TRACE ELEMENTS AND DENTAL DISEASE

M.E.J. Curzon
T.W. Cutress

Postgraduate Dental Handbook

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FOREWORD

During the past decade there has been a gratifying increase in demand for new knowledge in the art and science of dentistry on the part of practitioners of dentistry and dental specialists. The biological and dental sciences are currently in a period of rather explosive growth. Stimulated by the diversification of experimental methods and dental procedures, the basic dental sciences with clinical applications and clinical dentistry are growing particularly fast.

Dental sciences are currently considered as multidimensional, and individual differences are rather great. Dental scientists and practitioners know that the adaptation of techniques from other fields of science is not simple, usually indirect, and unusable unless radically revised, extended or reformulated for use in dentistry. The basic experimental method originating in the clinical dental sciences may now be joined by the methods of the biological and physical sciences and made technically feasible by the introduction of modern electronics and computers.

It is the goal of the Postgraduate Dental Handbook Series to present critical analyses based on impressive clinical and research experience. This dental series provides basic dental sciences with clinical applications and clinical dental sciences in a correlated fashion. It likewise describes current concepts in clinical dentistry that are of direct value to dental practitioners, dental specialists, dental students and dental hygienists throughout the world. By bringing together all our knowledge, the volumes in the Postgraduate Dental Handbook Series will fill a critical need felt by dental clinicians and dental investigators alike.

Dr. M.E.J. Curzon, Chairman of the Department of Caries Research, Eastman Dental Center, Rochester, New York and Dr. T.W. Cutress, Director of the Dental Unit, New Zealand Medical Research Council, Wellington, New Zealand, present a unique work on *Trace Elements and Dental Disease* for the Postgraduate Dental Handbook Series. This book is the first review and evaluation to describe all of the available information known on trace elements and dental disease. This work, therefore, is extremely useful for all dentists, dental researchers, and allied health professionals (animal husbandry, agriculture, and the broad field of medical research).

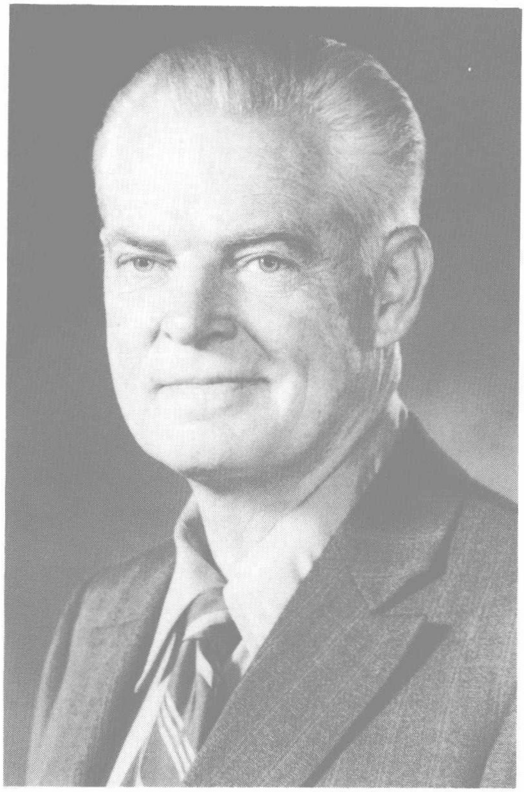
The purpose of this book is to help professionals involved in treating dental disease and, in the interest of optimal dental care, to gain a more global and comprehensive view of the subject of dental caries. Recognizing the present need for better understanding among dental practitioners, the authors and their contributors are internationally recognized authorities who present this subject in a comprehensive manner. The result is an amalgamation of thought from all areas of the world. These contributing authorities offer guidance in a practical and stimulating manner. Treatment recommendations have been developed by a systematic process of considering every possibility and weighing the advantages and disadvantages of each to arrive at the best treatment plan for the dental patient.

