The role of local factors in the etiology of periodontal diseases

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Early concepts of periodontal disease were derived primarily from histopathological observations. Prominent pathologists interpreted the histopathology in various ways and produced somewhat divergent theories on the nature and causes of periodontitis (see Loe in this volume). Some scientists contended that periodontitis was the result of trauma from occlusion that produced excessive forces on the connective tissue and bone. Others believed that the disease had a systemic origin and was closely linked with systemic diseases. Some argued that certain forms of periodontitis were degenerative in nature and were therefore similar to other degenerative processes in the body. And for thousands of years, Egyptian, Hebrew and Chinese writings had spoken of individuals who were "long of tooth" as a reference to individuals of old age. Some therefore argued that periodontitis was a natural consequence of aging.

The accumulations of hard and soft material, including microorganisms, on tooth surfaces had been associated with periodontal disease for many years and, beginning in the late 1800s, various periodontologists and microbiologists contended that parasites, protozoa, streptococci, spirochetes and certain black-pigmented anaerobes were responsible for periodontal disease. The presence of these various theories and their very vocal proponents resulted in varying concepts of therapy and very unpredictable treatment outcomes. If a patient with periodontitis presented for treatment to one of the proponents of trauma from occlusion, the patient might receive an occlusal adjustment and new dental crowns and bridges. Since some of these therapists would secondarily clean the teeth and others would not, the outcomes of this particular therapy were inconsistent.

During the first half of this century, with limited scientific evidence, multiple local factors were introduced as possible causes of periodontal pathology. There were really no means available at the time to develop a clear understanding of the importance of any specific factor or the relative influence of multiple factors. The period that followed, beginning in the late 1950s and early 1960s, used the scientific method and hypothesis testing to clarify the dominance of primary correlations with disease, that is, plaque and age, which led to the demonstration that bacterial accumulation is essential to disease initiation.

Although sophisticated experimental methods were rapidly applied to studies of periodontal diseases, experimental design and data analysis techniques were limited in their ability to evaluate the interaction of multiple factors. Such techniques for the study of the relative importance of multiple factors in chronic diseases have emerged only in recent years and are still under development. These limitations, as well as the normal dialectic thought process, have produced somewhat different concepts of the role of local factors in periodontal disease at different times.

A unifying concept began to emerge in 1965 when the experimental gingivitis model (79, 141) and extensive corroborating studies led to the clear demonstration that plaque was essential for the initiation of periodontal inflammation and disease. The principal concept was that plaque was the primary and essential disease-initiating factor that resulted in a transition from health to gingivitis, and if the gingivitis were untreated it might progress to adult periodontitis. Several other factors that had previously been considered important in the initiation of periodontal disease became relegated to a secondary role or were almost completely disregarded as having any role in the disease process. Given the single-factor hypotheses that were routinely used, it was easy to demonstrate that factors other than plaque and age were not the primary determinants of disease. These studies served a critical purpose of clarifying which factors primarily influenced disease and which were secondary factors. However, the experimental designs and analytical approaches used at that time were inadequate for evaluating the true role of many
of the secondary factors. The net result was that, except for pregnancy and a few other systemic conditions, the influence of secondary factors may have been greatly discounted for many years.

As new information emerged in the 1970s and 1980s on the potential role of certain bacteria and host responses in the etiology of periodontal diseases, the story again became complicated. Much of the difficulty in attempting to determine the role of various factors may be due to the persistence of traditional concepts of disease etiology and data analysis. Some of the complicating factors in this interpretation involved the fact that different forms of periodontal disease may have different interactions between the factors involved in the disease. For example, in localized juvenile periodontitis, increasing supragingival plaque and age have a much weaker association with disease than traditionally found in adult periodontitis. Such observations are obvious for juvenile forms of periodontitis but have not been well defined and may be much more obtuse for variations of the disease in adults. In addition, the interaction between multiple factors may be nonlinear and complex. For example, the influence of smoking on disease may be of a different magnitude in some individuals than in others. In recent years, studies involving sophisticated approaches to multivariate data analysis (28) and the determination of odds ratios have started to consider the influence of various combinations of multiple variables on disease outcomes.

It therefore seems appropriate to reassess the role of local factors in the etiology of periodontal disease in light of the new knowledge and concepts of disease etiology as well as insights gained from new approaches to data analysis. Unfortunately, limited data are currently available with these perspectives. The following discussion therefore represents the judgment of the authors based on the data that exist and is necessarily speculative. Many of the concepts remain to be proven with prospective studies. In many respects, the current concepts of the role of secondary factors in periodontitis are merely a refinement of the concepts that emerged in the mid-1960s, based on the increased understanding of the mechanisms by which secondary factors may influence the disease process. The concepts discussed here emphasize the primary and essential role of bacterial accumulation in initiating periodontal disease and attempt to clarify the specific interaction of secondary factors in this process (22). In the future, new experimental designs and analytical techniques will further clarify the relative strengths of these various influences in individual patients.

Although it is assumed that local factors may function differently in different forms of periodontal disease, the discussion here focuses entirely on gingivitis and chronic adult periodontitis, since most of the available data are in this area. The relationship between various factors in adult periodontitis may be very different from that found in other forms of the disease.

