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Chronologic History of Occupational Medicine

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Learning Objectives

- Give examples from antiquity of emerging practices that can be thought of as early occupational medicine.
- Recall the key figures in the 15th through 18th centuries whose writings dealt with occupational hazards and what might be done about them.
- Compare advances in occupational medicine made in Europe and America from the 19th century up to the present.

Abstract

Objectives: *To provide a chronologic review of growing knowledge in occupational medicine relating work and work hazards to health, and to provide a perspective on the lessions learned from the frequent inattention or misrepresentation of hazards.* ***Methods:*** *Many books on the social and medical history of work including epidemiology and toxicology were reviewed, as well as published papers and interviews.* ***Results:*** *Throughout history workplace hazards and occupational medicine have been shaped by the forces that shape work itself, social evolution, changing modes of production, shifting economic powers, and demographic changes in the workforce. Lest we think these changes are unique to the present time, this paper emphasizes the long-term and inevitable relationship between social structure and worker health. Hippocrates emphasized the relation between environment (air and water) and health, although he has less to say about the non-military work environment, perhaps because of the denigration of manual labor in Greece. The impact of work on health can be traced to the Edwin Smith Surgical Papyrus, written approximately 1700 BC. The earliest occupational physicians served military forces, and Galen was physician to Roman gladiators. Finger and wrist guards worn by Bronze Age archers represent early personal protective equipment. Writers of the classic period mention diseases and hazards of miners, and Pliny (1st century AD) mentions veils to cover the face. In the Middle East Rhazes included occupation in his case studies (9th century). Paracelsus, and Agricola were prominent, figures in the 15th century, with an emphasis on mining and health. Ramazzini's (c1700) work was widely translated in ensuing decades and is now well-known to all, but its influence between about 1800 and 1940 is inapparent. The emergence of a public health movement in the mid-1800s focused attention on the abominable conditions of many factories and on the living conditions, poor nutrition, high stress, poverty and ill health of the new factory working class, while paying scant attention to specific workplace hazards.* ***Conclusions:*** *The recognition of occupational diseases in the United States has often lagged by a generation behind the recognition of the same diseases in Europe. We are now into a second industrial revolution led by multinational corporations and information technology, shifting production facilities, and jobs moving around the world in search of cheap labor in the countries with the fastest growing population and the greatest poverty. Occupational medicine must be alert to the new challenges imposed by this revolution.* (J Occup Environ Med. *2005;47:96–114*)

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"What do you think we are? A bunch of epidemiologists"—Un-named colleague.

What indeed is occupational medicine, and how have we gotten here? I focus on two major themes: (1) the timeless challenge of acquiring knowledge about occupational illness in this article, and (2) the changing practice of occupational medicine itself during the past 150 years in a separate article. It is entirely appropriate that this volume, a tribute to Jean Spencer Felton MD, contain chapters on the history of occupational medicine. Felton contributed greatly to our knowledge of this history,[1] and this chapter would have been more erudite had he authored it. Indeed, many others could have written this review, each bringing to it their own experience and perspectives. I apologize in advance for ignoring or excluding topics or personages that other would have emphasized, or for drawing inferences that some readers may find offensive.

About 15 years ago, when I was researching an arcane topic, Felton was among the "seniors" that I interviewed by telephone (others were Irving Selikoff, Jacqueline Messite, and Leonard. Goldwater). Nowadays I would have sent an e-mail, and he would have been able to research an answer before responding, but he gave me the "real time" benefit of his experience. In the 1960s Felton authored a series of papers on historical aspects of occupational medicine, which were called to my attention, by my mentor, Leonard Goldwater, also an aficionado of history.[2,3] But Felton[4,5] was clearly interested in the future of occupational medicine, not just the past, and this paper follows that tradition, exploring lessons learned over the millennia. Long after his retirement from Columbia, I suggested that Goldwater—still very active in occupational medicine—write a history of the field. He smiled and suggested that I undertake the task—so this paper is part of that book conceived 20 years ago.

Why waste time reading about history when we have all those facts about chemicals, diseases, and now genes, receptors, transcription factors, and regulators, to master in preparation for multiple choice examinations? History is not merely a concatenation of facts.[6] The trends and interactions revealed by history, allow us to plan, as LaDou[7] warned, for changes that impact our specialty as well as careers.

Surely no area of medicine has more issues related to ethical practice than occupational medicine. In 1975 Howe[8] gave a somewhat-idealized definition of occupational medicine "a sub specialty of the field of preventive medicine concerned with 1) the appraisal, maintenance, restoration and improvement of the health of the workers. . . . 2) the promotion of a productive and fulfilling interaction of the worker with his work, 3) active appreciation of the social, economic, and administrative needs and responsibilities of both the worker and the work community, and 4) a health and safety team approach. . . . " This seems comprehensive enough to serve as a goal, but is not detailed enough to provide guidance. Roberts[9] also gave an extremely broad definition: "Occupational medicine is concerned with the prevention of disease, the maintenance and promotion of health among employed persons in their group setting, the community's health as it is affected by industry, and the consumers' health as affected by industrial products. Occupational medicine involves clinical medicine, toxicology, epidemiology, and administrative expertise." Felton[10] describes the various roles occupational physicians fulfill, and Walsh[11] and Draper[12] describe the contexts in which occupational physicians practice and some of the challenges and conflicts they report.

In addition to reading Felton's historical papers, I recommend reading Hunter,[13] and Teleky,[14] who take us back to antiquity, Goldwater,[15] Abrams,[16] who covers the period from 1830 to present in more detail, and LaDou,[17]who provides a sobering view of the current globalized climate. I have tried to expand rather than repeat. Many valuable books have been written illuminating the struggle for worker health, including Rosner and Markowitz[18] and Berman.[19] Others will be cited below.

Occupational medicine has a long-but-checkered past and an uncertain future.[7] As part of the broader field of occupational health and safety, occupational medicine focuses on the recognition and prevention of occupational disease, which I define as "conditions caused or influenced by exposure to general conditions or specific hazards encountered in the work environment." As we take work home with us, our workplace environment expands, and as work is restructured, job security and stress continue to be part of the occupational medicine environment.

Occupational medicine has made great progress scientifically, but has not always fulfilled its social responsibility. It would be unfair to pass judgment on an entire profession (as some have) by pointing to a few egregious instances of neglect, such as the conspiratorial refusal of physicians to recognize lung disease in coal miners[20] and asbestos workers,[21] or their role in obscuring the toxicity of lead.[22] The broader field of occupational health has also come up short of expectation, for example, its failure to prevent acute silicosis among workers (80% minority) in the digging of the Union Carbide tunnel at Gauley Bridge[23]. And it is reassuring to point instead to the example of Dr John Creech's publication of angiosarcoma cases identified at the B.F. Goodrich vinyl chloride plant where he worked.[24]

I was tempted to begin this history, like many authors have with Bernardino Ramazzini, usually heralded as the Father of Occupational Medicine. Reading a translation of his *De Morbis Artificum Diatriba* (originally published in 1700),[25] one is struck by the freshness and relevance of his teachings, by the mixture of the modern and mythic, and by the depth of his understanding of workers, work, and disease. I was tempted to quote at great length, but everyone in our field must read the book. Most of all, I realized with great humility that Ramazzini's frequent quotes from Plutarch, Hippocrates, Persius, and others were likely read in the original language, with which learned folk of the 17th century would have been familiar. However, if I could not read the original classics, preparing this paper at least forced me to open a number of excellent books that had sat too long unread on my shelves.

The Scope of Occupational Medicine

Occupational medicine performs a variety of tasks which are interrelated, interactive with cognate disciplines (epidemiology, industrial hygiene, toxicology, safety, ergonomics, psychology, nursing), and correlated with other medical disciplines (particularly pulmonary, dermatology, rheumatology, orthopedics, rehabilitation, and psychiatry).

Occupational physicians were among the first doctors to work for salaries and quickly ran afoul of an American Medical Association, for which salary was anathema, but this distinction became blurred as more and more physicians joined salaried ranks.[26] To be successful in occupational medicine requires the integration of preventive and psychosocial principles with diagnostic acumen and therapeutic creativeness. For many aspects of our practice, prevention looms large in our armamentarium; however, many doctors who treat workers do not have this background.[7,27] This review focuses on the historical aspects of recognition of work-related hazards and the gradual accumulation of knowledge regarding occupational disease.

A Chronological History of Occupational Medicine

It was fun reading and writing a history, but less fun deciding how to organize it. I have chosen to divide it into broad chronologic categories and to place within each of those periods a few of the people who illuminate the time, no doubt omitting many important figures, some by choice, others unbeknownst to me. The advance in the knowledge and understanding of work-related disease has obviously paralleled biomedical progress in general,[28] usually lagging far behind, but occasionally (as in the case of cowpox and anthrax) driving it.

