

Pan American Health Organization

PAHO/ACMR 11/5
Original: English

ELEVENTH MEETING OF THE
ADVISORY COMMITTEE ON MEDICAL RESEARCH

Washington, D.C.

19-23 June 1972

DENTAL CARIES: AN INFECTIOUS DISEASE

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DENTAL CARIES: AN INFECTIOUS DISEASE*

The notion that dental caries is a bacterial disease is certainly not novel, but the proof of this hypothesis and of the degree to which the infection is transmissible is comparatively recent.

As long ago as 1882, Miller propounded the chemicoparasitic theory to account for the pathogenesis of caries. In this he postulated that the destruction of the hard dental tissues could be attributed to the action of acid produced by microorganisms fermenting dietary carbohydrate. In the decade that followed, Miller's Theory has stood the test of time to a remarkable extent. A wide range of observations, mostly epidemiologic in type, have lent support to his implication of dietary carbohydrate in the disease process, and although there have been sporadic attempts to challenge the validity of the Miller Theory they have been remarkable at best for ephemeral ingenuity and at worst for the vocal persistence of their adherents.

The case against carbohydrate has become increasingly more formidable. Dental caries is recognized to be ubiquitous in civilized communities and its incidence has been closely correlated with dependence upon convenience foods which are usually rich in fermentable carbohydrate. Moreover, the disease has its maximum incidence and is most destructive during childhood and adolescence, where eating habits in most urban communities have encouraged carbohydrate consumption between meals and in considerable quantity.

There have been many studies showing that people living under rural and pastoral conditions are relatively free from caries, but that a change to urban life and the eating habits associated therewith is accompanied by the onset of tooth decay. In the case of remote communities, such as Tristan da Cunha, experience has shown that contact with urban influences has led to a grave deterioration in dental health. In the past these transformations in the apparent susceptibility of populations have been

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attributed to the introduction of refined carbohydrate into diets previously devoid, to a great extent at any rate, of such components.

The case against carbohydrate has been further strengthened by observations made during the two World Wars, when the incidence of dental caries was found to drop in countries deprived of sugar in particular. When sugar rationing ended after those wars were over, an upsurge in carbohydrate consumption by hitherto deprived populations was found to be associated with renewed caries activity. A human experiment supporting this correlation was carried out in Sweden, and became known as the Vipeholm Study. The diets of patients living in a mental institution were supplemented by confectionery between meals, and the consumption of the sweet and sticky foodstuffs led to a rise in caries which has been interpreted as an emphatic indication of the undesirability of between-meal snacks.

These are only a few examples of evidence incriminating sugary foods in the etiology of dental caries. As more and more data of this sort were collected, the dental profession came increasingly to regard dental caries as a disease caused by carbohydrate, and the parasitic part of Miller's Theory received correspondingly less attention. There are many reasons why this was so. Among the most important was the finding that individual children could in many instances be kept relatively caries-free by careful control of their carbohydrate intake. However, whereas the careful supervision of individual children by conscientious parents could produce this effect, the apparent resistance often lasted only as long as supervision could be maintained, and when the hidden delights of forbidden carbohydrate were discovered the upsurge in tooth decay often matched that seen in postwar populations released from sugar rationing. This pointed to a fact that has never been seriously challenged, namely, that the elimination of caries by dietary control is not a practicable proposition at a community level.

Especially in communities to which fluoridated water is not available, the dental profession, faced with a mounting incidence of caries, has traditionally concentrated on dietary considerations. Sugar restriction has therefore been preached, and those who are most concerned

have preached it most ardently. Sugar is however, practically ubiquitous in modern diets and to eradicate it completely--economic considerations apart--might even be beyond the abilities of an obsessive faddist.

