This paper is a review of the literature pertaining to the function of food in the preservation of the teeth. The historical, geographical, racial, and hereditary factors in the incidence of caries are discussed. It is shown that dental caries is the most prevalent of all diseases.

The structural development, growth, and calcification of the teeth are treated briefly in their relation to dental caries. Changes in the structure and dystrophies of the teeth due to diet, both pre-natal and post-natal, to illnesses and to drinking water are considered.

The nutritional factors in relation to dental caries are discussed under two main headings:

First, factors without the tooth, that may or may not enable it to resist caries.
1. Oral hygiene, which is now thought to be of less importance than formerly.
2. Acid destruction of the tooth, achieved by the action of Bacillus acidophilus, or some other micro-organism, fermenting carbohydrate food debris into an acid of sufficient strength to decalcify the enamel. This theory has strong evidence, but it does not explain why some teeth decay and others in the same mouth do not; neither does it explain arrested caries.
3. The particle size of the diet has been shown to be a factor in the production of dental caries in rats. Coarsely ground particles of food lend themselves to acid fermentation. This discovery does not seem to be of importance in human nutrition.
4. Relation of saliva, there is not any conclusive evidence that the calcium, phosphorus, titratable alkalinity, \( p_H \), or carbon dioxide combining power of the saliva have any effect upon, or any relation to dental caries.
5. The amylolytic and protolytic enzymes seem to have no action upon the teeth.

Second, factors within the tooth that may or may not enable it to resist caries.
1. The structure of the tooth. A well-formed well-calcified tooth is more resistant to decay.
2. The metabolism of the tooth. The circulation of lymph in the pulp and dentine is generally conceded. A few workers believe the enamel is also bathed in lymph. This theory is not generally accepted.
3. Vitamin C has a protective action upon the peridontal tissues. Some workers believe that high intakes of vitamin C will prevent dental caries. Vitamin C has been administered as orange juice, but the decrease in dental caries following its ingestion might be due to some other factor than vitamin C.

4. Vitamin D is necessary for the calcification of teeth and bones, but that it is the specific preventive factor in dental caries has not been proved.

5. The calcium phosphorus ratio, or the presence of large amounts of calcium or phosphorus in the diet are not specific factors in the prevention of dental caries.

6. A well-balanced diet, adequate in minerals and vitamins has been shown to be effective in preventing or lessening dental caries.

From the evidence presented in the literature one must conclude that no single factor is responsible for dental caries. A well-balanced diet, both before and after birth, and freedom from metabolic disturbances will result in the prevention of dental caries. The amounts of vitamin A, calcium, phosphorus, and vitamin D required to prevent dental caries are probably much higher than our present standards of nutrition indicate.
THE ROLE OF NUTRITION IN
DENTAL CARIES

by

MARY OAKES McCRAIN

A THESIS
submitted to the
OREGON STATE AGRICULTURAL COLLEGE

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE
July 1934
The writer wishes to express to Jessamine C. Williams her sincere thanks for sympathetic understanding and constant help in the preparation of this thesis.

Mary Oakes McClain
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THE ROLE OF NUTRITION IN DENTAL CARIES

The purpose of this paper is to review some of the mass of literature dealing with the relation of nutrition to dental caries and to determine which theory has the greatest possibilities for future research.

Teeth are important in our daily lives not only for their function in our physical organism, but for the way they can change our whole mental outlook. An aching tooth can make a night of seven hours into seven ages, and turn a formerly delightful companion into an unmitigated bore.

Dr. Raymond Gill, (97) in a lecture to the Oregon State Dental Association at Portland, during the summer of 1933, cautioned his listeners about the appearance of any dental restorations they might make. He said that the work of a dentist could, and frequently did give his patients inferiority complexes; that a dentist exerts a significant psychological influence over his patients. It may be that some of the unpleasant mannerisms we notice in other people are due to their sensitiveness about the appearance of their teeth.

Ryan and Bowers, (221) have a chapter upon focal infections in their book, "Teeth and Health". They show that dental caries and pyorrhea are often foci of infection which lower the resistance of the body to disease
germs of various types, hence are instrumental in causing diseases which seem unrelated to the teeth. They quote Dr. C.H. Mayo as follows: "Diseases of middle life are increasing. They are microbic, of a chronic, recurring character, and are carried into the blood stream from a few foci, the mouth being the source of the greatest danger. A crowned tooth is not a crown of glory and may cover a multitude of germs. Modern dentistry is relieving the world of much of its misery by watchful care of foci connected with the teeth, and the trend of modern medicine is bringing these fields closely together."

An article in the American Magazine, (6) of May 1918, tells of a man who had never been in a state of buoyant health until he had his teeth X-rayed and the infected teeth removed. An X-ray of the teeth should be a part of a thorough physical examination.

Ryan and Bowers, (221) say that 40 per cent of all the absences from school are due to defective teeth. In New York 67,000 children each year fail of promotion because of deficient scholarship caused by absences from school. This would mean that 26,800 children repeat their year's work because of dental troubles. In Oregon the per-pupil cost per year for elementary and secondary education is about one hundred and thirty dollars a year. (28) Hence toothache is a heavy burden upon the Oregon
taxpayer. The costs not so easily determined are lowered vitality, susceptibility to other diseases, and work poorly done. Dr. Osler, (221) declares that more diseases are brought about by decayed teeth than by excessive indulgence in alcoholic liquors.

**DEFINITION OF CARIES**

The following definition of caries is taken from "Diet and Health" by Dr. Hanke (102). Dental caries is the gradual decay of the tooth. It may involve the enamel, or both the enamel and the dentine.

**Caries of the enamel.** The first indication of caries is a white opacity. The enamel may be quite hard when this opacity is first noticed but after a time as the caries progresses it becomes roughened. This area becomes soft and may be removed by scraping. The spread of the process is along the axis of the enamel rods through the depth of the enamel toward the dento-enamel junction.

**Caries of the dentine.** Dentine is a more porous structure than enamel, because it has a higher percentage of organic matter and is perforated by tiny tubules extending from the pulp to the dento-enamel junction. Decay progresses more rapidly in the dentine than in the enamel. The inorganic salts of the dentine disappear, and the partially disintegrated organic matter of the
tooth shrinks and forms a dark leathery mass against the sides of the cavity. The tubules joining the cavity become greatly enlarged and packed with organic matter, composed largely of bacteria. The dentine around the cavity becomes softened and disintegrated.

The caries of the dentine does not follow the tubules of the dentine toward the pulp, but spreads over the surface of the dentine at the dento-enamel junction. In this way the enamel is undermined and will frequently fracture when some stress is put upon it, producing a large external cavity, even though the opening in the enamel previous to fracture might have been so small as to escape observation.

The location of carious lesions. Carious lesions may occur anywhere on the surface of the crown of the tooth but they are most frequently found in:

1- Pits and fissures of the occlusal surfaces of the molars and bicuspid, the buccal surfaces of molars, and the lingual surfaces of molars and incisors.

2- The approximal surfaces of the teeth.

3- Along the gum margin.

4- Under orthodontic appliances and clasps used to retain partial dentures.

5- In the tooth structure around a "leaky" filling.
THE HISTORY OF CARIES

Dental diseases are probably increasing with our civilization, but they are not peculiar to the twentieth century.

Caries in prehistoric times. An examination of 364 skulls of the Stone Age reveals the presence of caries in only 64 cases. (3)

Caries in ancient times. Dr. Hanke, (104) in a "Review of Dental Caries," in the "Journal of Nutrition" gives M.A. Ruffer, in the "Abnormalities and Pathology of ancient Egypt" as the authority for the statement that caries and suppurative periodontitis were not uncommon among the early Egyptians. Thoma, (251) states that his examination of many skulls of mummies of the period 4800 B.C., to 200 B.C., in the Peabody Museum of Harvard University, showed only two cases of true dental caries. He found many cases of dental disease, but these were the result of attrition. Frequently the tooth was so worn down that the pulp chamber was exposed. This resulted in infection and the formation of pus at the root. Some of the skulls show that the resulting inflammation had been treated by drilling holes from the mouth to the infected part. The methods of grinding grain left much grit in the flour and Dr. Thoma thinks this caused the extreme
attrition of the teeth.

G. Elliot Smith, (239) in "The Report of the British Association for the Advancement of Science" says that dental caries was uncommon in Egypt during the early part of the third dynasty, even though the people were living in a high state of civilization and probably luxury. In the latter part of the third dynasty the Alpine (Armenoid) race became numerous and continued to increase during the next two dynasties; dental caries increased with them. More than 80 per cent of the people suffered from decayed teeth. This seems to suggest that the alien peoples were more susceptible to caries than those of the Mediterranean race. Dr. Smith does not tell that the alien people made any changes in their mode of living.

The earliest record of dental caries in China is during the reign of the Emperor Huang Ti, about 2750 B.C. (2).

The Greeks and Romans had dental troubles. Hippocrates, (104) 460 B.C., describes a disease which is similar to our pyorrhea. Aristotle, (384-322 B.C.,) suggested that the viscous softness of the ripe fig caused particles of it to adhere to the mouth, and resulted in putrefactive processes. This is still the commonly accepted theory of dental decay. This theory found its great apostle in Miller, 1890. Celsus, (251) a celebrated
Roman physician, born about 30 B.C., advised extraction or filling with gold for carious teeth, and scraping, fixing with gold wire, and scarifying the gums of teeth which were loose. Galen, (3) (130-200 A.D.), said that a deficiency of nourishment not only caused the tooth to decay, but caused the cavities to become larger.

**Caries in early America.** The teeth of the American Indians even in our early history showed some decay, (169) but caries is increasing among the Indian tribes (246) as it always seems to when primitive races come in close contact with the white man.

A quotation from a Spanish writer in Prescott's "Conquest of Mexico," (210) mentions the beautiful teeth of the Aztec Indians. The writer says it was "bad form" for an Indian lad to leave the table until he had washed his face and hands and cleaned his teeth.

Livingstone-Jones, (136) says tumors, cancers, and toothache were unknown among the Thinglets of Alaska in the early days, but now the young people "suffer the tortures of the dentists." The older members of the tribe still have sound teeth.

**THE INCIDENCE OF CARIES**

The geographical incidence.

Caries are not limited to any portion of the earth's
surface. But people living in some countries seem to have better teeth than those living in other countries.

**Caries in the Far North.** The clinical observations of Dr. Lewman M. Waugh, (262) of the United States Public Health Service, show that the older Eskimos of Alaska had sound teeth, but the younger suffer from caries in varying degrees. Notka and Wainwright are the only places in Alaska where Dr. Waugh found the Eskimos free from caries. He ascribes the presence of caries to the changed diet of the natives.

In a study of the Eskimos along the Labrador coast during the summers of 1924, 1926, and 1927, Dr. Waugh (263) reported that the people of Ungava Bay were free from dental diseases, but those at the missions of Hope-dale and Makkovik had teeth in varying stages of decay. The last named regions are farther south. Dr. Waugh believes the cause of caries on the Labrador coast is the same as the cause in Alaska -- changed diet brought about by contact with our civilization.

The Eskimos in a small community in northern Greenland are very free from dental troubles. These people do not eat vegetable foods in any quantity, for such foods are not available. They depend upon sea animals such as the Narwahl and Belgua and the flesh and eggs of birds for their chief food. They do not waste any part of the
animals, except the liver of the polar bear, which they believe to be poisonous. (212)

Caries of the teeth were almost unknown in Iceland in the early days. This country was settled in the ninth century by colonists from Iceland and Scandinavia. They raised sheep, cattle, and horses, but no cereals. The modern Icelander, with the improved transportation facilities, has access to the foods of the world. His teeth are not as good as those of his ancestors. (212)

Caries in China. Dr. and Mrs. Agnew, (1) at the West China Union University, made a comparative study of the teeth of the Chiang tribes and the people of Chengtu, capital of the province of Szechwan. The Chiang tribesmen are mountain dwellers living in the border land between Tibet and West China. They are engaged in sheep raising, hunting, and gathering herbs. Their diet is chiefly the whole kernel of yellow corn and a small quantity of vegetables such as bage, peppers, cucumbers, and various kinds of beans. They have meat for special occasions. Fruits are scarce and poor. Vegetable oils are used to supply fats for the diet. The Agnews found peridontal disease almost universal and caries 35.8 per cent. The inhabitants of the populous city of Chengtu had 42.6 per cent caries and gingvitis and pyorrhea were equally common. The greatest difference was in the
children; those of the tribespeople had 32.5 per cent caries and those of the city 69.5 per cent.

This study does not indicate that the teeth of the Chinese are in the best possible condition; though they do show fewer caries than those of American children. Dr. McClendon, (184) of the Department of Physiology, University of Minnesota, advises a study of the Chinese diet to discover why the Chinese people have so few caries. He thinks that their freedom from dental disease must be due to the preponderance of vegetables in their diet, and to the coarser grinding of cereals for bread.

A study by Dr. Bert G. Anderson, (8) of the Medical School, Yale University, of the prevalence of caries in 975 Chinese, shows that caries decreases progressively as one travels from the coast to the interior. Dr. Anderson does not offer reasons for the decrease.

Caries in India. Colonel McCarrison, (183) says that caries are widespread among the inhabitants of India. Those most afflicted are the peoples living on diets in which cereals predominate. He says these diets are generally deficient in the vitamins A, C, and D.

Caries in isolated communities. Evelyn Sprawson, (240) of the Royal Dental Hospital, London, made a comparison of the teeth of the islanders of Tristan da Cunha with those of Pitcarn Island. These islands are both out
of the routes of steamships, they are both inhabited by people of British stock, and on both the inhabitants raise their own food. The people of the island of Tristan da Cunha, 140 in number, have very fine teeth. Dr. Marshal (240) examined the teeth of 54 of them. He found two decayed teeth in 21 people between the ages of three years and twenty years; 11 carious teeth in 21 people between the ages of twenty-one and forty-four years, and 21 carious teeth in 12 people between the ages of forty-five and ninety years.

