Reprint: Environmental Epidemiology And The Metamorphosis Of The Human Habitat

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Because of the many changes occurring in our environment, the epidemiologic evaluation of the effect of various environmental agents on human populations becomes of ever-increasing importance. This analysis is based upon two strategies which may be used in applying environmental epidemiology.

Introduction

THERE is no novelty to the consideration of environmental factors in epidemiology. One may cite Hippocrates, Arnauld of Villanova, Sydenham, Ramazzini, Potts, and Snow, and many others as noting the importance of air, water, and occupation, for acute and chronic disease. Today an increasing proportion of the population is exposed to changes in their environments and in the nature of the demands which these changes make on adaptive, somatic, and genetic mechanisms. Because we have learned but recently to measure various operations of such mechanisms, the potential for study of environmental epidemiology is far greater than in previous periods, and it is rapidly increasing. The variety of agents has changed as well, and continues to grow at a disturbing rate. Also there are recent increases in the potential for detection and analysis of pollutants and in the capacity for complex numerical analysis, although the systematic exploitation of this potential has been slow.

In the report of the Environmental Pollution Panel of the President's Science Advisory Committee, epidemiological studies seem to have been given at least as great or even greater urgency than laboratory toxicity studies^[1]. Contrasted to laboratory research the number of such epidemiological studies successfully carried out may be fewer, the cost per study greater, and the care needed in planning much greater.

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Strategies Based on Environmental Epidemiology

With the present rapid rate of change in environmental exposures, the need for detection and prevention of health damage is urgent. Environmental epidemiology offers two strategies for preventing and abating health impairment due to environmental exposures.

Strategy A-To collect and present quantitative data on realistic human exposures and effects which are of sufficient predictive validity to be used as satisfactory bases for public health policies and regulations. Strategy A may be used even when engineering data and methods of social organization are insufficient to permit confident predictions concerning the results of such regulations and policies. In this event surveillance is indicated in order to test the results obtained.

Strategy B-In the absence of information of sufficient predictive validity on effects of realistic exposures, to collect data for exposures of greater intensity and duration than normally occur. For this information to be used fruitfully in preventing health impairment, a prudent public policy requires, (a) surveillance of exposed human populations so that missing data can be obtained and, (b) a determined effort by epidemiologists to obtain informed policy decisions likely to minimize the risk of health impairment.

Methods

The methods needed in environmental epidemiology include:

1. Estimation of exposure-dose of pollutant and its variability in time, within and between populations.
2. Definition of specific or nonspecific effects related to environmental exposure.
3. Interaction of environmental exposures and effects with other agents and host factors.
4. Definition and evaluation of other factors which may produce geographical variation in effects.
5. Definition and evaluation of other factors which may produce temporal variation in effects.
6. Detection of effects in subpopulations of differing susceptibility.
7. Design and interpretation of experimental studies to test for possible causal mechanisms of the associations observed.

These methods will not be more thoroughly reviewed here as they have been discussed elsewhere^[2].

Toward a Model for Environmental Epidemiology

Table 1 presents a model intended for analysis by stochastic processes of the various types of environmental effects which may occur in the several life stages. Within each of these life stages we assume a series of intervals sufficiently short so that the proportion of the population in the indicated stages remains constant long enough for the effects of environmental exposure to be homogeneously applicable. The several attributes of the states indicated must be defined in an explicit fashion. Further, there may be additional states and the environmental effects listed may be an inadequate representation of all possible effects. Given a model of this sort, the goal of environmental epidemiology is to detect the associations between the exposure to measured environmental agents and the associated change in the

Table 1**Major effects and health states associated with environmental exposures of different stages of life**

