

Dental Caries in the Second Millennium

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Abstract: This historical review of dental caries diagnosis and management is based on information obtained from reports published between 1839 and 1965 and forty textbooks on caries diagnosis and management published since the nineteenth century. The history of understanding of any disease or condition in humans has passed through two distinct eras. The first, which lasted until the twentieth century and may still be ongoing today, is the “observational” era. The second, which has developed and revolutionized our understanding of the causes and treatments of all diseases, is the “scientific” era. During the observational era, treatments of oral or dental problems were based on neither biological nor scientific principles. Rather, experimentation without validation was, and to a lesser extent during the last fifty years is still, common. In terms of disease management, dental practice is still in the gray years of the “restorative era” and in the midst of the “preventive era” where the emphasis would soon shift towards early detection of biological markers of diseases and prevention of their initiation and progression. This review has found that most contemporary questions on caries diagnosis and management have been debated since the middle of the nineteenth century. There is a need for a comprehensive research program to provide scientifically based information to assist dental practitioners in caries detection, diagnosis, and management.

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This paper focuses on the history of dental caries with an emphasis on relevant developments in the second millennium. It provides a brief historical overview of important events, concepts, and scientific developments that have shaped our current understanding of one of the most common diseases in humans. In writing this paper we have focused on issues that are relevant to the agenda of the Consensus Development Conference on Dental Caries Diagnosis and Management Throughout Life. This historical review was not planned to be exhaustive; rather it provides a selective glimpse of the key findings related to the diagnosis, etiology, and management of dental caries.

In this paper, we will refer to findings from the pre-restorative and the restorative eras. During the pre-restorative era, although simple and crude restorative care was available, dental caries was mainly managed through either extraction of decayed teeth or resignation (individuals with carious teeth just tolerated and lived with tooth decay and its sequelae). We have estimated this period lasted until the 1850s, even though we understand that any firm time division is artificial. In the middle of the nineteenth century, the restorative era began during the second industrial revolution. It is also around that time that major advances in understand-

ing the biology and pathology of diseases in humans started to emerge.

Additionally, in the text of this paper, we have used the term the “observational era” to refer to a period of our history when healers observed diseases and their progress without using the scientific method to study and test hypotheses. By contrast, we refer in the text to the “scientific era,” when observations, theories, and hypotheses were tested using systematic methods. It is during this period, or the last 150 years of human history, that the knowledge base on causes and treatment of most diseases has rapidly advanced. The scientific era has had the most significant impact on the quality of life and on health of humans.

Pre-Restorative Era (up to 1850 A.D.)

While dentistry is a young profession that emerged in the mid-nineteenth century as a separate discipline that focused on treatment of diseases of teeth and their supporting tissues, dental and oral health problems have afflicted humans throughout history. Writings of Egyptians, Mesopotamians, Israelites, Indians,

Chinese, Greeks, Romans, Aztecs, Mayans, Incas, and Arabs have documented accounts of dental and oral problems and their treatments.^{1,2} In the pre-restorative era, many observations were made about the causes of dental caries; however, the understanding of dental caries and its causes and treatment did not advance much until the eighteenth century. The first full text on dental diseases and their treatment was published in 1728 when Pierre Fauchard, a French surgeon, wrote “Le Chirurgien Dentiste.” Fauchard rejected the toothworm theory of dental caries. Instead, he described enamel hypoplasia as “an erosion of the enamel”² and recommended that hypoplastic areas be smoothed using files. Fauchard recommended total excavation of carious cavities and filling them with lead, tin, or gold foil.

Until the eighteenth century, dental treatment was rather simple and was based on extraction of teeth, use of traditional remedies, or, as mentioned before, resignation (giving up). With the beginning of the second industrial revolution in 1875 (including the advent of the telegraph, transatlantic cable, telephone, incandescent light bulb, diesel engine, wireless communication, and airplane flight), dentistry was on the verge of experiencing a new revolution that focused on conserving teeth rather than extracting them.

The Restorative Era: 1850–Present

With the start of the second industrial revolution, significant economic and social changes took place in Europe and the United States. The dispersion of wealth and the creation of a class of middle-income working families in large cities created demands for restoring rather than extracting teeth.

Late in the nineteenth century, dentists were faced with an increasing demand to conserve teeth from the ravages of dental caries. Amalgam was first used in Europe, but in 1855, Drs. W. M. Hunter and E. Townsend in the United States published a formula of amalgam that consisted of tin, silver, and mercury.² While amalgam was initially criticized because of its mercury content and poor physical properties, it had improved to become the material of choice by the end of the nineteenth century.