The Early Days of Humankind—Lower Paleolithic

Anthropologists keep pushing our horizons of human history back in time through the discovery of bones indicative of multiple lineages of hominoid ancestors and through discovery of tools, art, and pottery which trace civilization into the distant past.[6,29] Tool use is one of the criteria distinguishing proto-humans from our primate ancestors and relatives, and anthropologists have identified primitive hand-held stone tools in Africa at more than a million years ago, although having seen these tools in museums in Kenya, it is clear that some faith is needed to distinguish the fractured, ill-shaped, rocks as man-shaped rather than natural phenomena. At the Olorgesailie site near Nairobi, however, the evidence for tool manufacture 500,000 years ago is more compelling.[29] Stone tools predominated until relatively recently, even when ceramics were being shaped and colored, hides sewn together, and cave walls painted at Lascaux, France. In the late Stone Age, agriculture arose probably about 12,000 BC in the fertile crescent, with the domestication of wheat documented in the Euphrates valley about 9500 years ago.

Through most of the Paleolithic Age, stones were simply picked up opportunistically and chipped and shaped. Quarrying for flint goes back about 10,000 years, and mining must have begun more than 6000 years ago, since crude copper tools have been dated even before that in the Middle East.

Late Paleolithic to 500 BC

Although the classic definitions of Copper, Bronze, and Iron Ages are Eurocentric, Europe apparently lagged some centuries behind Asia and the Middle East. The intricate workings of gold ornamentation also date back thousands of years. Only gradually over the centuries, as urban centers arose did craftsmen and artisans emerge as an economic force. Hunter[13] provides a very readable account of the hazards facing early hunter-gatherers, farmers, miners and craftsmen several millennia ago.

The history of occupational disease can be traced into antiquity and any advances in understanding work and disease, paralleled advances in understanding of the physical world. As humans evolved during the long Paleolithic Period, the main occupation was obtaining food. As gatherers evolved into hunters their encounters with dangerous animals—potential foods—increased. But in this period, the main workforces were soldiers, a hazardous occupation that continues today. Artifacts and illustrations from this period indicate that archers wore finger tubes and clay wrist guards for protection against bowstrings.[14]

Stone tools were replaced by the use of copper approximately 5000 years ago and then rather quickly by bronze and then iron approximately 3500 years ago (the actual dates varied geographically, and the estimates have also changed with time and dating procedures). Indeed, some evidence of iron use can be traced to almost 8000 years ago. The Greeks made high-heat furnaces sufficient for working iron, and by 2000 years ago iron manufacture had spread over much of the world, with a few cultures retaining stone age practices even into the 20th century.[6] By 1000 BC, mining was becoming more organized. Quickly, the hardening of iron into steel by adding carbon over a charcoal fire, was learned,[30] although the age of steel is usually dated only to 1850.[31] The period from 4000 to 3000 BC saw the widespread development of bronze, innovations in glazed pottery, and glass making,[32] each accompanied by its own hazards.

The history of technology, work, and associated hazards is fascinating in its own right,[13] but its importance here is the new hazards that arose and how they were recognized. Did the chippers of stone spear points suffer respiratory disease, or were they likely to die before disease was manifest? Early potters used glazes from a variety of minerals such as copper, lead, and cadmium, and painters using vermilion from cinnabar or yellow pigment were exposed to mercury or arsenic[3]; did they suffer central nervous system or chronic renal disease? Certainly miners, many of them slaves or prisoners, suffered severe disease, often dying after only a few months. Protective equipment varied from complete nakedness (Galen cited by Ramazzini[25]) to veils worn in some operations to protect the face (Pliny cited by Hunter[13]).

Grand-scale construction projects such as the Egyptian pyramids inevitably engendered traumatic injuries, and skeletons unearthed in the "worker villages" reflect healed, and in some cases apparently set, fractures. The Edwin Smith Surgical Papyrus, written approximately 1700 BC, was apparently a copy of original texts dating back 500 to 1000 years earlier.[33] This places it as contemporaneous with the millennium of pyramid construction, leading to suggestions that some of the neurosurgical and orthopedic cases discussed in the papyrus (including some very aggressive therapies), probably resulted from construction injuries. The Papyrus, often cited as the earliest neurosurgical treatise, would therefore also represent the earliest treatment of work-related injury. Primitive medicine was closely related to poisons, and the Ebers Papyrus (c1500 BC) describes many recognizable poisons.[34]

Classical Period

There is a troubling historical void in the 500 years before the Hippocratic period. Medicine flourished in China and ayurvedic medicine flourished in India, but I could not find accounts specifically relating to the occupation of patients or work-related conditions. There is much work for scholars of these traditions. During this period there is some evidence of a shift from spiritual to naturalistic explanations of disease. Observations of illnesses and mortality among miners date back to Greek and Roman times. Mining is the occupation that appears to attract most attention in this period. Writers from Hippocrates to Pliny the Elder, comment on the hazards of mining. However, since mineworkers were likely to be slaves or prisoners, there was little concern over their health, and indeed condemning prisoners to mine work was their "hard labor" as well as a death sentence.

Manual Labor in Greece

In my mind, one of the most telling passages regarding the historical plight of workmen in Ancient Greece and subsequently, is a passage from Xenophon's treatise *Oeconomicus* cited by Hunter,[13] and attributed to Socrates:

> "What are called the mechanical arts, carry a social stigma and are rightly dishonoured in our cities. For these arts damage the bodies of those who work at them. . . by compelling the workers to a sedentary life. . . in some cases to spend the whole day by the fire. This physical degeneration results also in deterioration of the soul. . . . And in some cities, especially the warlike ones, it is not legal for a citizen to ply a mechanical trade."

There we have both ergonomic and physical hazards leading to a diagnosis (physical degeneration), although the treatment was apparently social stigmatization. This devaluation of work and workers carried forward into the disregard for workers' health and safety characterized in many 19th century works of literature as well as in 20th century polemics such as Robert "Tressell"'s(1914). *Ragged Trousered Philanthropists.*[35] Vestiges remain today in the concept "cheap labor" and the unspoken concept of "disposable workers."

Hippocrates (circa 460–377 BC)

There remain many unresolved issues regarding the life and writings attributed to Hippocrates. Although many medical graduates take some form of an oath attributed to Hippocrates, little is taught about Hippocrates himself or the medicine he practiced. To him are ascribed books and treatises on many aspects of medicine, including an emphasis on environment (Hippocrates c400 BC). Hippocratic teaching, although focusing on balance among the four humors, was naturalistic and observational, rather than superstitious. The writings urge physicians to observe the patient's condition and their response to disease rather than only the disease itself. In seeking a balance between the organism and its environment, Hippocratic medicine would have been ripe for the recognition of diseases arising from work environments. Indeed, the Hippocratic treatise *Airs, Waters, and Places* (Hippocrates c400 BC)[36] emphasizes seasonality and air and water quality as potent influences on health, but the only mention of work refers to horsemanship and ability to use weaponry, perhaps because those Grecian doctors, as citizens were expected to treat other citizens rather than "workers." Yet the Hippocratic Oath extols physicians to provide services without regard to social class, and Hippocratic writings include observations on appalling working conditions, including miners and workers of metal as well as dye makers, tailors, horseman, and farm workers. He identified sciatica, impotence and sterility among horsemen, while farmers suffered fever and mental derangements and metal workers breathe heavily.[14] Aristotle (384–322 BC) believed that horsemen had heightened libido because of saddle friction.

The post-Hippocratic period was one of great diversity in schools of medicine. Alexandria became the leading Greek scientific center. Plato championed the Dogmatist school relying on reason rather than observation, in direct opposition to the Hippocratic approach.[37] With the ascendancy of Rome, medicine remained in the hands of Greeks, and the fortunes of physicians waxed and waned from valued to disdained. Likewise the humoral theory of health and disease was variously championed or rebuked. Greek remained the language of science, and several writers (Aristotle, Pliny) are remembered for their scientific observations and descriptions. Observations on work and hazards, however, are inconspicuous. Physicians were assigned to military units, and as mentioned above military medicine was really a progenitor of the occupational. Craftsmen were highly valued and gained status and were allowed to form guilds to protect their interests.[25]

Lucretius (c100BC–c55 BC)

Lucretius can be considered a natural philosopher as well as poet, probably the most important in the Roman era. His volume *De Rerum Natura* is usually translated *On the Nature of Things.* His observations on survival of the fittest anticipated Darwin by nearly two millenia. Of metal miners Lucretius wrote "Do you not see and hear that they perish after a brief span and how their vital force fails them" (cited by Ramazzini 1713[25]).

