SCIENCE

VOL. 78 FRIDAY, NOVEMBER 10, 1933 No. 2028

SCIENCE: A Weekly Journal devoted to the Advancement of Science, edited by J. MCKEEN CATTELL and published every Friday by

THE SCIENCE PRESS

New York City: Grand Central Terminal

Lancaster, Pa. Garrison, N. Y.

Annual Subscription, $6.00 Single Copies, 15 Cts.

SCIENCE is the official organ of the American Association for the Advancement of Science. Information regarding membership in the Association may be secured from the office of the permanent secretary, in the Smithsonian Institution Building, Washington, D. C.

RECENT DEVELOPMENTS IN THE STUDY OF DENTAL CARIES

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DENTAL caries, commonly known as decay of the teeth, is the most prevalent disease of mankind. Since there has been no known means of preventing the disease, dentists during the past one hundred years or so have been endeavoring to preserve the teeth by filling the cavities as they appear and by restoring, to the best of their ability, the lost dental tissues by artificial substitutes. In every generation the dental profession has made some attempt to study the underlying causes of the disease and to discover some means of its prevention. During the past few years, however, scientific investigations of this problem have been greatly increased and well-organized research groups have been making intensive studies of the disease. As a result of these studies certain definite facts have been established and many preconceived ideas have been shown to be fallacious. Although the problem has not been fully solved, distinct progress has been made and a clearer understanding of the true nature of the disease has been attained. It is the purpose of this paper to state the outstanding achievements of recent researches on dental caries.

The disease in question is most unique. There is no other pathologic process which even remotely resembles it. Dental caries is not comparable to caries of the bone. It is not a true necrotic process, nor is it attended by inflammatory reactions in the affected tissues. It is characterized by the formation of progressive lesions in the teeth, simple decalcifications by acids formed locally as a result of the fermentation of carbohydrates by certain aciduric types of bacteria. The process is dependent on the infestation of the mouth by specific types of bacteria capable of producing acids by the fermentation of residual carbohydrate food materials in the mouth, and capable of living in their own acid products. These bacteria

belong to the lactobacillus group and to the general type which is commonly designated as *B. acidophilus*.

These organisms may be held in contact with the teeth over long periods of time, in which position they are virtually outside of the body proper. That is, they are at no time in immediate contact with the blood serum or the natural immunologic forces of the body and may be subjected to them only through the intermediary of the salivary or mucous gland secretions. The organisms of caries have no direct pathologic action on the tooth enamel, nor do they live at the expense of that substance. Rather do they produce their specific effects indirectly through the acids which they elaborate during fermentation. These organisms are non-pathogenic inhabitants of the oral cavity, which live at the expense of their immediate environment.

The unusual character of this process and its wide variance from other forms of bodily disease have made it extremely difficult to understand, and much valuable time and effort have been expended in the fruitless attempt to correlate it with other forms of degenerative diseases. In the olden days dental caries was considered to be a necrotic process resulting from inflammatory changes in the tooth itself. With the development of histologic studies it became evident that the dentine and enamel contain no circulatory systems capable of inflammatory reaction. Still, the old humoralistic idea remains even to-day, in the form of a belief by many that the activity of dental caries is largely controlled by the hardness and softness of the teeth. The fact that clinical and experimental evidence has clearly shown that the activity of the disease is not necessarily related to the perfection of tooth structure seems not to have been universally grasped or its significance realized, for we still hear the admonition "Feed your teeth" for the prevention of dental caries. The great majority of students in this field, however, have long since agreed that the determinant causative factors in dental caries are not resident in the tooth itself.

There are those who have looked to mouth cleanliness and hygiene as means of preventing this dental disease. Except when carried to an extreme and impractical degree these measures have failed to give any high degree of protection. Clinical observations clearly indicate that the activity and extent of dental caries may be quite unrelated to the degree of mouth cleanliness. Relatively clean teeth may be extremely carious and filthy mouths may be wholly free from defect. It has been difficult to harmonize these observations with the concept of dental caries as a bacterial disease until, by quantitative cultural measures, it was definitely shown that, as a rule, in caries-free mouths, irrespective of the state of mouth hygiene, *B. acidophilus* is either totally absent or is present in relatively small numbers. In those individuals in which caries is active there are usually high numerical counts of that organism. As in other forms of bacterial diseases, filth and infection may not be synonymous. The important consideration is not filth itself but the character of the bacterial flora which it habitually contains. Mouth hygiene, therefore, may influence the rate and extent of dental caries but in itself does not determine the occurrence of the disease. That function is exercised by the degree of infestation by *B. acidophilus*, irrespective of the degree of mouth cleanliness.