Stage of life	Gestational	Developmental	Productive	Postproductive
Age	-9 mo to -5 mo	-5 mo to 12 yr	12 yr to loss of major social function	From loss of major social function to end of life
Environmental effect	Mutations vary with cumulation of environmental insults to germ plasm. Effects on maternal health.	Adaptability and vigor determined by environmental exposure (and by nutrition, infection, social, economic, and psychological variables).	Acute intoxication with uncertain long-term effects. Impairment of function with, when repeated, doubtful reversibility. Increasing body burden of storable pollutants, of sensitized or of inert tissue. Decreasing adaptability and vigor.	Cumulation of somatic environmental insults. Competition among "causes" of mortality. Social consequences from demographic effects of environment.
States	No detectable abnormality in genetic apparatus. Morphological deviate. Biochemical defect.	Resistant. (Disease or organ-specific). Biochemical defect. Increment of environmental pollutant stored. Increment in acquired resistance to pollutants. Dead.	Resistant. (Disease or organ specific). Susceptible. Biochemical defect. Increment of environmental pollutant stored. Increment in acquired resistance to pollutants. Reversible impairment. Acute disease. Chronic disease. Dead.	Unimpaired competence. Disabled by environmentally related condition. Disabled by other condition. Chronic disease. Dead.

Source: Goldsmith, J.R.

distribution of the population among states in all subsequent intervals that may be relevant.

It should be immediately obvious that assignation to some of the states cannot be made except in retrospect. For example, the body burden of stored pollutants may require analysis for such pollutants at autopsy or surgery, or the existence of susceptible or resistant populations may only be determined after a sufficient test of susceptibility which may occur at a future time. One important feature of this scheme is that it includes health data other than the mere presence or absence of disease.

It is also obvious that many factors influence the change of state; they include social and cultural variables, economic influences and nutrition (unless some of these be accepted as environmental variables).

It is apparent that when the attention is directed to the productive and postproductive stages of life, chronic disease epidemiology is closely related to environmental epidemiology. But it does not follow that all of the relevant data concerning environmental hazards have their effect during these two stages.

Epidemiologic Studies of Exposure to Ionizing Radiation

Epidemiologic studies of the effects of ingestion of radium in watch-dial painters provided the first quantitative information on health hazards of radiation exposure, and these data became the basis for most of the occupational health criteria and standards. When nuclear technology was in its infancy, the evaluation of general population exposures and the guidance for public health protection was derived according to Strategy B by numerical extrapolation, often with factors of arbitrary magnitude. However, additional epidemiologic studies have been carried out in individuals exposed to atomic radiation in Hiroshima and Nagasaki^[3] and exposures to the Marshall Island population^[4] have supplemented these data, but in each case the information is related to a single intense exposure.

Two other exposed groups have been studied rather extensively and a third group is just beginning to be studied. The first are occupationally exposed persons such as the population of United States radiologists and their progeny for whom several studies have been reported^[5]; uranium miners are another group recently subject to epidemiological evaluation^[6]. The second is the population of persons given radiotherapy in various countries^[7,8], and the third groups of populations are those exposed to rather high levels of natural background radiation^[9,10].

Excellent studies have been carried out on the development of leukemia^[11,12] and some similar data are available for other

malignant diseases. There is less clear-cut evidence, and less agreement with respect to nonspecific reduction in the human life span and genetic effects. Similar disagreement could be found on the importance of and expected frequency of somatic mutations in relation to radiation exposure.

In reviewing the available data, there are many indications of the need to apply good epidemiologic methods to this problem^[13,14]. One of the most extensive studies of the relation of congenital malformations to radiation of parents was reported by Macht and Lawrence^[5] based on a questionnaire addressed to 3,751 radiologists and 3,858 other physicians in medical specialties. Congenital malformations of the heart and erythropoietic system appear to be more common among the offspring of exposed in contrast to unexposed physicians (Table 2), but the prevalence of such conditions was low. The response rate of radiologists was 74 per cent for males and 67 per cent for females, and of nonradiologists 53 ½ per cent and 57 ½ percent, respectively, for males and females. There was no effort to establish quantitative dose exposures, admittedly a difficult problem over a long period of time; nor did there seem to be any systematic follow-up effort to improve the response rate. The results therefore have been considered inconclusive. Data were also presented on the ratio of male to female progeny and, in the offspring of persons exposed throughout their marriage, there appears to be a sex ratio change with an increasing proportion of female births. For the small fraction of the fetal deaths for which the

Table 2**Selected congenital malformations among offspring of exposed and nonexposed physicians**

