

**Lecture #3-8****Dental Caries****LECTURE OBJECTIVES****Be Able To:**

1. Describe the combination of factors that influence dental caries. Describe how a dental health care provider can impact these factors.
2. Write the chemical formula of hydroxyapatite.
3. Explain how ion substitutions impact hydroxyapatite tooth structure and chemical properties (e.g., resistance to acids).
4. Using chemical notation show how the addition of acid affects hydroxyapatite.
5. Explain how the non-covalent bonding of hydroxyapatite makes it susceptible to acids.
6. Explain the reversibility of early dental caries.
7. Define the critical pH of enamel. Explain how fluoride affects the critical pH of enamel.
8. Discuss the effectiveness of various types of carbohydrates in promoting caries. I.e., why are certain carbohydrates more cariogenic?
9. Explain why caries usually appear in certain locations on the teeth.
10. Discuss the different ecological niches where caries are formed and some of the differences in terms of the prominent acid-producing bacteria at these sites.
11. Give the sequence of events in plaque biofilm development from a perfectly clean tooth surface through to a carious lesion.
12. Discuss the role that plaque biofilm plays in caries development.
13. Explain how bacterial metabolism of carbohydrates can cause caries.
14. Describe the major functions of saliva.
15. Explain how saliva protects against caries formation.
16. Explain, and diagram, (including naming the major enzymes involved) the sucrose pathway used by cariogenic bacteria to produce energy, acid, and extracellular polymers involved in caries and plaque formation.
17. Explain that caries can be thought of as a disease caused by certain infectious bacteria acquired early in life, and discuss the evidence in animals and humans supporting this conclusion.
18. Explain the accepted acidogenic theory of caries formation and the role of sucrose and other fermentable sugars in this process.

19. List the characteristics of ‘mutans’ Streptococci that implicate it as a central cause of caries. Define Keystone Species.
20. Define and compare aciduricity, acidophilic, and acidogenic.
21. Describe the key role of insoluble, extracellular, branched dextran in aiding the formation of caries.
22. Describe the difference between a lactate hetero-fermenter and a homo-fermenter.
23. Explain how high sugar diets result in the selection of aciduric, acidophilic, cariogenic bacteria (i.e., ‘bacterial succession’)
24. Explain what ‘Stephan Curves’ are, and how they illustrate the interaction of sugars and bacteria in acid production in plaque biofilms.

**Theme.** Dental caries is an extremely common disease, which is the result of many converging factors, including a ‘unkempt plaque biofilm lawn’ as well as the modern, highly cariogenic diets that drive the overgrowth of opportunistic, cariogenic bacteria. Understanding how all these factors relate and work should help clinicians better treat and prevent carious lesions in your patients.

## DENTAL CARIES

### Introduction

#### A. Description

Dental caries is a disease of the mineralized tissues of teeth (enamel, dentine, and cementum) caused by the action of microorganisms on fermentable carbohydrates. It is characterized by demineralization of the mineral portion of these tissues, followed by disintegration of their organic matrix. Caries can result in bacterial invasion and death of the pulp and spread of infection into periapical tissues and beyond. *In its early stages, caries can be arrested and remineralization can occur.*

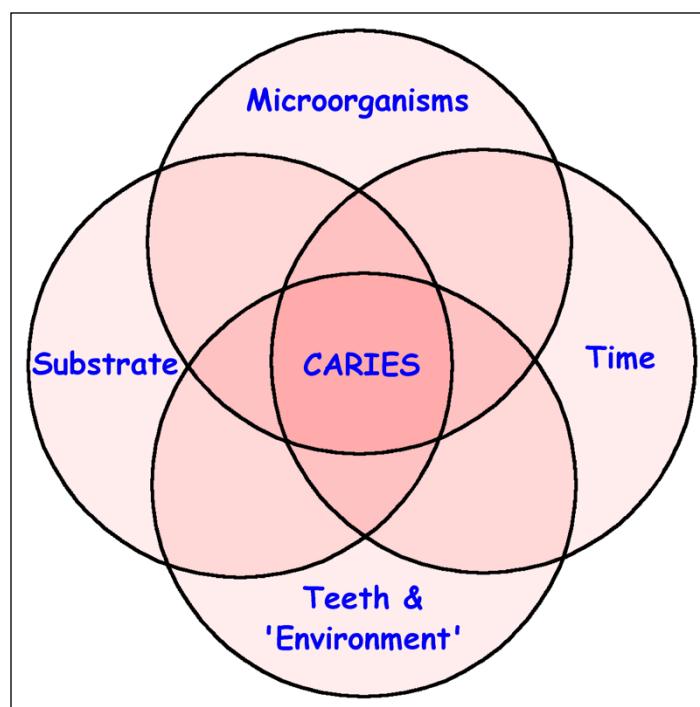
## B. Etiology of Caries

1. Worm theory: Pre-history - 18th century
2. Animalcule: 1680, A van Leeuwenhoek
3. Acidogenic Theory: 1881-1897, W.D. Miller

Some plaque bacteria are capable of fermenting suitable dietary carbohydrate substrates to produce acid, causing plaque pH to fall below critical levels. Repeated exposure to acid pH in time may result in demineralization at susceptible sites on the tooth surface, thus initiating the carious process.

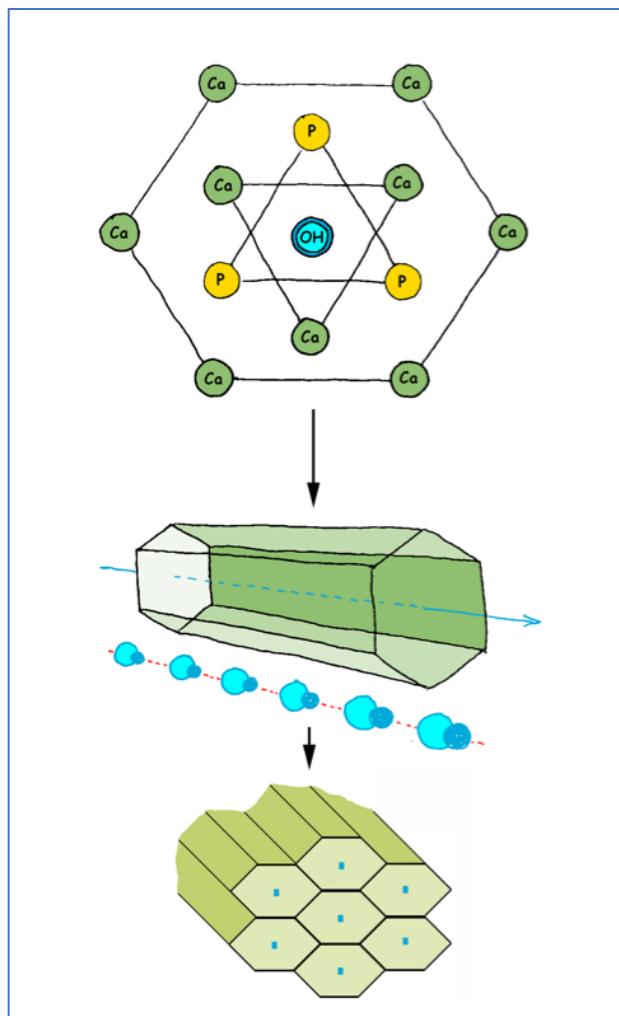
The formation of carious lesions depends on a combination of four major etiologic factors:

1. Metabolic substrates
2. Microorganisms
3. Teeth and their environment
4. Time



The figure illustrates the relationship between the four major etiologic factors involved in dental caries formation: 1) Substrate (e.g., the quantity and quality of dietary sugars) 2). Microorganisms (e.g., bacteria that can ferment dietary carbohydrates). 3) Time (e.g., the duration and frequency of carbohydrate consumption). 4) Teeth and oral environment (e.g., the 'quality' of the teeth, saliva, and immunity).

## Structure and Composition of Tooth Hard Tissue



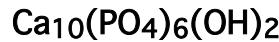
Hydroxyapatite is a structure held together primarily by ionic bonds (positive & negative charges). At its basic level it has a 'snowflake shape' of calcium and phosphates ions surrounding a central hydroxyl ion core. Many of these 'snowflakes' align along an OH<sup>-</sup> core to form long straight structures. These long structures further align in parallel within a protein 'form' to eventually make a 'rod-shaped' structure. Enamel rods can extend from the dentin/enamel (D/E) junction to the surface.

### A. Composition

1. Organic matrix
  - a. Protein (collagen, others), main component after HA
  - b. Other organic (mucopolysaccharides, chondroitin sulfate, etc.)