Contrary to the widely accepted view, *B. acidophilus*, the active causative agency in dental caries, does not inhabit all mouths alike. In some individuals the organism is totally absent and, when implanted therein repeatedly, does not grow but promptly disappears. In others it appears either intermittently or in very small numbers. In those individuals in which dental caries is active, as a rule, it grows luxuriantly and is constantly found on the teeth and in the saliva. In view, therefore, of this fact the next goal to be attained in the study of this problem is that of a fuller understanding of the exact mechanism by which the degree of activity of *B. acidophilus* in the mouth is controlled. That is, what are the conditions which inhibit its growth in one mouth and favor its active proliferation in another?

In the search for that important variable which determines the growth and degree of activity of the aciduric bacteria in the mouth, three general considerations appear to be most directly related to the process and might reasonably be expected to be significant. These are: First, the chemical constituents of the salivary and oral secretions; second, the possible immunologic principles of the saliva, and third, the character of the retained food debris remaining about the teeth. To these considerations others might be added which perhaps are more important but, at the present time, these are the most apparent factors directly related to the disease in question.

Proximate Factors in Dental Caries

I. *The Chemical Constituents of the Oral and Salivary Secretions:* Many phases of the chemical constituents of the saliva have been studied more or less intensively in the search for some characteristic chemical state which could be correlated with the activity of dental caries. At the present time the major interest is being centered upon the calcium, phosphorus and pH of the saliva, the opinion being held and frequently stated that these may act as controlling factors in dental caries. Furthermore, the feeding of calcium and phosphorus and alkaline-ash

foods has been recommended for the control of the disease.

During the past two years the University of Michigan dental caries research group has been engaged in a very intensive study of two well-selected groups of children, one of which was distinctly free from dental caries and the other extremely susceptible to it. The object of this study was to determine whether or not chemical differences existed between the saliva or the blood of caries-free as compared with caries-susceptible individuals. As the result of observations which were repeated on the same individuals at intervals of several months it was found that, although certain variations could be detected, there were no constant differences in the total calcium, total phosphorus or pH of the blood or the salivas of the two groups.

These investigations definitely indicate that, whatever controlling influence the saliva may have on dental caries it is not by virtue of its total calcium, total phosphorus or pH. Furthermore, in a correlated study of a small number of cases, no differences could be found in the total calcium, inorganic phosphorus, pH or the CO_2 combining power of the blood. These observations strongly negate the hypothesis that dental caries is the result of low calcium or low phosphorus content of either the blood or the saliva or is due to a condition of acidosis, statements which frequently have been made but are unsupported by adequate scientific evidence.

II. *Immunity against B. acidophilus:* Many attempts have been made to demonstrate some bactericidal agency in the saliva which might act as a controlling influence on oral sepsis, but as yet no such immunologic principle has been found. There are indications, however, that some form of bacterial control does exist for, as previously stated, *B. acidophilus* can not be induced to grow in many mouths in which that organism is consistently absent.

In a study of this question the Michigan group made extensive bacteriologic surveys of both the mouths and the intestinal tracts of caries-free and caries-susceptible individuals. They found that *B. acidophilus* was invariably present in the mouths and intestinal tracts of caries-susceptible individuals, but that it was absent or appeared intermittently in both the mouths and intestinal tracts of caries-free individuals. In view of the general impression that this organism is universally present in the intestinal tract we think it particularly significant that the only negative feces cultures were obtained in caries-free cases.

Certain observers (Boyd and Drain, Tucker and others) have been unable to demonstrate a constant relationship between oral *B. acidophilus* and dental caries and have questioned the significance of that organism as a specific etiologic factor in the disease. Bacteriologic studies in the field of dental caries are attended by certain difficulties, which may easily give rise to confusion and erroneous conclusions, especially to those who have no intimate knowledge of the disease under consideration. In making such bacteriologic surveys of the mouth it is most difficult and often impossible to determine whether, at any given time, dental caries is active or passive. Errors in such clinical assumptions will lead to erroneous conclusions. *B. acidophilus* may be present but not generally distributed throughout the mouth, even in cases of pronounced caries activity. It may be limited to certain definite areas of the teeth which are undergoing carious disintegration and be absent from other noncarious tooth surfaces. Consequently, diagnostic tooth scrapings which are not taken directly from actively carious areas may be negative. Conversely, in caries-immune or caries-arrested mouths qualitative cultures may be positive for *B. acidophilus* but if quantitative studies are made of such cases it will be found that these organisms are present in exceedingly low numbers and often are transitory in occurrence. Simple qualitative bacteriologic surveys of the mouth are therefore of doubtful value in the study of dental caries. The intensive bacteriologic and clinical studies of thousands of cases over a period of five years, which have been made by the University of Michigan group, leave no room for reasonable doubt as to the specificity of *B. acidophilus* as an active etiologic factor in dental caries. This view has been corroborated by the work of Rodriguez, Thompson and Enright.