The teeth of the people of Pitcarn are poor. The incisors seem more subject to decay than the molars, and the loss of the front teeth does not add to the pleasing appearance of the young adults of the island. Staff-Surgeon Lindop, (240) in the Admiralty Report for 1911, states that while the incisors of these people are poor their molars compare favorably with the teeth of the British blue-jackets.

On both islands eggs, fish, and fowl are the chief foods. Some vegetables are raised; chiefly onions, cabbage, turnips, and beets. Potatoes are raised on Tristan da Cunha and with fish, form the staple food. On neither of these islands are cereals cultivated. Jams, sugars, and sweets are practically unknown, except that sugar cane is cultivated on Pitcarn and syrup is made from its
juice. Tristan da Cunha has not had sweets for at least two generations. Milk is produced on Tristan da Cunha, and given to children when they are weaned. It forms a part of their food supply throughout their lives. There are no cattle kept on Pitcairn, and the goats on the island are wild and not suitable for dairy purposes. So the children get no milk after they are weaned.

The Island of Lewis in the Hebrides is another isolated community where the inhabitants have excellent teeth, and the lowest death rate in the British Isles, in spite of living in huts built of peat, having very thick walls and no chimneys. The domestic animals have access to the house, and chickens roost on the beds and chairs. The staple articles of diet are fish, oatmeal, and eggs. A favorite dish is cod's head stuffed with cod livers. Milk is not used to any extent, neither are vegetables.

Dental caries in the Tropics. The natives of Fiji Islands twenty years ago rarely had a decayed tooth, but now even in the remote districts far from the influences of towns decay is evident. The Fijian child is not taught to use artificial methods of cleaning the teeth, although young adult Fijians have adopted the use of the tooth brush. Milk has not been used in the diet until recent years. The chief foods are fish, meat, yams,
taro, tapioca and sweet potatoes. (92)

**Caries in Samoa.** Probably the lowest frequency of caries ever reported is given in an investigation made by R.A. Ferguson, (84) D.D.S., United States Navy, a member of the Public Health Department of American Samoa, of dental conditions among the natives of American Samoa. He examined 2,116 children in the public schools and 141 children in missionary schools. Of all these only 10.14 per cent had one or more carious teeth. The total number of teeth examined was 58,478 and 0.84 per cent were carious. In the "Jungle" schools, situated in those parts of the islands difficult of access, where the pupils live on native food and in the native manner, 807 pupils were examined. Of these only 3.22 per cent had cavities. To find out the condition of the adults, fifty Samoan soldiers were examined. These men were an average of thirty years old. They had 81 fillings and 48 extractions. The same number of American sailors stationed in Samoa were examined. These were an average of thirty-three years old; they had 259 fillings and 191 extractions. Dr. Ferguson says that the natives had been living on the American naval ration for an average of nine years, and the contrast would probably be greater if the Samoans had been compared with an unselected group of Americans. The recruiting statistics for 1932 show that
12,811 applicants for the navy were rejected because of dental defects.

The mainstay of the native Samoan diet is banana and taro, a plant with a starchy tuberous rootstalk. Coconuts, breadfruit, avocados, oranges, limes, and mangos are also eaten in season. Pig, chicken, and fish are flesh foods which are served on special occasions. Sugar is not eaten, however the stalks of sugar cane are chewed. Salt is not often added to food but some foods are boiled in sea water. The babies are breast fed until about the sixth month, then they are given a diet composed of banana soup and grated young cocoanut fruit.

Caries in America. Dr. Percy Howe (125) estimates that about 95 per cent of the children of the United States suffer from dental caries. A survey made during the school years 1922 to 1925 of the dental conditions among the school children of Missouri, Illinois, Georgia, and Maryland, showed that of 12,435 children under nineteen years of age, 98.8 per cent had one or more permanent teeth decayed or filled, 20 per cent of the children under six years old had one or more permanent teeth decayed or filled. (247) Dr. Steenbock, (243) says that bad as the teeth of Americans are those of the English are probably worse. Dr. Cross, (29) of the Forsyth Dental Infirmary for Children, Boston, says that 96 per
cent of the American children have defective teeth and 96 per cent of the children who come to America from the southern part of Europe have sound teeth. Dr. Brekhus, (45) of the dental school of the University of Minnesota, examined 10,445 students over a period of three years, and found that 2.11 per cent of them had perfect teeth.

The racial incidence of caries.

Dr. E.W. Fish, (86) of the Royal Dental Hospital offers the investigations of G. Elliot Smith, (239) and the observation of J.W. Field, (86) to prove that caries are racial in character. Dr. Smith found increased caries in Egypt when the Alpine race supplanted the previous inhabitants in the latter part of the third dynasty.

Field, (86) (1929) recorded that 100 Chinese and 100 Tamil coolies working together, having much the same food and exposure to sunlight, showed a difference in their susceptibility to dental caries. The 100 Chinese had 163 carious teeth and the 100 Tamils had seven. The Tamils chewed betel nut and its caustic content might have influenced the oral flora.

R.A. Ferguson, (84) reports the effects of marriage with other races upon the dentition of the Samoans. The mixture of Samoan and Chinese and Samoan and white had about equal susceptibility to caries and were more susceptible than the native stock. The Filipino-Samoan came
next, and the Japanese-Samoan was the least resistant to
dental caries of any of the races which were observed.
Jones, Larsen, and Pritchard (138) found that the Japanese
babies of Hawaii showed poorer dentition than the babies
of other nationalities which they studied. A dental ex-
amination was made in Shelby County, Tennessee, (191)
where the whites and negroes are about equal in number
and live in separate communities with their own schools
and churches. The examination included the school children
in the first six grades, and showed the white children
to have 73.7 per cent caries and the negro children to
have 41 per cent caries. The permanent teeth of the
children examined were better in the negro children than
in the whites, and the temporary teeth of the negro
children were very much better than those of the white
children. The food of the negroes contained more rough-
age, and less cereals than that of the whites. 17.9 per
cent of the whites did not use a tooth brush and 56.1 per
cent of the negroes did not. The author suggests that
the temporary teeth of the negro children might be better
because the negro women are usually happier than white
women during gestation.

Hess (113) found that negro children in New York,
from a district where rickets were prevalent, had better
teeth than white children who had never had rickets.
The Dental Supervisor of the United States Indian Service (60) writes: "With some exceptions the incidence of dental defects in Indian children is comparable to that of white children under similar environment."

The observations quoted above tend to discount the theory that race has much influence upon caries, if it had, the teeth of the Eskimos, Fijians, and Indians would not show increased caries. The people of the island of Lewis have the same racial background as those in the north of Scotland, but they have much better teeth. The inhabitants of Tristan da Cunha and Pitcarn are not of different racial stock, but they differ in freedom from dental caries.

**Hereditary immunity to caries.**

Some of the children used in Bunting's studies (55) were immune to dental caries. Dr. Bunting believes that this immunity may be transmitted from parent to child. Hanke, (102) also, speaks of the generally accepted statement that some people and certain races are immune to dental caries. He suggests that the constancy in the food habits of families, and even some races, may be responsible for the so-called hereditary immunity.

The position of the teeth in the jaw, the shape of the teeth, and the shape of the jaw seem to be inherited. Recent investigations regarding the teeth of twins seem
Diagram of a vertical Section of a Tooth

"Human Physiology" -- Brubaker
to add weight to the opinion that anomalies of tooth and jaw formation are passed from parent to child. (231)

**Age in relation to caries.**

The occurrence of caries is greatest between the ages of seven years and twenty years. After twenty there is a marked decrease. But people over twenty years of age can not afford to neglect their teeth, for there is no age of freedom from caries. There are often periods of temporary immunity for which there is no explanation. (142)

Dr. William Lintz, (173) kept a record of a large consecutive number of office patients. He found that 15 per cent more teeth were lost from the upper than the lower jaw. The teeth were lost in a definite order: the molars, the bicuspids, the central incisors, the lateral incisors, and last, the cuspids.

**The effect of economic status upon caries.**

Wealthy people do not seem to have better teeth than those who have only enough money for the necessities of life. (142) They probably keep their teeth longer because they can afford to visit the dentist at frequent intervals. Mrs. Mellonby found more decayed teeth among the children of the poor classes, but the children she mentions were probably below the minimum standard of living.
The structural development of the teeth

The following summary of the development of the teeth is taken from Tomes, "Dental Anatomy." (245)

The development of the enamel. About the fortieth or forty-fifth day of fetal development, in a situation corresponding to the future alveolar border, there is an ingrowth of epithelium extending along the whole length of the jaw. About the forty-eighth day club shaped thickenings appear at each point where a tooth is going to be formed. Very soon each little thickening assumes a bell shape; this is the beginning of the future enamel organ. A papilla-like specialization of the submucous tissue forms in the hollow of the bell: this is the dentine germ. So the enamel and dentine develop at the same time, the enamel organ from the epithelial tissue; the dentine organ from the submucous tissue. The cells of the enamel organ elongate, the nuclei recede toward the extremities, and the cells form a regular columnar epithelium. The cells are now called ameloblasts or adamantoblasts. Their function is to form enamel. How they perform this function is not definitely known. One theory is that salts are deposited in the cell tissue of the ameloblasts themselves, and the cell substance is thoroughly impregnated with these salts; the cell walls then form the organic matrix for the enamel. The other theory is that
the cells act as secreting organs for these salts. In any case there is very little organic material in the completed enamel. Tomes says some investigators estimate from 3.0 per cent to 5.0 per cent, but he thinks there is less than this. Thewlis, (252) is a late investigator in this field, and he estimates the organic material in the enamel at 0.5 per cent. Investigations of Segio Funaoka (90) show human enamel to be an aggregate of microcrystals arranged around a longitudinal axis of the enamel prisms, their crystallographic axes parallel to each other and to the longitudinal axis of the prism. The enamel covers the crown of the tooth. It is usually thickest in the cusps and thinnest at the margin of the gums. It is the hardest tissue of the body.

The development of the dentine. The dentine germ is at first an opacity without any visible structural change, except that it has more cells than the neighboring tissue. Then from the base of it prolongations pass outward and upward as they, in a measure, embrace the enamel organ. These elongations form the dental sac in which the tooth develops. As calcification approaches, a more highly specialized layer of cells becomes differentiated. The function of these cells is to form dentine, and they are called odontoblasts. Some investigators think the odontoblasts calcify the cell structure of the dentine, and
others believe that the odontoblasts secrete calcareous salts which they deposit in an organic matrix formed from the tissue of the pulp. Korff, (163) from studies he has made on the dog, pig, and calf, thinks that fibrils develop from the connective tissue of the dental papillae before the odontoblasts are formed. As the odontoblasts develop these fibrils form a mesh external to them and project through the spaces between the odontoblasts. The fibrous nature of this mesh disappears as a predentine substance is laid down. Later this predentine is calcified. The usual theory is that the dentinal fibrils are prolongations of the odontoblast cells. (254)

The dentine is formed upon the surface of the dentine bulb or papillae from without inward; so no portion of the dentine once calcified can receive any increase in dimensions. All additions to the dentine must take place upon the interior or pulp surface of the dentine cap. The dentine makes up the greater portion of the tooth. It is a very hard and highly elastic substance without definite cellular structure. The organic matrix of the dentine is easily distinguished in the decalcified tooth.

Composition of dentine. Tomes gives the following composition of the dentine:

Organic matter 37.91 per cent
Fat 0.40 per cent
Diagram showing what permanent tooth replaces each temporary tooth, and the order of succession of the teeth in each set.

"The Text-book of Anatomy" of American authors
Calcium phosphate and fluoride 66.72 per cent
Calcium carbonate 2.26 per cent
Magnesium phosphate 1.08 per cent
Other salts 0.83 per cent

E.W. Fish (85) gives the total calcium in dried human dentine as 34.03 per cent to 41.5 per cent. He says that the first few years after eruption there is a rapid increase in the percentage of calcium in the dentine. He does not find any difference in the calcium content of the dentine of molars, cuspids, and incisors. Carious teeth do not show a deficiency of dentine. Parathyroidectomy on cats was found to lower the calcium content of the dentine in their teeth, but the author makes no mention of decay as a result of the lessened calcium. Diets low in calcium fed to young dogs partially arrested the normal increase of the calcium content of the dentine. Lundstrom and Pond, (177) of the University of Pennsylvania, Medical School, assert that the composition of the dentine changes with age: That the ratio of calcium to magnesium decreased as one grows older. Sometimes the magnesium is increased as much as 50 per cent.

The pulp of the teeth. The pulp occupies the central portion of the tooth and is the formative organ for the dentine. It varies in anatomical character with the age of the tooth. When the tooth is young the connective
tissue, which is probably formed from processes of the cells, is very delicate and the cells are numerous. The spaces between the cells are filled with a jelly-like substance. When the pulp has aged, the bundles of connective tissue become larger. The pulp is the source of the vascular and nervous supply of the dentine; it is well supplied with blood and lymph vessels and nerves, which enter the tooth at the ends of the roots. (245)

**The formation of its root.** When the formation of the dentine and enamel has progressed to the extent that the crown of the tooth has grown its full length, the neck and roots are formed. The neck is that slightly constricted part of the tooth at the margin of the gum between the crown and the root. When the crown of the tooth first appears through the gum the root has not been calcified. As the dentine of the root is formed and calcified, it is coated with a closely adherent vascular membrane, which is really the follicle wall. When the tooth is completed this membrane forms the alvelodental periodontium -- the connection between the tooth and the bone of the jaw. The inner surface of this membrane -- that part next the tooth -- has a layer of large cells. These cells are called osteoblasts, and are a special development found where bone is to be formed. The osteoblasts form the cementum of the tooth, a bone-like substance
which covers the dentine of the root much as the enamel does the dentine of the crown. Behind this osteoblast layer of the periodontal membrane, is a reticulum, or network, which looks like connective tissue and has many interlacing processes, some of which are seen in the completed cementum and are known as Sharply's fibers. These fibrous bands extend from the alveolar bone toward the tooth. Many of them have their ends buried in the cementum and in the alveolar bone. (245)

**THE GROWTH AND CALCIFICATION OF THE TEETH**

The *fetal development of the deciduous teeth*. About the forty-eighth day of fetal development little club shaped thickenings appear in the alveolar membrane at each point where a tooth is to be formed. These are the dental papillae. Calcification of these growths varies according to the time that the tooth is to erupt. There is calcification of the deciduous incisors about the twentieth week of fetal life. A trace of calcification of the temporary molars and cuspids begins about the twenty-fourth week. The cusps of the molars are united about the thirty-third fetal week. At birth the crowns of the temporary teeth are in varying stages of calcification. Hess (112) analyzed the teeth of still-born infants and found that the deciduous incisors had 20 per cent of
their total calcium. The first deciduous molar had 21 per cent, the second deciduous molar 11 per cent, and the deciduous canines 7.5 per cent of the total calcium to be expected in a fully developed deciduous tooth.