This work differs from all prior undertakings concerned with dental disease. It does not present a series of minireports of research, nor does it overemphasize the biochemical, endocrinologic or technical matters. Rather, this book presents multiple points of view, disciplines, and a body of clinical and laboratory experience which constititute a course in dental caries that encompasses the relevant clinical and basic sciences. *Trace Elements and Dental Disease* provides the dental clinician with most of today's proven answers. A student of dental disease should find an up-to-date exposition, organized to provide a knowledge base to build upon for future work, or a yardstick with which to fit and assess contemporary or past works.

I wish to thank the coauthors and each contributor for assembling his entry in such an excellent manner. Its contents should still be useful a decade from today, which characterizes the contributors and authors and sets this book apart from its predecessors. The reader will find this work a useful blend of techniques and approaches to what has been an often difficult problem for the dental practitioner.

Alvin F. Gardner, Series Editor

PREFACE



In 1950, Fred Losee carried out a dental survey of caries prevalence in American Samoa. His findings led him to the conclusion that among other factors affecting caries was the influence of trace elements, originating in seawater, sea salt, or both. This work started Fred in the field of dental research, which was to occupy him for the rest of his career. By the time of his retirement in 1973, Fred Losee had accumulated a great deal of knowledge about the effects of trace elements on dental caries, and in 1974 he began writing a book on the subject. Unfortunately, with his untimely death in November 1975, the book remained only as a series of notes and outlines, together with a commitment for collaboration by the present editors.

Because of the importance of the subject, and the lack of a review on trace elements, we have produced the present book. In addition to providing for the first time under one cover the present knowledge on trace elements and dental disease, it is also a tribute to Fred Losee to commemorate his own research and his influence on many scientists.

CONTENTS

PART I
Background and Epidemiologic Effects of Trace Elements on Dental Caries

1 Introduction

M. E. J. Curzon

From the discovery of iron and then iodine, as elements essential to life, the study of trace elements and disease has developed into an extensive field of research. It is a measure of the interest in the subject that from 1820 to 1940 the trace elements iron, iodine, copper, manganese, zinc, and cobalt were proven to be essential to life, but between 1940 and 1974 the elements molybdenum, selenium, chromium, tin, vanadium, fluorine, silicon, nickel, and others were added to the list (Schwarz, 1974). This rapid increase in our knowledge has been largely a result of much better analytic techniques with low limits of detection that enable detailed work to be done on the role or potential role of trace elements on human health.

Trace elements are variously defined depending upon the field of chemical, physical, or biologic sciences being discussed. In the field of biology, elements that are present in only minute quantities in animal tissues are called trace elements, regardless of their abundance in nature. Thus, to biologists silicon and fluorine, among the most plentiful of the elements in the earth's crust and, therefore, major elements to geologists, are "trace elements." Those trace elements that are essential for life are further characterized as microminerals or nutrients and include such elements as copper, cobalt, iron, fluorine, manganese, molybdenum, selenium, silicon, tin, vanadium, and zinc (Schwarz, 1974). There are many remaining elements for which no specific function has as yet been identified and which are also known as trace elements. Some of these may yet be shown to be essential to life.

An essential element has been defined as one required by an animal for normal development and growth. Such elements are essential nutrients because they must be ingested. Macro (major) and micro (trace) nutrients have been identified. The macro elements essential for life have long been known and are required as constituents of proteins, cell walls, and structural tissues, and they also play a part in complex biochemical reactions. Within this category are phosphorus, nitrogen, and calcium—elements required in large quantities.

However, micro elements exert their influence at very low concentrations, their role being primarily catalytic, rather than being building blocks. The elements present in animals, often in minute amounts, perform functions essential for the maintenance of healthy life, growth, and reproduction. Inadequate intake of these nutrients may impair health at the physiologic or cellular level.

The actual concentrations of elements found in different tissues are, for the "inactive" elements, probably dependent on the environmental availability of the respective elements. However, the concentrations of at least some of the essential elements are dependent on specific homeostatic mechanisms; a few elements, the heavy metals in particular (lead, mercury, arsenic, cadmium), tend to accumulate within the body and produce toxic effects. It is interesting to consider the suggestion (Schwarz, 1974) that the nutritional requirements for the essential elements correspond more closely to the concentration of the elements in seawater than in the earth's crust. Some reference is made to this in the chapter on enamel, and a list of the abundance of various elements in seawater and the earth's crust is presented.