In the search for some general immunologic principle which might control the growth of that organism in the mouth and the intestinal tract the Michigan group have studied selected groups of caries-free and caries-susceptible children, whom they inoculated intradermally with filtrates of *B. acidophilus*. It was found that the majority of caries-free subjects showed no reaction, but in many of the susceptibles there appeared localized areas of erythema, 10 to 30 mm in diameter within eight hours after inoculation. Repeated injections of the filtrate failed to desensitize the positive cases.

A polyvalent vaccine was prepared from forty strains of *B. acidophilus* and was administered to five cases which had given positive skin tests. In two of these, the skin tests became negative and agglutinins against *B. acidophilus* appeared in the blood. Unfortunately, this study has been hampered by the fact that in certain of these cases large sterile abscesses were formed at the site of inoculation which persisted for a considerable period of time. A new series of experiments are now under way in which autogenous vaccines will be used.

In the study of the blood sera of caries-free and caries-susceptible individuals it was found that in the former group *B. acidophilus* agglutinins occurred in dilutions as high as 1/640, while in the latter they were present in low dilutions or were absent. These studies are only in their infancy, but the findings thus far obtained strongly indicate the existence of some form of general immunologic principle which controls the growth and activity of *B. acidophilus* in the mouth and the intestinal tract.

III. *Retained Food Debris:* The character of the oral bacterial flora is profoundly influenced by the amount and character of food debris remaining in the mouth. If the residual foods are largely proteins, proteolytic types of organisms will likely predominate. If they are chiefly carbohydrates, overgrowths of fermentative bacteria are favored. It is upon the residual carbohydrate food debris that the aciduric bacteria of caries depend for their maximum growth and for the source of material for acid production. If the mouth could be kept continually free from carbohydrates *B. acidophilus* would be either absent or very low in activity and, in the absence of fermentable materials, would be wholly unable to produce dental caries. The amount and character of carbohydrate food debris in the mouth and about the teeth constitutes, therefore, a very important factor in this dental disease.

Constitutional Factors in Dental Caries

It is commonly observed that the occurrence and degree of activity of dental caries is definitely related to certain constitutional states of the individual. Of these, the more evident are inherited characteristics, age, bodily health and nutritional status. These constitutional states, through their influence on general metabolism, unquestionably affect the nature of the salivary secretions, their chemical constitution, physical properties and total amount. In this manner the constitutional status of the individual may influence the activity of the aciduric bacteria in the mouth and thus determine the progress of dental disease.

I. *Heredity:* The existence of an inherited tendency for or against dental caries is indicated by the fact that in civilized communities 90 to 95 per cent. of all children suffer from the disease, while 5 to 10 per cent. of individuals are not so affected. That is, a small percentage of people have some inherent quality that protects them from aciduric invasions of the mouth which the great majority of individuals do not possess. The tendency to or the freedom from this disease very definitely runs in families, having many of the characteristics of familial inheritance.

II. *Age:* Although dental caries is very prevalent during childhood and adolescence, after the age of twenty there is a marked decrease in its activity. Many who have been seriously affected during the early years of life have little or no decay of the teeth during middle age. It appears, then, that when the individual reaches early maturity the changing metabolic status produces conditions less favorable to the activity of aciduric bacteria in the mouth and dental caries.

III. *Bodily Health:* It is commonly observed that severe illnesses and metabolic disturbances of various types may be followed by a marked activity of dental caries. A classic example of this is the increase of dental disease which so frequently follows pregnancy and childbirth. The metabolic disturbances associated with these general physical states undoubtedly influence oral conditions and dental health.