	Defective offspring of parents exposed	Defective offspring of parents nonexposed
Total with defects	348	229
Defects of:		
External ear	22	7
Pyloric stenosis	9	1
Erythroblastosis	14	3
Inter-ventricular septal defect	5	1
Other heart	8	0
Frequency of defective offspring	348/5,451 6.4%	229/4,484 5.1%

Source: Macht, S. H., and Lawrence, P. S. Am. J. Roentgen. 73:442. 1955.

sex was known there was a high ratio of males to females. The ratio was substantially higher in the exposed individuals than in the unexposed. A differentially greater sensitivity of males to radiological insult has been suggested because of the smaller mass of nucleoprotein in the male sex chromosome (y) than in the female (x). Decreased proportions of male live births may be a sensitive indicator of all types of environmental stress especially during the earliest stages of development.

There exist many other populations of persons whose radiation exposure can be estimated. These certainly could include populations of veterans who received compensation because of duodenal ulcer and who have thus been subjected to repeated radiological examination. Such individuals surely have had diagnostic radiation exposures in excess of those who have not had such studies.

Epidemiologic studies appear likely to produce, sooner or later, data suitable for Strategy A, with respect to radiation exposure.

Community Exposures to Carbon Monoxide

Carbon monoxide is one of the most thoroughly studied of industrial contaminants and a great deal is known about its toxicity and the mechanisms affecting high-level exposures. Less is known about its effects at low levels over long periods of time. Exposures to CO occurred during World War II among Scandinavian truck drivers and taxi drivers whose vehicles used “producer gas” as fuel. Grut^[15] presented data suggesting that chronic carbon monoxide intoxication was occurring among these individuals, though the clinical findings were nonspecific and no characteristic pathology was established. Lindgren^[16] subsequently studied a fairly large population of occupationally exposed persons working for the most part in metallurgical industries. His conclusion was that no chronic carbon monoxide syndrome could be established and this view is the one which prevails in most western countries, including the United States. Lindgren’s study documented exceptionally well the nature of the carbon monoxide exposures associated with cigarette smoking. Relatively little attention has been given to the possible consequences of carbon monoxide exposures associated with cigarette smoking^[17].

Methods for detecting carboxyhemoglobin through the analysis of expired air, first developed by Sjöstrand^[18] and subsequently applied by Jones, et al.^[19], and Ringold et al.^[20], have now made it possible to obtain valid and relatively easy estimates of the carboxyhemoglobin levels in population samples. Goldsmith, Terzaghi, and Hackney^[21] have demonstrated that community exposures to atmospheric pollution can cause an increase in carboxyhemoglobin. Goldsmith^[22] has emphasized the importance of the body burden of carbon monoxide in setting air quality criteria for motor vehicle exhaust in California,

based on Strategy A. The standard is 30 ppm average for eight hours on the basis of this exposure being sufficient to lead to at least 5 per cent carboxyhemoglobin. Typical data for the effect of smoking on carboxyhemoglobin through the use of expired air analysis are shown in Table 3 and Figure 1. The combined effect of community exposure and of cigarette smoking is shown in Figure 2.

Additional studies of effects of acute exposure to realistic levels are needed concerning the question of whether the 5 per cent carboxyhemoglobin which may frequently occur from atmospheric air pollution from motor vehicle exhaust in certain locations, does in fact affect the survival of patients with acute vascular episodes as predicted on the basis of physiologic data. There is considerable interest in how low a level of atmospheric carbon monoxide can produce significant effects on red blood cell production, hemoglobin metabolism, and delivery rates of oxygen to the tissues. This question becomes fairly important when it is recognized that in certain parts of California there have been episodes of community carbon monoxide exposure sufficient to cause more than 5 per cent carboxyhemoglobin in the exposed population for longer than 27 hours (Table 4)^[23].