In 1883, a battery-powered electric dental engine was developed. The mechanical improvement continued to ease the practice of dentistry with the introduction of faster dental engines and handpieces during the late nineteenth century.

These developments in technology, however, were not associated with advancement in knowledge of the diagnosis, etiology, and management of dental caries. This task was left to the pioneering works of Tomes, Webb, Black, and Miller, among others.²⁻⁴

Etiology of Dental Caries

Dental caries is a complex disease, the “cause” of which has received significant research attention during the nineteenth and most of the twentieth centuries. During the observational era, different causes were associated with dental caries. The dominant theory at the beginning of the scientific era, in the middle of the nineteenth century, was the “worm theory.”⁵ At the International Medical Congress held in London in 1881, Drs. Miles and Underwood proposed that dental caries development was dependent on the presence and proliferation of “organisms.” They claimed that dental caries was caused by direct action of microorganisms that penetrated the dental tubules and destroyed the organic component of the dentin leaving the inorganic parts to be broken down and washed away in fluids of the mouth.^{3,6-7}

In 1881, Dr. W. D. Miller presented the results of his experiments.⁸ Miller’s studies found that acid produced by microorganisms in the mouth caused caries of the enamel, and caries in dentin resulted from acidic decalcification. Bacteria produced the acids that led to the demineralization of enamel and dentin. He also noted that bacteria did not need to be present in enamel or dentin to initiate demineralization. Miller’s research led to a storm of debate and controversy.⁸

Following the dissemination of Miller’s findings, dietary and nutritional factors received extensive study for most of the last 150 years. Again, much of what was reported was based on observations such as those related to the physical and chemical characteristics of diet or nutrients,⁹⁻¹¹ changes in the environment surrounding teeth such as saliva and microorganisms,¹²⁻¹⁷ or changes in the structure of teeth.^{20,21} By the mid-1920s, it seems that the environmentalists won over those who argued that the structure of teeth play a major role in the caries process.²² The nutrition-caries hypothesis was partially discredited by the finding that populations who were malnourished had lower caries prevalence than those who were well nourished.²³ Also discrediting that hypothesis were findings from the pivotal and undoubtedly one of the most unethical studies ever reported in the dental literature, the Vipeholm Dental Caries Study, which found that frequent consumption of sugar increases the risk of developing dental caries.²⁴

Throughout the twentieth century, many researchers and dentists recognized that dental caries is a product of the interplay of many factors.^{25,26} In his article on “dental caries redefined,” Dr. Keyes explained the interplay between the local cariogenic bacteria in plaque, fermentable carbohydrates, “constitutional factors” related to “species and strains,” and the tooth structure.²⁶ The work of Drs. Keyes and Fitzgerald proved that dental caries is an “infectious process” of the teeth.^{27,28} Their work led to the definition of dental caries as multifactorial disease with an interplay of three principal factors: the host, the microflora, and diet. This model was proposed before²⁹ is still valid today, even though we may know more about the biological determinants and interactions among the different factors.³⁰

Definition and Diagnosis of Dental Caries

By 1880, dental caries was defined as a “disintegration of the tooth substance, molecule by molecule”³¹ and a disease that was caused by the fermentation of “foods” inside the mouth.³ Dental caries was recognized as a process that always starts on the surface of teeth, progresses slowly towards dentin, and progresses more rapidly in dentin than in enamel.³¹ It also was observed that decay is not found on tooth surfaces that are “smooth and constantly worn by attrition or mastication.”³¹

The detection of a carious lesion deep into dentin in teeth that had either no evidence of caries when examined clinically or only had a small “pin-hole cavity”³² led to the development of the theory that caries can be initiated inside the tooth structure. The problem of “hidden caries” seems to have been noticed as early as 1868.³³ By the 1880s, dental caries was recognized as a process that may show as “decalcification” or caries in the enamel.^{34,35} G. V. Black in an analysis of the field of caries diagnosis in 1910 concluded that caries in enamel, or early caries, “appears in the teeth of patients . . . from day to day” and these lesions were usually found in pits and fissures of occlusal surfaces, proximal and labial and buccal tooth surfaces. He contended that “the whole subject of caries of the enamel is the most important one in its relation to everyday practice.”³⁴ At the 1948 consensus conference, dental caries was defined as