**The postnatal development of deciduous teeth.** After the child is born the calcification of the teeth continues until the crowns are formed, then the teeth are said to erupt. The cutting of the teeth is not the active process the term "eruption" seems to imply. The tooth is not pushed upward by the growth of the root. The growing tooth does not move, but is carried to the surface of the gum by the growing alveolar bone. As the alveolar bone grows, the upper portion, or gum margin, of it is resorbed, this resorption bringing the tooth into prominence. The practice of giving babies something hard to bite when they are teething has a sound physiological basis, for the pressure helps in the resorption of the growing bone. (163)

**The eruption of the deciduous teeth.** The time of eruption of the teeth depends upon many factors; the physical development of the child, the type of food eaten, and illnesses of the child. The average eruption given in a bulletin of the United States Public Health Service (259) is found in Table I.
TABLE I

ERUPTION OF THE DECIDUOUS TEETH

<table>
<thead>
<tr>
<th>Deciduous Teeth</th>
<th>Time of Eruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two Lower Incisors</td>
<td>5-7 months</td>
</tr>
<tr>
<td>Two Upper Incisors</td>
<td>6-8 months</td>
</tr>
<tr>
<td>Two Lower Lateral Incisors</td>
<td>7-9 months</td>
</tr>
<tr>
<td>Two Upper Lateral Incisors</td>
<td>8-10 months</td>
</tr>
<tr>
<td>Four First Molars</td>
<td>10-14 months</td>
</tr>
<tr>
<td>Four Second Molars</td>
<td>2 years</td>
</tr>
<tr>
<td>Four Cuspids</td>
<td>2-2(\frac{2}{3}) years</td>
</tr>
</tbody>
</table>

From "United States Public Health Service, Keep Well Series No. 12." Treasury Department, 1931
The fetal development of permanent teeth. The papillae of the first permanent molar (the six-year molar) appears about the seventeenth week of fetal life, that of the permanent incisors and cuspids about the twenty-fourth week, and of the permanent bicuspids about the twenty-ninth week.

At birth there are forty-four teeth in varying stages of development. The twenty deciduous teeth are in the process of calcification. There is a divergence of opinion about the stage of development of the permanent teeth at birth. Table II gives the investigations of some of the best known workers. Hess (117) found 0.1 per cent of its total calcium in the first permanent molar at birth. Bunting (174) in his study of the teeth and jaws of 25 new-born and still-born infants found the permanent teeth to be only dental follicles of soft embryonic tissue. Kuglemass and King, (166) agree with this finding. Logan and Kronfeld (174) are, also, of the opinion that there is no calcification of the permanent teeth before birth. But Legros, Magitot, Pierce, Black and Brady state that the first permanent molar is calcified during fetal life. (174)

The postnatal development of permanent teeth. The papillae of second permanent molars appear about six months after birth, and that of the third molar when the
child is about five years old. Table III gives the time of calcification of permanent teeth.

The eruption of permanent teeth. About the sixth year the temporary teeth may be noticed to have wider spaces between them and to occupy a more anterior position in the jaw. Their roots are being resorbed. The root at or near its end becomes excavated in hollow cap-shaped depressions which deepen and coalesce until it is absorbed. This resorption is effected by some giant cells called ostoclasts. The way these ostoclasts work is not known. (254) As the roots of the teeth are resorbed the alveolar bone at the gum margin is also resorbed and replaced by the newer growth of the bone from below. As the bone grows upward the permanent teeth are brought to the gum margin and finally erupt. There are only twenty deciduous teeth, so the jaw has to grow larger to make room for the thirty-two permanent teeth. The bicuspids take the place of the temporary molars. Table IV gives the usual time of eruption of the permanent teeth.
<table>
<thead>
<tr>
<th>The Tooth</th>
<th>Legros and Magitot</th>
<th>Pierce</th>
<th>Black</th>
<th>Brady</th>
<th>Churchill</th>
<th>Logan and Kronfeld</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Incisors</td>
<td>1st month</td>
<td>1st year</td>
<td>1st year</td>
<td>1st month</td>
<td>1st-2d month</td>
<td>3-6 months</td>
</tr>
<tr>
<td>Lateral Incisors</td>
<td>1st month</td>
<td>2d year</td>
<td>2d year</td>
<td>2d year</td>
<td>2d month</td>
<td>3-15 months</td>
</tr>
<tr>
<td>Cuspids</td>
<td>1st month</td>
<td>3d year</td>
<td>3d year</td>
<td>3d year</td>
<td>4⅔ months</td>
<td>3-6 months</td>
</tr>
<tr>
<td>First Bicuspid</td>
<td>1st month</td>
<td>4th year</td>
<td>5th year</td>
<td>4th year</td>
<td>3d year</td>
<td>1⅔-2 years</td>
</tr>
<tr>
<td>Second Bicuspid</td>
<td>1st month</td>
<td>5th year</td>
<td>4th-5th year</td>
<td>4th year</td>
<td>4th year</td>
<td>2-2⅔ years</td>
</tr>
<tr>
<td>First Molars</td>
<td>6th fetal month</td>
<td>25th fetal week</td>
<td>Before birth week</td>
<td>25th fetal week</td>
<td>9th fetal month</td>
<td>1-4 months</td>
</tr>
<tr>
<td>Second Molars</td>
<td>3d year</td>
<td>5th year</td>
<td>6th year</td>
<td>5th year</td>
<td>4th year</td>
<td>2-2⅔ years</td>
</tr>
<tr>
<td>Third Molars</td>
<td>12th year</td>
<td>9th year</td>
<td>8th year</td>
<td>8th year</td>
<td>8th year</td>
<td>7-9 years</td>
</tr>
</tbody>
</table>

From "The Journal of the American Dental Association" 20: 379. March, 1933
### TABLE III
**APPROXIMATE TIME OF GREATEST CALCIFICATION**

<table>
<thead>
<tr>
<th>Age</th>
<th>Teeth Calcified</th>
</tr>
</thead>
<tbody>
<tr>
<td>The First Three Years of Life</td>
<td>First Molar</td>
</tr>
<tr>
<td></td>
<td>Central Incisors</td>
</tr>
<tr>
<td></td>
<td>Lateral Incisors</td>
</tr>
<tr>
<td></td>
<td>Incisors</td>
</tr>
<tr>
<td>From Three Years to Six Years</td>
<td>Bicuspids</td>
</tr>
<tr>
<td></td>
<td>Second Molars</td>
</tr>
</tbody>
</table>

**TABLE IV**

**ERUPTION OF THE PERMANENT TEETH (50)**

<table>
<thead>
<tr>
<th>Permanent Teeth</th>
<th>Time of Eruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Four First Molars</td>
<td>5-7 years</td>
</tr>
<tr>
<td>Two Lower Incisors</td>
<td>5-7 years</td>
</tr>
<tr>
<td>Two Upper Incisors</td>
<td>6-8 years</td>
</tr>
<tr>
<td>Four Lateral Incisors</td>
<td>6-8 years</td>
</tr>
<tr>
<td>Four Bicuspids</td>
<td>8-10 years</td>
</tr>
<tr>
<td>Four Second Bicuspids</td>
<td>10-12 years</td>
</tr>
<tr>
<td>Four Cuspids</td>
<td>10-12 years</td>
</tr>
<tr>
<td>Four Second Molars</td>
<td>11-14 years</td>
</tr>
<tr>
<td>Four Third Molars</td>
<td>17-25 years</td>
</tr>
</tbody>
</table>

From "United States Public Health Service, Keep Well Series No. 13". Treasury Department, 1921
Dystrophies of the teeth.

Changes may occur during either prenatal or postnatal life which affect the development of the teeth. The deviations from the normal are hyperplasia, hypoplasia, and atypical arrangement. (250) The causes of these malformations are inherited tendencies; diseases which affect the health of the parents such as syphilis, tuberculosis, diabetes, nephritis, blood dyscrasias, endocrine dysfunction and osteomalacia; diseases which affect the health of the child after birth, and malnutrition of the parent or the offspring. Dentification disturbances during prenatal life affect only the deciduous teeth unless there should be some dysfunction that would affect the follicle of the permanent teeth. The permanent teeth seem most affected by the first three years of life. (117)

Changes in the form of teeth due to illness.

Dr. P.C. Thibault, (250) of Paris, has studied the teeth of many children and he believes that every toxic infection leaves its mark upon the teeth. Complete dystrophies alter the form and dimensions, while partial dystrophies cause erosions. These are classified as capsular depressions, linear erosions, semilunar notching, and irregular edging. The capuliform depressions are seen
following bronchopneumonia, gastroenteritis, and eruptive fevers. The linear erosions follow chronic intestinal conditions and poor alimentary hygiene. Notchings and edgings are found following tetany and rickets. Hutchinson's teeth represent complete dystrophy and are characteristic of syphilis. Dr. Hess (115) says there is no characteristic pathological lesion of the teeth which is distinctive of rickets. In the long bone the diagnosis is established by the presence of osteoid tissue, and of the overgrowth of cartilage, but in the teeth the criteria is simply hypoplasia and caries, which are not specific lesions, but result from various factors: congenital, dietetic, and hygienic.

**Structural changes in the teeth of animals due to diet.**

The chemical composition of the teeth of young animals may be changed by the food they receive. Karshan (146, 147) found that the incisors of young rats fed a diet low in calcium had less calcium, phosphorus, and total ash than the incisors of rats fed diets adequate in calcium. The addition of vitamin D to a diet low in calcium increased the calcium content of the incisors. The variations in the teeth were not as great as those in the tibae of animals, showing that the growing teeth are less sensitive than the growing bones to changes in the diet. The changes were more pronounced in the dentine
than in the enamel of the incisor. Rosebury and Karshan (216, 217) found the enamel of fully formed rat molars and incisors to be normal in spite of diets low in calcium or in vitamin D. Mellanby (200) produced hypoplasia in dog's teeth by interference with the intake of calcium, phosphorus, or vitamin D.

Smith (234, 235) found a change in the composition of rat incisors due to a shortage of vitamin A. There was a decrease in the percentage of total ash, an increase in the percentage of calcium and a decrease in phosphorus. The incisors became white and opaque; they became short and blunt, and did not grow normally. These reports refer to the findings of Shabita, who stated that rats on a diet deficient in vitamin A had teeth with abnormal formation of the enamel, cementin, and dentine.

The lack of vitamin C in the diet of guinea pigs produces a very definite change in the structure of the teeth. In fact, microscopic variations from normal take place in the teeth of guinea pigs before any change is demonstrable in the other body tissues. (121) The changes produced in the teeth of guinea pigs by lack of vitamin C are in the odontoblast layer. The odontoblasts grow shorter, more rounded, and show a different arrangement. They secrete hard tissue between themselves, and become more like osteoblasts placed in bone canals; the Tomes'
canals are widened; new bone is formed instead of dentine; there are frequently hemorrhages in the pulp, and resorption of the pulp tissue. This resorption of the pulp sometimes continues until hollows filled with fluid can be found in the pulp tissue. (225)

Day (66) reports hypoplasia of the dentine of the teeth of young guinea pigs, born of a mother on a diet deficient in vitamin C. The teeth of the mother suffered more than the teeth of the offspring.

Changes in human teeth due to diet.

Prenatal diet. The evidence of the influence of prenatal diet upon the structure of teeth is not very conclusive. Louise Knappes (157) made a study of twenty-five children with perfect teeth and twenty-five with rampant dental caries. She found that the mothers of the children having perfect teeth ate more fruits and vegetables during pregnancy than the mothers of the group with poor teeth. One mother, whose child had excellent teeth, said that her own teeth were poor so she had made a definite effort to eat foods that would cause her child to have good teeth. This study is interesting, but it can not be evaluated as a scientific experiment; it has too many variables. The author said it was difficult for the mothers to give much information about their diet. Dietetians find there frequently is a wide variation be-
tween the food people actually eat and the food they think they have eaten.

Mrs. Mellanby (199) states that if the food of the mother is low in vitamin D or calcium, the deciduous teeth of her offspring will show defective calcification.

In forty-four experiments conducted on seventeen pregnant women living on their usual home diets, the Toverunds (256) found that almost all of these cases showed a negative calcium and phosphorus balance during the last two months of pregnancy. They believe more calcium phosphorus is required than is generally thought necessary. A negative calcium and phosphorus balance during pregnancy would lower the composition of the fetus in these elements, which are used largely to form teeth and bones. Thus a predisposition toward rickets and dental caries would be established. (256) Experiments on dogs carried on by these authors verify their opinion that the teeth of the offspring will not have as good structure as they otherwise would if the diet during pregnancy is inadequate in minerals.

Dr. Steenbock (242) suggests that the first step in the prevention of caries is to see that the teeth are well-formed. They must have a good organic matrix and sufficient mineral elements to complete their structure. Vitamin C has been shown to be necessary for the formation
of the organic matrix of the teeth of animals; (121) it is probably as essential for human teeth. Deciduous teeth are partly formed before birth, hence their structure depends upon the diet of the mother.