Studies of atmospheric carbon monoxide and carboxyhemoglobin in traffic policemen have been carried out in Paris by Moureu and his associates^[24]. Some of the results are shown in Figures 2, 3, and 4. These data represent two different types of populations; the first type are traffic policemen at four busy intersections in Paris whose blood carboxyhemoglobin was determined before and after approximately five-hour exposures to 10 ppm. The second group consists of drivers of motor vehicles which have been involved in accidents. The distribution of the values of these two groups are shown in Figure 2. When the data are separated for traffic policemen according to whether the policemen are smokers or not, the results (Figures 3 and 4) suggest that the cigarette smokers who started work with relatively high carboxyhemoglobin levels, and who cannot smoke during work, tended to excrete carbon monoxide and at the end of their period of duty had lower carboxyhemoglobin. The smokers who started duty with low levels tended to have an increase. Those who started with levels of about 5 per cent blood carboxyhemoglobin showed very little change. However, in the study confined to nonsmokers (Figure 4) it is seen that these exposures in heavy traffic do increase the carboxyhemoglobin by measurable levels.

There is not yet general agreement as to how little carboxyhemoglobin will produce interference with important functions of the body. Interference with sensory and psychomotor functions tends to be first detectable between 2 and 5 per cent carboxyhemoglobin. Possibly levels in this range also interfere with the delivery of oxygen to the tissues by the circulating blood.

In addition, there is a possibility that adaptation to carbon monoxide may occur as has been suggested by Killick^[25].

Table 3
Proportion of smokers and median expired carbon monoxide among a population (3,311) of longshoremen*

Smoking pattern	Per cent of study population by smoking pattern	Median CO ppm		Median % COHb‡	
		Inhaler	Non-inhaler	Inhaler	Non-inhaler
Never smoked	23.1 (764)†	3.2		1.3	
Exsmoker	12.1 (401)	3.9		1.4	
Pipe and/or cigar smoker only	13.4 (445)	5.4		1.7	
Light smoker (Half pack or less)	13.0 (429)	17.1	9.0	3.8	2.3
Moderate smoker (More than half a pack and less than two packs)	31.3 (1,035)	27.5	14.4	5.9	3.4
Heavy smoker (Two packs or more)	7.0 (233)	32.4	25.2	6.9	5.5

*Source: California State Department of Public Health, Bureau of Chronic Diseases.

†The number of subjects is given in parentheses. The smoking pattern of four persons was not ascertained.

‡The per cent COHb was estimated from regression.

Figure 1. Distribution of expired CO in longshoremen, by smoking pattern ILWU study, 1961 (Normal Subjects).

Source: Moureu.

Figure 2. Carboxyhemoglobin level, policemen versus motor vehicle drivers with accidents (Paris, 1963).

Table 4**Carbon monoxide pollution episodes in California, 1963–1965**

	No. of episodes 30 ppm for 8 hr or more	Max. duration above 30 ppm hr	Max. 8 hr average
Inglewood*	77	27	44
Burbank*	32	20	56
West Los Angeles*	7	14	41
Pasadena*	4	12	37
Downtown Los Angeles*	3	12	32
Long Beach*	2	11	32
Riverside	1	10	32
Sacramento	1	10	32

No other station exceeded standard.

*L.A. stations were not corrected for water vapor content of atmosphere.

Source: Bureau of Air Sanitation, California State Department of Public Health.

Realistic levels may also cause an increased production of red cells as suggested by Sayers, et al.^[26] It seems likely that in following up the physiologic consequences of low levels of carbon monoxide over a period of time, a role may be found for this substance in producing the increased frequency of cardiovascular and chronic pulmonary disease that are observed in cigarette smokers^[27].

Intervention to reduce the effects of carbon monoxide has been demonstrated to be practical in the case of motor vehicle exhaust by the actions of the state of California, and subsequently the United States Public Health Service and by authorities in other countries^[28,29].

As Lindgren^[30] has pointed out, the highest carbon monoxide levels in cigarette smoking occur with the latter part of the smoking of a cigarette; this may be a type of exposure which also could be prevented. It is thus important to carry out further epidemiologic studies of human health effects on low-level carbon monoxide exposures.