## 2. Mineral

- a. Hydroxyapatite, main component (calcium ions, phosphate ions, hydroxyl ions formed into a hard crystal lattice)



- b. Other positive substitution ions: lead, zinc, strontium, silver, nickel, iron, etc.
- c. Other negative substitution ions: carbonate, fluoride, etc.

## 3. Water

## 4. Cells (in dentine)

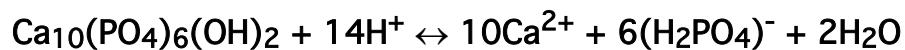
Proportions: approximate percent by weight

	Enamel	Dentine
Organic	4	20
Mineral	95	70
Water	1	10

## B. Properties

1. Substitution ions: In the hydroxyapatite crystal lattice, other ions of appropriate size and charge, can substitute for the various inorganic ions:
- a. For calcium: lead, strontium, radium, etc.
  - b. For phosphate: carbonate, etc.
  - c. For hydroxyl: fluorine, chlorine, etc.
2. The resistance of enamel to chemical attack depends (in part) on:
- a. The regularity with which the hydroxyapatite crystals line up. The more regular the hydroxyapatite alignment, the more stable the physical structure.
- Note:** With enamel maturation, the regularity of the hydroxyapatite crystals tends to increase ‘spontaneously,’ leading to decreased caries susceptibility. In mature enamel, the crystals are very long and thin, at times extending from the dentin/enamel interface to the enamel surface.
- b. The presence of substitute ions that can either increase or decrease susceptibility to chemical attack, depending upon the particular substitution.

3. Other substances, such as sodium-ions, magnesium-ions, calcium-phosphate, calcium-carbonate, and calcium-fluoride can be absorbed onto the hydroxyapatite surface.
4. The mineral lattice is porous (even in mature enamel), so free ions and other compounds can diffuse into it. Thus, the composition of hydroxyapatite can vary from one part of a tooth to another.
5. Hydroxyapatite can be dissolved by acid, but the reaction is reversible (pH dependent):



- Note 1.** Hydroxyapatite is essentially insoluble at neutral pH in saliva.
- Note 2.** Calcium and phosphate-ions are water soluble, but at their normal concentrations in body fluids (especially saliva), they are near their solubility product constant (i.e., essentially a saturated solution).
- Note 3.** If the above reaction goes to the right, dissolution (or demineralization) occurs. If it goes to the left (in the appropriate environment), remineralization results.
- Note 4.** The pH below which dissolution of tooth enamel predominates in the oral cavity is about 5.5; this is termed the Critical pH.
- Note 4.** The Critical pH of cementum and dentin are slightly higher than for enamel, having to do with increased ease of acids penetrating their less dense structures, as well as higher  $\text{CO}_3$  substitution rate (~4-7%) compared with enamel (~3%).
- Note 5.** However, Critical pH cannot be considered a fixed value, because the critical pH varies depending on such things as the concentration of fluoride, calcium and phosphate ions in the surrounding fluids, and solubility properties of the mineral at a specific toothsite, within a specific person's mouth.
- Q?** Remember your college chemistry? How does adding or subtracting Calcium or Phosphate ions on the right of the equation above change the reaction parameters?
- Last Note.** I will use Fluorine and Fluoride interchangeably. Fluorine is the element. While fluoride actually refers to the fluorine ion or to a compound that contains the element fluorine. Hairsplitting!

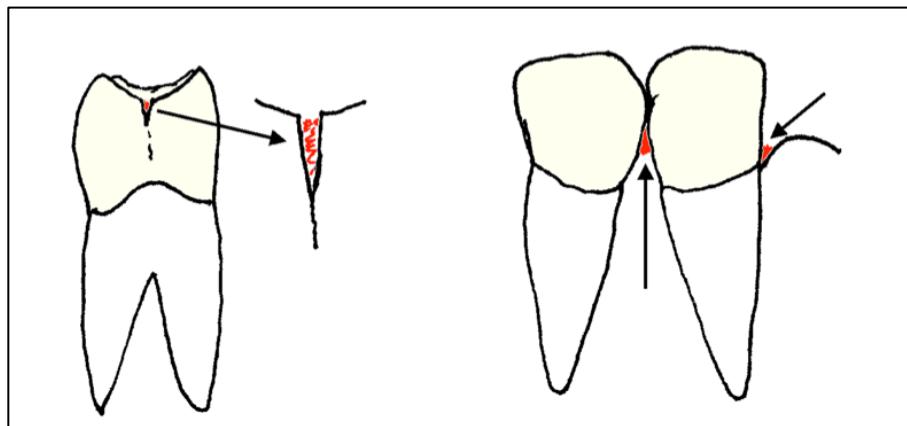
## Sites of Caries

### A. General Characteristics of Caries-Susceptible Sites

1. Favorable for plaque retention (hard to ‘mow the lawn’)
2. Limited access for saliva

### B. Susceptible Sites

1. Pits and fissures
  - a. Pits and fissures on occlusal surfaces of molars and premolars
  - b. Buccal pits of molars and palatal pits of maxillary incisors
2. Approximal surfaces of adjacent teeth just cervical to the contact point
3. Cervical margin just coronal to the gingival margin
4. Exposed root surfaces, in patients with gingival recession
5. Margins of deficient restorations
6. Tooth surfaces adjacent to dentures, bridges, and orthodontic appliances



The major caries-susceptible sites have limited saliva access, which favors plaque retention. These sites allow the number of bacteria to become large and the plaque to become thick and less aerobic – allowing cariogenic bacteria to accumulate and form sizable colonies, which in turn results in any acids produced to linger locally.

## Plaque Development

### A. Sequence

HA  $\Rightarrow$  Salivary Proteins  $\Rightarrow$  Pellicle  $\Rightarrow$  Plaque Biofilm  $\Rightarrow$  (Calculus)

### B. Pellicle (also called - Acquired Pellicle)

1. Definition: acellular, homogeneous, organic film that forms on enamel and other hard surfaces by selective adsorption of charged proteins and glycoproteins, mainly of salivary origin.

#### 2. Characteristics

- a. Forms spontaneously on teeth
- b. Bacteria not necessary for formation
- c. Can be removed only by *meticulous* cleaning
- d. If removed, rapidly forms again (minutes to a few hours)
- e. Modulates the mineral homeostasis of tooth surfaces (how?)
- f. Forms suitable environment for bacterial pioneer species' adherence and multiplication  $\rightarrow$  (plaque biofilm)

### C. Plaque Biofilm

1. Definition: soft, non-mineralized bacterial deposit that forms on teeth

#### 2. Composition

- a. Plaque-tooth interface (generally pellicle)
- b. Microbial layers and colonies
- c. Extracellular matrix (soluble and insoluble)
  - Carbohydrates: glucans (glucose polymer), fructans (fructose polymer), and other polysaccharides. Produced by plaque bacteria. Primary component of matrix.
  - Protein, nucleic acids, etc.

3. Role in caries: suitable environment for acid-production (acidogenic), and diminished saliva protection mechanisms.

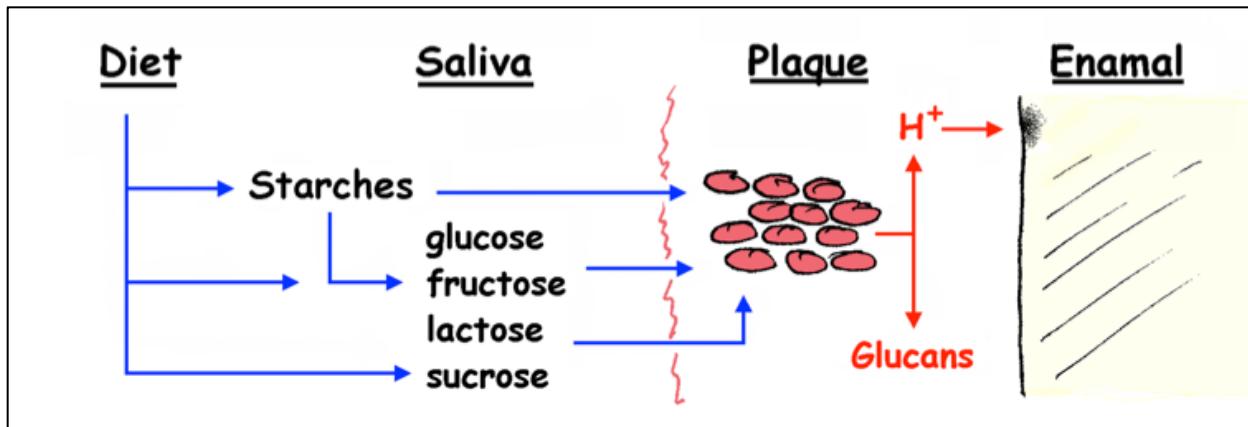


Figure illustrates the relationship between dietary carbohydrates, saliva, and plaque biofilm. Dietary carbohydrates, especially simple sugars, are fermented by some plaque bacteria to produce acid ( $H^+$ ) and extracellular polymers (e.g., glucans and fructans). As the plaque thickens, the effects of saliva (e.g., washing and buffering) decrease, making the acid accumulation more pronounced. In the end if too much acid is produced and accumulates for extended periods -> a caries lesion is formed.