Pliny the Elder (23AD–79AD)

Gaius Plinius Secundus wrote *Naturalis Historia* (77AD), an encyclopedic compendium of knowledge on many subjects, particularly involving the natural world, but also technology and warfare. Although often denigrated for repeating fanciful tales, Pliny's observations on many topics were respected and cited for centuries. Pliny wrote, "The fumes from silver mines are harmful to all animals" and "when well shafts have been sunk deep, fumes of sulfur or alum rush up to meet the diggers and kill them." He wrote also about veils made from animal bladders worn on the face to protect miners (cited by Ramazzini 1713[25]). Pliny is perhaps most famous for getting too close to Pompeii perhaps out of curiosity, and dying from the eruption of Vesuvius.

Galen (ca129–ca200)

Most of what we learn about Galen are his superstitious views, lauded by the Church, and ultimately rejected in the Renaissance after 1500 years of hegemony. But Galen also produced important medical and surgical descriptions based on direct observation. For this review, I recognize Galen's role as physician to the gladiators in the court of Marcus Aurelius. He also wrote about visits to mines and observations of workers exposed to acid mists.[25] Galen was an accomplished surgeon who wrote detailed description of surgical procedures and instruments. Galen was responsible for wound treatment in a workforce where wounds were a regular occurrence, and he exploited this clinical base to publish anatomic observations, some sound, some fanciful, which dominated medicine until supplanted by Vesalius's dissections and drawings in the 1500s. Lyons and Petrucelli[37] attribute Galen's durability to the positiveness of his assertions liberally mixed with teleological explanations, which appealed to the Church. From Roman to medieval times, poisons figured prominently in political and social life, if not in the occupational sphere.[34]

The Dark Ages

Between Galen and Ramazzini (1700 AD), there is little evidence of attention to occupational health or disease. Alchemy became the dominant concern of chemistry,[32] and the treasure of literature preserved in Alexandria was destroyed through a series of events. During this period important if fragmentary changes in medicine and the natural sciences occurred, often despite vigorous church opposition. We are accustomed to calling much of this period (up to 1200) as the Dark Ages, but that epithet applies mainly to Europe, for there were cultural and technological advances in the Middle East and Asia, unfettered by European religious dogma. And the ancient Greek literature was preserved by and influenced Arab scholars, while it was largely forgotten in Europe.

The fragmentary nature of this history is its chief characteristic. The Dark Ages remains, to a large extent, a "black box" when it comes to extracting intellectual impact on modern technology and medicine.[38] The Middle East emerges as home of potential innovators, whereas European thinking was still Aristotelian, and deviant thinkers risked martyrdom. Trade around and across the Mediterranean began to flourish in the 9th century, plagued by battles among warring families and city-states.

The 12th century saw the rise of scholasticism. Historian Stiefel[39] identifies bright lights of rationalism as early as 1100, but these flashes hardly illuminated the darkness, and probably remained largely unknown to their contemporaries, isolated by space and by time from later innovators. Construction, particularly of cathedrals, became as important to Europe as it must have been to classical Greece and Egypt, or to the Amerindians of the 600-1200 AD period. New architectural concepts expanded construction horizons of size and ornamentation. As tourists today, we can see the surviving structures representing the successful technological experiments with structure and form, emphasizing size and grandeur. But the record of injuries and deaths involved in their construction, is yet to be elucidated. And guidebooks may praise the artists and nobles, but remain silent on the construction workforce. Emerging guilds in Germany and later in England took measures to protect master craftsmen (for example, restricting age of entry into apprenticeship), but records do not provide a record of protective measures.[14]

Rhazes 9th Century

Abu Bakr Muhammad ibn Zakariya al-Razi (c. 850–923), known in Western literature as Rhazes, was a leading medical figure in the Middle East (Persia). He wrote more than 200 treatises, few of which have survived. His encyclopedic work, "Continen," drew on the Greek literature but was not above criticizing Galen. He is credited with teaching differential diagnosis and advocating care of the poor. He was an advocate of ethical practice and a harsh critic of quackery and fraud. Most interestingly, many of his detailed cases include a statement of occupation: a cotton-merchant, cloth merchant, goldsmith, bookseller. His texts were translated and used in European medical teaching for several centuries.[40]

1200 to 1600 Medieval Period and Renaissance

By the 13th century, Europe was readying itself for new knowledge. Ironically, the Crusades, although church driven, had brought Europeans into contact with Arabian thought and with the Greek classics that were preserved in the Middle East.

The Medieval Period saw the rise in transportation, trade and technology.[41] Although Stillman[32] questions whether Roger Bacon (1214–

1292) actually invented gun powder, Bacon published its formulation in 1242, creating both a new war weapon and a new industry to support it. However, as evidence of slow technology transfer, not until 1627 was gunpowder used for underground blasting, changing the way in which mining was conducted.

Environmental regulations appear to have preceded occupational protections. In some French cities (ca 1350) slaughterhouses were required to dispose of animal waste away from residential areas, and in the late 1400s certain shops such as potters could not operate in residential areas.[14]

Long[41] states that "A new confidence in reason and in human ability to discover rational laws opened up the world of nature as a legitimate area for scrutiny and investigation" (see Table 1 for chronology). In the West, scholars began to free themselves from strict Aristotelian principles, and a new technology, embracing mathematics, arose, incorporating principles more freely developed in the Arab world.

Labor and employment changed in this period as well. The 13th century, which gave the world Dante and Aquinas, was a period of rapid ferment and development of international commerce. New universities were founded in Britain, France, and Italy. There was a major construction boom in many European cities, as new architectural strategies allowed the construction of larger cathedrals, calling in turn for more stone and stone workers. Glass technology expanded the use of stained glass, which although largely a tourist novelty today, was a driving force in construction and trade in the 1200's and 1300s. There was a demand for skilled tradesmen in all aspects of construction and decoration. Workers encountered hazards that were largely undocumented and underwent treatments of uncertain quality, and probably died at a younger age than their employers.

Although literature is silent about occupational medicine in this period, one might infer that craftsmen were relatively well-off and were probably well-attended by physicians of their time, taking into account that the humoral theory of disease still prevailed. Chase[42] argued that the outbreak of Plague in the mid-1300s forced a change in the understanding of "poisons as explanatory devices." Muendel[43] points out that even in the 1300s, iron workers who made and repaired tools were skilled craftsmen, literate and capable accountants. His examination of the technology, materials, and tools, however, gives no indication of the hazards, injury, burns, illness that must have permeated the smoke-filled workplaces.

As national states emerged in the 1400s through consolidation of city states, authority became centralized and control of trade increased. At the same time the lowest class of people became dehumanized even further, and interest in their health must have been at a low point as Hafter[44] illustrates with the French textile industry of the Medieval period. The 1500's saw rapid exploration of the World and the Americas and the flowering of culture exemplified by Michael Angelo and Leonardo DaVinci, as well as science (Coperinicus, Vesalius).

Ulrich Ellenbog (1440–1499). In Germany in 1473, Ellenbog wrote on the occupational hazards faced by goldsmiths and metalworkers, describing how to avoid lead and mercury poisoning.[34] This brochure was written for smiths, and includes "open windows" and "covering the mouth with a cloth."[14] Although citations consistently ascribed this work to 1473, it was apparently not published until 1524.[14] In any case, I find no mention of Ellenbog by Ramazzini.[25] It is reported to be the first work specifically on industrial hygiene.[14]

Agricola (1494–1555). Georgius Bauer, better known as Agricola, is best known as author of *De Re Metallica.* His work *Zwölf Büchern vom Berg- und Hüyttebweseb* [*Twelve Books on Mining and Smelting*, 1556] deals with every aspect of mining, smelting, and refining of gold and silver. It was finally published a year after his death. Although a practicing physician, he devoted more attention to geology and paleontology and is sometimes considered the father of geology. Born in Saxony, he worked in the Joachimsthal mining region. Among many technical and engineering descriptions are accounts of the diseases and accidents that befall miners, including ailments of the joints, lungs and eyes, and the means to guard against them. Although not precise, it clearly reflects knowledge of the harmful effects of dust.

> "dust penetrates into the windpipe and lungs, and produces difficulty in breathing and the disease which the Greeks called asthma. If the dust has corrosive qualities, it eats away the lungs, and implants consumption in the body." (cited by Hunter 1974:p28).