Epidemiologic Studies of Sulfur Oxide and Related Atmospheric Pollutants

Following the work on animals by Amdur^[31] and Mead^[32], the measurement of airway resistance has been used by a number of investigators for detecting effects on the airways from inhalation of sulfur dioxide. It has been reported by Toyama^[33] that 1.5 ppm of sulfur dioxide will cause significant but transient increase in airway resistance. Frank, et al.^[34], reported increased airway resistance within one minute of exposure at five and 13 ppm; with the exception of one subject, one ppm did not cause any significant change. Perhaps this one individual represents a type of individual who is unusually sensitive. These studies have all been carried out in healthy individuals, whereas what one needs to know is what the effects of this pollution may be on persons with chronic respiratory disease. Hine, et al.^[35], report the experience of a student exposed to 2 ppm SO₂ who developed acute asthmatic wheezing resembling a paroxysm of acute asthma. This student had a history of asthma but had had no recent attacks.

Lawther^[36] noted also the wide variation in susceptibility to experimental exposures to sulfur dioxide. One of the subjects studied tolerated 30 ppm with scarcely any reaction, but a second had marked increases in airway resistance when exposed to 10 ppm. Correlations of airway resistance and other lung functions after a brisk walk out-of-doors in London's atmospheric pollution suggested a possible association of these changes with pollution, and also with temperature. In longitudinal studies Lawther showed that the average condition of a group of chronic bronchitic patients appeared to be worse when both sulfur dioxide and suspended particulate levels were elevated. In the discussion of acute episodes of atmospheric pollution, Lawther^[37], reviewing Martin and Bradley's data, has concluded that when pollution exceeds 0.75 mg per cubic meter of suspended matter plus 0.71 mg per m³ of SO₂ (0.25 ppm), increased mortality can be expected to occur in the environment of London. When pollution in London exceeds 0.3 mg of suspended

Source: Moreau.

Figure 3. Carboxyhemoglobin level of policemen (smokers) before and five hours after exposure to between 10 and 12 ppm CO (Paris, 1963).

Figure 4. Carboxyhemoglobin level of policemen (nonsmokers) before and five hours after exposure to between 10 and 12 ppm CO (Paris, 1963).

matter plus 0.6 mg per m³ of sulfur dioxide (0.21 ppm of sulfur dioxide), increased morbidity similarly occurs among a group of patients with chronic respiratory disease, whose average condition is noted by diary entries. Thus, there seems to be available epidemiologic findings for use of Strategy A for acute exposures under conditions prevalent in London. However, this does not necessarily apply to long-term effects, or effects under different climatic conditions.

Under conditions prevalent in the United Kingdom, the study of Buck and Brown^[38] (Table 5) suggests that there are significant

correlations of male bronchitis mortality by area with smoke and sulfur dioxide in at least two classes of areas—county-boroughs and boroughs. Other factors also influence these distributions. Reid^[39], and Holland and Reid^[40] also have put forth affirmative evidence suggesting the effect of atmospheric pollution on chronic respiratory disease morbidity. Comparable methods have been used by Holland, et al.^[41], and by Deane and Goldsmith^[42] in the United Kingdom and on East and West coasts of the United States (Table 6).

There has been a dramatic diminution in recent years in London in the suspended particulate matter, though there has

Table 5

Correlations of standard mortality ratios (SMR) for lung cancer and for bronchitis with pollution and other variables by class of area for locations in the United Kingdom (Males-mortality 1955–1959)

	London borough	County borough	Borough	Urban district	Rural district
Number of locations by class of area	19	49	70	61	15
SMR lung cancer	148	114	108	91	88
SMR bronchitis	151	129	113	106	77
Persons/acre (1961)	48.9	15.6	13.3	6.4	0.8
Social index (1951)	171	158	130	119	112
Average pollutant levels (mg/M ³ -March, 1962)					
Smoke	168	281	203	185	85
SO ₂	274	259	221	173	94
Significant correlations* with male lung cancer					
Person/acre† (1961)	—	0.67	0.65	0.52	—
Social index (1951)	0.69	0.49	—	—	—
Smoke (March, 1962)	None	None	None	None	None
SO ₂ (March, 1962)	None	None	None	None	None
Significant correlation with male bronchitis*					
Persons/acre (1961)	—	0.46	—	—	—
Social index (1951)	0.85	0.51	0.56	—	—
Smoke (March, 1962)	—	0.57	0.49	—	—
SO ₂ (March, 1962)	—	0.73	0.49	—	—

*Significant values are said to be present when the probability of the true value being zero is less than one in a hundred. If no significant correlation is observed, no number is given.