Jones, Larsen, and Pritchard (138) concluded from a study of infants in Hawaii that there is a parallelism between the bone forming and the dentine forming tissues and that hypoplasia of the dentine does not necessarily imply that the enamel is also hypoplastic. They say that the dentine and enamel originate from different layers of the organism. The dentine is derived from the mesoderm and the enamel from the ectoderm. This is their explanation of why some types of hypoplastic teeth do not decay. They give two examples of babies with distinct hypoplasia of the dentine. One died at birth; it had osteogenesis imperfecta. The other had severe rickets and died when a few months old. The unerupted incisors of these infants showed good enamel calcification, but very poor dentine formation. They refer to a study made in 1932 for examples of babies with hypoplasia of the enamel. (139) This study indicates that the enamel had disintegrated after it had formed. Two case histories were given. One was the stillborn child of a mother ill with nephritis, the other a Japanese baby who had died of starvation when it was four months old. The enamel of the unerupted in-
cisors of these infants was soft and chalky and badly disintegrated but the dentine was well formed. The authors say that acid imbalance, caused by nephritis and starvation, was probably responsible for the dissolution of the enamel. To accept this statement one must grant that acidosis can cause the fluids of the tissues to become sufficiently acid to dissolve unerupted teeth.

Variations from normal in the structure of teeth may be caused by glandular disturbances affecting the metabolism. (244) The effect of the parathyroids upon tooth structure has probably been more extensively investigated than the other endocrine because the parathyroids definitely influence the utilization of calcium. (144)

Postnatal diet. The factors which affect the temporary teeth would produce the same effect upon the teeth formed after birth if their influence continued. But it is not always necessary for a child to have hypoplastic and irregular permanent teeth even if his temporary teeth are malformed. Dr. C.L. Drain (75) showed pictures of children with very poor temporary teeth, then pictures of the same children taken six to eight years later. The permanent teeth which had erupted during the time that elapsed were well formed and well calcified. If the hypoplastic teeth are due to some glandular disturbance, or the effects of a disease it would not be possible to
make such a complete transformation through diet, unless the immediate cause could be corrected by good food. The children shown in Dr. Drain's photographs were in the hospital undergoing treatment for diabetes and for coeliac disease.

The effect of lack of calcium, phosphorus, or vitamin D upon the structure of human teeth is shown in the permanent teeth of children who have had rickets in infancy. Hess (115) says there is no particular form of dystrophy, characteristic of rickets but frequently hypoplasia results from this disease.

We have to depend upon animal experimentation for the effects of lack of vitamin C upon the structure of the teeth of people. The results in the case of guinea pigs and monkeys are very definite and there seems to be enough similarity in the physiological processes of these animals and man to warrant the conclusion that latent scurvy in children "can lead to changes in the pulp tissue and dentine of human teeth similar to those determined for the guinea pig." (102)

Bloch (34) did not find that the teeth of Danish children who were in a home for the blind, because of xerophthalmia in infancy, were different from the teeth of children who showed no evidence of ever having been deficient in vitamin A. Boyle (44) from the examination of
the rudiments of a six year molar of a three and a half months old infant who died of vitamin A shortage believes that lack of sufficient vitamin A will cause an interference with the calcification of the dentine and almost complete atrophy of the enamel organ.

Boyle points out that there were 64 xerophthalmia patients in the Danish home for the blind, referred to by Bloch, and 58 of these had defects in their teeth. Only 19 had positive histories of rickets, so some of the other 39 hypoplastic teeth might have been due to the shortage of vitamin A. It is true that the defects in structure might have been due to lack of vitamin A but they might equally well be due to some other factor. Our knowledge of the action of food upon the structure of human teeth will have to be gained by careful observation of clinical results interpreted through the knowledge gained by animal experimentation.

The effect of drinking water upon the structure of the teeth.

Marshal (181) speaks of the difficulty of evaluation of the results of Mrs. Mellanby's research regarding the value of vitamin D in the diet of children in three institutions. In institution No. 1 a supplement of treacle was fed; in institution No. 2 a supplement of olive oil; in institution No. 3 a supplement of cod-liver oil. The
hardness of the water varied from 7.2 parts calcium carbonate to 100,000 parts water, in institution No. 2 to 24.2 p.p.m. in institution No. 3. He says: "the question naturally arises as to what influence this difference in hardness, expressed as parts per 100,000 of calcium carbonate, exerts upon the degree of calcification of the bone and teeth. Until this point can be settled, it will be difficult to evaluate her results. They are described as due to the influence of the added dietaries."

J. Forbes Webster (264) referring to a statement that Great Britain had the worst teeth in the world and Glasgow the worst in Britain, says that part of the blame is due to the softness of the Glasgow water. He suggests that the city of Glasgow add lime to the water.

Assuming that water which had 6 parts calcium salts per 100,000 parts of water was "hard" Rose (143) found that the percentage of people having healthy teeth of those who drank soft water was 1.3 per cent to 4.3 per cent. Of those who drank hard water 4.3 per cent to 20.2 per cent had wholly healthy teeth. Walters (143) found 18 per cent caries in a group drinking water having 15.96 parts calcium salts to 100,000 parts of water and 36 per cent carious teeth in a group drinking water having 6.2 parts calcium salts per 100,000 parts of water. The information given above is taken from an editorial review
in the "Journal of the American Medical Association" and, as the author of the review points out, the investigators did not consider the mineral content of the food. An analysis of the mineral content of the city water supply of our large centers of population correlated with the dental health of children of school age would be interesting.

Mottled teeth. Mottling is a dystrophy of the teeth. It affects their appearance rather than their function. The enamel becomes opaque and chalky white. In some cases it is pitted and corroded. It may stay in this white condition or it may stain. (238) The discoloration usually follows the lip line and ranges in color from a very dark brown, almost black, to a light yellow. This defect is not found in the deciduous teeth that are calcified previous to birth, so it is evidently not dependent upon the nutrition of the mother. (189) The first report made in American literature upon this subject was by Black and McKay in 1916. (30) Smith and Lantz (237) found mottled teeth occurred in communities in Arizona where the drinking water was high in fluorides. Smith also showed that a diet "adequate in calcium and phosphorus intake during the years of enamel formation will not prevent the development of mottled enamel if the child is exposed to the environmental factors of an endemic community." (238)
McKay (189) gives an interesting report of the water supply of Oakley, Idaho. The community changed its water supply seven and one half years previous from one containing 6 parts per million fluorine to one containing 0.5 parts per million fluorine. Not any children born since the change have mottled enamel, those born before all had this defect. Dean (67) made a survey of the areas of mottled enamel in the United States. Because of the similarity of mottled teeth to those caused by parathyroidectomy Steenbock and Parsons (244) fed animals toxic doses of sodium fluoride and then analyzed the parathyroid glands of these animals. They were convinced that fluorine does not interfere with calcium metabolism through changes in the parathyroid. How it does act has not yet been discovered. Fluorine is not thought to be necessary for the formation of the teeth. (226) However, the only method of avoiding mottled teeth seems to be to avoid drinking water having high concentrations of fluorine during the periods the teeth are forming enamel. There does not seem to be any method known by which large quantities of water may be treated to remove the fluorine. (189)
Theories of the etiology of dental caries

Reasons why the etiological factor has not been found.

Decayed teeth probably furnish the dentist with nine-tenths of his practice, (260) but the forceps are the only undisputed cure for them. There are a number of reasons for the difficulty in finding the causitive factor of caries. Some of the most obvious are given below.

No suitable experimental animal. There is no suitable experimental animal with teeth shaped and arranged like those of a human being. The dog, the guinea pig, and the rat are the animals commonly used for experimental work. The guinea pig has teeth with growing pulp. The incisors of the rat also grow after they are fully developed; the molars do not, but the cusps of the rat molar are not covered with enamel. The teeth of the dog are not shaped like human teeth, and it is very difficult to produce caries in dogs. The food habits of these animals in their natural state are not like those of people, but they can be made to eat experimental diets. The results obtained from experimental work on these three species of animals must be carefully studied to see that they conform to clinical experience, before they can be applied to human beings.
Experiments on people. Experimental work on human beings is almost an impossibility; the results that are published are clinical experience, rather than controlled experiments. Orphanages are used most frequently to study the effects of diet, or some other therapeutic treatment, upon the teeth of children. These are group studies, and hence, do not consider the individual child except as a member of the group. The children vary in physical development, psychological attitudes toward food, and in metabolic conditions. So the diet planned for a number of children would not give the same results for each child. The children must frequently manage to get foods that are not part of their dietary régime. Dr. Drain (77) in a lecture at the meeting of the Oregon State Dental Association, in Portland, said that when he gave his dietary, which he has found very successful in controlling dental caries, to mothers they frequently said, "Why, Doctor, my child does eat these foods," but when they began to keep an accurate record they found that there were frequently discrepancies between what the child actually ate and what they thought he ate. If we could keep people under as carefully controlled conditions as we can experimental animals, we could surely obtain much more convincing experimental evidence. The only place where we can nearly approximate these conditions is in a
hospital, and there we are not usually dealing with healthy people.

**Caries not always distinguished.** Dr. Thoma (251) pointed out in his book, "Teeth and Diet," that the teeth of the Egyptians were better than many investigators supposed. The teeth became worn and the pulps exposed and infected from attrition, not caries. This is not usual in our civilization because we eat refined foods, but it is not unusual in primitive peoples. The final result of attrition and caries would be similar -- the infection of the pulp and the loss of the tooth. Even well calcified enamel could be cracked by very coarse food or some strain. The result would resemble caries.

**Little cooperation in research.** The interest in the cause of caries is intense and reports concerning the etiology which vary greatly have been published. If several groups of workers in different parts of the world would work on some one phase of this problem, compare their results, and repeat the work which is questioned, it would be possible to eliminate some of the factors that are now offered as causes of caries, since it is often possible to arrive at the correct solution of a problem by a process of elimination. Many of the articles which are published give the impression that the investigators had certain results in mind before the investigation was
started and their findings substantiate their particular theory; other investigators who have different theories can read into the same findings evidence for their theses.

Two main theories of the etiology of caries.

The present day theories of caries may be divided into two large classes:

1 - Caries in the teeth are due to forces outside the tooth causing the disintegration of the enamel and dentine.

2 - Caries in the teeth are due to some breakdown within the tooth itself which renders it susceptible to outside disintegrating influences.

The tooth paste manufactures use the first, in its extreme and now discarded sense, for their slogan, "A clean tooth never decays." The second theory might in its extreme interpretation be, "A well-nourished tooth never decays." Most modern investigators believe both diet and cleanliness are essential. Their disagreement is concerning the primary factor in dental caries.

The first theory was set forth in detail in "Micro-organisms of the Human Mouth," published by Miller (1890). It was commonly accepted for some years, and is still held by well known investigators. Some of these are Gies, (95) McIntosh, (188) Rodriguez, (83) Bunting, (58) and Sim Wallace. (260)
The second theory is newer. This is not really a single theory. For the proponents of the theory that caries are due to a breakdown within the tooth itself, do not agree as to the one factor essential for maintaining the integrity of the tooth. Calcium, phosphorus, vitamin C, and vitamin D each has its supporters.

The oral hygienists. The oral hygienists believe that cleanliness of the oral cavity is the sole factor in the prevention of dental decay.

Lorrion, (175) of the New York School of Dentistry, says that brushing the teeth is an effective method of preserving them. Even though the brushing will not remove plaques from the teeth, it removes bacteria from the surfaces not covered by plaques, and stimulates the gums.

Dr. Hartzell (108) in a paper read before the Seventy-third Session of the American Dental Association, February 1932, said that a thorough cleansing of the mouth, the surface of the tongue, and all the surfaces of the teeth would prevent caries and pyorrhea. He recommended sodium ricinoleate to be used for a thorough cleaning of the mouth twice a day. During the discussion which followed the presentation of this paper, Dr. Bunting said that many people who had visited Dr. Hartzell's office could testify to the success of Dr. Hartzell's methods. Dr. Bunting also said, "in the process of reducing infect-
ive overgrowths in the mouth, dental calculi and other sources of trauma are removed; hence traumatic and infective stresses which militate against the health of the oral tissues are reduced to a minimum. "The brushing would have a stimulating effect upon the circulation in the periodontal tissues. He concluded with: "Explain it as we may the fact remains that the establishment and maintenances of a condition of strict oral hygiene is the most effective means of controlling periodontal diseases known today." (108)

A very short article called, "Rules for Dental Health," (17) and formulated by an imposing list of British dental authorities, including Sir Harry Baldwin, "Dental Surgeon to His Majesty the King," and Sir Norman Bennett, the president of the British Dental Association, gives the conservative view of the care of the teeth. It shows a willingness to use the findings of the nutritionists, but no inclination to disregard oral hygiene.

It is substantially as follows:

1 - Correct feeding both before and after birth especially in the vitamins A, B, C, and D will aid in the development of good teeth and prevent their decay.

2 - The actual cause of tooth decay is an acid produced by the fermentation of carbohydrate food
in the mouth.

3 - Raw foods are valuable, especially coarse ones, for they cleanse the teeth in the process of mastication, and add, as a rule, to the alkalinity of the saliva.

4 - Brushing the teeth and gums is especially valuable. Always brush the teeth before going to bed. A good mouth wash is one teaspoon of salt to a glass of water.

5 - Seek professional help; always visit your dentist at least twice a year.

Even so simple a statement as the need of brushing the teeth does not go completely unchallenged. Dr. William Wallace (261) states that if brushing the teeth is to be indulged in it ought to be constant, regular, and of the same force from day to day; that spasmodic brushing is dangerous. He says that the masticatory areas of the teeth are kept free from caries by the friction of the food when one is eating, and the non-masticatory areas, those between the gingival sulcus and the masticatory shearing line, are kept free from caries by a mucoid film. That forces which fall on the latter area are alien to the teeth and brushing will cause cavities in this area. These cavities are situated midway between the gum margin and the masticatory tangential line, on the labial and
buccal surfaces of the teeth, exactly where brushing would be most effective in displacing the mucoid film, and where it is most easily applied. He says that when he was teaching in the Glasgow Dental Hospital, from 1906 till 1914, he challenged his students to find an instance of a cavity of this type where there was no history of brushing, and although there were concerted efforts to refute his statement, no single instance was forthcoming.