While all this attention has been directed toward carbohydrate, little has been said or done about the bacteria that act upon it to the ultimate detriment of the teeth. The bacteria have, as it were, been sheltered by the culpability of their substrate. One would presume, too, that the manifest impossibility of rendering the mouth sterile did much to deter any who might have questioned the validity of directing the dental profession's attack against diet alone. Yet as long ago as 1924, J. K. Clarke, a microbiologist, undertook an investigation at the instance of the Dental Committee of the Medical Research Council in London, in an attempt to ascertain whether there was a specific microorganism associated with early carious lesions. He concluded that there was, and he identified Streptococcus mutans as the suspect. He described the disease as an infection and stressed that bacterial colonies adhered closely to the enamel.

Far too little attention was paid to this work in the years that followed. When one seeks reasons for this missed opportunity, the unique nature of the oral microbiota is seen to account--certainly in a considerable degree--for contradictory findings and apparently insuperable difficulties. An outstanding feature of the oral flora is that the population of mouth organisms in young subjects is neither constant nor homogeneous in its composition. This is nothing more than a reflection of ecologic variations, since although the general conditions obtaining in the mouth favor bacterial growth, it is much less a single region than a conurbation of microenvironments, sometimes remarkably secluded from one another. Thus, for example, very different organisms will populate the crevices of a fissured mucosa, the dorsum of the tongue, the depths of a periodontal ulcer, or the plaque that is adherent to tooth enamel. Where such widely varying conditions exist, adaptive modification will ensure great heterogeneity of bacterial populations. It is for this reason that the examination of a smear taken from the mouth at random is for the most part an interesting but aimless exercise. The bacterial composition of a drop of saliva is not reliably or even remotely representative of the teeming oral microbiota.

The extreme complexity of this situation was at last overcome by the advent of germ-free techniques, and the whole question of the role of bacteria in the carious process was elucidated by Orland et al. (1954) when they showed that rodents maintained on a cariogenic diet did not develop carious lesions in the germ-free state.

This discovery was the starting point for a wide range of experiments that revitalized research into the causes and prevention of tooth decay. Investigation showed that it was possible to implant strains of S. mutans in hamsters and to produce dental caries in those animals. More than that, workers at the National Institute of Dental Research in Bethesda were able, for the first time, to adduce convincing proof of the transmissibility of this disease in rodents. Litters of caries-susceptible hamsters were divided into two groups, one of which received an antibiotic capable of suppressing the caries-inducing organisms. Animals receiving the antibiotics were caries-free, and their progeny were caries-free even when fed on a high carbohydrate, caries-promoting diet. However, when these progeny were caged together with litters from the control groups, they developed caries. It was clear from these experiments that the transmission of cariogenic organisms took place from the infected animals to those hitherto uninfected following the treatment of their mothers with antibiotic.

Several strains of streptococci have since been isolated from human mouths and have been shown capable of inducing caries in rodents. At the Royal College of Surgeons of England, caries has been induced in non-human primates following implantation of the same type of organism. Bowen has shown that S. mutans can not only be transmitted from man to monkey but also from one monkey to another, and from one generation to another. In the course of a long series of studies he has shown that the causative role of S. mutans in dental caries satisfies Koch's Postulates. Organisms have been isolated from the plaque of caries-active human subjects, grown in pure culture, implanted into the mouths of pregnant monkeys, later recovered from caries-active tooth surfaces in offspring, and finally reisolated in pure culture. These experiments have all been made possible by utilizing techniques for labelling organisms, either by induced

antibiotic resistance or by the use of fluorescent antibodies--techniques not available to those who pioneered the study of bacteria in relation to dental caries.

It can fairly be said that the case against the microorganism, like that against sugar, is now irrefutable. Details remain to be elucidated, but the total concept is no longer hypothetical. A new dimension in scientific understanding of the unholy alliance between bacteria and the substrate provided by diet has emerged from studies of the dental plaque.