†Social index is the proportion of unskilled workers /1,000 males of 15 years and over (1951 census).

Source: Buck and Brown^[38].

Table 6

Comparison of respiratory findings among outside workmen in the United Kingdom and the United States and representative pollutant levels for each area*

	United Kingdom				United States			
	London		Country towns		Baltimore, Washington, and Westchester County		San Francisco Los Angeles	
	Age 40–49	Age 50–59	Age 40–49	Age 50–59	Age 40–49	Age 50–59	Age 40–49	Age 50–59
Number of men examined	113	137	267	159	396	229	361	119
Persistent cough and phlegm (%)	25.7	38.7	24.0	18.9	22.2	25.8	21.6	24.4
Persistent cough and phlegm + chest illness episode (%)	10.6	10.9	7.5	5.0	6.8	7.0	4.0	7.6
Sputum volume, 2 cc or more (%)	28.9	42.9	22.1	23.5	7.1	10.0	8.6	14.3
FEV _{1.0} (liters) mean values. Nonsmokers only	2.8	2.6	3.0	2.8	3.5	3.1	3.7	3.3
Suspended particles (μg/M ³ -24 hr)								
Mean	239		206		123		114	
Max.	770–4,000		1,000–3,000		150–500		175–340	
Sulphur dioxide (ppm)								
Mean	0.1		0.02		0.05†		0.01‡	
Max.	0.2–1.3		0.1–0.26		0.25		0.04	

*After Holland and Stone. Am. J. Epidemiol. 1965, p. 82; cited levels of pollutants represent estimates only and were not always concurrently or comparably measured.

†Washington, 1962–1963.

‡San Francisco, 1962–1963.

Source: Goldsmith.

been a small increase in sulfur oxides, the former being due to the implementation of the Clean Air Act. Presently there is considerable concern that the rising levels of sulfur oxides, the control of which is more difficult than particulates, might be a factor in the generation of chronic respiratory disease. Relevant patterns have been observed from a number of other countries: Japan^[43], Czechoslovakia,^[44] and Australia, to cite examples. In the latter, Bell, et al.^[45], studying exposures to sulfur oxide in the vicinity of a large smelter and with relatively little particulate pollution present, observed respiratory symptoms but no alteration in respiratory function and no increase in the more serious symptoms, in shortness of breath or in days of disability.

Thus we may suspect that increasing urban sulfur oxide levels as one of the by-products of heating and power-generation in urban areas may be associated with increased respiratory symptoms but not necessarily the more serious implication of the symptoms with respect to bronchitis and emphysema. However, this question requires urgent evaluation.

In other locations, where the amount of combined sulfur oxide and particulate pollution is great and respiratory morbidity is also high, for example in certain parts of Czechoslovakia and Japan, epidemiologic studies both before and after the indicated control of particulates should be helpful in answering the questions remaining concerning the relative importance of particulate pollution on one hand, and sulfur oxide pollution on the other.

These remarks generally apply to suspended soots. However, particulates are difficult pollutants to define. Relatively little has

been done in characterizing particulate pollutants with respect to particle size, specific surface area, chemical composition, or specific absorptive capacity. It is this latter which probably is involved in the mechanisms by which certain types of particulate pollution tend to synergise the effects of irritant gases.

Effects of Environmental Temperature on Health

Unusual environmental temperature levels are so commonly observed and so spontaneously reacted to by most populations that there has been a tendency to overlook the systematic contribution they may make to morbidity and mortality and even to inaccurately attribute to temperature, changes which were being observed.