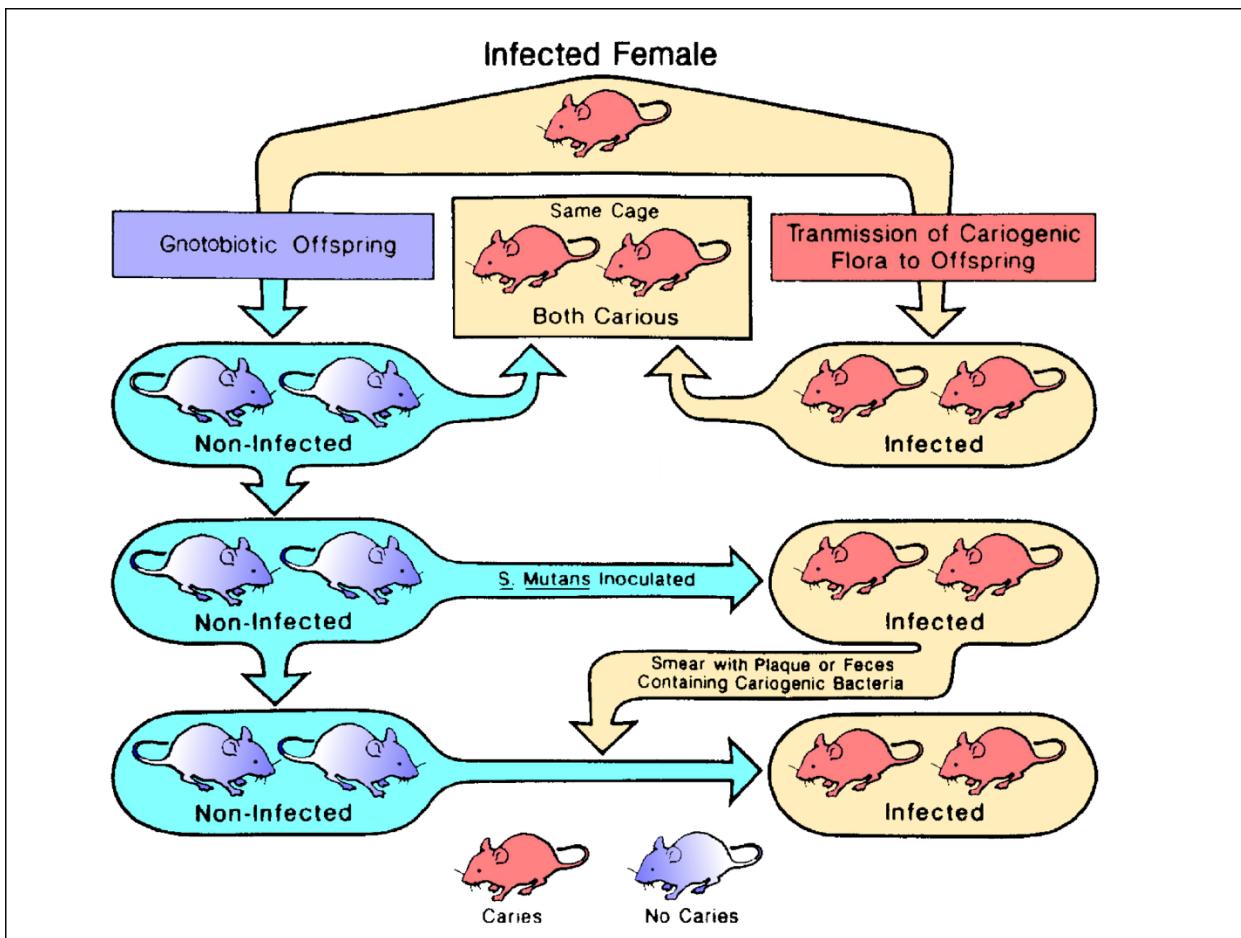
#### D. Calculus (sometimes called Tartar)

1. Definition: plaque biofilm in which inorganic deposits have caused mineralization. Greatly increases risk for developing gingivitis and periodontitis.

## Role of Bacterial Metabolism

### A. Identification of Bacteria

1. Appropriate bacteria must be present to produce caries.
  - Germ-free animals do not develop caries even when fed a highly cariogenic diet.
2. Through tests on animals with known oral flora (= gnotobiotic animals), bacteria capable of causing caries can be identified (these are called add-back experiments): e.g., *Streptococcus mutans*, *Lactobacillus spp.*, and *Actinomyces spp.*



Experiments conducted with gnotobiotic animals (= ‘known life’; germ-free animals that have only one or a few known microbes added) have shown that caries is caused by infectious microorganisms. These experiments have also shown that both sugar and plaque bacteria - most importantly cariogenic bacteria such as, *mutans Strep. Strep*, *Lactobacillus*, and *Actinomyces* are required to cause caries.

**Question?** Do you think the ‘bubble boy’ on Seinfeld would have dental caries?

3. Many characteristics suggest that 'mutans' Streptococci are a chief cause of caries at most tooth sites.

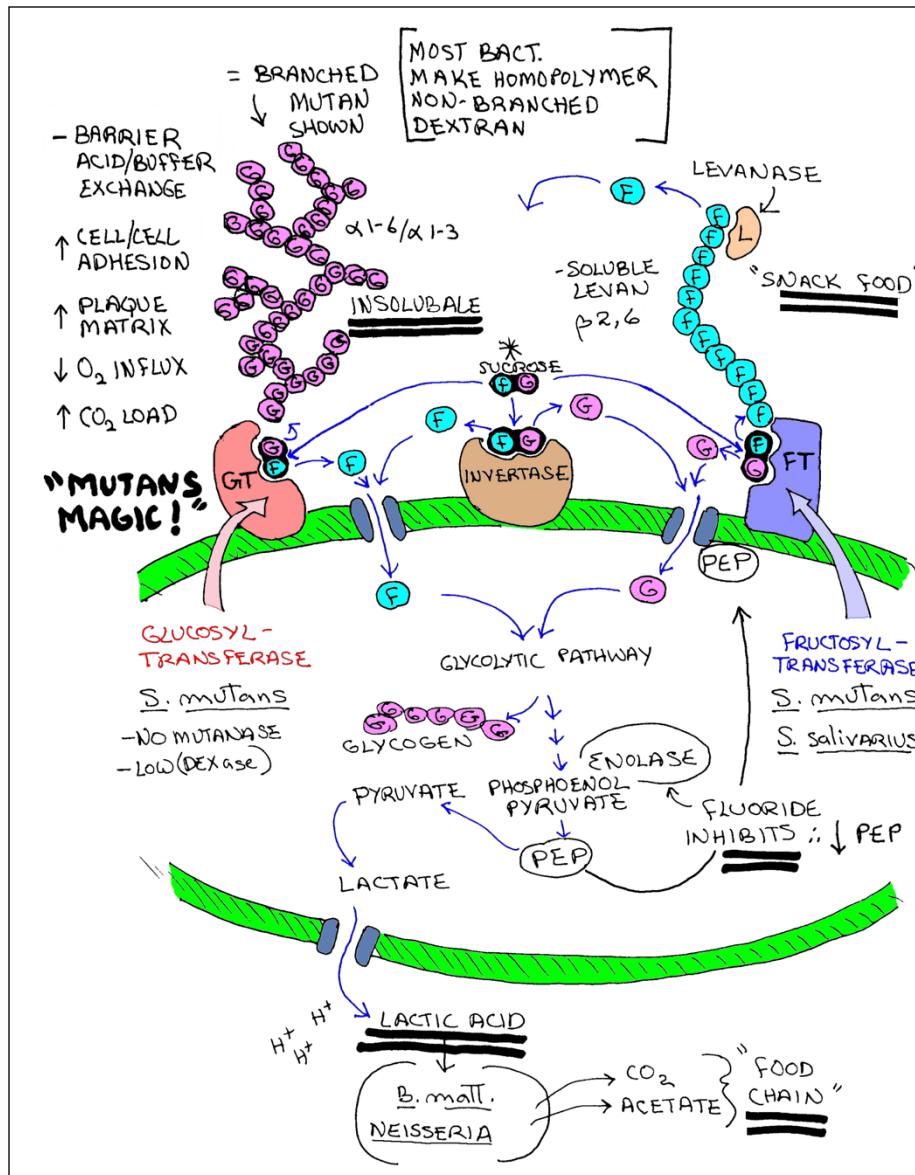
## "MUTANS" STREPTOCOCCI

### PROPERTIES

$\begin{array}{l} \text{S. mutans} \\ \text{-- Sobrinus} \\ \text{-- ratus} \\ \text{-- cricetus} \end{array}$