. . . a disease of the calcified tissues of the teeth. It is caused by acids resulting from the action of microorganisms on carbohydrates,

is characterized by a decalcification of the inorganic portion and is accompanied or followed by a disintegration of the organic substance of the tooth. The lesions of the disease predominantly occur in particular regions of the tooth, and their type is determined by the morphologic nature of the tissue in which they appear.³⁶

Unfortunately, most operative dentistry textbooks published in the twentieth century have emphasized the detection-treatment decisions rather than diagnosis of the carious process.^{37,38} Even in the year 2000, some dental “experts” have failed to recognize the phenomenon of early carious lesions and advocated the immediate restoration of such lesions.³⁹ Neither the reimbursement system for dentists nor the evaluation systems of dental students have recognized the detection and remineralization of enamel lesions as activities that dentists or dental students should be rewarded for doing.

Arrested caries was described in 1880^{31,40} and in the early part of the twentieth century.⁴¹ Recommendations to arrest or cure dental caries via cleaning to remove bacteria had been made in 1909.⁴²

The condition we now call “early childhood caries” was described at least by 1884 as the “labial decay of childhood.”⁴³ The condition started on the enamel of the labial and buccal tooth surfaces and a green or brown stain usually preceded it. In 1912, Harries coined the term “comforter caries” based upon his observations of children who had otitis media and used “comforters” or “pacifiers.”⁴⁴

The variation among dentists in diagnosing dental caries is not a new phenomenon. A dentist reported the problem in 1869.⁴⁵ The variability of diagnosis among dentists was also noted in 1941 in a study that included eight dentists “all of whom had years of clinical experience and who were considered careful investigators” who examined thirty-three individuals. Agreement was achieved on the number of carious lesions in only one patient.⁴⁶

Preventive Management

As described earlier, many interventions were suggested based upon observations that had not been rigorously evaluated. One of the most scientifically untested slogans in dentistry has been and still is, to some extent, the concept of “extension for prevention.” Dr. M. H. Webb proposed this concept more than one hundred years ago.⁴⁷ Despite the lack of scientific documentation supporting the concept of extension for pre-

vention,⁴⁸ its liberal use in cavity preparation continued for most of the twentieth century.

Around the time of Miller's death in 1907, a young dentist unknowingly ignited a new revolution through his keen observations in preventive dentistry. Dr. F. S. McKay, who was practicing in Colorado Springs, Colorado, noticed that many of his patients had "mottled enamel." He pinpointed the problem, after several field investigations, as related to the drinking water. In 1930, H.V. Churchill,⁴⁹ a chemist with the Aluminum Company of America, discovered that fluoride may be the cause for the enamel mottling, the condition that we now refer to as "fluorosis."

In 1931, Dr. H. T. Dean was assigned by the United States Public Health Service to study the association between fluoride and "mottled enamel," which led to associating fluoride with reduced dental caries prevalence and severity.⁵⁰ Dean led a series of field investigations that confirmed the association between fluoride in the drinking water and fluorosis and the potential beneficial effect of fluoride in caries prevention.^{51,52} In a classic research program, it was found that adjusting the fluoride concentration to around 1.0 ppm (parts per million) could lead to a significant reduction in dental caries prevalence and severity in children with minimal cosmetic side effects.⁵³

From the early 1960s through the late 1970s, the "Halcyon Days"⁵⁴ of fluoride research took place in the United States and other parts of the world.⁵⁵⁻⁶⁷ While the mechanism of action of fluoride as a cariostatic agent is still being debated, there is strong evidence that fluoride, provided systemically in drinking water or applied topically through exposure to fluoridated water, toothbrushing, or other means, is effective in reducing the burden of dental caries.⁵⁶⁻⁷⁹ By the 1950s, topical applications of fluoride were widely provided by dentists in the United States.⁵⁵

Although fluoride is effective in preventing caries on all tooth surfaces, occlusal surfaces remain the most vulnerable to caries attack. A major breakthrough in resolving this problem came when it was discovered that creating small tags or roughness on the enamel surface by the application of a weak acid (phosphoric acid) significantly enhanced the retention of an acrylic filling material.⁸⁰ This discovery led to a series of research initiatives on acid etching, adhesion, and sealant materials for preventing dental caries in pits and fissures.⁸¹