Because a rapid increase in an emergency hospital admissions for asthma was observed in New Orleans, and subsequently there was found an association of these asthma epidemics with certain meteorologic conditions, it became of some interest to see whether air pollutants were, or could be, a cause of these asthma outbreaks^[46]. The evidence with respect to New Orleans seems rather strongly suggestive. In an effort to see whether similar things were occurring in other parts of the country, data were collected on the occurrence of the asthma attacks by time of day or year. Greenburg, et al.^[47], noted that there was an abrupt increase in asthma attacks with the onset of cold weather in New York City. Similar observations have been made by Tromp^[48] in the Netherlands, who has suggested a mechanism by which this might occur. In his opinion, patients who are subject to asthma attacks have inadequate defense mechanisms against changes in

Table 7

Observed mortality (as per cent of expected) Los Angeles and Orange Counties (1939 and 1955 combined)

Age group	Under 73°	73°–77°	78°–82°	83°–87°	88°–92°	93°–97°	98°–102°	103°–107°	108° plus
50–54	110.5	102.2	98.1	92.6	114.6	117.6	142.5	167.7	298.8
55–59	100.1	99.8	111.6	93.9	99.1	131.7	156.4	222.1	243.0
60–64	101.4	101.6	105.3	91.0	117.5	102.5	107.6	173.0	251.1
65–69	112.0	96.7	90.3	108.4	103.8	95.8	177.0	214.4	260.4
70–74	99.6	112.4	94.3	95.4	118.0	108.1	176.0	238.7	330.6
75–79	89.6	99.0	97.4	115.2	101.6	116.0	207.1	257.6	419.2
80–84	97.6	99.7	105.6	98.4	124.0	107.4	210.0	332.2	515.0
85 plus	99.7	94.2	103.2	102.3	111.2	102.0	257.4	323.5	541.5

Source: Oechsl and Buechley^[51].

Table 8**Predicted mortality (as per cent of expected) by age and temperature**

Age group	Temperature								
	70	75	80	85	90	95	100	105	109
50–54	99.8	99.3	99.8	101.2	104.2	111.2	127.1	163.5	224.2
55–59	99.0	99.4	100.1	101.7	105.4	113.8	133.1	177.2	250.8
60–64	99.1	99.5	100.3	102.3	106.7	117.0	140.3	193.8	283.0
65–69	99.2	99.6	100.6	103.0	108.4	120.8	149.2	214.0	322.1
70–74	99.2	99.8	101.0	103.9	110.5	125.5	159.8	238.4	369.5
75–79	99.3	100.0	101.5	105.0	112.9	131.1	172.8	268.0	426.9
80–84	99.4	100.2	102.1	106.3	115.9	138.0	188.5	303.9	469.5
85 plus	99.6	100.6	102.9	108.2	120.4	148.2	211.8	357.2	599.8

Based on the Prediction Equation with 1939–1955 Data

Mortality = $98.806 + e^{(-15.13 + 0.038 \text{ Age} + 0.1655 \text{ Temperature})}$ Source: Oechsli and Buechley^[51].

temperature. Additional epidemiologic studies are clearly indicated in order to better understand this phenomenon and quite possibly these studies could lead to efforts to prevent this type of effect through better medical or environmental management. Such studies could lead to use of Strategy A.

Heat waves are commonly recognized as carrying a substantial hazard. On examining the excess mortality from them, it has been found that this is proportionately higher for mortality attributed to vascular conditions of the central nervous system^[49]. Excess mortality is particularly noted among the elderly, many

of whom are patients in nursing homes and hospitals. However, there are medical and nursing techniques whereby the adverse physiologic reaction to these heat waves can be minimized^[50]; hence the possibility exists that intervention can prevent some of the excess morbidity and mortality.

Oechsli and Buechley^[51] have pointed out the relationship of age and the level of the excess temperature as factors in producing excess mortality. They have studied age-specific mortality in Los Angeles and Orange Counties during the periods from August 21 to October 10 in 1939, 1947, 1955, and 1963. For each

Figure 5. Observed mortality (ATMR) by age and temperature, Los Angeles and Orange Counties 1939 and 1955 data combined.

Figure 6. Observed mortality (ATMR) by age and temperature, Los Angeles and Orange Counties, 1963 data.

year except 1947 (a control year) there was a heat wave with temperatures over 100°. Expected age-specific mortality was calculated for each year by excluding a nine-day period including the heat wave. (An arbitrarily chosen nine-day period was excluded for 1947.) They then calculated an age-temperature specific mortality ratio (ATMR) for each day of the period, using the previous day's temperature, since a 24-hour lag appeared to be present. The data from 1939 and 1955 were remarkably similar and are combined in Tables 7 and 8 and shown in Figure 5; that for 1963 showed a lesser effect, Figure 6. It has been suggested that introduction of air conditioning might be an explanation but this is not yet proven.