Doubtless it would be difficult to bring any evidence against that challenge, for it is hard to find people who do not brush their teeth, at least once in a while, and it is very seldom that a cavity appears on the surface of the tooth between the gingival margin and the masticatory surfaces.

The dental literature available to the writer has not shown any other dental authority who holds the views of Dr. William Wallace regarding the danger of the tooth brush. Brushing the teeth generally seems to be thought a desirable practice, though there is doubt about the efficacy of the process as a preventive of dental caries.

Mouth washes are, also, much used for the hygiene of the oral cavity. Certainly their use is to be recommended for the physical comfort and sense of cleanliness they give, but it has not been shown that they have an inhibiting effect upon dental caries.
An experiment was conducted by Bunting (55) on children in orphanages to try the effects of diet, mouthwash, and both diet and mouthwash. Records were made at the beginning of the experiment of the size and location of the cavities and fillings. These findings were checked again at the close of the experimental period. One group of 156 children at the Mammee Orphanage were given a nutritionally adequate diet and used hexylresorcinol as a mouthwash three times a day. A group of 118 at the Lampeer Orphanage received the same diet and the mouthwash. This diet was low in sugar, it contained fruit, and green vegetables, and one quart of milk for each child daily. A group attending the Lincoln School and living at home received a good diet at home; they used a mouthwash twice a day, five days a week, at school. The group at the Coldwater State School were given the type of diet mentioned above, but not any mouthwash. Some of the children brushed their teeth and some did not. A sixth group at the G.P. Orphanage had no change made in the ordinary institutional diet, and were not given a mouthwash. The experiment lasted for a year except in the Lincoln School group. It was for the school term of nine months.

The results of this experiment showed that the group at the Coldwater School, who had received only the diet, were practically as free from caries as the children who
had received both the diet and mouthwash at the Lampeeper and Mammee Orphanages. Those attending the Lincoln School and living at home and those on the rather inadequate diet of the G.P. Orphanage had about the same conditions regarding caries. So the only conclusion was that a well selected diet is more inhibitive than a mouthwash to dental caries in children. The authors think that the high carbohydrate content of the diet, especially the candy that the Lincoln School children and the G.P. Orphanage children ate, might have caused the dental caries. The writer of this review thinks that in any effect the mouthwash might have been shown more clearly if the G.P. Orphanage children had used the mouthwash three times a day, seven days a week, instead of the Lincoln School children twice a day, five days a week.

In the same report (55) Dr. Bunting gives the results of thirty-six adults, twenty-four of whom reduced the Bacillus acidophilus in their mouths very materially by using hexylresorcinol as a mouthwash three times a day for from two to eight weeks. The effect upon the teeth of the adults was not mentioned.

Dr. C.L. Drain, (75) of the University of Iowa, at a public lecture in Portland, said that if one were to examine the mouths of an unselected group of children today one would find as many cavities in their teeth, as one
would have found in a comparable group fifty years ago. Though more of the present day children would probably have their cavities filled, yet, mouth therapy is being practiced more today than ever before. A perfectly clean mouth is impossible of achievement. The teeth are situated in the dark, warm, moist buccal cavity, an environment that is very favorable to the growth of microorganisms. Anything which would kill all the bacteria would destroy the delicate membranes lining the mouth. This is not meant to belittle the work of the dental hygienist; for as Dr. Hyatt (131) points out in his book "Hygiene of the Mouth and Teeth," these workers by filling existing cavities and teaching proper methods of caring for the mouth add to the physical comfort and mental self-respect that comes from a knowledge of being clean, even if cleanliness is only comparative.

Caries due to the acid formed from the fermentation of carbohydrates. Miller demonstrated that mouth organisms produce lactic acid in fermenting carbohydrate food debris, and that lactic acid decalcifies tooth enamel. In 1922, McIntosh, James, and Lazarus-Barlow (138) isolated an organism they called Bacillus acidophilers. When sound human teeth were placed in a broth culture of this medium, white opaque spots appeared on the surfaces of the teeth indicating decalcification of the enamel.
The research carried on at the present time at the University of Michigan by Bunting, Koehne, Hadley, Jay, and Hard has led them to accept the following hypotheses:

(55)

1 - "Dental caries is a destruction of the hard substance of the tooth by a process, the initial stage of which is decalcification by acids."

2 - "The acids responsible for caries are not generally distributed in the saliva, but are localized and concentrated upon certain areas of the tooth's surfaces."

3 - "Carious lesions occur most frequently in pits and fissures of the occlusal surfaces and on the lingual surfaces of the teeth, at which location there are opportunities for stagnation and retention of foreign matter. They do not occur on the smooth surfaces that are easily cleansed."

4 - "All initial lesions of caries contain acid forming bacteria capable of producing and living in acids of sufficient potential to decalcify the enamel."

5 - "The hardness or softness of the teeth may affect the rate of progress and the extent of caries, but does not alone determine its occurrence. Caries, as a rule, runs a more rapid and extens-
ive course in hypoplastic teeth than in the hard, well-formed varieties, but instances commonly occur in which the poorest formed teeth are free from disease."

6 - "Malhygiene of the mouth frequently favors the inception of dental caries, and increases its activity, but does not determine its occurrence. Mouths that are habitually unclean are often wholly free from caries, and, conversely, mouths that are scrupulously clean may be seriously affected by the disease."

7 - "The process of dental caries is related to and often determined by certain constitutional states and conditions of bodily health. The nature of these influences and the manner in which they affect the course of this disease is not understood at this time."

They believe that the acids that decalcify the enamel are protected from the action of the saliva by plaques of mucin and food debris.

**Human experimentation.** The first study of Bunting (59) and his co-workers was made in 1925. At this time, they reported a 100 per cent correlation between the presence of Bacillus acidophilus in the oral cavity and in the
intestines. They did not find such definite correlation between the absence of dental caries and the absence of Bacillus acidophilus in the mouths of the people they studied. Continued investigations by these workers led to the report of similar results in 1926. They found only one individual, out of 184 caries-free people studied, whose saliva gave a positive culture of Bacillus acidophilus. Further studies (132) showed that there were at least four types of this organism. There is one rough type that is found in the mouth; but this organism is much more prevalent in the intestinal tract than in the mouth. In 1933 a paper by Jay, Hadley, and Bunting stated the conviction of these workers, based upon the large number of determinations they had made, that there is always a distinct relationship between Bacillus acidophilus and dental caries. They do not believe that caries-free mouths are absolutely free from Bacillus acidophilus, but they do believe that the number per cubic centimeter of saliva is very low in caries-free mouths; and if there is active caries, that there is a much larger number of these organisms present in the saliva. Jay (134) showed that the number of organisms in a caries-free mouth increases greatly two or three months before there is any manifestation of dental caries. However, he sometimes found a great increase in the number of organisms in a caries-free
mouth, followed by a decrease to the usual low count, and no evidence of caries in the teeth. He was at a loss to account for the sudden invasion of the bacteria, and equally puzzled by the evident checking of the growth. He does not report any blood or saliva tests made on these people. Tests of the body fluids of the same individual at times when the oral flora is markedly different might yield valuable information. Jay always found a heavily infected mouth before the onset of and during active caries. Examinations of the feces indicated that only those people who were free from dental caries showed no evidence of Bacillus acidophilus in the intestinal tract. Bacillus acidophilus is very common in the feces and is usually considered a part of the normal intestinal flora.

The Michigan group contend that, "though the Bacillus acidophilus is almost universally present in the mouths and intestinal tracts of the majority of the population, there remains a minority in whose mouths this organism, not only does not reside, but is also apparently unable to exist. It is among this fortunate minority that we find those peculiar individuals whose teeth do not decay." (134)

They found that giving five caries-free children acidophilus milk to drink for four days did not implant the organism in the mouth and saliva cultures remained
negative. The cultures of the feces in four cases were positive following the ingestion of the milk, but after eleven days the cultures were negative except in one case. Two of the five children were given lactose in addition to the milk, and one of these developed diarrhea, and no culture was taken until the eighteenth day; that proved negative. The other gave a positive culture on the eleventh day, and no further cultures were obtained.

This study does not show that dental caries can be induced by drinking acidophilus milk; but neither does it show that Bacillus acidophilus could not be implanted. The study was made of a small number of children; the milk was given only four days.

Boyd and Drain (42) could find no relationship between the presence or absence of Bacillus acidophilus or any other bacteria of the aciduric type and dental decay. Schoenthal and Brodsky (223) found gram-positive acidogenic bacteria in all mouths. Johnstone, Kaake, and Agnew (135) carried out experiments on children in various institutions in Toronto. They made two determinations, a year apart. They found "that children who had an increased number of cavities in their mouths showed a higher incidence of Bacillus acidophilus than at the first determination. Those whose teeth showed no change had either a higher, lower, or somewhat similar incidence when the
second estimation was compared to the findings of the first survey." They, also, found that there was a variation in the bacterial count at different times of the day, and from different parts of the same mouth. Tucker (258) made bacteriological determinations of the children at Mooseheart, when Hanke was studying for the effect of orange juice upon dental caries. He found that scrapings from the tooth surfaces of 422 children yielded microorganisms in practically every case. Streptococci were isolated most frequently, but Bacillus acidophilus, staphylococcus albus, and yeasts also developed in an acid medium. Aciduric streptococci were found in the mouths of practically all the children. Bacillus acidophilus was found most frequently in the mouths of children who had three or more carious teeth; but it was not always found in the mouths of children who were highly susceptible to dental caries. It also occurred frequently and consistently in the mouths of children who had never had any dental caries or who had developed no new carious lesions for two years. He states, "Our work does not support the theory that L. acidophilus is the specific cause of dental caries."

The Michigan group suggest some conditions that may have prevented the research workers mentioned above from confirming their findings regarding the relationship of
Bacillus acidophilus to dental caries. They believe that determination of the flora of the saliva must be made frequently, because there is a great difference in the number of Bacillus acidophilus present at various times, but in general the caries-free mouths do not show any evidence of Bacillus acidophilus. They, also, say that it is difficult to determine which of the carious mouths are in a stage of active and which are in a stage of arrested caries, unless the subjects are under frequent observation.

Animal Experimentation. Lilly (170) reported an inability to produce caries in rats with a diet high in carbohydrate. He attempted to implant the Bacillus acidophilus in the mouths of the rats by weekly inoculations. Jay (132) et al., also, were unsuccessful in an attempt to find dental caries in the mouths of rats which were on a diet of finely ground material that was nutritionally adequate, but contained varying amounts of sugar. They sometimes found the type of Bacillus acidophilus that is found in rat feces in the mouths of these rats. They gave the rats a broth culture of Bacillus acidophilus from human mouths, but even this did not implant the smooth type Bacillus acidophilus in the rats. They, also, put rats on the coarsely ground diet of Hoppert, Weber and Canniff (123) and found a change in the flora of the
rat mouths; the flora was aciduric and the form of Bacillus acidophilus present more nearly resembled the smooth type found in human mouths. Johnston et al (135) found no caries in rats on an adequate diet; those on diets deficient in essential food factors had caries. The rats with caries and those without showed both high and low counts of Bacillus acidophilus. They could find no correlation between caries in rats and the presence of Bacillus acidophilus.

Specific organism of dental caries. Rettger, (214) and Tucker (258) question the conclusions of Bunting that Bacillus acidophilus is the specific micro-organism concerned in the production of dental caries. Tucker's findings are quoted above. Rettger says he has found a high acid producing streptococci just as prevalent in carious mouths as Lactobacillus acidophilus. If decay is due to an acid producing micro-organism it might just as well be the streptococci as the lactobacilli. Jay and Bunting (134) quote the work of Howe and Hatch, reported in the "Dental Cosmos" for October 1917, for evidence that the coccal forms are present as mouth contaminants and the bacilli are associated with caries. These workers inserted temporary fillings in open cavities without attempting to disturb the bacterial flora. These fillings were removed after periods varying from six weeks to
three months and the cavities were cultured. They were able to isolate aciduric bacilli from each of these cavities. When the cavities were cultured without a temporary filling being used the coccal forms were isolated as well as the aciduric rods. So far as the writer of this review has been able to learn, there is not any definite proof that dental caries could not be due to a coccal form; on the other hand, there is no evidence that it could. The oral flora simply has not been studied to any extent, in the literature available to the writer.

The acid destruction of the tooth. Bunting (53) states that destruction of the enamel of human teeth has taken place "in vivo" by the application of Bacillus acidophilus cultures, protected by gold clasps, to sound human teeth. The Michigan group do not believe that the acid produced by the bacteria is free in the oral cavity. If it were, the teeth would all decalcify. They believe that the bacteria are in the crevices of the teeth and are protected by plaques which can not be dislodged by brushing or other sources of disturbance. This plaque also holds the acid produced by the bacteria against the surface of the enamel and prevents the weakening of this acid by the fluids of the mouth. Downs, (72) who has studied these plaques, says they are made up of mucin from the saliva and food debris, and adhere very closely
to the surface of the tooth. They are permeable, but not readily permeable, to fluids. The plaque must be differentiated from the temporary food collections and calculus, and from the mucin film which normally covers the teeth. Plaques are easily removed from the accessible surfaces of the teeth by a motor driven brush and pumice, but they also form in inaccessible places, where it is almost impossible to remove them. The ordinary home care of the teeth will not remove plaques. They can be digested by proteolytic enzymes, but the process is very slow. Plaques have been produced artificially by placing the extracted teeth in bread crumbs and saliva and keeping them at mouth temperature.