Dental plaque is the term applied to describe a tenacious accretion occurring on the tooth surface. It becomes readily visible with the aid of disclosing solutions, and is not amenable to complete removal by ordinary oral hygiene or by masticatory friction. If teeth are freed of these deposits by thorough mechanical cleansing carried out by a dentist, new plaque will start to form soon after saliva comes into contact with enamel. This initial deposit, presumed to be composed of denatured salivary glycoprotein, affords a site for colonization by certain mouth bacteria, especially S. mutans, and recent work has shown that the elaboration by these organisms of extracellular polysaccharides adds in varying degree to the bulk of plaque and probably to its adhesiveness. Thus it comes about that bacterial aggregations use tooth surfaces as a lodgment site and that metabolic products of these bacteria, in particular fermentation products, are held in contact with the tooth for periods much longer than would be possible if saliva were not excluded from enamel by the diffusion-limiting properties of a sticky pabulum.

These findings offer some explanation of the cariogenicity of sucrose in particular. It is not only fermentable to acid by common mouth organisms, but can be converted to extracellular polymers of either dextrose or fructose so that the characteristics of plaque inimical to tooth enamel are enhanced. Moreover, it can be stored intracellularly in the form of amylopectin and subsequently fermented so that all the conditions that predispose to acid attacks upon the enamel are provided. The obvious culpability of sucrose should not however, be allowed to

obscure the cariogenic capacity of other sugars, nor should it encourage the misconception that bacteria deprived of a particular sugar are unable to adapt to a different substrate.

This latter fact is of great importance in assessing methods for preventing tooth decay. It is because organisms are so adaptable that the eradication of their pathogenic effects by dietary control is not practicable, and that the principle of suppressing components of the flora by the continuous use of antiseptics or antibiotics is open to question. Nevertheless the incontrovertible proof that dental caries is a transmissible infection encourages the belief that it is amenable to eradication, at least to the extent that has been achieved in the case of other pandemic diseases of microbial origin. It is possible that measures directed against the dental plaque could come to constitute the best method, since it is this milieu that contributes so greatly to the unusual pathogenesis of the disease. It is also possible that a form of immunity may be inducible, even if the organisms themselves are not eradicated. The fact that caries prevalence diminishes to a very great extent after adolescence suggests a form of acquired immunity, although there are other possible explanations for this phenomenon.

For many reasons, the possibility of inducing immunity by a means such as vaccination is theoretically difficult to accept. In the first place the tissue under attack--tooth enamel--is devoid of a blood supply, so that neither a pathway for antigen to the antibody-forming organs or of antibody to the site of attack can easily be postulated. It is true that saliva contains immunoglobulins but it has been argued that the problem of diffusion through plaque by any but the smallest molecules of saliva is difficult to conceive. The validity of this argument is open to question if the attachment of salivary protein to tooth-enamel is postulated to precede the build-up of plaque. In the face of all these theoretical improbabilities, it is remarkable that Bowen has demonstrated repeatedly and beyond doubt that nonhuman primates can be successfully vaccinated against dental caries. The vaccine used in his first experiments contained live streptococci and is therefore considered unsuitable for administration to human subjects. Further experiments being carried out are directed toward overcoming this disadvantage.

From what has been said it is clear that both experimental and epidemiologic studies have contributed significantly to a growing knowledge of the pathogenesis of caries. Laboratory experiments have been largely responsible for providing proof of the infective nature of the disease, while epidemiologic observations have not only served to identify the effects of refined carbohydrate but have opened the way to the most effective means yet devised for reducing incidence at a community level, namely, the fluoridation of water supplies. The discovery of an unusual pattern of prevalence in a Colombian population has raised an interesting possibility of combining epidemiologic and laboratory research. Such a project, now being undertaken under the auspices of the Pan American Health Organization, is centered on the town of Heliconia.

Among several semi-isolated communities in the mountainous region surrounding Medellín, Colombia, Heliconia is remarkable for an unusually low incidence of dental caries. This feature was identified by Colombian investigators (Mejía et al., 1969) in the course of a nutritional study carried out in the province of Antioquia. The incidence of caries as measured by the number of decayed, missing, or filled teeth (DMF Index) of 267 Heliconia children between the ages of eight and 14 years revealed by far the lowest figures ever reported in Colombia. The DMF Index of this group was at most half that of Antioquia as a whole, and much less than half that of otherwise comparable towns of the region. No fewer than 25 per cent of the children studied were completely free of dental caries, a proportion that would be the envy of most modern communities since the disease is usually rife in this age group and to find fewer than 1 per cent caries-free is the rule rather than the exception.