1. SUGAR TRANSPORT GOOD AT LOW pH
2. ACID PRODUCTION = HOMOLACTIC FERMENTER  
(HETEROLACTIC FERMENTER = LACTIC ACID)  
ACETIC "  
ETOH  
CO<sub>2</sub>
3. ACIDURICITY =  
ACIDOPHILIC = GROWS WELL AT LOW pH
4. PRODUCES INSOLUBLE GLUCAN ("MUTAN")  
↓ BUFFER AVAILABILITY, ↑ ACID CONC.
5. PRODUCES INTRACELLULAR POLYSACCHARIDE ("SNACKS")  
EXTRACELLULAR LEVAN

'Mutans' Streptococci have many characteristics that point to their role as a keystone microbe in the development of caries: 1) They have excellent sugar transport at low pH (most oral bacteria do not). 2) They are **homolactic** acid fermenters (i.e., they produce almost exclusively lactic acid as a by-product of sucrose fermentation). 3) They are **aciduric** - tolerating a highly acid environment, and **acidophilic** - actually preferring a somewhat acid environment. 4) They utilize 'extra' glucose to make insoluble glucans (glucose polymers), which shields them (and their nearby neighbors) from saliva, and thus maintains the acid in the local environment. 5) They utilize 'extra' fructose to make extracellular levans (i.e., fructan polymers), which they use as 'snacks' between meals. A keystone bacteria, that helps transform healthy plaque into a cariogenic biofilm!



The way plaque bacteria deal with sugars, especially sucrose, is key to caries development. Because of ubiquitous sucrose in our 'modern' diet, we have selected plaque bacteria that are able to utilize sucrose rapidly for energy and store some for later consumption. Most bacteria will use excess sugars to form extracellular, non-branched, soluble, polysaccharide chains. *Strep. mutans*' unique glucosyl-transferase (GT) on the other hand can also make branched, insoluble, extracellular, polysaccharide chains. This forms a protective ECM 'dome' over the *S. mutans* micro-colonies within the plaque biofilm, and also contains their acid production for longer periods of time close to the tooth surface. *S. mutans* using fructosyl-transferase (FT) also exploits excess fructose, which mostly comes from breaking the disaccharide sucrose, to form extracellular levans (i.e., fructans) that it can use as 'snack-food' between meals! *S. mutans* is also a homolactate fermenter - it usually produces two lactic acid molecules for every monosaccharide it ferments. Finally, *S. mutans* competes well in acidic environments (= **acidophilic**) by being relatively resistant to acid (= **aciduric**). Thus, *S. mutans* are a major keystone bacteria of dental caries formation. Note: high concentrations of fluoride are able to 'poison' the Glycolytic Pathway and thus 'wound' *S. mutans*, as well as other cariogenic bacteria.

4. A diet high in sugar and processed, refined carbohydrates (i.e., a cariogenic diet) selects for aciduric (able to tolerate high acid environments) bacteria such as *Strep.*, *Lacto.*, and *Actino*. This is an example of ‘bacterial succession.’

Cariogenic bacteria are poor competitors at pH 7, but good competitors at pH 4-5.

	Before glucose (pH 7)	After Glucose Pulses + buffers	After Glucose Pulses no buffers
Lact. casei	0.1	0.2	36.0
A. viscosus	0.1	13.0	2.0
Strep. mutans	0.3	1.0	19.0
Veillonella dispar	10.0	29.0	41.0
Strep. oralis	15.0	17.0	1.0
Strep. gordonii	28.0	25.0	0.2
Prev. intermedia	31.0	6.0	<0.01
Fuso. nucleatum	15.0	10.0	<0.01

Percent viable count in sample. In vitro.

The table shows an in vitro experiment where plaque is 'pulsed', in vitro, with 10 glucose rinses (with or without buffer) every hour, for 10 hours. In 'healthy' plaque *S. mutans* and *Lactobacillus spp.* are found in very low numbers. After feeding the plaque with sugar the aciduric bacteria such as *S. mutans* and *L. casei* increase. This increase is most dramatic when buffers are excluded, as would be the case in thick plaque or a xerostomic patient.

5. The pH of the environment strongly affects metabolic acid production and results in bacterial succession. Succession occurs because each bacterial species, or strain, has a limit to its ability to grow at low pH, and in addition, has a limited acid-producing capacity at these lower pH conditions. Evolution at a micro scale!

Bacterial Succession.

	Healthy	White Spot	Cavitated
Strep. mutans	4.0	22.0	43.0
Strep. sobrinus	0.2	5.0	6.0
Veillonella dispar	10.0	20.0	15.0
Strep. mitis	16.0	12.0	8.0
Strep. sanguinis	7.0	4.0	3.0

Percent viable count in plaque sample. In vivo.

The table shows that plaque taken from active caries sites has a higher percentage of *mutans Streptococcus*. This is an example of bacterial succession from bacteria that succeed at more neutral pH to those that succeed better at more acid pH (i.e., cariogenic bacteria are acidophilic).

**Table 6.8** Acid production from glucose by oral bacteria

Bacterium	Terminal pH*	Rate† of acid production at	
		pH 7.0	pH 5.0
<i>S. mutans</i>	4.01	280	75
<i>S. mutans</i> (fresh isolate)	—‡	850	180
<i>S. sobrinus</i>	4.13	149	—
<i>S. sobrinus</i> (fresh isolate)	—	1700	400
<i>S. gordonii</i>	4.36	63	15
<i>S. sanguis</i> (fresh isolate)	—	900	0
<i>S. mitis</i>	4.34	167	—
<i>A. naeslundii</i>	4.57	57	—
<i>A. viscosus</i>	4.44	76	—
<i>L. casei</i>	3.86	164	—

\* Terminal pH after 15 minutes

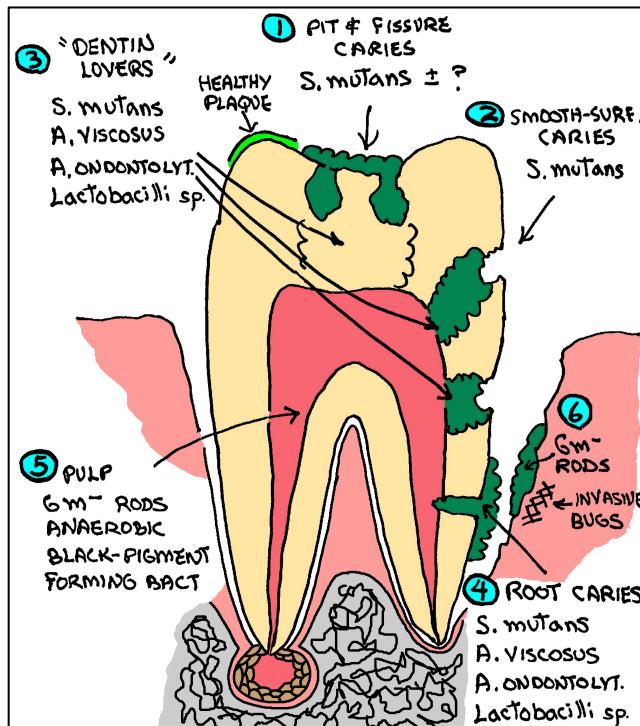
† Rates are expressed as nmol of acid produced per minute per mg (dry weight) of cells at a constant pH 7.0 or pH 5.0

‡ Not determined.

The table shows that many bacteria can metabolize and produce acid at a neutral pH. However, mutans Streptococci species (i.e., *S. mutans* and *S. sobrinus*) are able to metabolize and produce significant acid even at a lower pH. This is one of the reasons they are acidophilic, and why they compete best at these lower pH levels.

**Q?** From the above data, which of the bacteria will be able to compete best in the very lowest pH? Why?

6. The tooth surface presents many different ecological niches (e.g., smooth surfaces, root surfaces, coronal surfaces, etc.) that caries can form and each site may promote a different combination of acid-forming bacterial populations.