Agricola advocated improved ventilation, providing details on design[14] and advocated protective equipment, including leather boots and gloves as well as "loose veils" to protect miners against dust, a rather modern concept. He also described a variety of causes of traumatic injuries including falls from ladders or into shafts and cave-ins. In those days safety was largely the province of the guilds formed by miners for their protection. Guilds had facilities for assisting miners who became injured. Subsequently mining developed a class structure separating owners from miners, and weakening the guild protections.[45] Disease tracked technology, as Hunter[13] traces the increase in pneumoconiosis to the introduction of the pneumatic drill.

Paracelsus (1493–1541). Theophrastus Bombastus von Hoehenheim, better known as Paracelsus, often is cited as the father of the "dose makes the poison" concept, ie, "All substances are poisons; there is none which is not a poison. The right

TABLE 1
A Chronology of Advances in Occupational Health (courtesy EOHSI)

Period	Personage	Product
Late 1400s	Ulrich Ellenbog (1440–1499)	Pamphlet on lead and mercury poisoning among gold miners (1473, published 1524)
Early 1500s	Paracelsus 1493–1541	Dose makes the poison and treatise written 1531–34; published (1567) "On the Miners' Sickness and Other Diseases of Miners"
1556	Georg Bauer, Agricola 1494–1555	*De Re Metallicus.* "Twelve Books on Mining and Smelting" (1556)
1656	Samuel Stockhausen	"Treatise on the Noxious Fumes of Litharge, Diseases caused by them and Miners' Asthma" (1656)
1700–1713	Bernardino Ramazzini, Carpi, Italy 1633–1714	*De Morbis Artificum Diatriba* "Diseases of Workers" (1700, 1713)
1705–1716	Friedrich Hoffmann	*De metallurgia morbifica* (1705) "Consideration and notes on the fatal vapors of charcoal" (1716)
1753	James Lind (1716–1794) British Navy	*Treatise on Scurvy*
1761	J.A.Scopoli (1723–1788)	Described mercury poisoning at Idria in 1761
1775	Percival Pott (1714–1788)	Identified scrotal cancer caused by soot in pre-pubertal chimney sweeps
1778	Jose Pares y Franques, Spain	"Catastrophic Illness of the Mercury Mines of Almaden"
1798	Marine Hospital Service	Forerunner of the U.S. Public Health Service, established to care for merchant seamen.
1831	Charles Turner Thackrah (1795–1833)	"The effects of the principal arts, trades and professions…on health and longevity" (1831)
1837	Benjamin McCready (1823–1892)	*"On the Influence of Trades, Professions, and Occupations in the United States, in the Production of Diseases"* (1837)
1842	Edwin Chadwick Britain 1800–1890	"Report into the Sanitary Conditions of the Labouring Population of Great Britain"
1844	Frederick Engels (1820–1895)	"The Condition of the Working Class in England in 1844"
1848	Rudolf Virchow 1821–1902	Investigates typhus among miners of Silesia. "Nothing but prosperity, culture and freedom could bring about improvement." (cited by Abrams 1994)
1849	Josiah Curtis	"Hygiene in Massachusetts"
1850	Lemuel Shattuck, Massachusetts 1793–1859	"Report on the Sanitary Condition of Massachusetts"
1869	Massachusetts	Establishes first Bureau of Labor Statistics
1878	Knights of Labor National Convention	Calls for a federal occupational safety and health law
1880	Germany	Initiates employer-paid Workers' Compensation insurance.
1888	George Ireland	Wins APHA Competition with essay on "Preventable Causes of Disease, Injury, and Death in American Manufactories and the Best Means and Appliances for Preventing and Avoiding Them"
1898	Sir Thomas Morison Legge (1863–1932)	The first medical inspector of British factories. 1912: *Lead Poisoning and Lead Absorption*
1902	Thomas Oliver (England)	"Dangerous Trades"
1910	Crystal Eastman	Work Accidents and the Law
1910	John Fitch, Pittsburgh	"The Steel Workers" describes working conditions and hazards in foundries
1914	W. Gilman Thompson	"The Occupational Diseases, Their Causation, Symptoms, Treatment and Prevention" (1914).
1925	Harrison Martland, New Jersey	Report on osteogenic sarcoma in radium dial painters.
1925–1943	Alice Hamilton 1869–1970	"Industrial Poisons" in the United States (1925) "Industrial Toxicology" (1934) "Exploring the Dangerous Trades" (1943)
1946	Harriet Hardy 1906–1993	Publicizes beryllium disease
1970	Occupational Safety and Health Act	Initiates OSHA and NIOSH

dose differentiates a poison and a remedy." He traveled widely in Europe and garnered both supporters and detractors as he railed against prevailing scholasticism in medicine.[13] He tried to break the continued reliance on Galenic doctrines. Like Galen, he too experienced occupational medicine directly, serving as an army surgeon (1518–1525). He was a practicing physician who experimented with a wide variety of cures. His 1567 monograph of occupational diseases of miners and smelter workers, *Von der Bergsucht und anderen Bergkrankheiten* [*Phthisis and Other Diseases of Miners*] was written 1531–1534, but was published posthumously as were most of his works, which had a continued impact into the early 1600s.[32] Paracelsus described dyspnea and cachexia from mining, connected it with breathing, but apparently did not recognize dust as the causative factor.[135] Likewise, he wrote extensively on chemical reactions, although his understanding of how they occurred was flawed,[32] and was more interested in drug treatments rather than exposure prevention.[14]

Paracelsus made significant contributions to pharmacognosy and used mercury, lead, and arsenic as part of his pharmacopeia. To him is attributed the first use of mercury inunction in the treatment of syphilis, which persisted into the 20th century. Of this practice, Ramazzini[25] later wrote critically, calling doctors who treated by mercury inunction the "lowest class," as if they were deserving of their mercury poisoning.

17th Century

Although Greek science was more advanced in the centuries B.C. than in the subsequent millennium, it had only the bare inklings of experimentation, so that knowledge was observational and inductive. Aristotelian ideas persisted unchanged and almost unchallenged. From various sources, notably Zinsser (1934),[46] one sees the history of early science in general as idiosyncratic, seriously lacking in generalizations.

When van Leeuwenhoek developed the microscope in 1677, allowing direct visualization of gametes, not to mention microorganisms[47] (de Kruif 1926) it opened an entirely new dimension of scientific inquiry. In Germany, Stockhausen (1656) recommended that miners (particularly lead miners) avoid dust inhalation, rather than pursuing Paracelsus' medical model.[14] Articles on the hazards of production of white lead and mirror-making appeared in the *Transactions of the Royal Society of England* as early as 1670.[14] In the closing years of the 1600s, Ramazzini assembled his observations into a book *De Morbis Artificum* Diatriba,[25] first published in 1700 and revised in 1713, shortly before his death.

18th Century

Bernardino Ramazzini (1633–1714). Ramazzini is known quintessentially for the admonition to physicians: "To the questions recommended by Hippocrates, he should ask one more—What is your occupation."[13,25] Ramazzini considered epidemiology and sanitation as his major endeavors, and he is known today for his detailed clinical descriptions of occupational disease in a wide variety of workforces. Ramazzini's work covers many trades including miners, healers and midwives, chemists and apothecaries, potters, smiths, glaziers, mirror makers, painters, sulfur, gypsum and lime workers, cleaners of privies, fullers, oil pressers, tanners, cheese makers, tobacco workers, corpse carriers, wet nurses, vintners, bakers, sifters, measurers of grain, stone cutters, laundresses, flax, hemp and silk workers, bathmen. He pioneered ergonomics, invoking posture as a cause of disease with emphasis on sedentary work; runners and standers, and athletes and porters, singers, farmers, fishers, soldiers, learned men, nuns, grinders, brick makers, well diggers, hunters, soap makers were vulnerable. And this list is not exhaustive. It is hard to imagine a clinician today whose experience spans such a wide scope of occupations.

Ramazzini visited workers and workplaces and observed first hand how various types of work were performed and the stresses they placed on the body. He advocated periods of rest, the need for exercise, and change of posture. Lack of ventilation and temperature control contributed to disease and susceptibility. He recommended washing hands and faces and even recommended quitting a trade when respiratory conditions arise.

There are far too many revealing quotes in Ramazzini, but in his preface, we read his raison d'être. Ramazzini was no Luddite, frequently emphasizing the benefits of production to society

> ". . . all the arts both mechanical and liberal; they are certainly a precious boon, but as usually happens in human affairs it is not without an admixture of the malign. For we must admit that the workers in certain arts and crafts sometimes derive from them grave injuries, so that where they hoped for a subsistence that would prolong their lives and feed their families, they are too often repaid with the most dangerous diseases and finally, uttering curses on the profession to which they had devoted themselves, they desert their post among the living. While I was engaged in the practice of medicine, I observed that this very often happens, and so I have tried my utmost to compose a special treatise on the diseases of workers."