In the past, the differentiation between local factors and systemic factors may have seemed relatively clear. However, today it is recognized that many systemic factors act not only at the systemic level but may have differential effects at the local periodontal level. For example, steroid hormones produce a variety of systemic effects, including vascular and connective tissue changes and influences on the inflammatory and immune systems. However, due to the density of steroid receptors in the gingival tissues (137, 145) and the direct influence of steroid hormones on the microbial ecology in the gingival sulcus (64), hormones also exert a differential effect on the gingiva, which may be in addition to or different from its systemic influence. Similarly, the presence of certain bacteria in the subgingival area may induce not only a systemic immune response but a somewhat different localized immune response in the gingival area (30, 46, 67). It therefore seems that the lines between local and systemic factors have become blurred in many instances. For the purposes of this discussion, we attempt to focus on factors in which the dominant effect is primarily local. Thus, local factors refer to anything that influences the periodontal health status and is reflected and may be measured locally but has no overt systemic influence.

This discussion also assumes that chronic adult periodontitis refers to people over the age of 35-40 years who have clinical evidence of plaque and calculus and of loss of attachment and supporting bone. This classification also assumes certain biological boundaries, including the absence of overt systemic disease, the absence of overt problems with host defense mechanisms and the assumption that, in an intact host, there are redundant mechanisms for protecting the host from bacterial insults.

Other characteristics of chronic adult periodontitis are assumed as part of the definition used here. These include the concept that essentially everyone who accumulates plaque will develop gingivitis (79) and that most of these individuals will ultimately progress to chronic adult periodontitis (10, 72, 82, 83). The individuals who either are resistant to the development of periodontitis or demonstrate more aggressive forms of the disease are not included in our
chronic adult periodontitis group. There is substantial evidence in chronic adult periodontitis that plaque accumulates and matures ecologically in a predictable pattern (76, 103, 139, 141, 142). Both gingivitis and periodontitis have been strongly correlated with the maturation of plaque and the specific bacterial components characteristic of later stages of maturation. The role of local factors in the etiology of periodontitis is discussed in light of these boundary conditions. However, recent studies involving twins (98) indicate that genetic factors play a prominent role in both gingivitis and periodontitis, and these findings apparently apply to chronic adult periodontitis. Although this is critical information, the role of the genetics of the host is not directly discussed here (see Genco & Löe in this volume).

**Classification of local etiological factors**

Given the strength of evidence supporting the relationship between plaque accumulation and periodontitis, a simple coherent concept developed that described periodontitis as the outcome of persistent inflammation resulting from plaque accumulation. It was recognized, however, that some individuals with host differences, such as localized juvenile periodontitis, exhibited a different etiology. In addition, even for chronic adult periodontitis patients, in which no overt host problem exists, loss of attachment and disease progression could not be explained solely by the presence of accumulated plaque (51, 74). As a result, recent efforts have attempted to correlate the presence of certain bacteria with disease initiation and progression. Although extensive energy has been devoted to this effort in chronic adult periodontitis, clear correlations between specific bacteria and disease initiation and progression are still somewhat elusive. Fig. 1 depicts one view of the current situation. The arrows do not represent causality but show where one factor influences another factor. Fig. 1 may be explained as follows.

As plaque accumulates, gingival inflammation is initiated and the plaque begins a maturation process that is both predictable and repeatable. This maturation of plaque leads to ecological changes that result in the detection and increase of certain groups of bacteria that have pathogenic potential. These bacteria augment the inflammatory process. Connective tissue destruction results from nonspecific inflammatory mechanisms as well as more specific inflammatory mechanisms related to certain bacteria. The nature and extent of the connective tissue destruction is also influenced by host characteristics.

This map describes the initiating factors responsible for the loss of attachment in chronic adult periodontitis. In recent years all other factors have been relegated to the role of secondary or modifying influences on the disease process. Modifying factors influence some aspect of the primary initiating factors. Fig. 2 lists some of these modifying factors under

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**Fig. 1. General concept of the etiology of chronic adult periodontitis**

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Primary disease influences

![Diagram showing the relationships between plaque accumulation, presence and quantity of certain bacteria, connective tissue destruction, and loss of attachment.]

**Modifying Influences**
- Oral hygiene
- Tooth malposition
- Tooth anatomy
- Restorations
- Gingival contours

**Modifying Influences**
- Maturation of marginal plaque
- Host defenses
- Pocket depth
- Restorations
- Subgingival environment

**Modifying Influences**
- Genetic influence
- Inflammation
- Particular bacteria
- Smoking
- Calculus

Fig. 2. Local factors in chronic adult periodontitis

The primary manner in which they influence the disease process. For example, oral hygiene, tooth malposition, tooth anatomy, gingival contours and overhanging restorations most likely alter plaque accumulation. The presence and quantity of certain bacteria, some of which have periodontal pathogenic potential, are primarily influenced by the plaque maturation but have also been shown to be influenced by pocket depth (86, 102), calculus (110), overhanging restorations (68) and the nutritional and environmental characteristics of the subgingival area (84, 85). There is also some preliminary evidence that smoking may alter the bacterial ecology (66). Connective tissue destruction may be influenced by the nature of the inflammation process, the presence and quantity of certain bacteria, the nature of an individual's anabolic and catabolic balance and local modifying factors (Fig. 2).