IV. *Diet and Nutrition:* Perhaps the most notable recent contribution to the study of dental caries has been the accumulation of evidence pointing to foods and nutritive functions as factors of major importance in the disease. This knowledge has come largely through three general fields of inquiry, namely, racial studies, animal experimentation and human dietary experiments.

A. *Racial Conditions:* It is a well-known fact that dental caries is distinctly a disease of modern civilization. The natives of Alaska, Newfoundland, South America, the South Sea Islands, Africa, interior Europe and Asia who live segregated lives quite remote and untouched by modern civilization are almost wholly free from dental caries. When these people adopt civilized life or move into civilized communities their children become highly susceptible to dental disease. In a study of the essential differences between uncivilized and civilized life which might be related to the prevalence of dental caries the most outstanding characteristic is that of diet. As long as primitive man lives on the simple foods which are indigenous to his locality, he has little need for a dentist, but when he adopts the white flour, sugar and canned goods of civilized life he and his children invariably are stricken by dental disease which is often more severe than among civilized communities.

B. *Animal Experimentation:* In many of the early studies of diet and nutrition which were made on animals it was observed that, with the feeding of certain deficient diets, caries-like lesions appeared in the teeth. Since that time extensive animal experimentations have been carried on to determine what form of dietary deficiency is most important in the production of dental caries. Certain observers have stated that vitamin C is most important, others that calcium, phosphorus and vitamin D are more significant, and still others believe that the acid-base balance is a determining factor. In all the animal experimenta-

tion so far reported there is found no conclusive evidence in support of any of these views. The original statement of McCollum and Grieves—that the percentages of caries developing under the various diets are interesting but they do not point definitely to any one characteristic of diet as being more significant than another in its relation to dental caries—has not been controverted.

C. *Human Experimentation:* During the past few years a number of caries research projects have been carried on in which practical application of the several dietary theories regarding this disease have been actually tried on groups of children under observation. The observations made in these experimentations and the published data are extremely valuable contributions to the study, notwithstanding the fact that there is considerable difference of opinion as to the interpretation of the findings. Perhaps the most notable of these are the dietary studies of May Mellanby, Boyd and Drain, H. F. Hawkins, Milton T. Hanke, Sherman L. Davis and the University of Michigan group. In some of the dietary programs which were employed in these studies certain food factors were accentuated as being most important dietary deficiencies and any beneficial effects which were observed were attributed to the fortification of these elements. Mellanby and Davis stressed the feeding of calcium and vitamin D, Hanke fed large quantities of vitamin C bearing foods, and Hawkins emphasized the calcium and alkaline-ash intake, while Boyd and Drain and the Michigan group studied the effect of adequate, well-balanced diets on dental health. It is interesting to note that all these observers report an appreciable decrease in the activity of dental caries as a result of the particular dietary method which they used. In some instances it amounted to almost a complete control of the disease during the period of observation. Those who accentuated calcium and phosphorus, vitamin D and C or the alkaline-ash content point to the improvement of dental conditions in the cases which they fed as a proof of the importance of these food elements. It must be remembered, however, that not one of these projects was an adequately controlled experiment. In every instance in which a single element was increased other food principles were also included which may have been equally important protective principles, with the possible exception of certain experiments of Mrs. Mellanby. There is, therefore, no conclusive evidence to be found in the dietary experimentations thus far reported to warrant the assumption that any one food factor is more important than another in its relation to dental caries.

In an analysis of these dietary experimentations there is a certain trend or common denominator which runs through them all; namely, that all the dietary programs, irrespective of the particular view-point stressed, provided fairly adequate and well-balanced rations. A notable exception to this principle has been found by the Michigan group in a colony of three hundred children who are receiving an inadequate diet but have exceptionally fine dental conditions, low *B. acidophilus* counts and little or no dental caries. These children, who have been observed over a period of four years, are residents of an orphanage. Their diet has been practically uniform during this period and has been considerably below the standard nutritional requirements in calcium, phosphorus, vitamins D and C and caloric values. One other food factor existed which may be significant. The sugar intake was reduced to the lowest possible minimum. The children received little or no candy, no sugar in beverages or on cereals and no highly sweetened cakes or preserves. The desserts were limited to raw apples. Whether or not the exceptionally fine dental conditions and the freedom from dental caries which prevailed throughout this period of observation can be attributed to some particular dietary principle or to the low consumption of sugar can not be definitely stated at this time.

Further studies of the effect of various types of adequate diets and the feeding of different forms of sugar on dental caries are being made by the Michigan group on children in the University Hospital under the direction of Martha Koehne.