**Immunology.** A group of children were inoculated interdermally with a filtrate of Bacillus acidophilus. (132) Many of the caries-free children showed no reaction. In the caries-susceptible children localized areas of erythema, 10-30 m.m. in diameter, appeared within eight hours after the inoculation. Repeated injections of the filtrate failed to desensitize susceptible persons. Eighty-three caries-susceptible persons were tested with this filtrate and 90 per cent of them gave positive reactions; 9 per cent of this group gave negative reactions. Of forty caries-free persons tested, 70 per cent gave negative reactions and 30 per cent gave positive reactions.
The Michigan investigators (134) state that they would like to continue their investigations on other caries-free people but it is difficult to find a large enough number of people. Two people who were considered their best "immunes" developed cavities at twenty and twenty-two years of age while under their observation.

A polyvalent vaccine was prepared; it was successful in raising the Bacillus acidophilus agglutinin titer in two children who were inoculated but severe abscesses developed after the administration of the vaccine. Experimental work on rats convinced Jay (134) and his coworkers that the rough strain of Bacillus acidophilus was the irritant that caused the abscesses. Further studies need to be made to remove the irritant before these workers can report any definite results.

The possibility of vaccination for dental caries is very interesting and if it is possible would be the greatest discovery of all time toward the control of this disease. Its discoverers should rank with Jenner and Pasteur as benefactors of humanity. It is difficult to determine how this artificial immunology can be achieved. Dental caries differs from infectious diseases as we know them. It is not easily transmitted, so far as we know, and is outside the body proper on the most inert tissue of the body. Carious lesions are not attended by any de-
finite inflammatory reactions in the affected tissues, though certain opaque areas around the decayed spot in the dentine are thought by many workers to be an endeavor of the tooth to protect itself from further decay. How would immune bodies in the blood stream affect these organisms which never come in contact with the blood? If dental caries is due to the action of bacteria, it has not been shown that it is due to toxin produced by the bacteria.

Diet in relation to Bacillus acidophilus. The Michigan group believe that there is a relationship between the quantity of carbohydrate food ingested and the presence of Bacillus acidophilus. Since they believe that the presence or absence of this organism determines dental caries or freedom from caries, they believe that the lowering of the intake of carbohydrate food will lessen the susceptibility of dental caries. Jay (134) tells of the study of five cases of adults. The people were under close supervision; both the sugar and starch intake were much restricted. These patients were selected because of their extreme susceptibility to caries; this susceptibility made them willing to forego the pleasures of sweet foods. The chart of one woman was given. This chart is said to be representative of the group. The mouth flora previous to the diet period was from 75,000 to 290,000 per cubic
centimeter of saliva. Within one month after the low carbohydrate diet was adopted the count dropped to 900 organisms per cubic centimeter. A return to the customary diet which was high in carbohydrates brought the count to over a million. Sweets were omitted and only a small amount of starchy food eaten and the count dropped to 130,000. When this small amount of starch was withdrawn the count went down to 100 organisms per cubic centimeter of saliva. There is nothing in the report to show that the patient was more or less susceptible to caries during the three months this study was in progress. Could it have been carried out over a period of years on more people it would be more valuable, providing it can be proved that the rate of decay of the teeth is proportional to the number of Bacillus acidophilus present in the saliva.

Koehne (161) believes that dental caries may be lessened by limiting the consumption of artificially sweetened food, and that the impaction of sugar about the teeth is very apt to lead to caries. To prove this, thirteen children were given adequate diets and extra calories in the form of candy; ten of them developed caries within a year. Another group of fourteen were given a diet like the first group, but were permitted no sweets. Nine of these showed arrested caries within a year. Case studies
were made upon two groups of Ann Arbor children, one group had advanced caries, the other group were caries-free. The caries-free children were hearty eaters; they had meals of a uniform quality and ate regularly; they ate some candy and simple desserts. In contrast, caries-susceptible children were fussy about what they ate; their meals were irregular and they ate candy between meals. A study (160) of children in an orphanage showed that an inadequate diet does not always produce caries. The diet of these children was low in minerals and vitamins and total calories. When it was improved so it was higher in milk, eggs, fruit and butter, the children grew better, but their teeth did not show any lessened caries. The original diet was high in carbohydrate. Koehne (160) says that the only explanation for the low incidence of caries in these children was their low consumption of artificially sweetened food and the uniformity and regularity of the meals.

The following quotation is from an article by Koehne, and others, in the "Journal of the American Dietetic Association" March 1934. "There is strong evidence that Bacillus acidophilus growing in protected areas of the mouth is the primary cause of tooth decay. The kind of food one eats is of importance chiefly as it provides the medium for the growth of these organisms. If the diet
provides a pabulum in the mouth or in the intestinal tract that is favorable for the growth of these organisms, caries will probably result, irrespective of the nutritional balance of the diet unless the teeth are so shaped and arranged that all tooth surfaces are readily cleaned and offer no possibilities of food impaction, or unless the person is protected by a natural immunity."

It is presumptuous for a person of no experience to criticize the work of a famous authority. But, why would not the high cereal content in the diet of the orphanage children be more apt to become impacted about the teeth and thus furnish a better medium for the growth of acid producing bacteria than would a diet that contained less of its carbohydrate in the form of starch and more in the form of sugar? Sugar is readily dissolved in the oral fluid and should not become impacted. Drain (76) says that it is not the things we put in our diets, but the things that we omit that causes our dental troubles. Then why should candy be harmful, if it does not replace other foods that are necessary for healthy bodies? Brodsky (223) could find no correlation between candy eating and dental caries. Tisdall (49) says, "The danger of excessive sweets in the diet, as far as dental decay is concerned, seems to be in the tendency for sweets to dull the appetite for the phosphorous containing foods, such as
egg yolk, milk, meats, leafy vegetables, and grains."

There is a very large number of research workers who agree with Bunting and the other investigators at the University of Michigan. Dr. Sim Wallace (260) says, "Caries is purely the result of fermentation processes commencing externally to the enamel." He does not offer any evidence in support of his statement. Shaw, (227) writing in the "South African Medical Journal," states, also without any proof of his assertion, that "caries is a chemo-parasitical process." The predisposing causes for the present prevalence of caries are the increased consumption of sugar, refined cereals, pastry, and tinned foods. All of these foods are soft; they do not require enough chewing to keep the jaws in a healthy condition; and they are low in vitamin content. Shaw (227) thinks that the feeding of soft foods to children is a cause of the high incidence of dental caries in their teeth. Hatton, (109) in a review of dental caries in the "Journal of the American Dental Association," says that caries was thought to be due to acid attacking the surfaces of the teeth; later nutritional theories developed, but they have had too many failures. Probably we will eventually find that caries is due to some factor in the environment of the tooth acting upon the surface of the enamel, and having its origin in bacterial action, not nutritional
disturbances.

Size of the food particle in relation to dental caries. In 1934, McCollum (151) called attention to the decay he found in the molars of rats on a stock ration, which had been adequate for growth and reproduction for generations of rats. Of 196 rats fed this ration for 275 days or more, 103 had caries in their molar teeth. He found that on a moderately severe rickets-producing diet it would take about 110 to 205 days from weaning to produce caries in the rat's teeth, and a severe caries-producing diet would take 86 days or more for the production of caries.

Shabita (161) was the first to produce caries in a short time. He used a ration of brown rice and powdered spinach and, in some cases, produced caries in as short a time as twenty days.

Hoppert, Weber, and Canniff (123) found dental caries in stock rats on a diet which had supported growth and reproduction for three generations. It consisted of 60 per cent ground yellow corn meal, 30 per cent whole milk powder, 6 per cent linseed meal, 3 per cent alfalfa meal, and 1 per cent sodium chloride. Oatmeal when substituted for corn meal did not produce caries. When the corn meal was finely ground and substituted for the more coarsely ground meal used in the original diet, caries were not produced. The
meal first used was the ordinary meal as it comes from the mill. The authors do not believe that decay was due to any lack of mineral or vitamin in the diet, but to the impaction of the corn meal around the teeth, and the resulting opportunity for bacterial fermentation of the food and the production of acid. The authors could not find that the addition of vitamins A, C, or D, in the form of orange juice and cod-liver oil, or the addition of calcium salts to the ration of coarsely ground meal prevented or lessened the occurrence of caries.

The results of this experiment were verified by Lilly and Wiley. (171) They found that diets adequate for growth and reproduction, according to the accepted standards, produced caries in 66 per cent of albino rats in 100 days, and in 100 per cent in 125 days. The corn meal of the diet was coarsely ground. When the meal was cooked, or was finely ground caries were not produced. The authors are sure that there was sufficient calcium and phosphorus in the diet. The addition of vitamin D did not prevent caries.

Klein and McCollum, (154) also, carried out this experiment. They thought that there might be a lack of phosphorus in the ration containing the coarsely ground corn meal, because the coarse and fine corn meal and been separated by sifting. They did not find a significant
difference in the phosphorus content, though there was slightly more in the finely ground meal. The coarsely ground meal had more phosphorus than oatmeal, and oatmeal did not cause caries. They could find no relationship between the calcium to phosphorus ratio and caries, and no relationship between the ash content of the bones and caries.

Shelling and Asher, (229) also, found the physical form of the diet important in the production of caries in the rat.

Hoppert et al, (123) explain the production of caries in rats fed on an adequate diet by the fermentation of the impacted particles of corn meal. They say that the finely ground meal was so tightly packed in the sulci of the molars that moisture did not penetrate it, so there was no fermentation. The coarsely ground meal was not so firmly impacted and fermentation took place. Jay (132) reported that the bacterial flora of the rat's mouth differed with the diet. That the finely ground ration, even though it did contain sugar, did not cause a large number of Bacillus acidophilus to inhabit the mouth, but with the change to coarsely ground meal there was a change in the flora to the Bacillus acidophilus.

Since a number of investigators have been able to produce dental caries in the molars of rats by a change
in the physical character of the diet, it seems to be certain that the fineness or coarseness of the ration must be a factor in the decay of the molar teeth of rats. How much bearing this finding can have upon the puzzle of human dental caries remains to be seen. Since the corn particles are hard, might not the caries of the rat's molars have been due to fracture of the teeth? The diet of people is usually a combination of soft cooked foods and fibrous raw vegetables and fruits. It is not similar in physical qualities to raw corn meal. There probably have been many cases of fracture of the teeth from using them to crack nuts or for some other function for which they are not adapted, but in general our diets are more apt to lead to under-development of the jaws because we eat quantities of soft food. The races that have excellent teeth have not lived on foods having common physical characteristics.

The action of the saliva toward the prevention of dental caries. This theory involves two groups of factors governing dental caries.

1 - The local factor which is the splitting of the carbohydrate food into lactic acid.
2 - The composition of the saliva which enables it to neutralize lactic acid.

The first factor has been considered. The second
factor, or the ability of the saliva to neutralize the acids of carbohydrate fermentation, would depend upon the composition of the saliva, its ability to reach the parts of the tooth where acid is being formed, and the amount of acid produced. The neutralizing power of the saliva would depend upon the pH of the saliva, and the buffer salts it contains, and its CO₂ capacity. (87)

Enright (83) coated sound extracted teeth with asphaltum, leaving only a small portion of the tooth exposed. He put these teeth in various buffer solutions representing a wide range of pH values. Some of these had varying amounts of tricalcium phosphate added to the solution. The teeth were stained and examined. He concluded that the tricalcium phosphate of the saliva kept the teeth from being dissolved in the mouth. Benedict (20) and Forbes (87) used the method of placing weighed dry powdered enamel in various buffered solutions of weak acids, and concluded that the calcium and phosphorus content of the saliva prevents the enamel from dissolving at pH values above 5.0.

Broderick, (46) won the Cartwright Prize of the Royal College of Surgeons, 1932, with an essay based upon the assumption that pyorrhea and caries are antagonistic lesions. That pyorrhea is dependent upon alkalosis of the blood and caries upon acidosis. These are reflected in
the saliva by the deposition of the excess calcium upon the teeth in the case of pyorrhea, and by the opposite reaction in the case of caries -- the withdrawal of the calcium from the teeth by the acidity of the saliva. In a later paper, 1933, he says that any disturbance of the acid-base balance of the body will affect the saliva, and ionization between the teeth and the saliva will follow. The direction the ions will take depends upon the pH of the body fluid. Price (212) states a similar theory.

Hawkins (110) concludes from the examination of 140 caries-free and many caries-susceptible people, that in caries the phosphates are not only deficient, but are low in the dibasic forms and this condition makes the saliva acid in reaction and low in calcium. All the caries-free people he examined had a high percentage of calcium in the saliva, or an alkaline saliva, some had both.

While many of the older writings gave the reaction of the saliva as slightly alkaline, many of the present workers think the normal saliva is slightly acid. Stern (245) using the colorimetric method of determination on the saliva of 100 children, between the ages of six and fourteen years, found the pH to range from 6.6 to 7.0. Eleven children with no caries had a range of pH 6.6 to pH 6.9, and sixteen with advanced caries showed pH
6.6 to pH 7.0. Hanke (102) found the range of the saliva from both carious and noncarious mouths to be pH 6.1 to pH 6.3. He used filter paper saturated with thymol blue as an indicator. He could not find that an adequate diet with large quantities of citrus fruit made any change in the hydrogen ion concentration of the saliva.

Youngberg (268) could find no relation between the phosphorus content of the saliva and dental caries. Horton, Marrack, and Price (124) examined 741 children and found a relationship between the calcium in the saliva and dental caries, but there was much overlapping. The children with no carious teeth had from 6 to 14 mg. of calcium per 100 c.c. of saliva and the children with seven or more carious teeth had from 2 to 9 mg. of calcium per 100 c.c. of saliva. The investigators think that the lessened calcium is a secondary change due to the caries. There is so much overlapping that there is probably some other cause than caries for the variation in the calcium. The Michigan group (58) could find no relationship between the presence of dental caries and the calcium, phosphorus, or pH of the saliva. They did find that the saliva of caries-free had about 44 per cent higher carbon dioxide capacity than the saliva of the children with active caries. (129)

Karshan, Kransnow, and Krejci (148) found, in many
instances a higher phosphorus content of the saliva of caries-immune than caries-susceptible people, but the differences overlapped each other, and so were not significant. They could find no significant differences in the pH, titratable alkalinity, or calcium values of the saliva of carious and noncarious people. Their findings are confirmed by the work of Boyd and Drain. (40)

Diet does not seem important for its effect upon the saliva. Tests were made for calcium, phosphorus, and the pH concentration of the saliva of children; then the children's diet was supplemented with one quart of milk and two ounces of tomato juice. This improvement lessened the development of caries, but did not change the analysis of the saliva. (128) Hawkins (110) advises the eating of alkaline foods. The diets that are generally found successful in controlling caries -- those of Bunting, McBeath, Boyd and Drain, and Hanke are all alkaline in reaction, but there does not seem to be any evidence that these diets have controlled caries by a change in the acidity, calcium, or phosphorus of the saliva.