In this review we have elected to classify the 90 naturally occurring elements, first, according to their known essentiality in human and animal life and, second, to their role as a major or minor element, rare inactive elements, very rare elements, or toxic minor elements. This arbitrary classification is seen in Figure 1-1.

For the purposes of this text trace elements are defined as all the naturally occurring elements of the periodic table excluding the major components of hydroxyapatite—calcium, phosphorus, oxygen, and hydrogen.

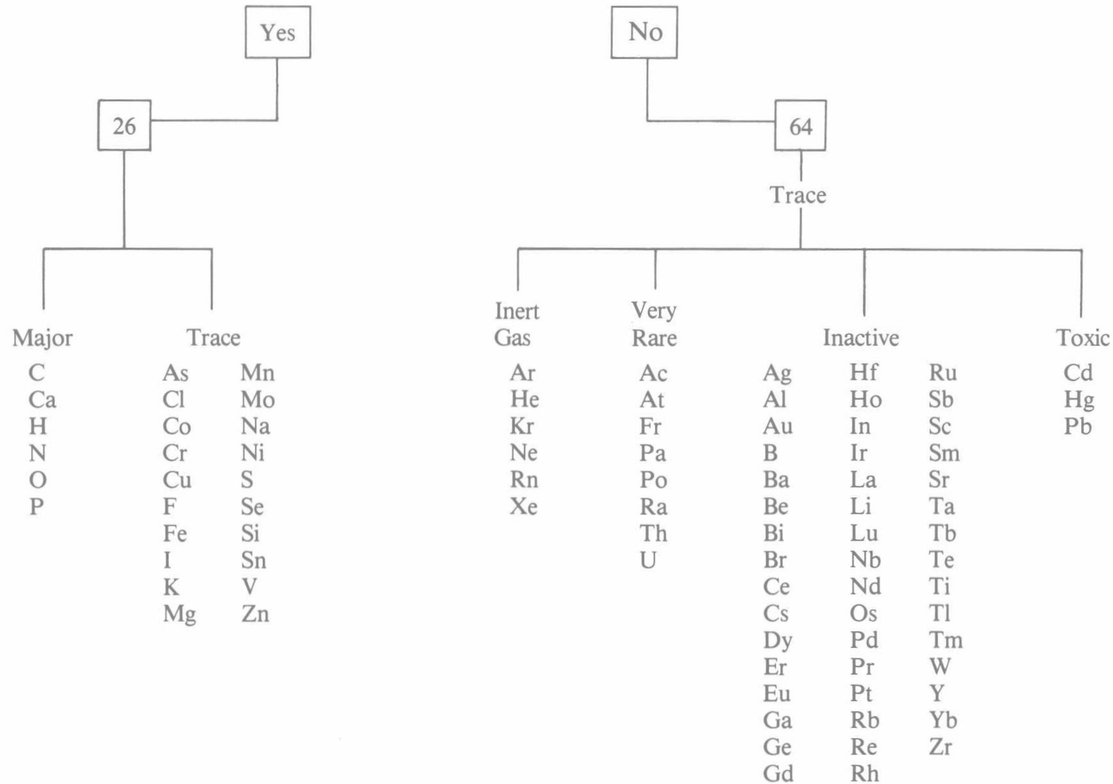


Figure 1-1 Classification of 90 naturally occurring elements essential to animal life.

TRACE ELEMENTS IN DENTISTRY

The dental profession was actively involved with the field of trace elements and dental disease at an early stage. In 1908 a mine chemist, F. S. McKay, suggested at a meeting of the El Paso (Texas) Dental Society that mottled teeth and a concomitant resistance to caries were related to a factor in drinking water. This factor was subsequently identified as fluoride, a trace element now known to be essential for calcification, growth, and fertility (Schwarz and Milne, 1972, Messer et al, 1972). Thus, the influence of trace elements on a dental disease was established early in the history of dental research.