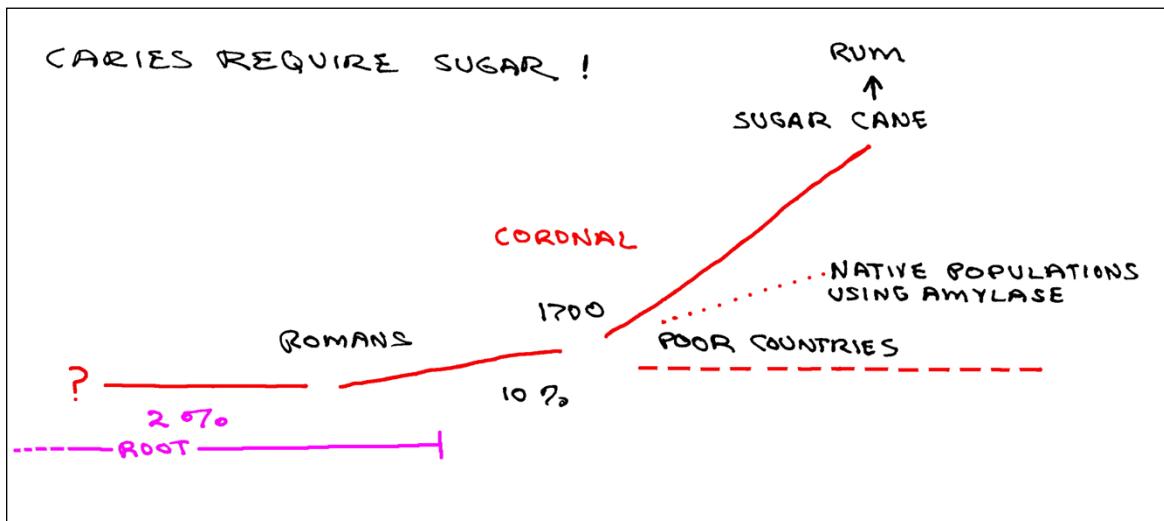


The figure shows the major locations of plaque-related diseases, and the major bacterial species responsible for these diseases. Caries form at four major locations: 1) Pits & fissures, *S. mutans* is by far the major player here. 2) Smooth-surface caries, *S. mutans* again is the major player. 3) Dentin, *S. mutans* is again important, but other bacteria (*Actinomyces* and *Lactobacillus spp.*) play increasing roles as soon as the 'harder' enamel is 'cracked open' by the *S. mutans*. 4) Root caries, similar to dentin. 5) Endodontic infections are usually mixed infections of various gram-negative, anaerobic/facultative bacteria. 6) Gingivitis & periodontitis are caused primarily by gram- anaerobic/facultative bacteria, which result from plaque overgrowth and maturation.

7. Although **caries vaccines** are a possibility in the future, considerable research is still required to reach this goal. The same is true with **replacement therapies**, which involve inoculation with genetically modified, less pathogenic *S. mutans* strains. **Probiotic therapies** will probably be the first to be used to decrease caries. The biggest problem is determining which bacteria to use. Maybe someone will come up with a 'specific weed kill'; oh, wait **STAMP** might just be it! (We'll talk about all of these shortly.)

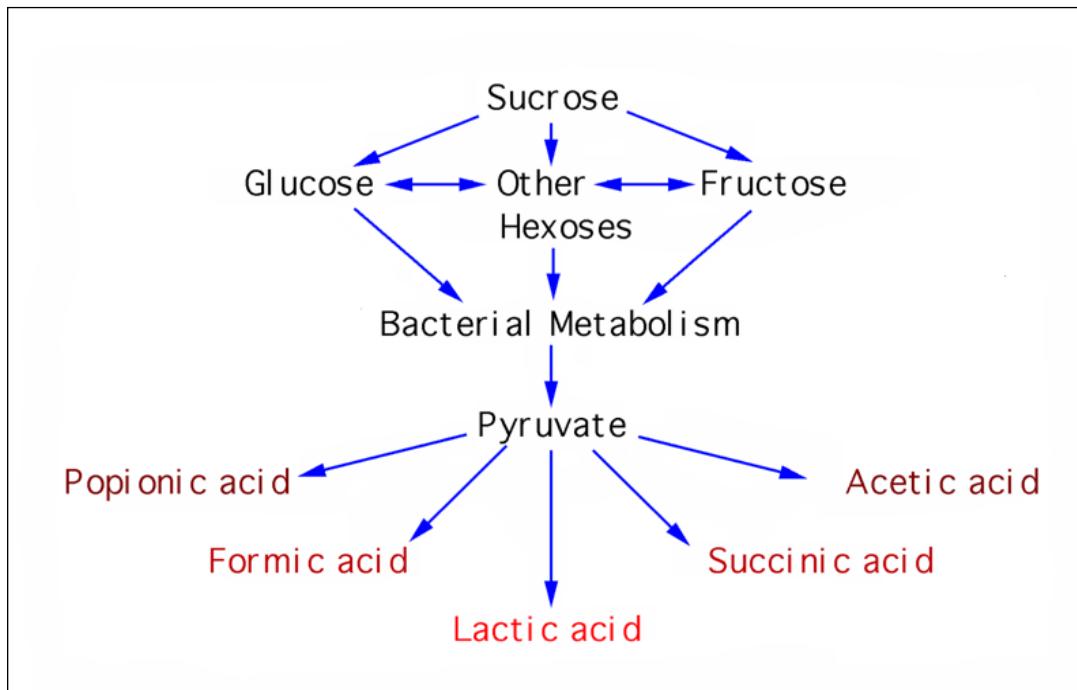
**Q?** Which bacteria would you use in your patent pending "Dr. (insert name here), Magic Smile™ Probiotic Solution?" How, and when, would you apply these bacteria?

## B. Role of Dietary Carbohydrate



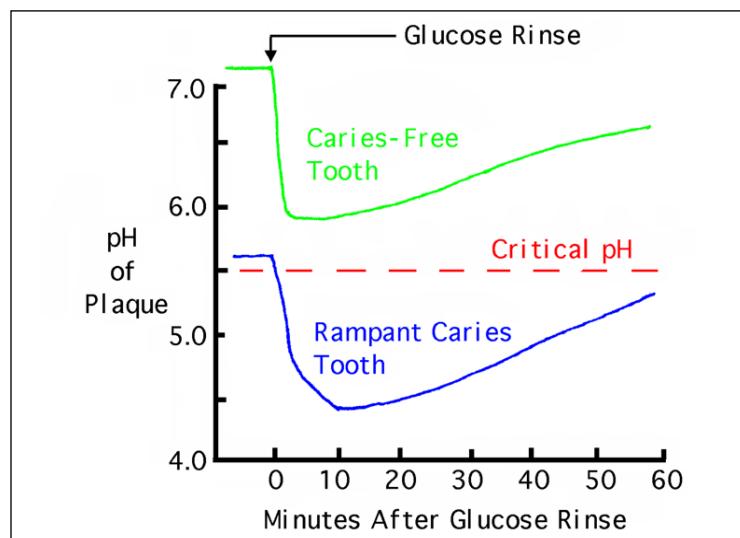
Throughout most of history coronal (enamel) caries has been infrequent. It was only with the advent of farming, which provided a steadier supply of carbohydrates, and finally the production of inexpensive sugar that the explosion of coronal caries started.

1. The source of  $H^+$  (i.e., acid) in caries: bacterial metabolism of dietary carbohydrate, especially simple sugars, to produce acids.



Acidogenic sugar metabolism by oral bacteria. Most bacteria in supragingival plaque utilize sugars as an energy source. However, the various bacterial species produce an assortment of end-products from sugar breakdown, including things like alcohols, but mostly many different acids. Lactic acid is the most 'dominant' of the commonly produced acids.

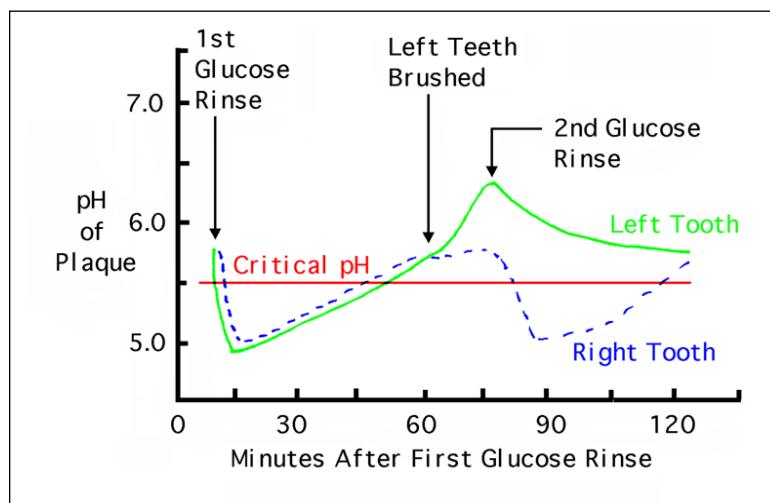
2. Certain fermentable dietary carbohydrates lead to rapid and sustained pH drop (e.g., ‘Stephan curve’) in plaque biofilm.