The Eskimos are the famous example of a people with a diet high in acid producing food who do not show any evidences of poor dentition as a result. The people on the Island of Lewis also have good teeth and live on a diet high in potential acidity. Lennox mentions the diets
of the African Bushman, living chiefly on meat, the Herero, living almost entirely on soured milk, and the Ovambo, living on millet seed and milk, as very fine examples of diets that are quite different in their end products when they are metabolised, yet all have the ability to prevent caries.

**Enzymes of saliva.** The saliva contains enzymes that may command the attention of one interested in the etiology of dental caries. Myers (205) studied the relationship between the amylolytic activity of the saliva and its chloride and phosphorus content. He found in 21 subjects that the higher indices of amylolytic were characteristic of a higher chloride and phosphorus content; that the people with the lower indices had better teeth than those with higher indices. However, he found much variation in people on different days, and that a cold would lower the starch digesting power of the enzyme as much as 50 percent. His work has not been confirmed.

Hanke (104) disposes of the theory that the tooth might decay from protolytic enzymes, produced by bacteria in the mouth, attacking the organic structure of the tooth, by saying that these enzymes do not act on living substance. Bibby (27) has shown that the organic structure of the tooth is keratin and is almost impossible of digestion. He demonstrated "in vitro" that the protolytic
enzymes have little effect upon it.

Summary of the theories that dental caries is due to forces outside the tooth.

1 - The general theory is that dental caries is due to the acid produced by micro-organisms acting on carbohydrate food debris, and raising the acidity of the saliva sufficiently to decalcify tooth enamel.

2 - The earliest prophylactic treatment emphasized the cleanliness of the mouth, to lessen the amount of food debris and to reduce the bacterial count. This treatment shows positive results in some cases, but has many inconsistencies. Mouths which receive no care frequently have excellent teeth; and mouths that are scrupulously cared for often have extreme susceptibility to caries.

3 - A later method is to control the fermentation of the mouth by a diet low in fermentable carbohydrates, particularly sugars, and artificially sweetened food; and to improve the general health with an adequate diet. In just what ways the improved diet protects the teeth is not known. It has not yet been demonstrated that people who live largely on carbohydrates have
poor teeth.

4 - The micro-organism responsible for fermentation is considered by some investigators to be Bacillus acidophilus. There is no conclusive proof that it might not be a streptococcus. The possibility of vaccination for dental caries is being investigated, but it has not yet been proven.

5 - The physical character of the food has been shown to be an important factor in the production of dental caries in the molars of rats, but there is no evidence that it has the same effect upon human teeth.

6 - The calcium and phosphorus content of the saliva, its hydrogen iron concentration, carbon dioxide combining power, and titratable alkalinity have been investigated by many workers. The results are inconclusive. Some investigators have found a higher calcium or phosphorus content in the saliva of the caries-immune than in the caries-susceptible; others have found that there is no correlation between the composition of the saliva and dental caries.

7 - The investigators who can find no change in the composition of the saliva when caries is rampant
and when it is arrested explain their finding by saying that a plaque, composed of mucin from the saliva and food debris, holds the bacteria and the acid produced by the bacteria against the enamel of the tooth, preventing the neutralization of the acid by the saliva, and the saliva from becoming more acid.

8 - Not any of the theories of decay explain:

a - Why some teeth decay while others in the same mouth do not.

b - Why plaques in some mouths seem conducive to decay, in others they seem a protection to the surface of the tooth.

c - Why caries are frequently spontaneously arrested.

d - Why dental caries is more difficult to control when the organism is undergoing periods of stress, such as rapid growth and illness.

**Dental Caries is Due to Some Systemic Factor within the Tooth.**

Dental diseases have the advantage of being easier to diagnose than most other diseases. The tissues involved are open to inspection. Inasmuch as systemic disturbances are generally believed to produce changes within the oral tissues, it is possible that the teeth may, as Dr. Drain
remarked, serve as barometers to indicate the condition of the body. If the teeth are affected by diseases of the body, they must just as surely respond to that condition of the body which Dr. Sherman refers to as "bouyant health."

It was formerly thought that the tooth once formed remained an unchanging structure, except as it might be destroyed by outside influences. Now there is coming to be a generally accepted belief that the tooth is as responsive to the influence of food as the other tissues of the body. Though the response of the tooth may not be as rapid as that of some of the other tissues, it is just as certain.

The next step is to determine how the metabolism of the tooth is carried on. Not so much research has been attempted upon this phase of the nutrition of the teeth, probably because the prevention of dental caries has seemed more important than learning the exact mechanism by which this prevention takes place.

Probably the only protective mechanism outside the tooth is the saliva. The available information about the saliva is contradictory.

The first protective forces within the tooth, is the structure of the tooth itself. The enamel of some teeth seems more resistant to etching "in vitro," when exposed
to the action of weak acids, than does the enamel of other teeth. Some teeth have cracks and fissures and do not have the dentine fully covered with enamel. There is some argument about the decay in hypoplastic teeth, but it seems generally accepted that good structure is an important factor in the preservation of the teeth. Dr. Guies has said "if you want good teeth select your grandparents carefully." (95) A small group of investigators, chiefly at Columbia University, believe that there is a protective mechanism within the tooth itself; that the tooth has a circulation within the pulp and the dentine, and a limited circulation within the enamel. The circulation within the pulp and dentine seems to be more generally accepted, but the possibility of any circulation within the enamel is considered doubtful.

Some research workers believe that there is one or more specific factor of primary importance responsible for the well-being of the teeth; while others stress the need for a well-balanced diet and make no attempt to single out any one factor more than another.

The mechanism of circulation within the tooth. In the first part of this paper reference was made to the pulp of the tooth. The pulp is a fibrous tissue containing blood and lymph vessels and nerves, characterized by a layer of odontoblasts immediately against the inner wall
of the dentine. The plasma seeps through the endothelial walls of the capillaries and bathes the cells of the pulp; from this intercellular fluid the odontoblasts select the constituents necessary for the nutrition of the dentine. (102) The fluid secreted by the odontoblasts is passed to the dentine by fibrils which are offshoots from the odontoblasts; they are tiny branching tubes which permeate the dentine in all directions, thus carrying nourishment to all parts of it. These tubules were thought for some time to be solid material; that is how they came to be called dentinal fibrils. The mistake was due to the fixing agent, used in the preparation of the tooth, coagulating the lymph and making the tubule appear solid. (37) The dentinal fibrils transport this fluid, which may be called dentinal lymph, to the dento-enamel junction and throughout the dentine. The residual fluid then passes back in the "circumtubular" space between the dentinal fibril and Newman's sheath (a highly resistant membrane of protein, which lines the dentine tubule.) Some of the fibrils do not end at the dento-enamel junction, but the enamel for a short distance. They connect with the enamel lamellae, and tufts, which pass the lymph to the enamel rod sheaths, the structures which cover each of the enamel prisms and are the end structures in this distribution of dental lymph. (37)
The function of the dental lymph is twofold: first, it achieves the post-eruptive calcification of the dentine; second, it maintains a protective mechanism against the external agents of dental caries. As the tooth ages more calcium is deposited in the dentine, hence the tooth hardens itself. One of the theories of the means by which decay might be prevented was that the dental lymph permeated the dentine and enamel, and if it had a high enough buffer value, neutralized the oral acids. (37) Illness, dietary disturbances, or endocrine dysfunction might reduce the buffer value of the dental lymph and caries would result. There seems to be a degenerative change in the fibrils; some of them become impermeable to fluids, so they can not transport the lymph. (37) The work of Karshan, (148) who showed that dentine had a pH of 7.8 to 8.0 and enamel a pH of 7.3 to 7.6, caused a revision in the theory mentioned above to the suggestion that the dental lymph does not of itself neutralize oral acids, but it maintains the high alkaline reserve of the enamel and dentine by a constant supply of mineral salts. (36)

In ground sections of a tooth opaque areas are frequently seen. They have been ascribed to the heat of erosion due to grinding, but it is now considered that these areas were formed before the tooth was extracted. Bodecker and Applebaum (39) ground a section of jaw which
contained an unerupted tooth, a normal erupted tooth and two teeth with fillings. The normal erupted tooth and the unerupted tooth did not show these opaque areas, but the teeth that had fillings had opaque areas in the dentine around the fillings. This has led to the belief that the hypercalcified areas are formed in an effort of the dentine to protect itself from further destruction. This area may be due to secondary dentine (199) or to the deposition of calcium salts within the dentine. (86) In this way the tooth is separated from the carious lesion, and the spread of caries may be controlled by the kind of calcified area that is found around the carious lesion in the tooth. If enough calcium salts are secreted and a hard area formed, that condition known as "arrested caries" takes place. (85) Hypoplasias, erosions, abrasions, and decay all cause the formation of sclerosed areas in the tooth under the seat of the trauma. The irritation that produces hardening of the dentine will hasten the contraction of the pulp tissue and the formation of secondary dentine in the pulp chamber. (23)

The metabolism of the dentine is quite widely accepted among investigators; but Dr. Bodecker (38) seems to stand alone in the belief of metabolism in the enamel. Some of the doubts are summed up by Dr. Steenbock, (243) in a lecture given at the Oregon State College in 1933.
He said that we now know the teeth are living parts of the body and carry on metabolic processes as do other living tissues, but more investigation will be needed to convince scientists that the enamel is supplied with nutrients, for it is a very dense structure almost entirely composed of organic salts and highly resistant to corrosive agents. Dr. Sim Wallace (260) is more emphatic. He says, "The enamel prisms are normally inorganic and quite incapable of metabolising. Any matter which may surround them, whether the latter is lymph or keratin, liquid or solid, organic or inorganic, alive or dead. The only indication of life is in that part of the enamel into which the dentinal tubules extend. The fibrils may react from injury but the enamel does not. There is no known circulation of lymph in the enamel, and the so-called lymph has no lymphocytes and is nonvital. There is no reaction to the action of acids on the surface of the enamel even though the dentinal fibrils may possibly secrete calcium salts. If the enamel can be repaired at all, it is only by a cement substance secreted by the dental fibrils. Defects in the enamel persist throughout life, except as they change from external agencies."

Other investigators have pointed out that the enamel has no cell structure, with cell neculi, and cell enzymes; it is very slightly permeable to salts and gases.
(95) Keratin is a substance insoluble in lymph and chemically inert. If acid typical of oral fermentation were applied to the surface of a tooth "in vivo" and if the enamel were not damaged and the acidity of the acid diminished then there would be some basis for considering that the enamel neutralizes acid, but if the enamel were attacked and the acidity of the acid diminished one would need to consider the enamel as nonvital.

One of the objections to the theory of metabolism within the tooth, is that pulpless teeth do not decay more rapidly than teeth with pulp. This, to the writer, does not disprove metabolism within the tooth, for the tooth with its pulp removed and root canal filled would not be a part of the body insofar as metabolic processes are concerned. The pulpless tooth would bear no more relation to the body than a tooth carved from ivory, or than a silver plate used to reinforce a broken bone. The writer has not been able to find statistics giving the rate of decay in pulpless teeth. The saying that they do not decay more rapidly than other teeth, may be like many other statements taken for granted and may or may not prove true upon investigation. From the available literature, the impression has been gained that teeth with dead pulp tissue are regarded as foci of infection, and there is a difference of opinion about the advisability of filling
pulp chambers. Not enough pulpless teeth have been left in the mouth to furnish an adequate basis for comparison.

The effect of the various nutritive factors upon dental caries. Hypotheses of the ways immunity to dental caries might be produced through diet may be placed in four groups:

1 - Immunity to caries may function by providing a circulatory mechanism within the tooth, and a dental lymph which neutralizes the forces attacking the enamel.

2 - The structure of the tooth may be modified to resist attacking forces.

3 - The attacking forces may be reduced so as to be less harmful to the enamel.

4 - Immunity to caries may be achieved by all of these factors working together.

The first theory given above has been discussed in the presentation of Dr. Bodecker's (37) findings regarding the metabolism of the tooth. The second has been considered in that section of this paper devoted to the structural changes in the teeth due to diet. The third is considered in the acid decalcification of the teeth, the particle size of the food, and the reactions of the saliva. The fourth is probably the way the various food factors act in protecting the organism from dental caries.
The nutritive factors investigated for their effect upon dental caries are vitamins A, C, and D, and calcium and phosphorus.

The function of vitamin A. The early work (200) was on the "fat soluble" vitamins, and no distinction was made between vitamins A and D. The effect of vitamin A has been considered under the structural development of the teeth; its effects upon fully formed human teeth has not been determined. When vitamin A is deficient in the diet of rats there is a change in the incisors. First, there is shrinkage of the odontoblasts, followed by irregular growths of dentine toward the pulp chamber. The odontoblasts finally become incorporated in this dentine matrix. The enamel formation ceases; the ameloblasts become shrunken and atrophied. They are frequently replaced by a layer of stratified epithelium. (267)

Klien and Shelling (153) found caries-like lesions present in the molars of rats that had been fed diets deficient in vitamin A and adequate in vitamin D.

Mrs. Mellanby (200) was able to develop hypoplasia in dogs by a diet low in "fat soluble" vitamins, but she could not develop caries.

Bloch (34) could find no higher incidence of caries in the teeth of Danish young people, who were in a home for the blind, as a result of severe vitamin A deficiency.
in childhood, than in the teeth of people who had adequate vitamin A.