Seasonal variations in mortality have been the subject of reports by Perkins and Goldsmith^[52], who have suggested that the occurrence of substantial seasonal fluctuation may be a general index of the contribution of a variety of environmental factors, including temperature, infectious agents, food contamination, humidity, and even such factors as the opening of school or the gathering of large groups of people for holidays. While the observed seasonal variations only permit Strategy B to be applied, the observations of Oechsli and Buechley suggest that with further work quantitative statements may be made which will permit Strategy A to be used.

Discussion

The foregoing examples are intended only to illustrate the numerous problems to which environmental epidemiology could and should address itself.

Epidemiology flourishes when associations suggest intervention, with consequent improvement in health. Infectious disease epidemiology flourished because the associations observed suggested intervention on the basis of the "germ theory" and laboratory criteria of the presence of and reaction to bacteria and viruses. Chronic disease epidemiology has not flourished to the same extent, possibly because it lacks a simple theory and related laboratory criteria. Chronic disease epidemiology has suggested successful intervention largely in conditions associated with en-

vironmental agents (occupational cancer, radiation-produced disease, pneumoconioses). It has suggested intervention in the matter of cigarette smoking effects, but the success of the intervention is yet to be proven.

The argument of this paper is that the epidemiological evaluation of reactions to controllable exposures to environmental agents, that is, environmental epidemiology, can and should flourish. Effective intervention is possible for many environmental exposures; a strong theoretical basis is feasible; laboratory methods are abundant for measuring both the presence of and the reaction to these exposures. The field of environmental epidemiology can profit greatly by the advances in technic for study of dependent (i.e., health) variables which have been made by chronic disease epidemiology. It can also contribute to chronic disease epidemiology the better identification and measurement of independent variables when these are environmental exposures and conditions. Environmental epidemiology has the advantage of being able to study and possibly prevent health impairment which has not yet led to disease. Hence it has a great potential contribution toward prevention.

The social urgency for the development and flourishing application of environmental epidemiology derives from the rapid, often unplanned and frequently drastic changes which man and his technology are making on the planet which is his habitat. We may poorly understand the consequences of this metamorphosis, but we cannot be excused from the obligation to improve our understanding and to act on it. Environmental epidemiology is a discipline which is useful in guiding the metamorphosis of this planetary habitat.

Summary

Environmental epidemiology, the evaluation of the effects of environmental agents and attributes on human populations inadvertently exposed, is not a new discipline. Because of the many changes occurring in the type and extent of these exposures it assumes new importance.

Two strategies are proposed for applying the results of environmental epidemiology.

Strategy A—To collect and present quantitative data on realistic human exposures and effects which are of sufficient predictive validity to be used as satisfactory bases for public health policies and regulations.

Strategy B—In the absence of information of sufficient predictive validity on effects of realistic exposures, to collect data for exposures of greater intensity and duration than normally occur.

When applied to radiation exposure problems, the present situation is most clearly described by Strategy B, but studies are suggested whose results might permit the use of Strategy A.

Carbon monoxide control from motor vehicle exhaust is based on Strategy A. Possibly some of the health effects from cigarette smoking are also related to carbon monoxide exposure. Psychomotor effects from low-level short-term exposures should be studied, as well as effects of long-term exposures on red blood count and hemoglobin metabolism from long-term exposure.

Sulfur oxides occur commonly with soot in polluted urban areas, particularly under conditions prevalent in London. Epidemiological studies permit use of Strategy A for acute effects and Strategy B for long-term effects. Control of particulates is more easily accomplished than control of sulfur oxides, the long-term effects of which are still in need of study.

Both increases and decreases in the outdoor temperature are associated with measurable, possibly preventable health effects, the former with increased deaths especially from vascular accidents in the elderly, and the latter, among other effects, with increased attack rates from asthma. Strategy A would be appropriate.

These examples illustrate the potential usefulness of increased emphasis on environmental epidemiology.

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