**Stephan Curves** showing the pH drop in plaque biofilm that accompanies a glucose ‘feed.’ Plaque associated with rampant caries start at a much lower ‘resting’ pH than does ‘healthy’ plaque on a caries-free tooth. This allows the pH to drop below the critical pH for an extended period of time in the plaque associated with rampant caries.

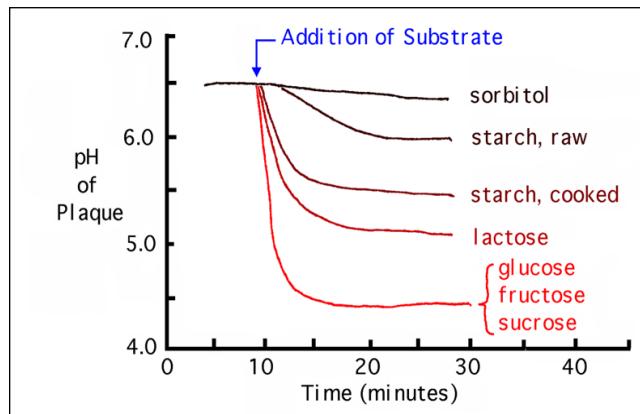
- Q? Why does the ‘resting’ pH of plaque biofilm associated with caries start at a lower pH than the healthy plaque biofilm?

3. The presence of plaque is required to produce a pH at or below the critical value.



The figure illustrates an experiment that demonstrates the need for plaque bacteria to metabolize sugars to acids. By simply brushing the tooth ('mowing the lawn') the amount of acid is greatly reduced.

4. The effectiveness of a given carbohydrate in promoting caries depends upon:
- The ability of cariogenic bacteria to metabolize the carbohydrate.
  - The ability of the carbohydrate molecules to diffuse into plaque.



Not all carbohydrates (CHO) are created equal! Plaque bacteria have the ability to utilize highly processed CHO and especially, simple sugars much more effectively than more complex CHO.

5. The frequency of sugar consumption is much more important than amount.

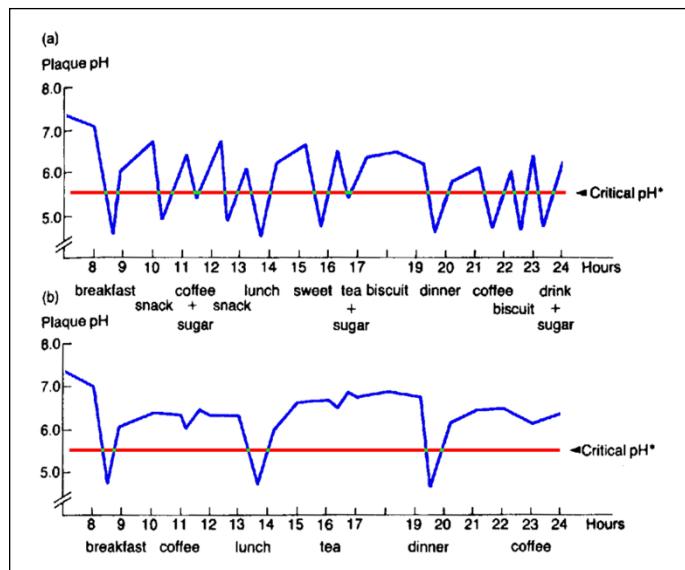


Illustration of the changes in plaque pH in an individual who (a) has frequent intakes of fermentable carbohydrate during the day, or (b) limits their carbohydrate intake to the main meals only. While 'grazing' is probably natural, grazing in an era of ubiquitous, simple sugars is probably not good for tooth health.

## Saliva

- A. Definition: Watery secretions of the Parotid, Submandibular, and Sublingual salivary glands (main source) as well as the minor glands of the oral mucosa (minor source)
- B. Regulation
  - 1. Activated by autonomic reflexes
    - a. Parasympathetic stimulation: copious flow, watery, Parotid mainly
    - b. Sympathetic stimulation: low flow, thick (mucoid), Submandibular and Sublingual primarily
  - 2. Flow stimulated by
    - a. Taste (sour, salt, bitter, and sweet; in that order)
    - b. Chewing – Sour taste plus chewing are why citrus-flavored gums work so well to stimulate saliva!
    - c. Sight, smell, etc. of food (minor in humans)
    - d. Food in mouth
  - 3. Flow rate
    - a. Unstimulated: 0.2-0.5 ml/min
    - b. Stimulated: 1-10 ml/min
    - c. Between meals during the day: small (i.e., unstimulated)
    - d. Sleep: very, very small
    - e. Many diseases and medical treatments can influence (usually lower) flow rate. (See xerostomia, below)
- C. Major Functions
  - 1. Aid in swallowing and digesting food
    - a. Lubricate food to aid swallowing
    - b. Dissolve food to enable stimulation of taste bud sensory endings
    - c. Digest foods, particularly carbohydrates (salivary amylase)
  - 2. Formation of tooth Pellicle (sometimes called the Acquired Pellicle)

- a. Charged salivary proteins, especially Statherin, Proline-Rich Proteins (PRPs), and some Mucins make up the majority of the Pellicle, which bind to charged hydroxyapatite of teeth
- b. Provide binding sites for the 1° colonizers (e.g., mitis Strep)
- b. These proteins also inhibit excess mineral precipitation onto the tooth surface. Thus, the tooth doesn't grow in size after it erupts – a good thing, don't you think!

## 2. Protective

- a. Mucoid coating on oral mucous membranes forms chemical barrier and thermal insulator
- b. Reduces tendency to caries:
  - 1) Flushes away carbohydrates
  - 2) Contains  $\text{Ca}^{2+}$  and  $\text{PO}_4^{3-}$  for tooth remineralization
  - 3) Contains antimicrobial agents (e.g., lysozyme and Ab)
  - 4) Acts as chemical buffer to maintain mouth pH near neutral (e.g., bicarbonate, buffer system)
  - 5) Source of 'recycled' topical fluoride

## D. Effects of lack of saliva (xerostomia, “dry mouth”)

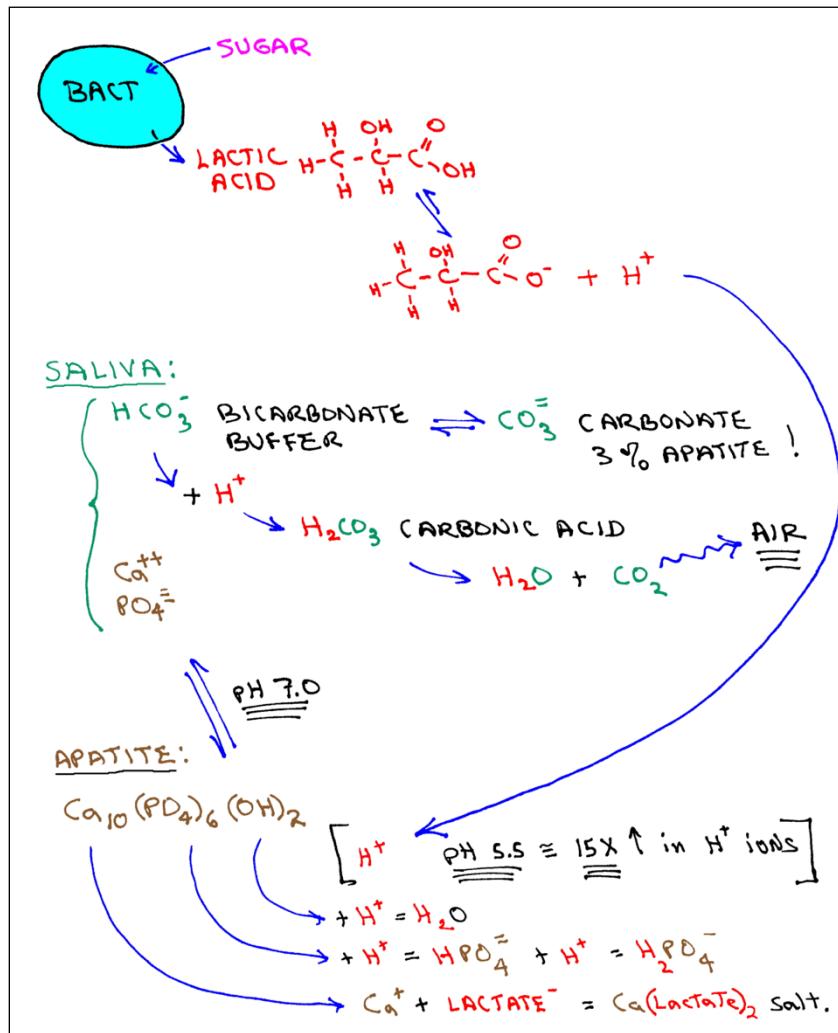
1. Tendency to oral ulceration
2. Difficulty in swallowing dry foods
3. Thermal and chemical sensitivity
4. Altered taste
5. Dysbiosis of the oral microbiome -> Increased tendency to caries

**Note:** "Dry mouth" occurs in all people during sleep. This is why regular, bedtime, oral hygiene is particularly important!