SUMMARY

The chief consideration in a study of this kind is obviously the prevention of the disease in question. Effective preventive measures, however, must be based upon a full knowledge of the factors involved in the production of the disease. Unfortunately, at the present time there are certain missing links in the evidence concerning the etiology of dental caries which prevent a clear statement of facts in their entirety. Because of our present lack of knowledge as to certain details, the measures employed for the practical control of the disease are necessarily of the trial and error method in which there are many opportunities for misapprehension and erroneous conclusion. The rationale of any preventive procedure may only be evaluated by a clear knowledge of the established facts and a correlation of the unknown with the known.

Certain of the more important facts which should be borne in mind in the evaluation of new theories or experimental evidence may be stated as follows:

(1) Dental caries is a bacterial disease of the oral cavity which is characterized by acid fermentations and a decalcification of the teeth.

(2) The occurrence of dental caries is not determined by the structural quality of the tooth nor by the degree of cleanliness of the mouth.

(3) Dental caries is definitely favored by certain phases of civilized life.

(4) Dental caries is related to certain constitutional states of the individual, such as inherited characteristics, age and bodily health.

(5) A small percentage of people are hereditarily immune to *B. acidophilus* and by the inhibition of the growth of this organism in the mouth are thereby protected from dental caries, irrespective of all other considerations.

To this list may also be added the fact that certain dietary programs appear to be inhibitive of dental caries. The manner in which diet exerts a controlling influence on the disease; whether it is through the determination of the character of the local food residues in the mouth or through the production of metabolic states which determine the activity of the aciduric organisms in the mouth is not known. Nor, indeed, has it been determined precisely what types of diets are most beneficial in this regard.

At the present time the greatest promise for the ultimate solution of the problem seems to lie in the study of the chemistry of the saliva and its immunologic reactions against the organism of dental caries, and in a further study of diet in its relation to dental disease. To this end it is highly desirable that group studies be made in which the allied sciences, chemistry, nutrition, bacteriology and dentistry may be correlated in a truly scientific attack on this very difficult and important problem in human welfare. It is only by studies of this broad nature that any adequate concept of the nature of this disease or the means of its prevention may be attained.

THE ENGINEERING FOUNDATION

By ALFRED D. FLINN
DIRECTOR

OBJECTIVES AND POLICIES

THERE are basic laws of nature in the field of ethics that are as certain in operation as the natural laws in the field of physics. Engineers are as vitally concerned with economics, which lies partly in each of the fields of ethics, engineering and finance, as with mechanics, in the field of physics.

The Engineering Foundation devotes its resources, therefore, to human as well as technical aspects of engineering problems of wide interest. It promotes research and other activities having as main objectives "the furtherance of research in science and engineering and the advancement in any other manner of the Profession of Engineering and the good of mankind," in the language of its deed of gift.

The foundation's aid to the advancement of the profession extends to activities aimed at better understanding and application of natural laws fundamental to both physics and ethics. Hitherto emphasis has been on technical research, although humanic subjects have received attention, too. Such appeared to be the preponderance of need in our country's development until recent years—or rather that was the need of which engineers and industrialists were most conscious. Within a few years the consciousness of need has shifted, and consequently the emphasis in the foundation's program may advisedly be shifted correspondingly.

Leadership, cooperation and effectiveness are keynotes in the foundation's policies. They are personal traits of its founder, Ambrose Swasey, of Cleveland, Ohio.

ORGANIZATION AND ADMINISTRATION

The founder is one of the surviving organizers of The American Society of Mechanical Engineers. For several years he considered how best to make a gift to assist his fellow engineers, through his own society or some other organization, in working out problems for which no means had then been provided. After consulting friends competent to advise, he anonymously proffered a gift in May, 1914, to the United Engineering Society, now known as United Engineering Trustees, Inc. This corporation was created in 1904 under a special act of the New York legislature by the three national societies of mining, mechanical and electrical engineers to hold and administer for them jointly real estate and funds, "to advance the engineering arts and sciences in all their branches, and to maintain a free public engineering library." The American Society of Civil Engineers became a member of this group in 1916. Since the tenth of August of that year there have been four founder societies.

Mr. Swasey's conception was unique. He committed his gift not to a self-perpetuating board, but to a group of national engineering societies. He avoided the inclusion of any personal name in the name of the foundation. He did not wait until the end of his life. He gave while he could enjoy the satisfaction of seeing his money at work. He added to his first