This theme recurs in his chapter on mirror makers who use liquid mercury:

> "At Venice on the island called Murano where huge mirrors are made, you may see these workmen gazing with reluctance and scowling at the reflection of their own sufferings in their mirrors and cursing the trade they have chosen." (Ramazzini Chapter VIII).

Ramazzini was a generalist, emphasizing two causes of occupational disease:

> "The first and most potent is the harmful character of the materials that they handle, for these emit noxious vapors and very fine particules inimical to human beings and induce particular diseases; the second I ascribe to certain violent and irregular motions and unnatural postures of the body, by reason of which the natural structure of the vital machine is so impaired that serious diseases gradually develop therefrom."

These observations are timeless—the latter easily a preface to modern works on musculoskeletal disease.

Ramazzini used observations to draw inferences about causation. He was often on the right track, occasionally quite wrong. Felton (1997) suggested that except for a few disciples, *De Morbis Artificum Diatriba* languished until resurrected by the

English translation in 1940 and the subsequent promotion by Pericle Di Pietro.[48] However, the fact that there were many editions and translations of his work into Italian, French, German and English throughout the 1700's indicates that he was widely read and well-known, at least in that period. Since the 1950s Ramazzini has been recognized as the father of occupational medicine.

As with many occupational health specialists today, Ramazzini was probably unique among contemporaries in his sympathy with workers; he writes about bringing "bile to the noses of doctors" if they heed his call to visit workers.

James Lind (1716–1794). Lind, the father of nautical medicine, studied at Edinburgh and joined the navy as a surgeon's mate in 1739. He is best known for his controlled experiments treating and preventing scurvy with lemons and oranges (not limes), and his *Treatise of the Scurvy* (1753) called attention to the importance of preventing the disease, which often killed or incapacitated whole crews. Why wasn't the cure adopted by the British Navy until decades later? Medical historian Lloyd wrote: "Briefly it may be said that Lind was an undistinguished physician in the eyes of his contemporaries, the naval medical service being on the lowest rung of the professional ladder."[49]

J.A. Scopoli (1723–1788). Scopoli was retained to provide medical services to the mercury miners of Idria (former Yugoslavia). He clearly described chronic mercurial poisoning in *De Hydrargyro Idriensi Tentamina Physico-Chymico-Medica* (Venice, 1761). As physician assigned to the mercury mines, he can probably be considered the first company physician of modern times. Shortly thereafter (1778) Pares y Franques published an account of mercury poisoning at Almaden in Spain.[50]

Percival Pott (1714–1788). In 1775, Pott published observations on the high rate of scrotal cancers in London chimney sweeps (mainly pre-pubertal boys). Pott proposed that soot, accumulating in the scrotal folds, caused the cancer. Thus Pott can be identified as a pioneer of observational epidemiology (predating John Snow by a century) as well as the father of environmental carcinogenesis.

In the late 1700s Thomas Percival described conditions in the mills of Ratcliffe, which stimulated parliament to pass of the Factory Act of 1802, supported by Sir Robert Peel a progressive mill owner. The Act limited work hours to 12 and required ventilation and sanitation. Although progressive the act was ineffective.[51]

1700s in America

Colonial America was deliberately maintained in a preindustrial state by Britain to eliminate competition and to provide agricultural products. Before 1823, England severely constrained emigration of skilled craftsmen in order to prevent other countries from developing competing industries.[52]

Felton stated that "The story of occupational medicine from 1776 on can be told only with a parallel delineation of the emergence of commerce and manufacturing."[1] At first manufacturing was confined to homes or small family-owned, service-oriented shops. In the mid-1700s, a laboring class slowly emerged in competition with slave labor. Entrepreneurs copied British factory machinery, and the industrialization of America began.[1] In America, the class system in industry was set by the early roles of actual industrial slavery, particularly in southern textile mills. Workplace safety probably began with an emphasis on fire safety.

Nineteenth Century (1800s)

Charles Turner Thackrah (1795–1833). I begin this section with Thackrah, who, despite an untimely death from tuberculosis, was prescient in his contribution to occupational medical knowledge. At the age of 31, he founded what became the Leeds University School of Medicine, challenging London's monopoly on medical education. *The Effects of the Principal Arts, Trades and Professions. . . on Health and Longevity*[53] called public attention to the plight of factory workers, describing "disorders prevalent in the several kinds of employ. It will be remembered that the subject is new." In general, he emphasized the social and economic plight, but recognized occupational hazards.

Thackrah was perhaps the first to recommend substitution, the first principle in industrial hygiene: ". . . in many of our occupations, the injurious agents might be immediately removed or diminished." Thackrah covered a breadth of occupational sectors, child labor, and awkward postures. He called attention to long hours of child labor in flax mills. He recognized that dust affected the lungs of miners and metal workers, and made a connection between dusty trades and tuberculosis. In the pottery industry he recommended substitution for lead glazes, or at least a change in work practices (cited by Hunter).[13]

Benjamin McCready (1823–1892). McCready wrote *On the Influence of Trades, Professions, and Occupations in the United States, in the Production of Diseases* in 1837. This is sometimes recognized as the first U.S. contribution to occupational medicine. However, like Thackrah, it was largely a sociological document.

In England William Farr computed mortality rates in various occupations, highlighting risks in factory workers and miners.[51] The rise of awareness of occupational health and safety in this period has been chronicled by Legge,[54] Goldwater,[2] Felton,[1] and Abrams.[16] Health and disease were closely connected to the advancing industrial revolution and its accompanying social and demographic revolution. During the 1800s, small shop manufacturing was out-competed by factories, and their owners became wage-laborers.[55] Hunter[13] writes of "dreadful conditions in many trades" in the mid-19th century. Britain passed a Factory Act in 1833 and a Mines Act in 1842, which stemmed some of the worst abuses, although child labor continued. Large numbers of young women recruited for textile mills lived in marginal housing and worked 14-hour days.[1] Thackrah[53] wrote a treatise on removing workplace hazards to promote longevity, and he is known also for his writing on child labor in cotton mills. But in the ensuing decades the emphasis was on the social correlates of work more than on specific workplace hazards. Beginning in 1836 child labor laws were enacted, and in 1842 Massachusetts limited children younger than 12 years of age to 10 work hours a day.[1] The social conditions of workers and work captured more public and medical attention than the specific hazards, although long hours, crowded conditions, low (and often decreasing pay), speedups, were documented by Virchow, Thackrah, and others.

Although public health emerged in the mid-19th century, it had relatively little impact on work hazards themselves. States seemed to have a laissez-faire approach to rapid industrialization, and the gap between labor and management widened, allowing ample room for social critics. Among these, Frederick Engels (1845) wrote *The Condition of the Working Class in England in 1844*,[56] emphasizing the increasing poverty wrought by industrialization. Engels was interested mainly in the structure of work and its impact on health, but wrote also of workplace exposure to lead,

In America, Ware[55] (1924) describes starvation wages that must have made work, or at least life, incredibly stressful. Working conditions and management-labor strife figure prominently, but although some craft associations established funds to pay sick benefits, there is scant discussion of work-related health or disease. Ware summarizes the report of Dr Josiah Curtis (1849) on the Merrimack Company in Lowell, Massachusetts. Turnover was rampant, with an average work duration less than 1 year. Curtis made some impressive calculations regarding the lack of ventilation and lack of fresh air, including calculations of the desired amount of air for a typical mill room housing 55 workers. He reported that there was no active air exchange during a period of weeks and that temperature was an added burden. Curtis clearly understood the importance of ventilation.

Ware[55] also cites a letter from John Allen in a popular labor newspaper of the period *Voice of Industry* (September 1846) condemning the U.S. factory system for the ill-housing it provided and the poorly ventilated work leading to chronic illness: "You compel them to stand so long at the machinery that varicose veins, dropsical swelling of the feet and limbs, and prolapsus uteri, diseases that end only with life, are not rare, but common occurrences." Half of the typhoid patients hospitalized at Lowell Hospital (1840–1849) were mill workers, which the hospital physician attributed to "imperfect ventilation of the mills," but more likely reflected common source infection from lack of sanitation in company housing.