## E. Treatments for lack of saliva

1. Artificial saliva
2. Increased oral hygiene
3. Dietary control (e.g., decrease sugars)
4. Fluoride therapy

- Q1?** Do you think patients with Sjogren's syndrome would be at increased risk of Dental caries? Infectious endocarditis?
- Q2?** Do you think patients with chronic renal failure would be at increased risk of dental caries? How about pts. with diabetes?



Certain plaque bacteria, most notably *Strep. mutans*, are able to ferment dietary sugars to lactic acid. If enough acid is produced the pH will fall below the critical pH and demineralization of the tooth hydroxyapatite structure will begin. Saliva contains buffers that are able to somewhat mitigate this. Saliva also contains  $\text{Ca}^{2+}$  and  $\text{PO}_4^{3-}$  ions that can remineralize the tooth hydroxyapatite structure once the pH rises back above the critical pH.

- Q?** Eating Disorders (ED) are one of the more common mental health issues, with an estimated 10% of the population suffering at some point in their life. One of the more common practices of ED patients is to frequently induce vomiting. This results in the mouth being bathed in stomach acids. What would be the impact(s) of this practice on tooth health? Why?



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**Healthy bite.** This ancient Egyptian had healthier teeth and jaws than most living humans.

The Maya of the two villages are before-and-after images of a population undergoing the so-called nutrition transition in which people switch from a traditional subsistence diet to an Industrial Age diet of refined sugars and processed foods. At the meeting, an unusual mix of paleoanthropologists, archaeologists, dental researchers, and food scientists explored what is known about the diets and dental health of ancient humans, and how that information might be useful to dentists today. “How does our oral environment today differ from those in which our teeth evolved?” asked co-organizer Peter Ungar of the University of Arkansas (UA), Fayetteville. “Can an understanding of this discordance inform clinical research and ultimately dental and orthodontic practice?”

### Online

[scim.ag/pod\\_6084](http://scim.ag/pod_6084)

Podcast interview

With author Ann Gibbons ([http://scim.ag/pod\\_6084](http://scim.ag/pod_6084)).

# An Evolutionary Theory of Dentistry

**Why are our teeth so rotten? Biologists point to a mismatch between our diets and lifestyles and those of our ancestors**

**DURHAM, NORTH CAROLINA**—Remember the Coca-Cola jingle that went, “I’d like to buy the world a Coke and keep it company”? Well, it worked. And here’s what happens when everyone can buy a soda every day in a small town on the northern tip of Mexico’s Yucatán Peninsula: Young adults in the town of Dzilam González had three times as many cavities as those who live in a poorer, more isolated village nearby where people can’t afford soft drinks every day, according to a new study. In the poorer village, people eat a traditional diet of maize tortillas at every meal. The richer village has a pizzeria in its central square, shops with ads for soft drinks, dentists’ offices—and significantly more tooth decay in people aged 20 to 30, according to a new study by Elma Vega Lizama and Andrea Cucina of the Autonomous University of Yucatán in Mérida, Mexico.

Cucina presented the study of these two Maya villages at a recent meeting\* here. The work offers an elegant demonstration of the

message that emerged at the meeting: Human teeth, jaws, and mouths are not adapted in a healthy way to the diet of modern industrial society. We evolved to thrive on coarse seeds, nuts, tubers, fruit, and meat. In our skele-



**Not-so-sweet tooth.** This German jaw from the 16th to 18th century shows the perils of a poor diet in tooth loss, cavities, and gum disease.

tons, too, our evolutionary history leaves us prone to medical problems (see sidebar, p. 974). But when it comes to our mouths, the mismatch between our adaptations and our environment causes the dental cavities, overcrowding of teeth, overbite, and gum disease that run rampant today.

### When the ancients smiled

The meeting began with grim slides of primates with terrible teeth and swollen gums, demonstrating that humans aren’t the only ones with toothache. “Trauma, dysplasia, hypoplasia, arthritis, cysts—it’s all there in animals,” says anatomist Christopher Dean of University College London (UCL). “These are usual in wild animals in the last decades of their life, as part of the aging process.” But tooth decay and gum disease get worse with a soft, sugar-rich diet in captivity.

Cavities and periodontal disease used to be diseases of aging in humans, too. In fossils of ancient humans, “you can count the number of cases of dental caries [cavities] on one hand,” says UCL bioarchaeologist Simon Hillson. Researchers, such as Ungar who have examined thousands of fossilized human ancestors estimate that cavities appear in fewer than 2% of teeth from earlier than 20,000 years ago.

Traditional foragers, such as Australian aborigines in the 1940s, still had beautiful teeth, with cavities in only the very old. (Other foragers with diets rich in plant carbohydrates, which are sugars, are an exception.) Gum disease and malocclusion—problems in the way the upper and lower teeth fit together,

CREDITS: AMARNA PROJECT; LESLIE WILLIAMS

\*“Evolution of Human Teeth and Jaws: Implications for Dentistry and Orthodontics,” National Evolutionary Synthesis Center, 28–30 March, Durham, North Carolina.

## NEWSFOCUS

such as overbite—are also surprisingly rare in prehistoric teeth, says Robert Corruccini of Southern Illinois University in Carbondale, who reviewed 20 years of research on cross-cultural differences in occlusion.

This clean bill of dental health began to deteriorate, however, as farming started to take root as early as 13,000 years ago in the Middle East and later in other parts of the

world. Roughly 9% of Neolithic people—the first farmers—had cavities, as they began to consume cereal grains rich in carbohydrates, Ungar says. Even so, many millennia elapsed before dietary changes resulted in serious oral damage. For example, the skeletons of 93 commoners excavated at Amarna, Egypt, who apparently died between about 1330 B.C.E. and 1350 B.C.E., had surpris-

ingly good teeth, says UA anthropologist Jerome Rose. These Egyptians ate more carbohydrates than hunter-gatherers did, in the form of coarse bread, but they also ate so much grit and fiber that the surfaces of their teeth—including any cavities—wore down rapidly. “The wear was fast enough to erase decay until late in life when decay showed up between teeth,” Rose says.

### The Burdens of Being a Biped

Just as many dental problems are rooted in our evolutionary history (see main text, p. 973), a number of musculoskeletal issues are also traceable to our past, in particular to the switch to walking upright more than 7 million years ago. “We’ve taken a body that was adapted to being horizontal to the ground and made it erect,” says Bruce Latimer, a comparative anatomist at Case Western Reserve University in Cleveland, Ohio. “We’ve had to change nearly every bone in the body, and as a consequence, there are many things that humans suffer from that no other animal does.”

Shifting from a four-legged support system to a two-legged one put extra stress on the legs and vertebrae. Adaptations in the feet, knees, hips, pelvis, and spine accommodate these forces, but at a cost. Imperfect evolution and constraints on how our bodies could change have left us with vertebrae that break more easily, weaker bones, and feet prone to heel spurs and sprained ankles.

Our relatively inactive lifestyles and longer life span only exacerbate our orthopedic imperfections. A brief tour of the body reveals a number of design flaws, the legacy of our past.

**Spine.** Back pain is the leading health complaint in the United States. In dogs, horses, and even chimpanzees, the backbone is a series of vertebrae neatly stacked and evenly spaced to form a relatively stiff, gently curving beam. Not so with the human spine, which is highly flexible and can even bend backward. Yet this flexibility creates wear and tear on joint surfaces and predisposes us to osteoarthritis.

Furthermore, evolution has left our spines with an S-shaped curve, which is necessary to keep the upper body centered over the hips. Thus the lower spine curves toward the belly button, causing a hollow low in the back and bringing the torso upright. To keep the head centered, the thoracic vertebrae in the chest curve in the other direction. “Spinal curvatures cause a lot of problems in humans that other animals don’t have,” particularly slipped disks and broken vertebrae, says Carol Ward, an anatomist at the University of Missouri, Columbia.

One type of break, called spondylolysis, affects about 6% of the U.S. population and is a leading cause of lower-back pain in teenage athletes. In this condition, the neural arch—a triangle of bone that surrounds the spinal cord—detaches from the rest of its vertebra, allowing the spine to slip forward relative to the back of the pelvis, pinching nerves and causing pain.