During the twentieth century, other approaches to prevent dental caries have been proposed and tested. In the early 1940s, it was evident that patients who are caries-active frequently consume sugar-containing drinks or foods.⁸² However, attempts to reduce the frequency or amount of consumption of sugary foods and

drinks were not successful when pursued by dentists or in community settings.^{83,84} In 1945, a paper was published on the reduced fermentation of sorbitol in saliva and the potential use of this natural sugar as a substitute for sucrose (sugar),⁸⁵ and an experiment conducted in 1956 confirmed this finding.⁸⁶ Research to find alternative sweeteners led to the testing of xylitol in clinical trials in Turku, Finland,⁸⁷ and of adding xylitol to chewing gum.⁸⁸

Restorative Decision-Making

For most of the nineteenth and twentieth centuries, dental caries was managed through removal of demineralized enamel or dentin and placing synthetic materials to restore anatomical form, function, and esthetics. In addition to the technological advances in anesthesia and tissue-cutting instruments and devices (handpieces), the field of restorative dentistry has benefited significantly from the revolutionary advances in new dental materials and the invention of the dental air turbine handpiece in 1946.² These advances have led to the provision of sophisticated restorative care and, consequently, the saving of teeth. However, failure to deal with the problem of diagnosis and clinical decision-making may have led to overrestoration as well as underrestoration of decayed teeth.^{89,90}

The attempt to deal conservatively with dental caries seems to have picked up momentum in the last ten years of the twentieth century with the advent of new materials and tools. The third edition of a major textbook of operative dentistry included a detailed chapter on caries diagnosis.⁹¹ The most common practice today is still the complete removal of all soft decayed tissue regardless of the level of infection and histological destruction. A number of studies that have tested the outcomes of sealing-in dental caries, even when it is in dentin, have documented successful outcomes.^{92,93} There have been calls for changing the paradigm from "drilling and filling" to managing the disease as an infection.^{94,95}

Today and the Future

Looking at our progress throughout the second millennium, we have achieved unprecedented successes using the scientific method to improve not only the understanding of the caries process but also its prevention and treatment. The technical capabilities of the dental care system have dramatically improved during the last fifty years. Scientific research has been the most

important tool that has advanced our knowledge and reduced the burden of dental caries in the United States and other countries. In the twenty-first century, we need to re-establish new research programs on dental caries. These programs should be focused on resolving the problems described in the Surgeon General's first report on oral health.⁹⁶ Recent advances in biology and engineering should open new doors for the prevention and management of dental caries and, most importantly, a better understanding of the etiology of the disease. These new research programs should develop new methods that can validly and reliably assess the caries activity in enamel and dentin. Advances in MicroElectroMechanical Systems (MEMS), nanotechnology, sub-micron fiber-optic biochemical sensors, energy transducer supermolecules (artificial photosynthetic antennae), and in-vivo nanosensors open the door for new research initiatives to develop novel approaches to diagnose and prevent dental caries. Advances in tissue regeneration may open the door for new methods to restore damaged (or decayed) tooth structure.

Research provides solutions to the future; today, however, we need to deal with current realities. Although we have reached a relatively high degree of excellence in restoring teeth, placing high-quality restorations in teeth that should not have been surgically cut and restored represents the lowest overall standard of care. We must focus on resolving the current diagnostic dilemmas and develop protocols to reduce the chances of false positive or negative decisions. Our disregard for the complex issues of detection, diagnosis, and decision-making in teaching and practice must be corrected.

The plea of G. V. Black, made in 1909, to study and understand early carious lesions (in enamel) should receive our utmost attention.⁵ We need to shift our focus from defining dental caries as "cavities" to detecting the stages of the caries process, as Magitot recommended in 1886.³⁴ To achieve this goal, we need to reward dentists for keeping teeth healthy and arresting or reversing early carious lesions.

In prevention, dentistry has not developed any new innovations to prevent dental caries during the last fifty years. Fluoride is not the only solution; neither are dental sealants. For these two interventions and others like xylitol or anti-microbial agents, there is a need to develop protocols to define appropriate uses in clinical practices.

Finally, we need to reconsider the warnings from Gies^{25,97,98} and G.V. Black⁵ early in the twentieth century that the dental profession must not develop its technological base at the expense of its biological foundation. Prevention and treatment of dental caries, a major oral health problem in the United States,⁹⁶ should be

based on scientifically validated information. This goal should be a major focus of the dental community in the twenty-first century.

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