In England, Chadwick (1842) and in Massachusetts Shattuck (1850), emphasized the health problems rampant in the new industrial towns.[13,55] Crowding, poor sanitation, immigration, and poverty combined to produce disease. While championing the health of mill workers, apparently neither author focused on hazards in the mill itself as contributors to ill health, although air pollution from the mill was seen as a problem to the nearby worker-residents. In 1848 Virchow, the father of social medicine, attributed an outbreak of typhus among miners of Silesia to wanton capitalism. This cost him his job, but again the risk factors he emphasized were poverty, undernutrition, and overwork rather than specific job hazards.[55] The abolishment of slavery established the need for replacement by laborers, without changing the mind set of the mill owners.[57]

Mining continued to be a most unsafe occupation, but evidence of chronic disease was documented as well. Harting and Hesse provided the first description of occupational lung cancer in the Schneeberg miners, and measured airborne dust, although they were unaware of radon gas as a contributory agent.[58]

Just as cathedral construction had introduced new hazards in the 12th century, bridges and tunnels involved new technologies in the 19th century, and caisson disease became a common and vexing problem.[1] The transcontinental railroad facilitated the development of the western United States. However, Zinn[59] explains that workers pushing rail line through the west in the late 1800s were sometimes attacked by Indians trying to defend ancestral hunting grounds against the inexorable advance of Europeans. A century later, in the mid-1960s, I was conducting ecologic studies in Amazonian Brazil. Upon reaching the end of a road north of Manaus, I learned that after many efforts, the building of roads had been abandoned because hostile "Indians" kept killing road workers. Today, highway construction workers must defend against speeding automobiles, and every year some are killed on road-building tasks.[60]

After reading about this period, I am struck by how many occupational health issues were addressed first in Europe and later in the United States—limitations on child and women's labor hours, for example, workers' compensation, and compensibility of various diseases.[62] Each of these advances took a long time to reach from one country to another. Abrams[16] captures some of the atmosphere of what must have been excruciating battles between labor and management, over details of worker and social protection.

1880s to 1920s

This period begins with the ascendancy of the "Robber Barons" characterized by their aggressive capitalism, exploitation of workers and consolidation of power,[62] leading to antitrust laws and a rise in American socialism. Also, for the first time we can point to occupational medicine practice in the United States.[27] The late 1800s and early 1900s saw the development of occupational medical services in a number of industries. This trend grew slowly at first, mainly in heavy industries with a high risk for serious injury situated in rural area where the services of surgeons were valuable. Details on this growth are provided in a separate paper.[27] Otherwise, industry was slow to recognize the importance of occupational medicine in maintaining a healthy and productive workforce, even after Oliver (1902) described dangerous, dusty, and toxic workplaces in Europe[63] and W. Gilman Thompson (1914) did the same in the United States.[64]

The steel industry affords a case study. Contrast the nearly contemporaneous coverage of United States Steel Corporation by Cotter[31] (1917) and Fitch[65] (1910).

Cotter depicts a beneficent, paternalistic, "corporation with a soul,"[66] emphasizing profit sharing, house loans, and voluntary wage increases. Fitch countered that the profit sharing plan gave industry a clear account of how much wage a worker would defer, which led immediately to wage reductions. Company housing and loans to build houses, tied workers to the company. And the main outcome of the US Steel Monopoly, according to Fitch, was to break the unionization of the steel industry. Without the union, the company had complete control over work conditions and hours, and efforts to reduce the 12-hour workday were effectively thwarted, despite the impact of longer shifts increasing injuries and lowering productivity.[65,67] Conversely, the steel monopoly allowed the corporation to transfer technology, including safety technology, from one factory to another.[66] Interestingly, neither author has much to say about the medical care provided U.S. Steel workers.

As the safety profession emerged, the American Society of Safety Engineers established and held the first national conference on industrial diseases in the United States (1911). Corporations began to employ safety professionals. Analyses of accidents became formalized and there was a strong tendency to blame workers for unsafe acts rather than employers for unsafe conditions.

Thomas Morrison Legge (1863–1932). In England, Sir Thomas Legge (not to be confused with California's Robert Thomas Legge, professor of industrial medicine), became the first medical inspector of factories. Ironically, this followed 20 years after the enabling Factories and Workshop Act was passed in 1878. Among his accomplishments was a treatise on *Lead Poisoning and Lead Absorption*.[68] Legge was one of the drafters of the Geneva white lead convention (1921) recommending the banning of indoor lead paint, but the British government favoring continued use of lead, did not sign the convention, and Legge retired as Senior Medical Inspector of Factories.[13] Legge reported on occupational disease notification, which even today remains a public health challenge.[69] Legge is also known for his work on anthrax—the quintessential occupational infectious disease—then well-known in handlers of animal products. Indeed, one of the important lessons for the future is that occupational medicine specialists rather than communicable disease specialists are most likely to be knowledgeable about anthrax. Legge covered a wide range of industrial ailments including cataracts (glassblowers), skin cancer, liver disease and metal poisoning. He introduced occupational medicine into medical school curriculum.

Occupational Disease in Literature

If medicine of this period was slow to recognize work-related disease, the literary world was not. Writers such as Charles Dickens (1812–1870), George Bernard Shaw (1856–1950), and Upton Sinclair (1878–1968), to name a few, depicted working hazards, worker living conditions, and child labor. Dickens' *Oliver Twist* depicts the induction of young boys into the chimney sweep trade. Most famous (although environmental rather than occupational), perhaps, is Dr Stockman in Henrik Ibsen's (1828–1906) *An Enemy of the People,* whose role as a whistle blower, calling attention to pollution in the city baths, earned him the violent enmity of his fellow townspeople.

Shaw (1894), writing about the risk factors for prostitution in a long-banned play, *Mrs. Warren's Profession*, articulated the connection between poverty and occupational disease. "If on the large social scale we get what we call vice instead of. . . virtue it is simply because we are paying more for it." Mrs. Warren spoke of her sisters . . .

> "Well, what did they get by their respectability? I'll tell you. One of them worked in a whitelead factory twelve hours a day for nine shillings a week until she died of lead poisoning. She only expected to get her hands a little paralyzed; but she died."—Mrs. Warren in *Mrs. Warren's Profession* (G.B. Shaw, 1894).[70]

Alice Hamilton MD (1869–1970). It is hard to put Alice Hamilton into a period, she lived so long, accomplished so much, and remained an active social critic into her nineties. If Ramazzini was the father of occupational medicine, it is perhaps not sexist to call Hamilton' its mother. She was Harvard's first female faculty member, although as Harriet Hardy, her colleague pointed out, she was not allowed to sit with male faculty at graduations. In 1908 Hamilton was appointed to chair a Commission on industrial diseases in Chicago, which led her to write a survey of occupational disease in 1911, and she focused on lead workers particularly.[71] She specialized in toxicologic diseases of workers, producing a volume on Industrial Toxicology,[72] and eventually a compelling memoir *Exploring the Dangerous Trades* (1943).[73] Her explorations were varied, and she brought respectability to field investigations and workplace observations. Although Hamilton was an expert on certain hazards such as lead, it is probably her role as a social reformer, particularly her constant attention to unsafe workplaces, which had the greatest impact.[74]

Hamilton integrated medicine, workplace hygiene, and social context. Her observations on the place of new immigrants in the industrialization of America is timely today and sounds too much like the Greek Xenophon quoted above:

> There was a social stigma to industrial work. Every new wave of immigrants was quickly gobbled up by factories, and to some extent replaced preceding waves. New immigrants were poor, grateful, compliant, and often of limited literacy. Many times in those early days I met men who employed foreign-born labor because it was cheap and submissive—such workers did not rebel against poor working conditions, in a day when "assumption of risk" dictated that workers were responsible for their own health misfortunes.[74] (page 5).

And she was not shy about contrasting American industry with its European counterparts:

> "It is a pity that I cannot recall any instance of help from the organized industrialists to obtain for American workmen the sort of protection provided years ago in European industrial countries." Industry fought social reform in labor, which Hamilton attributed in part to "our instinctive American lawlessness."[74]

Hamilton investigated lead industries, visiting many plants and studying several workforces. Hamilton proposed reducing lead poisoning through shorter hours, higher wages, and control of lead dust and fume. She reported that unionized workers had a lower risk of lead poisoning than unorganized workers.[71] Her study of a Zanesville, Ohio, pottery factory found equal risks for men and women, thereby contradicting a popular belief that women were more susceptible to lead poisoning. Despite her stature as lead expert, Hamilton's work was observational and descriptive rather than experimental. Although she spoke out against the introduction of tetraethyl lead in gasoline, she was challenged to produce data that was not yet available, and which would be entirely under the control of the lead and automotive industry.[22,75,76] In the 1920s medicine was increasing its reliance on scientific studies. This was the period when R.A. Fisher (1925) greatly advanced statistical testing,[77] although it would be several decades before statistics became a routine part of the biomedical literature.