Ward, Latimer, and their colleagues surveyed thousands of human skeletons in the 1990s and determined that the problem lies in inadequate spacing between the joints connecting the vertebrae. If the lower vertebrae are too crowded, the bone is chronically pinched, eventually causing it to dissolve and the neural arch to separate. “When people don’t have that correct spacing, they tend to get spondylolysis,” Ward says. X-rays can reveal vulnerability to this condition, Latimer notes, and children with narrow vertebral spacing should avoid gymnastics, swimming butterfly stroke, and other sports that involve excessive back arching.

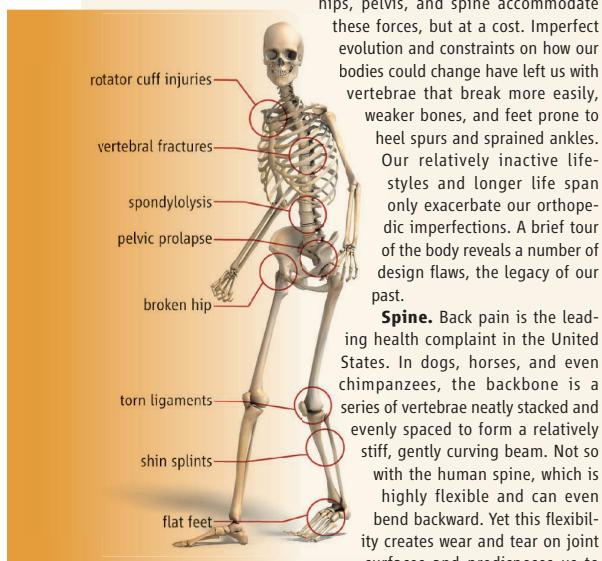
**Feet.** To cope with the added load on just two feet, the foot evolved a shock-absorbing arch by bringing what was a grasping big toe into line with the other toes. When that arch fails to form fully, as in people with flat feet, fatigue fractures can result. And when the big toe’s tendon gets misaligned from improper shoes, bunions develop. Latimer blames heel spurs, plantar fasciitis, hammer toes, shin splints, chronically sprained ankles, and even varicose veins on our erect posture.

**Fragile bones.** The added load on two feet also caused knee and hip joints to expand, creating more surface area to absorb foot-fall forces. But the joints—and vertebrae as well—evolved to be bigger by enlarging the spongy, inner bone and thinning the hard, outer bone. As a result, human bones are less dense than those of other primates, a team led by mechanical engineer Christopher Hernandez of Cornell University, who studies osteoporosis, reported on 19 October 2011 in *PLoS ONE*.

Bone builds mass during childhood—more so if stressed with exercise—then loses mass during adulthood. With humans having ever longer life spans, bones, particularly vertebrae, may become fragile and break spontaneously. Apes lose bone mass as they age as well, but they don’t suffer fractures because their bones are so much denser to begin with. Humans could have more apelike bones if they got more exercise as youths, as early humans did, Ward says. “If we treated our skeletons the way they were designed to be treated, they would serve us better later in life.”

Bipedality leaves its mark in other parts of our bodies, too, for example in the difficulty of childbirth and in our vulnerability to rotator cuff injuries of the shoulder. Understanding these connections can suggest preventive measures, as in the case of spondylolysis, notes Latimer, who urges such understanding even if there’s no immediate biomedical application. He helped organize a series of workshops through the National Evolutionary Synthesis Center to come up with evolutionary medicine curricula about musculoskeletal disorders. “If you don’t understand the evolutionary background,” he says, “you are treating the symptoms without understanding the underlying cause.”

—ELIZABETH PENNISI



**Walking can be a pain.** Bipedalism leaves the human body vulnerable to a range of problems, just a few of which are pinpointed here.

hips. Thus the lower spine curves toward the belly button, causing a hollow low in the back and bringing the torso upright. To keep the head centered, the thoracic vertebrae in the chest curve in the other direction. “Spinal curvatures cause a lot of problems in humans that other animals don’t have,” particularly slipped disks and broken vertebrae, says Carol Ward, an anatomist at the University of Missouri, Columbia.

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The Egyptians' coarse diet also had a positive impact on jaw development. Chewing stresses stimulate growth of alveolar bone, the thin layer of bone surrounding the roots of teeth, which causes children's lower jaws to grow more robust and longer, with little overbite or malocclusion. As a result, when the ancient Egyptians closed their jaws, their upper and lower incisors (the four front teeth) met in an edge-to-edge bite, with good spacing between the teeth in their robust faces. People today, who eat softer foods, have a "scissors configuration" bite, in which the upper incisors protrude over the lower incisors, because the lower jaw is smaller than the upper one.

**Perils of a sweet tooth**

In Europe, less than 10% of individuals had cavities until Alexander the Great brought sugar to Greece in the 4th century B.C.E., according to earlier studies, says pediatric dentist Kevin Boyd of Children's Memorial Hospital in Chicago, Illinois. Cavities increased first in Greece, then Rome; their incidence also rose throughout Europe in the Middle Ages. But the biggest spike was from 1800 to 1850, when Britain took control of the West Indies and imported far more sugar than previously. Sugar helped fuel the Industrial Revolution, which was a transition from an agriculture-based economy to a machine-based economy. In 1874, the British reduced the tax on sugar, and it became available to all social classes. "In London, mostly 1800 onwards, they have absolutely dreadful teeth," Hillson says.

The damage caused by refined sugar is well known: It alters the optimum pH of 5.4 in the mouth, making saliva more acidic. That saliva, as well as acid produced by bacteria in plaque, dissolves minerals in the enamel, causing cavities. By the middle of the 20th century, between 50% and 90% of the population in Europe and the United States had cavities. This improved in the 1970s when water was fluoridated. But for the first time in 40 years, the U.S. Centers for Disease Control and Prevention recently noted an increase in cavities in children aged 2 to 5 years. Dentists blame snacking and sugars in juice and sodas.

In the latter half of the 20th century, overcrowding of teeth and malocclusion became rampant. Today, nine in 10 adolescents in the United States have some malocclusion, and half could benefit from orthodontic treatment, Corruccini says. Impaction of the third molars, or wisdom teeth, occurs 10 times more frequently in people eating an Industrial Age diet than in hunter-gatherers. "Our



**Following the old ways.** Maya in the Yucatán of Mexico who still eat a traditional diet have fewer cavities.

teeth are underdeveloped because softened, highly processed foods do not provide the chewing stresses needed to stimulate normal growth of the jaw during childhood," Corruccini says.

As researchers at the workshop reviewed the data, it became clear that the biggest challenge for our teeth wasn't the initial transition to agriculture, as many researchers had once thought. It was the Industrial Revolution and then, in the 1980s, another marked increase in refined sugars in processed foods, such as high fructose corn syrup in sodas. "Caries and malocclusion is not a Neolithic problem, but an industrial problem," Boyd says.

After establishing the complexity of the problem, the researchers began to consider solutions. "If we remove carbohydrates from the diet, do we have less disease? Is this something I should be recommending to my patients?" asked dentist John Sorrentino of Hopewell Junction, New York.

The answer, it appears, is not simple, other than the obvious advice to cut back on refined sugars. The role of starch in causing cavities is not well known and needs study, Hillson says. Boyd suggested that consuming sugars with more fiber, such as fructose in fruit, lessens the damage because the sugars are absorbed more slowly in the gut, rather than rapidly in the mouth. But our ancestors consumed a variety of diets, so the solution may not be as simple as trying to recreate a hunter-gatherer's diet. "There was not a single oral environment to which our teeth and jaws evolved—there is no single caveman diet," Ungar says. "Still, we need to acknowledge

that our ancestors did not have their teeth bathed in milkshake."

Further research is needed on how sugar affects the balance of species of bacteria in the mouth, such as *Streptococcus* strains, which are linked to cavities in humans. These complex communities of bacteria mix with minerals from saliva and immune cells to form plaque on the teeth. Our immune systems react to the bacteria, causing gum disease. "Normally, young kids are more resistant to the effects of plaque than adults," Dean says. But with more sugars in the diet, plaque-forming bacteria may flourish, which may trigger a bigger immune response and inflammatory reaction. That, in turn, can lead to a higher risk of systemic diseases such as cardiovascular disease and diabetes. But the response to plaque varies: "Everyone's mouth is its own ecological field," Dean says.

As for malocclusion and jaw disorders, Corruccini noted that a "fringe" branch of evolutionary dentistry has emerged in which children do mouth exercises and wear devices that put stronger force on their growing jaws. Ungar admitted feeding beef jerky to his own children to boost chewing stresses on their developing jaws, but he says the jury is still out on those methods to reduce overbite. "An understanding of this discordance [between traditional and modern diets and lifestyles] can inform clinical research and, ultimately, dental and orthodontic practice," Ungar says.

For now, one thing is perfectly clear: Our teeth have not evolved a defense against sodas. "People should understand that evolution is not as fast as the cultural changes we're seeing," Cucina says. —ANN GIBBONS

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