydrogen fluoride | 3 | 3 |
| 2. Particulate fluoride | 2 | 3 |
| 3. Sulphur dioxide | 2 | 0 |
| 4. Carbon monoxide | 0 | 0 |
| 5. Coal tar volatiles | 0 | 0 |
| 6. Alumina | 2 | 0 |
| 7. Asbestos | 3 | 0 |
| 8. Silica (anthracite) | 3 | 0 |
| 9. Welding fumes | 3 | 1 |
| 10. Pitch dust | 2 | 0 |
| 11. Coke dust | 3 | 0 |
| 12. Carbon particulate | 1 | 0 |
| 13. Acids and caustics | 2 | 0 |
| 14. Solvents | 1 | 0 |
| 15. Lubricating oils (cutting) | 2 | 0 |
| 16. Ammonia | 2 | 0 |
| 17. Plastics | 2 | 0 |
| 18. Cleaning agents | 0 | 0 |
| 19. Fiberglass | 2 | 0 |
| 20. Chlorine | 3 | 0 |
| 21. Silver solder brazing | 3 | 2 |
| 22. Mercury | 0 | 1 |
| 23. Polychlorinated biphenyls | 0 | 1 |
| 24. Lead | 0 | 1 |
| 25. Paint aerosol | 2 | 0 |
| 26. Chromates | 2 | 0 |

"0" = none, "1" = slight, "2" = moderate and "3" = severe

Using these two rating systems, two calculations were made for each individual in the study. The first computation was based on the number of jobs that an employee had, the corresponding duration of each of the jobs, and the intensity of exposure to each of the 26 materials at each corresponding job as follows:

$$R_j = \sum_{i=1}^{265} D_i \cdot E_{ij} \qquad \begin{array}{l} i = 1,2 \ldots\ldots 265 \text{ (possible jobs)} \\ j = 1,2 \ldots\ldots 26 \text{ (toxic materials)} \end{array} \quad (1)$$

where: D = duration worked on job in months; E = intensity-of-exposure rating for a particular toxic material for a particular job and R = risk-of-exposure index for all jobs for each particular toxic material.

At this point, each individual had a catalog of 26 "risk-of-exposure" indices which summarized the duration and intensity of his exposure to each of 26 materials during his entire time at the smelter.

The next calculation used the previously calculated "risk-of-exposure" indices ($R_j$), along with the intrinsic toxicity ratings for each organ system, to produce a pulmonary risk index and a musculoskeletal risk index for each individual. The calculation was as follows:

$$C_k = \sum_{j=1}^{26} R_j \cdot O_{jk} \qquad \begin{array}{l} j = 1 \ldots 26 \text{ (toxic materials)} \\ k = 1,2 \text{ (organ systems)} \end{array} \qquad (2)$$

where: C = organ system specific risk index for all toxic materials for all jobs; R = risk-of-exposure index for all jobs for each particular toxic material and O = intrinsic toxicity rating of a particular material for a particular organ system.

Thus, the organ system specific risk index takes into account the intensity of exposure to a toxic material, the duration of exposure to a toxic material, and the multiplicity of exposure (equation 1), and the degree of toxic impact of the material on the organ system in question (equation 2).

For purposes of analysis, the frequency distributions of both the pulmonary and musculoskeletal risk indices were used to categorize the entire cohort into 3 exposure groups with equal numbers of workers, which are hereafter referred to as "low," "medium," and "high." Analyses were carried out comparing disease frequencies among groups. Thus, the "low" exposure group served as a control for the "high" exposure group.

## RESULTS AND DISCUSSION

The results are detailed in another paper[1]. Examination of the relationship between mean $FEV_1\%$ and low, medium and high risk revealed a significant inverse relationship with a stepwise decrease in function from low to high. Comparison of high, medium and low musculoskeletal risk groups using the index showed a strong relationship between risk and a past history of back and neck surgery and fractures. The risk groups were standardized for age and smoking history. All females were excluded from the analysis since they constituted such a small group.