Delayed Recognition of Disease in the United States

By the early 20th century, despite the ups and downs of several depressions, industry was supplanting agriculture as the motor of the American economy. In 1906, Upton Sinclair[78] documented the work in meatpacking plants (although he later lamented that his novel influenced policy regarding food safety, but not worker safety). The United States lagged far behind Europe in studies of toxicology, workplace hazards, and occupational disease.[63,73] Alice Hamilton (see below) emphasized this lag in several chapters, for example, with respect to phossy jaw in the match industry:

> "This episode in the history of industrial disease is very characteristic of our American way of dealing with such matters. We learned about phossy jaw almost as soon as Europe did. The first recognized case was described by Lorinser of Vienna in 1845; the first American case was treated in the Massachusetts General Hospital only six years later, in 1851. But while all over continental Europe and England there was eager discussion of this new disease, many cases were reported and all sorts of preventive measures proposed, practically nothing was published in American medical journals from 1851 to 1909, both laymen and public health authorities contenting themselves with the assurance that all was well in our match industry."[73]

Workers' Compensation insurance started in the United States around 1911, generation after the first laws were introduced in Europe.[61] The pattern of delayed recognition of disease by the U.S. occupational medicine community is recurrent. The use of fritting (fusing lead with glaze constituents) was required in the pottery industry in England by 1903, but American industry did not adopt this until about 1920, after which lead poisoning in the pottery industry greatly decreased. However, Germany had eliminated lead from pottery glazes altogether a generation earlier.[75]

Asbestos disease was obscured for a generation, as major producers Johns Manville Company and Raybestos-Manhattan conspired in the mid-1930s with the trade journal *Asbestos* to keep information on asbestos disease out of the United States (see appendix 1 in Castleman 1996).[79] Likewise, the compensability of byssinosis was recognized in England in 1941 but not in the United States until 1969.

Robert Kehoe (1893–1992). Despite the work of Hamilton, the United States was slow in responding to lead, largely because of the tremendous influence of Robert Kehoe, director of the Kettering Laboratory at the University of Cincinnati, who between 1925 and 1965 was the leading researcher and authority on lead in the United States.[76] Kehoe pioneered toxicokinetic studies of lead in humans and focused attention on clinical manifestations of lead poisoning among workers. He was also medical director of Ethyl Corporation, producer of tetraethyl lead, and in this dual role he maintained that as long as workers were protected from clinical lead poisoning, they need not worry about lower lead levels (less than 80 μg/dL), and society need not worry about lead in the environment. Largely on his authority, objections to introducing lead into gasoline were overcome.

Robert Kehoe realized the alchemists' dream of turning lead into gold (Lloyd Tepper, personal communication), and pioneered industry-academic relationship. His leadership role in American occupational medicine is discussed separately.[27] His occupational medicine residency at Cincinnati was one of the first, but although revered as a teacher, so strong was his personality and industrial support, that his strong but regressive views on lead dominated United States policy for almost a half century. He assumed leadership roles in the American Public Health Association, adding that agency's voice to the "no problem" viewpoint. The multiple roles Kehoe played, create a clear impression of conflicts of interest.

Nriagu[76] and Needleman[22] credit Claire Patterson (1965)[80] as being the first scientist to challenge Kehoe, but it was probably the era of environmental awareness and Senator Muskie's hearings on air pollution which were an essential context for re-focusing attention on health effects of lead. Nonetheless, more than a decade passed before the phasing out of lead from gasoline began, and it was achieved for the purpose of protecting catalytic converters, not for protecting fetal development.

Post-World War I

Decades of prosperity (1920s), deep economic depression (1930s), war (1940s), and postwar recovery (1950s), characterized by unbridled resource exploitation and disregard for the environment, preceded a decade that we call "the sixties," a brief period of environmental awareness and social justice. Social and environmental awareness reached its height in the 1960s, creating the context that the legislation on mine safety, and the occupational safety and health act could be passed.

The 1920s begins with strong unions, postwar industrial growth, and optimism. Class-consciousness was high and socialism was at its peak in the United States. Corporations grew rapidly and many (possibly most) large corporations developed some form of corporate medical departments (discussed in a separate paper).[27] The depression of the 1930s had a profound impact on all aspects of employment. But the Walsh Healey Act of 1936 was a landmark (affecting federal contracts of $10,000 or greater): "No part of such contract will be performed. . . in any plants, factories, buildings, or surroundings, or under working conditions which are hazardous, unsanitary, or dangerous to the health and safety of employees engaged in the performance of said contract." With the industrial expansion of World War II the Walsh-Healey Act gained great importance, although it could not guarantee safe conditions throughout.

The rapid growth of science funding and postwar industrial growth of the 1950s, particularly spurred by Cold War defense spending, saw advances in toxicology,[34] industrial hygiene,[81,82] epidemiology,[83] and risk assessment.[84] Statistics, once arcane, became the mainstay of the biomedical literature, and the $P < 0.05$ criterion emerged, probably inappropriately, as a cornerstone of hypothesis testing. Occupational medicine began to benefit from evidence-based information derived from epidemiologic studies. A landmark advance in epidemiology was the publication of Sir Austin Bradford-Hill's paper on establishing causation. Often overlooked is that this was presented first to an occupational medicine meeting.[85] Although industrial medicine was marginal in the grand scheme of American medicine, occupational physicians and colleagues in nursing and industrial hygiene, conducted a variety of research, and even by 1957 Felton was able to identify 85 books that dealt with occupational health or disease,[86] which he considered a sign of a thriving discipline.

Occupational Safety and Health Act (OSHA; 1970). The OSH Act legislation was a landmark, or at least a watershed, in our history. It provided a federal standard for health and safety. Although last minute changes, allowed states to keep their own plans and staffs if they chose, the Act nonetheless recognized the responsibility of employers to provide a safe and healthful workplace insofar as possible. Establishing OSHA and NIOSH were important, although they have been subject to political shifts in the ensuing decades.[87] The strengths and weaknesses of the Act and of the agencies themselves, has been the subject of several books, and as I wind down my chronology, I have chosen to defer to others on this crucial topic.[88]

Selected Figures of the Mid 20th Century

By the mid-1900s there are simply too many outstanding contributors to discuss, and even listing their names would inevitably slight some. I mention five who played key roles in advancing knowledge and apologize to many others slighted in view of time or space.

Wilhelm C. Hueper (?-1979). Wilhelm C. Hueper MD was a dominant and controversial figure in occupational toxicology in the mid-20th century. His 1942 volume on *Occupational Tumors and Allied Diseases*[89] ran to 896 pages, covering an incredible range of topics with many modern concepts including thresholds, latency, susceptibility, and interactions. Prevalence rates in an industry are compared to background rates (albeit without benefit of *P* values). This uni-authored reference work is breathtaking and sobering, documenting how much was already known before World War II, while illustrating the gaps (twice as much text devoted to skin cancer than to respiratory cancer).

As a departure he recognize the importance of chronic disease: "The situation existing. . . is less alarming with regard to the acute industrial poisonings than to the chronic poisonings. . . "; Hueper's own studies in pathology of occupational disease extend back into the 1920s in Germany and continued in the United States, with a spurt of activity on occupational carcinogenesis in the 1940s and 1950s. He published extensively on environmental carcinogenesis, and he provided a critical review of issues of causation. Hueper believed that the aplastic anemia seen in benzol workers represented marrow depression, whereas leukemia represented at least a transitory hyperplastic response. He cites many case reports linking benzene with leukemia, long before this cause was considered "established." Twenty years later Hueper (then "Chief of the Environmental Cancer Section of the National Cancer Institute) published *Chemical carcinogenesis and Cancers* (1964).[90]

Although, he was involved in a broad range of carcinogenesis issues, including diethylstilbestrol on the one hand and uranium mining and lung cancer on the other, Hueper probably made his greatest contribution to studies of bladder cancer,[91] the type of cancer most consistently linked with chemical exposures. The culmination of Hueper's career was a magnum opus on *Occupational and Environmental Cancers of the Urinary System* (1969).[92] He was among the first to recognize that bladder cancer was a final common pathway for a large variety of chemicals.

While Hueper was focusing attention on asbestos and coal tar, he erred in attacking the notion that tobacco was a major public health problem and argued that it was a minor contributor to occupational diseases. This was long before Irving Selikoff produced the evidence linking smoking and asbestos as synergistic causes of lung cancer.