Although there was an early start with fluoride, dental research has not seriously considered other trace elements until relatively recently. Indeed, dental research has been almost mesmerized by the element fluorine, to the virtual exclusion of consideration of other trace elements. In a recent review Hurny (1978) stated that within the past 30 years about 30,000 papers have been published on fluoride alone. It is unfortunate if fluoride alone of all the elements should be assumed to have the unique property of influencing susceptibility to caries. Such uniqueness has not yet been demonstrated. Fluoride is known to become incorporated into the enamel apatite, influencing its chemical, crystallographic, and biologic characteristics; this is known to be true of at least several other elements such as strontium, magnesium, and carbon. Therefore, it is understandable that in recent years, particularly as techniques suitable for analyzing a wide range of elements have been developed, interest in elements other than fluoride has increased.

It is the objective of this book to bring together the present knowledge and thoughts on trace elements in dental disease. The literature about fluoride as a trace element is extensive, and the reader is referred to those textbooks covering this element exclusively. In this volume, fluoride will be considered only where interactions with other trace elements occur.

Part of the problem in deciding which are the trace elements for purposes of discussion is analytical. Indeed, the original term *trace element* arose because analytical techniques were initially too crude to determine accurately the concentrations of an element present in a piece of tissue. Analytical chemists, therefore, reported the presence of an element in trace amounts, hence trace elements. The problem today is not that, but rather the opposite one of not being able to determine whether a trace element was really present in a tissue, or whether it was acquired during the analytical process as contamination.

It has generally been accepted that the term *trace* refers to a relative content of a constituent of not more than 100 ppm (100 parts/10^6 or 100 mg/l). However, for our purposes we have decided to review the literature on all elements we have defined as trace elements, although for many elements very little information is available.

Of all the dental tissues, more analytical work has been carried out on enamel than on any other because its chemical composition may materially affect the occurrence of the major dental disease, caries. Research has sought to define those elements found in enamel, and which elements affect the caries process.

Losee et al (1974) reported that at least 41 elements of the periodic table are incorporated into the dental enamel during development, Table 1-1. It is interesting that, with the exception of lead, no elements with atomic numbers above 60 are regularly present in young enamel.

One factor influencing the selection of the elements incorporated into enamel, and also related to essentiality for life, is the relationship of an atom's size and charge density. Only 3 of the 24 elements known to be essential for life in mammals have an atomic number above 34 (Losee et al, 1974). This selective process was suggested by Losee as also being applicable to enamel because of the seven elements reported in their study in the greatest concentrations (> 10 g/g dry wt), only strontium (No. 38) had an atomic number above 34.

There appears to be a selective process during enamel formation and development that restricts the incorporation of elements to those below 60, if not below 38. Of course, other elements may be acquired onto or into the surface enamel after tooth eruption. Such posteruptive uptake of some trace elements can take place in sound enamel, whereas many others will accumulate only if the surface or subsurface of the enamel is hypomineralized by developmental factors or by subsequent demineralization (Little and Steadman, 1966). Such posteruptive uptake of trace elements may also be affected by the presence of dental restorations,

Table 1-1
Summary of Trace Elements in Dental Enamel of Permanent Teeth

Concentration Range ppm	Elements
> 1000	Na, Cl, Mg
100–1000	K, S, Zn, Si, Sr, F
10–100	Fe, Al, Pb, B, Ba
1–10	Cu, Rb, Br, Mo, Cd, I, Ti, Mn, Cr, Sn
0.1–0.9	Ni, Li, Ag, Nb, Se, Be, Zr, Co, W, Sb, Hg
< 0.1	As, Cs, V, Au, La, Ce, Pr, Nd, Sm, Tb, Y
Not detected	Sc, Ga, Ge, Ru, Pb, In, Te, Eu, Gd, Dy, Ho, Er, Tm, Lu, Hf, Ta, Re, Os, Ir, Pt, Tl, Bi, Rh

prosthetic appliances, orthodontic bands, or the use of dentifrices or mouthwashes. Food composition, often reflecting variations in the geochemical environment, may also affect posteruptive accumulation of trace elements.