As with any apparent resistance to dental decay at a community level this calls for investigation, especially since, in the study reported, fluoride was unlikely to be a responsible factor; urine analyses had been carried out and this element was not present. Subsequent analyses of soil have done nothing to provide any firm indication that differences in trace element composition could be acting in a caries-preventive manner.

There are, of course, many communities, especially in the more remote parts of the world, where tooth decay is not a particularly common

disease. The situation in Heliconia is however of particular interest and may indeed be unique, for two reasons. The first is that other equally remote communities in the same province have not been similarly spared from the ravages of caries. The second, and perhaps the more remarkable, is that the local diet contains an unusually high proportion of sugar. This is consumed in the form of panela, a staple foodstuff of the region. Panela is sold in the form of solid bricks of sugar produced, essentially, by boiling the juice of crushed sugar cane. In an area where milk is not plentiful, panela is frequently added to water and given to babies in their nursing bottles--theoretically a prescription for inducing rampant caries. The fact that a substrate known to be harmful does not result in damage to teeth raises the possibility of an unusual resistance to or absence of the microorganisms that normally act upon such substrate.

The further studies now being carried out under the auspices of PAHO are directed toward a search for differences, at a bacteriologic level, between the caries-resistant children of Heliconia and their counterparts in the otherwise comparable community of Don Matias, where caries is particularly rife. The work has been conceived as a collaboration between research workers in the University of Antioquia, Medellín, and the Royal College of Surgeons of England.

Because some years have elapsed since the observation of relative caries resistance was made in Heliconia, a new survey was regarded as an essential first step to the present study. This was carried out by personnel from the Dental School of the University of Antioquia. During May 1972, Dr. W. H. Bowen, a dental microbiologist at the Royal College of Surgeons, was sent to Medellín to set out the methods for conducting the bacteriologic survey and to initiate local scientists into techniques he has successfully used in similar studies on experimental monkeys. The plan of the study, in brief, is to select suitable groups of children exhibiting high and low caries incidence, and to collect, under comparable and controlled conditions, samples of their dental plaque. These will be examined in the laboratories of the Dental School of the University of Antioquia for the purposes of: (a) quantifying streptococci and lacto-

bacilli; (b) distinguishing qualitative differences between subjects with high and low caries incidence; (c) estimating the acidogenic potential of plaque in the two groups; (d) estimating the microchemical constitution of plaque in the two groups. The immediate purpose is to test the hypothesis that the relative resistance to caries in Heliconia is attributable to the absence of an infective agent capable of fermenting sugar to form the acid that initiates tooth decay; or, alternatively, that this relative immunity may result from the presence within the oral flora of an organism antagonistic to cariogenic streptococci. The ultimate purpose is directed toward attacking the problem of caries by attaining an exact understanding of the microbiologic factors concerned in the production of this disease. It is estimated that the project should last approximately 18 months, during which further exchanges of personnel between the Royal College of Surgeons and the University of Antioquia will take place.

It may seem far-fetched to envisage the eradication of a disease that has for so long been so prevalent. Nevertheless, it is worth reflecting upon the fact that with its recognition as a disease of bacterial origin must come the realization that other infections, also once accepted as inevitable, have proved amenable to modern antibacterial measures. Although the history of dental caries extends back to antiquity and its pandemic proportions have been known for centuries, the deployment of measures directed specifically against cariogenic microorganisms is in the earliest stage of development. For this reason alone there is a real need to extend and expand studies of bacteria in relation to caries--and perhaps especially to caries resistance. Information gained from research of this type could well provide the means for encountering the deleterious effects upon teeth that have come too readily to be accepted as an inevitable concomitant of modern urban life.