Hueper was viewed as a troublemaker and whistle blower and was passed over for head of his Division at the National Cancer Institute. He received a variety of awards, including Society for Occupational and Environmental Health[93] and the NIH Director's Award.[94] As statistical epidemiology emerged in the 1950s, Hueper cautioned about its limitations; negative studies were particularly worrisome to him.[95]

Harriet L. Hardy (1906–1993). While working as college physician at Radcliffe, Hardy began an association with the famous lead researcher Joseph Aub, who subsequently suggested she fill a vacant position at the Massachusetts Department of Labor. There she inherited Dr Irving Tabershaw's studies of "Salem sarcoid" in the fluorescent lamp industry, which lead to her long-term involvement with beryllium.[96,97] This recognition was probably instrumental in her collaboration with Alice Hamilton on a revision of Hamilton's toxicology text, and *Industrial Toxicology* by Hamilton and Hardy became a widely used text for the next generation and continues now in its 5th edition with little competition.[98]

Thomas F. Mancuso (1912–2004). Mancuso's death in 2004 invites another volume of comparable papers. He was for a half century a leading light in occupational epidemiology.[99] In the 1950s Mancuso published a series of papers emphasizing the toxicologic effects of chemicals such as cadmium, manganese, mercury, and hydrogen sulfide among others. Following almost immediately on Lars Friberg's report of cadmium and cancer,[100] Mancuso and Hueper[101] published epidemiologic evidence of chromium and cancer in American industry, work that he updated and summarized as recently as 1997.[102] Mancuso pioneered cohort occupational studies, and published important papers on asbestos,[103] including demonstrating the potency of chrysotile causing mesothelioma.[104] The Atomic Energy Commission asked him to study health of its nuclear workers, but withdrew funding when Mancuso proposed a long-term study, which eventually demonstrated that Hanford nuclear workers developed disease at radiation levels that were then considered safe.[105] Mancuso played an important role in examining the methodology of workplace health studies, identifying new ways of using national data bases such as social security disability data.[106]

Leonard J. Goldwater (1903–1990). Goldwater began his professional work in New York where he did pioneering studies on hematologic responses of workers to benzene. He was an accomplished historian,[72] interested in the social dimensions of occupational health, and published a number of studies of comparative systems. As early as 1941, Goldwater observed that an absolute lymphocytopenia was a relatively frequent and early manifestation of benzene hematotoxicity.[107] In 1959 he summarized a database on cardiac classification which became valuable for assessing worker fitness.[108] When he joined the faculty at Columbia in 1960 as founder of the Division of Environmental Health Sciences, he began a series of experimental studies of mercury and an extensive study of mercury exposure and effects in a variety of populations, including dentists resulting in 15 papers on mercury toxicokinetics. Upon his "retirement" from Columbia in 1968, he joined the faculty at Duke where he remained active as a teacher until his death in 1990. He was a consistent advocate of science-based and data-based policy and regulation and conversely his papers are rich in data.[109]

Irving J. Selikoff (1915–1992). Selikoff was already a leading figure in the field of tuberculosis for his contribution to the discovery of isoniazid, when he began examining workers exposed to asbestos in the 1950s. In the ensuring four decades, Selikoff and his colleagues produced an extensive body of work, documenting the high rates of asbestos-related diseases, in a variety of occupations.[110] His observations of asbestos fallout, during construction activities in Manhattan, led New York to ban the use of sprayed-on asbestos. His study of insulation workers called attention to the synergism of smoking and asbestos, which remains today one of the best examples of a multiplicative interaction.[111] He is best known for his untiring efforts to call attention to the hazards of asbestos, linking epidemiology, pathology, and clinical exposure assessment, and cautioning about risk assessment.[112] He assembled at Mt. Sinai, a team of researchers with diverse talents to document the seriousness of asbestos.[113] His mortality study of the insulation industry showed that about 10% died from asbestosis, 20% from lung cancer, and 10% from mesothelioma and cancers of the digestive tract.[114] Even the most hazardous occupations—-mining, construction, police and fire, or the military, fall short of imposing a 40% mortality rate on their workforce. But his horizons were broad and he wrote extensively on epidemiology,[115] for example on the limitations of death certificate research.[116] Selikoff's contribution to occupational medicine extend far beyond the literature. He was highly regarded as a teacher. Selikoff founded the Division of Environmental Medicine at Mt. Sinai Medical School, and established an occupational medicine residency, which has produced many leaders of the field. He was one of the founders of the Collegium Ramazzini, an international body that links science and policy to protect worker health and the environment.

Jean Spencer Felton (1911–2003). Felton's life has been recently summarized in an obituary by LaDou,[117] and in this space I only recognize his major contributions to the history of our field and its teaching. He was an academic (both at Oklahoma and the University of California) and a practitioner (at Oak Ridge National Laboratory, at U.S. Naval Hospital, and as Director of Occupational Health Services of Los Angeles). Felton identified the history of occupational health as one of his special interests and it is entirely appropriate that he wrote the introduction to the latest reprint of Alice Hamiltons's autobiography.[118] He was a prolific writer, and chose interesting topics, for example, his paper on Benjamin Franklin's work on lead poisoning.[119]

Discussion

Having immersed myself for several months in historical literature, I can only lament the many threads that I have ignored in reading due to time or omitted in writing due to space. And I have consciously stepped aside from many of the important issues in the epidemiologic aspects of occupational medicine from which cometh our strength. Whole books could be devoted to occupational epidemiology, apart from the methodologic issues.[83,120] Of particular concern has been the difficulty of achieving adequate power, or setting to high a bar for establishing associations. Workplace clusters, whether three cases of angiosarcoma in a Kentucky plant[24] or 300 bladder cancer cases in a New Jersey plant[121] have been very informative.

My case studies of asbestos, lead, coal, benzene, solvents, carcinogens, have to be presented separately. I continue to be fascinated by miners, perhaps because New Jersey no longer supports a mining industry, but more likely because of all that was written 2000 years ago, and the fights that nonetheless continued into the late 1900's.[122] Shift work[123] and duration of work vis-à-vis productivity, will be addressed separately.

Child labor continues to be a problem that occupational physicians can address. Women in the workplace and reproductive and family rights have posed issues ranging from New Jersey's radium dial painters[124] and World War II Rosie the Riveter to the recent increased role in all economic sectors.[125,126] The history of protective discrimination leading up to the U.S. Supreme Court's Johnson Controls decision bears a chapter of its own.

Future of Occupational Medicine

Although occupational medicine, one of the tiniest specialties in all of medicine, struggles for recognition, there is a debate over whether it has a future—whether this struggle for recognition is even worthwhile.[7,127,128] We struggle with a conflicted history. For many years there was a stigma attached to physicians working in industry on a salaried basis and conflicts of interest prevail (see companion paper).[27]

As a clinical discipline, occupational medicine, offers the opportunity to discover and document diseases related to work, a tradition that must be continued and enhanced.[129] As an epidemiological discipline, occupational medicine has the tools to explore the changing relation between work and disease. For most of its development, occupational medicine has been behind the times, forced to do retrospective exposure assessments, because new hazards were not anticipated. Industrial hygienists have included "anticipation" as one of their principles, so occupational medicine should move forward with the same attitude of anticipation.

Lessons learned from this chronology are straightforward. Although there is a tendency to believe that major occupational diseases have been conquered because their cause is known, this is illusory; exposures and disease still occur. Moreover, new technologies pose new hazards, while changes in the organization of work and the demography of workforces provide new receptors, maintaining a fertile ground for our discipline. And if our future is uncertain in North America and Europe, what can we expect in the rapidly industrializing "developing nations," which are accumulating factories without the accompanying regulatory or professional infrastructure.[130] Technology transfer may be proceeding at a rapid rate, and transfer of knowledge in occupational and environmental health and safety needs to keep pace. Vested interests can be expected to retard the acquisition of new knowledge and its translation into policy. Protecting workers will be difficult where labor is cheap and life is cheapened. Ethical issues continue to lie at the center of occupational medicine practice and several volumes have addressed these problems and challenges.[131,132] I have not undertaken to duplicate these.

Occupational physicians must develop an international perspective.[133] This may not be necessary when treating walk-ins in a clinic, but is a basis for understanding what is happening to work itself. As unbridled population growth continues in the poorer nations there will be a surplus of labor, lack of job security, and employers will continue to take advantage of disposable workers. Population growth has long been linked to poverty,[134] both because of limited land and food resources and because of unemployment and low wages. Exploitation by multinational corporations will not necessarily improve their lot.[17] There are some bright lights. My colleagues in some corporations have advocated successfully that their corporation maintain the same protections for its overseas workers as it does for its expatriate American workers. This is welcome news. Yet, I am reminded of a Swiss pharmaceutical company whose New Jersey plant destencilled the skull and crossbones from chemical drums before they were transferred to the factory floor. American workers were treated as third-world workers.

Overpopulation contributes to the expanding authority of multinational corporations, the International Monetary Fund, the World Trade Organization, and other influences which impede progress in workplace health and safety. These agencies can also slow or confuse the gathering of scientific information on causation. It has happened before—often. Faced by these forces, it is no surprise that use of the Precautionary Principle must play an increasing role in protecting health and the environment.

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