In a program of supervised diets of 800 children in institutions Mrs. Mellanby (193) found that caries could be reduced as much as two-thirds by adding cod-liver oil to the children's food, but she got a like reduction in caries by the addition of vitamin D in the form of viosterol. Hess (114) and Kuglemass (166) could not find that the lack of vitamin A had any effect upon the fully formed teeth. Vitamin A affords to the mucous membrane a greater power to resist infection, hence protects the soft tissues of the gum. It is also essential for the formation of good tooth structure. These probably are the only effects vitamin A has upon the prevention of dental caries in human teeth.

The effect of vitamin C. Lack of vitamin C produces important changes in the tooth and the membranes surrounding the tooth. (78) The two diseases of the periodontal membranes which are ascribed to insufficient intake of vitamin C are pyorrhea, alveolaris and gingivitis. (106) Since the theme of this discussion is the decay of the tooth, these diseases are outside the scope of this work. "Diet and Dental Health," (102) by Milton T. Hanke, gives an excellent description of these diseases, and some very fine colored plates showing the teeth and
their surrounding tissues in health and in disease.

The first symptom of scurvy in a guinea pig is manifested in its teeth. Hojer (121) thinks that the tooth of the guinea pig is the most reliable index of scurvy in the animal. The feeding of orange juice or some other food rich in vitamin C will restore the original structure of the tooth, unless the pulp is very much disintegrated as a result of the vitamin C deficiency. (125)

The guinea pig is very susceptible to scurvy; and has teeth which are constantly growing, so there is some doubt about how much of the observations on the guinea pig may be applied to human beings. But it is generally agreed that vitamin C is essential to dental health. The only question is the amount of vitamin C that is needed for full protection of all the tissues.

The most extensive work to show the effect of vitamin C upon dental caries was carried out by Dr. Hanke (102) on 341 children at Mooseheart, for three and a half years. Observation over a period of years had convinced Dr. Hanke of the following premises:

1 - None of the people with dental disorders were eating an adequate diet.
2 - Not many people were eating food they should eat.
3 - The majority of people without dental disorders were eating adequate diets.
4 - A low intake of vitamin C is the rule, not the exception.

5 - Dental disorders of all kinds might be found in people eating food inadequate in vitamin C.

The daily diet which Dr. Hanke considers adequate for the adult is composed of the following essential foods: 8 to 32 ounces of milk, children should have 32 ounces; 1 to 2 eggs; \( \frac{1}{2} \) to \( \frac{3}{4} \) head of lettuce; 8 ounces of fruit other than oranges; 12 to 16 ounces of vegetables; meat once a day, 16 ounces of orange juice. Other foods are added for fuel value.

This diet would need to be modified according to the age of the children, but orange juice was given to all the children at Mooseheart. During the control period from October 1929 to October 1930 the children received this diet without the orange juice. In the fall of 1929 dental examinations of the children were made by two dentists, all cavities were filled, and the teeth cleaned. For one year careful tests were made of the blood and saliva of the children; the progress of caries for the year was determined. During this year the children had their usual diet. The findings were:

- 20.8 per cent of the children had no carious teeth.
- 23.8 per cent of the children had 1 carious tooth.
- 21.0 per cent of the children had 2 carious teeth.
34.4 per cent of the children had 3 or more carious teeth.

The same program was carried out for the next year beginning in the fall of 1930, but the children were given one pint of orange juice with the juice of a lemon in addition to their previous diet. The results are given below:

4.7 per cent of the children had no carious teeth.
10.9 per cent of the children had no carious teeth for 2 years.
49.8 per cent of the children had no caries arrested.
16.4 per cent of the children had caries retarded.
18.2 per cent of the children had caries unchanged.

The next six months the children had the same diet as the first year of the test -- the adequate diet without the pint of citrus fruit juice. The results are shown below:

16.6 per cent of the children had arrested caries or no caries.
20.1 per cent of the children had 1 carious tooth developed.
19.0 per cent of the children had 2 carious teeth developed.
44.3 per cent of the children had 3 carious teeth developed.
A summary of the findings for the three periods is given below:

From October 1929 to October 1930, 79.2 per cent of the children had progressive caries.

From October 1930 to October 1931, 33.7 per cent of the children had progressive caries.

Dr. Hanke ascribes the arrested caries in these children to the effects of vitamin C. This does not prove that other constituents of orange juice were not involved. He found that the children who were most susceptible to caries in the control period were the children who were hardest to check during the experimental period. There did not seem to be any correlation between the phosphorus and calcium in the blood serum and the progress of caries, nor the height and weight of the children and the absence of caries. Hypoplastic teeth did not seem to decay more readily than other teeth.

The work of Eddy, (78) Howe, (125) and Kugelmass and King (116) supports the findings of Hanke regarding the need of abundant vitamin C in the diet.

Hess (113) and some other research workers have asked why, if vitamin C is essential in large amounts, the Eskimos have such good teeth. Dr. Hanke's answer to this is that probably races can accustom themselves to living on small amounts of any dietary necessity. People who are
not able to endure deprivation die, and the ones who live and reproduce are the people who do not need so much of the essential factor. In other words a survival of the fittest, but the ability to use less of a necessity, has to be developed through many generations.

The effect of phosphorus. There is probably more disagreement about the effect of calcium, phosphorus, and vitamin D upon the teeth, than any other phase of nutrition in relation to dental caries. Everyone knows that these food factors are essential; the questions are about the quantity of each metabolized, and the ratios of one to the other. If phosphorus is the essential factor in the prevention of dental caries, it has seemed to many investigators that the fluids of the body should show a higher phosphorus content for caries-free than for caries-susceptible people. Dobbs (68) from clinical investigations covering two years is quite certain that the blood serum of caries-immune people is much higher in phosphorus than the blood serum of caries-susceptible people. He says that the blood of people with rampant caries is high in calcium and low in phosphorus. Hawkins (110) agrees with that statement. Kugelmass and King (167) say that care should be taken to have a high phosphorus intake for carious children. Price (212) explains that the high phosphorus content of the diet of people on the Island of
Lewis and of the Eskimos is accountable for their excellent dentition.

The Agnews, (4) after many experiments with rats on diets low in minerals, and vitamins, concluded that the level of phosphorus in the blood serum was the factor which determined dental caries in rats. Klein (152) considers the balance between calcium and phosphorus the most important phase of the question. He fed rats diets adequate in calcium and low in phosphorus, with large doses of viosterol and developed caries; but the rats fed diets low in calcium, high in phosphorus and doses of viosterol did not develop caries. Neither did rats fed a ration adequate in calcium and phosphorus show caries. Mrs. Mellanby (200) did not find the calcium phosphorus ratio as important as vitamin D for adequate dentition in dogs.

Karshan, (146) Jundell, (145) Brodsky, (223) Hubell, (128) Koehne, (161) Bunting, (55) and Boyd and Drain, (40) could find no relation between the serum calcium or phosphorus and the state of the teeth. Mull conducted successive examinations on 358 pregnant women from the twenty-eighth week of pregnancy to the seventh week post-partum and could find no correlation between the amounts of calcium and phosphorus in the blood stream and dental caries.
The effect of vitamin D. The effect of vitamin D is to enable the body to make use of calcium. No amount of vitamin D can take the place of calcium.

Mrs. Mellonby, (193) in a study lasting two years, on a group of 800 institutional children, found she could reduce caries two-third by feeding either cod-liver oil or a concentrated vitamin D preparation. In a study made in 1928 she investigated the effects of supplementing the diet of children with three different foods -- treacle, olive oil, and cod-liver oil. She found the cod-liver oil was effective. The children getting olive oil and treacle had an increase in caries of about 45 per cent. Those getting cod-liver oil had 9.8 per cent increase in carious teeth.

The Mellanbys believe that oatmeal contains a de-calcifying agent, and if oatmeal is given children the diet must be higher in vitamin D, than it would need to be otherwise. In many animal experiments they have produced hypoplasia in the teeth of puppies by diets high in cereals and low in vitamin D, but they have not been able to produce caries in the teeth of dogs. Edward Mellonby, in a lecture delivered at the University of Edinburgh, after the award of the Cameron prize for 1932, said that with about 200 c.c. of milk per day, and unlimited oatmeal gruel or bread caries could be produced in the teeth of
puppies in six or eight weeks.

Other workers have not confirmed the findings of the Mellanbys in regard to the harmful effects of cereals in the diet. They are usually considered a good food for the production of energy, but since they are not rich in minerals and vitamins, they should not crowd milk, fruits and vegetables out of the diet.

The effect of an adequate diet. Boyd and Drain (77) were probably the first to stress the effect of a diet as adequate as our knowledge of the nutritional needs of the body permits. The first man noticed that the teeth of diabetic children had improved upon the diabetic diet. Then they determined that insulin had no part in this arrest of dental caries; that the sole cause was food. They insist upon the following foods being included in children's diets "each day, each week, each month, each year." 1 quart of milk; 1 teaspoon of cod-liver oil; 2 large servings of vegetables, other than potato; 2 large servings of fruit, one should be a raw citrus fruit; 1 or 2 eggs; 6 teaspoons of butter, 1 serving of meat. They stress the fact that children are frequently offered these foods, but they do not always eat them.

The program of procedure is as follows:

1 - The condition of the patient's mouth is determined.
2 - The general physical condition noted.
3 - If there are any abnormalities suspected, a physician makes an examination.

4 - The patient or the mother is given a blank form and records the food eaten for three days.

5 - Dietetic errors are pointed out to the mother and the child when the diet chart is returned.

6 - A list of well-balanced meals including the foods listed above is given to the patient.

7 - There is a "check-up" at frequent intervals.

This dietary plan is much like the diet of Bunting (55) which was found effective in the control of caries. It is, also, like the diet Dr. Hanke recommends except that it is not so rich in citrus fruit. Howe, (127) McBeath, (182) and Hewett (119) agree that these dietary recommendations prove a satisfactory means of controlling dental caries. Again inadequate amounts of some foods, not too much of any particular food, is stressed as the cause of dental caries by the Iowa group of investigators. While there may be a few patients in whom it is impossible to arrest caries, one finds, as a rule, that the diet has not been followed in every particular when the carious processes continue.

SUGGESTIONS FOR FURTHER RESEARCH

The present place for research in this field has not been continued over long enough periods in the life of the
same child. Most of the experiments have lasted only three years, and some only a few months. Too many of the investigations have been group observation only.

The teeth begin to develop about the fortieth or forty-fifth day of fetal life, so the study of nutrition in relation to dental caries should begin with the beginning of life in the fetus and should continue in the same person until the eruption of the three molars. This procedure would be difficult to follow. Such a study would require:

1 - An accurate record of the diet of the mother during pregnancy.
2 - The metabolic condition of the mother during pregnancy.
3 - The diet of the child from the time it is born including a record of the actual food ingested.
4 - The blood composition determined by tests every three months.
5 - Monthly tests of the saliva
   a - bacteriological
   b - chemical
6 - The time and severity of any diseases or other disturbances of metabolism.
7 - The time of eruption of the teeth.
8 - Any diseases or dystrophies of the teeth.
With information of this character about children living their normal home lives, it should be possible to determine the etiology of dental caries in man and thus eradicate the most prevalent of human diseases.

SUMMARY

1 - The literature pertaining to the function of food in the preservation of the teeth has been reviewed. The historical, geographical, racial, and hereditary factors in the incidence of caries are discussed. It is shown that dental caries is the most prevalent of human diseases. About 95 per cent of Americans are sufferers from this disease.

2 - The structural development, growth, and calcification of the teeth are treated briefly in their relation to dental caries. Changes in the structure and dystrophies of the teeth due to pre-natal and post-natal diet, to illnesses, and to drinking water are considered.

3 - The nutritional factors in relation to dental caries are discussed under two main topics.

First, factors without the tooth, that may or may not enable it to resist caries.

1 - Oral hygiene, which is now thought to be of less importance than formerly.

2 - Acid destruction of the tooth achieved by the action of Bacillus acidophilus, or some
other micro-organism fermenting carbohydrate food debris into an acid of sufficient strength to decalcify the enamel. The acids are protected from dilution by the saliva and held against the tooth by a plaque. A good diet has been found useful in preventing the destruction of the tooth. This theory has strong evidence but it does not explain why some teeth decay and others in the same mouth do not; neither does it explain arrested caries.

3 - The particle size of the diet is shown to be a factor in the production of dental caries in rats. Coarsely ground particles of food lend themselves to acid fermentation. This discovery does not seem to be of any importance in human nutrition.

4 - There is not any conclusive evidence that the calcium, phosphorus, titratable alkalinity, pH, or carbon dioxide combining power of the saliva have any effect upon, or any relation to dental caries.

5 - The amylolytic and protolytic enzymes seem to have no action upon the teeth.
Second, factors within the tooth that may or may not enable it to resist caries.

1 - The structure of the tooth. A well-formed well-calcified tooth is more resistant to decay.

2 - The metabolism of the tooth. The circulation of lymph in the pulp and dentine is generally conceded. A few workers believe the enamel is also bathed in lymph. This theory is not generally accepted.

3 - Vitamin C has a protective action upon the peridontal tissues. Some workers believe that high intakes of vitamin C will prevent dental caries. Vitamin C has been administered as orange juice but the decrease in dental caries following its ingestion might be due to some other factor than vitamin C.

4 - Vitamin D is necessary for the calcification of teeth and bones, but that it is the specific preventive factor in dental caries has not been proved.

5 - The calcium phosphorus ratio, or the presence of large amounts of calcium or phosphorus in the diet are not specific factors in the prevention of dental caries.
6 - A well-balanced diet, adequate in minerals and vitamins has been shown to be effective in preventing or lessening dental caries.

From the evidence presented in the literature one must conclude that no single factor is responsible for dental caries. A well-balanced diet, both before and after birth, and freedom from metabolic disturbances will result in the prevention of dental caries. The amounts of vitamin C, calcium, phosphorus, and vitamin D required to prevent dental caries are probably much higher than our present standards of nutrition indicate.
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