Some of the characteristics of a working population that make the quantitation of a personal risk index both difficult and yet desirable are as follows:

It is difficult to identify an appropriate control group for a working population. The general population includes individuals who cannot work because of disease or disability and is, thus, on the average invariably less healthy by most biological measurements than the working population. Also, it is difficult to find a comparable working population which does not have some other type of toxic exposure. A great deal of time, effort, and money can be spent in seeking out a comparable working population, and if found, their motivation to participate in a study is usually low. A personal risk index allows one to develop an internal control and compare those with a high risk to those with a low risk. This is highly desirable even though the low risk control group may not have been completely unexposed.

The work force is very mobile. Frequently, a single worker may hold 20 to 30 different jobs within an industry over the period of his employment in that industry. Additionally, an individual will frequently work in more than one plant or industry over the course of his working lifetime. Further, each worker spends variable time periods in variable jobs, and thus has a job history which is unique.

It is important to identify "high risk" jobs in order to avoid placing individuals with a predisposition to disease in these jobs as well as being able to identify individuals who are at "high risk" because of past exposure. These individuals can then be more closely monitored for early signs of disease and further exposure can be avoided.

Some of the characteristics of the workplace which make a quantitation of risk desirable as well as difficult are as follows:

1) A single job may expose a worker to multiple toxic materials. TLV's or standards frequently only relate to exposure to a single agent.
2) Many of the toxic materials involved are difficult to measure in the environment, or may be present infrequently or in highly fluctuating amounts and thus be difficult to quantify using industrial hygiene methods. Some processes generate multiple or final by-products which are of unknown composition and unknown toxicity. Additional unknown materials may be present as contaminants.
3) Measurements taken over a prolonged period of time generate masses of data that are difficult and time consuming to record and organize. Conversely, if environmental measurements are made for short periods of time, they may be unrepresentative of the daily, weekly, or monthly exposure of an individual due to variable work practices.
4) It is desirable to be able to identify high-risk jobs in order to focus on these areas when installing engineering controls or using personal protective equipment.
5) Delineation of a dose-response curve is the optimal situation when attempting to set workplace standards which will effectively protect the largest numbers of workers. A quantitation of risk can be extrapolated to a dose by correlating environmental measurements with estimates of intensity.

Other techniques have been used to assess risk. An example of a relatively simple risk assessment system was employed by Roach in a study of coal miners[3]. Here the exposure was to one toxic material and there was one target organ, the lung. Where actual measurements of dust concentration were available, each individual's risk was assessed by multiplying the measurement's value by the months that the individual worked on the job. Where measurements were not available, concentrations were estimated for each job relative to one another, given an arbitrary rank, and this rank was then multiplied by the duration spent on that job. Thus, each individual was given a risk index and an attempt was made to predict the amount of disease based on this risk assessment system. This type of model is usually used in generating threshold limit value standards. The problem here is that each material is considered as if it were the only material present in the workplace.

A much more complex situation was studied in the rubber industry by Gamble and Spirtas[2]. In this study, toxic materials were so numerous and so poorly known that risk was assessed using functional job categories. That is, no attempt was made to identify toxic materials, estimate intrinsic toxicity, or predict what organ systems would be affected. Jobs were put into categories according to similarity of process and materials handled and assigned an identifying code number. The duration of each experience in these functional categories was summed. Workers with a history of a large amount of time in a job category were compared with those with a small amount of time in the same job category. This system estimated risk on the basis of duration and functional job categories. This technique, while it does not consider all of the parameters examined in this paper, is useful where target organ effects are unknown.

## CONCLUSION

A method for estimating risk was developed which considered multiple factors related to occupational exposure including intensity, duration, multiplicity, and intrinsic toxicity quantified for the major target organs. It appeared to be a useful predictor of target organ effects when used in a study of aluminum smelter workers. Its use in epidemiologic studies for assessing risk and for the development of internal controls is suggested.

## REFERENCES

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