The papers of Losee et al (1974) and Curzon and Crocker (1978) reported on the analysis of large numbers of whole human enamel samples. We have concentrated on those trace elements listed in these two studies as the basis for our selection of elements. From the list of elements reported as detected in enamel, there is no evidence available to show that the elements cesium, cerium, praseodymium, or neodymium have any effects on dental disease. These are, therefore, arbitrarily eliminated from our consideration. On the other hand, there are two elements, cobalt and arsenic, recorded as below detection by Losee et al (1974) for which there is slight evidence of a relation to dental disease. They, therefore, are included.

The remaining trace elements will be discussed separately when there is evidence of a relationship to, or influence on, dental disease. Others will be discussed as groups, essential elements, nonessential elements, or toxic elements. Hereafter, all trace elements will be referred to by their chemical symbol.

TRACE ELEMENTS AND DENTAL CARIES

Evidence of a relationship of trace elements to caries prevalence has accumulated to a degree that indicates that further research be undertaken on this subject. Although the inverse relationship between fluoride availability and dental caries is beyond dispute, the data given in some of the early reports, such as those of Arnold and co-workers in 1948, give an indication of effects on caries by factors other than fluoride. From Arnold's and other reports, it can be seen that caries prevalence for a number of communities was substantially different than that in comparable communities despite a similarity in fluoride levels. As an example, in Clarksville (Tennessee) with 0.2 ppm F in the drinking water, the mean number of decayed, missing, and filled teeth (DMFT) in 12 to 14-year-old children was 4.58, whereas in Key West (Florida) with 0.1 ppm F in the drinking water the mean DMFT index for comparable children was 10.70 (Arnold, 1948). No cultural or racial difference appeared to explain the twofold difference in DMFT between Clarksville and Key West, and F differed by only 0.1 ppm. Other elements are suggested as possible factors.

Several trace elements in the water supplies have been claimed to be either cariostatic or cariogenic. Spectographic analyses of water from the towns with low F of Oak Park, Waukegan, and Quincy (Illinois), and the towns with high F of Aurora, Joliet, and Galesburg (Illinois) showed that

DMFT figures in the United States Public Health Reports (Arnold, 1948) are actually as closely related to levels of B and Sr as to F. From published trace element information for water supplies in the United States (Dufor and Becker, 1962), it was reported (Losee and Bibby, 1970) that high levels of Ba, Li, Mo, Sr, and V were significantly correlated with lower caries prevalence. Conversely, the same authors showed a positive correlation between Cu and Pb levels and high caries. Using caries prevalence data and analyses of water supplies in a study of statistical correlations of caries and trace elements, Adkins and Losee (1970) observed that these same elements were significantly and positively related to dental caries.

Biologic apatite, such as in enamel and dentin, differs from a pure hydroxyapatite by its inclusion of very small amounts of proteinaceous material and trace elements. While the organic fraction reflects the residue of odontogenesis, the trace elements reflect the composition of the tissue environment during the period of tooth formation and the oral environment after tooth eruption. These environments differ in many ways, including the trace element composition of ingested water and foodstuffs which in turn are dependent on geographic, dietary, and cultural factors. These same factors are often observed to be closely associated with the prevalence of caries.

Analysis of dental enamel has been carried out many times to determine its trace element composition. In 1937 Drea attempted to identify those trace elements that naturally occur in enamel. Analytical techniques at that time were not good enough to measure accurately low concentrations of elements, and in earlier studies, just as in the paper by Drea, elements were listed as present in trace quantities. With the advent of analytical techniques such as atomic absorption spectrophotometry, lower and lower detection limits have been possible, such that quantities as low as $< 0.01\ \mu g/g$ can now be easily detected. Consequently, studies of the associations between trace elements and dental caries have become possible (Curzon and Crocker, 1978; Schamschula et al, 1979); these will be discussed in detail later. It is apparent that the trace element composition of teeth may be associated with their susceptibility to caries.

Since 1953 several epidemiologic studies have examined, or reported, relationships between dental caries and trace elements such as Mo, Se, Sr, and V. Subsequent animal and in vitro studies have either supported or contradicted these findings. Overall a body of literature has thus developed within the last 20 years which we felt was now at a stage to merit review.

TRACE ELEMENTS AND PERIODONTAL DISEASE

Little attention has been given to the possibility that excesses of trace elements may affect periodontal health. It could be postulated that