The nature of the interactions in Fig. 2 demonstrate that evaluation of the role of local factors in the etiology of disease is complex and cannot be easily assessed, even with the most sophisticated statistical models. For example, as seen in the single-variable studies of the 1960s and 1970s, the role of secondary factors may be easily overwhelmed by the dominance of primary factors. This sometimes resulted in the conclusion that the secondary factors were not significantly associated with disease. Recent approaches to the analysis of epidemiological data may provide a more realistic view of potential secondary influences. For example, statistical isolation and combination of multiple factors allow one to conclude that, although smoking does not initiate periodontitis, it significantly increases the risk of disease (9).

Thus, it is now easy to understand how secondary local factors have either been discounted as having nothing to do with periodontitis or have been confusing due to inconsistent correlations with disease. The proper assessment of their role must involve both multifactorial experimental designs and multifactorial analysis. Few studies meet these criteria, and therefore much of the evaluation of the role of secondary factors must involve extrapolation of the existing studies.

Although periodontal inflammation is initiated by plaque accumulation, the severity of inflammation and the extent of periodontal tissue destruction that results is determined by the nature of the host response of the specific individual patient. In recent years, epidemiological studies from various populations have well documented that the prevalence of diseased sites varies greatly among individuals and that variation is not explainable solely by the amount of dental plaque (51, 73, 83, 98, 99).

Given the above perspective, it is now reasonable to reconsider the potential role of individual local factors in the etiology of periodontal disease.

**Local factors that primarily influence plaque accumulation**

Several local factors have historically been associated with periodontal disease. Their role in the disease has often been described as hindering the removal of dental plaque. Some of these factors, such as tooth malposition, are shown in Fig. 2 as directly influencing plaque accumulation. These factors may certainly have other influences on the disease process, but at present all available evidence suggests that the primary effect of each particular factor on the disease may be explained almost entirely by the influence
shown in Fig. 2. The factors that influence the amount of dental plaque that accumulates supragingivally are oral hygiene, tooth malposition, tooth anatomy, overhanging restorations and gingival contours.

Oral hygiene

Good oral hygiene, in particular good toothbrushing, has long been associated with better periodontal health than poor oral hygiene. However, before the critical role of plaque accumulation had been demonstrated, some investigators contended that oral hygiene practices may prevent disease by stimulating the gingiva (39). Numerous studies from the late 1950s to the early 1980s demonstrated quite convincingly that oral hygiene influences disease primarily by eliminating or reducing plaque accumulation (6, 79, 88, 138, 141).

Tooth malposition

Various parameters of malocclusion or tooth malposition have been correlated with periodontitis (19, 35, 36). Earlier concepts suggested that this relationship may actually involve traumatic occlusion (40), but it is now generally accepted that the primary effect of malposition is the effect on plaque accumulation due to more difficult cleaning around malpositioned teeth (20, 60, 128).

Tooth anatomy

Several factors related to tooth anatomy, including root formation, such as enamel projections (94), lingual grooves (31, 70), root depressions (45) and furcations (61, 62, 113) and others (57), have been historically associated with periodontitis. Enamel projections, lingual grooves and furcations probably primarily influence the accumulation of plaque, since the anatomy provides a surface configuration with little access for cleaning (124). This protected area allows plaque to accumulate, mature, calcify partially or completely and retain toxins; the patient has limited access to cleaning this area and great effort is required to clean it professionally. Although such anatomic areas may also have altered fiber relationships, proper cleaning of these areas or alteration of the area to allow proper cleaning reduces the risk of disease (90). Such observations suggest that the primary influence of these anatomic factors is on plaque accumulation.

Tooth anatomic factors such as plunging cusps and open contacts that potentially allow food impac-

tion have also been associated with periodontitis (69, 109). It is unclear whether such associations are the result of disease or whether they actually contribute to the disease. If the latter is true, the mechanism of such an association is unclear.

Overhanging restorations

Almost 40 years have passed since Waerhaug (147) provided the first scientific evidence that dental restorations placed in a subgingival location were detrimental to periodontal health. Since that time much clinical (4, 15, 91, 127), histological (149) and bacteriological work (68) has confirmed the close association between periodontal disease and the subgingival margins of fillings, crowns and inlays. Damage to the periodontal tissue might occur during the preparation and fabrication of the restorations; the materials used might contain components that irritate tissue; and the physical or chemical properties of the restorations may cause retention of bacterial plaque in the long term.

Preparation with any rotating instrument below the gingival margin represents a trauma of varying degree to the crevicular epithelium and the subepithelial connective tissue. Similar acute damage is produced by the use of retraction materials when impressions are made or when temporary restorations are worn. Such lesions are, however, considered to be reversible, and if the local environmental conditions are favorable, a new epithelium proliferates to cover the exposed connective tissue wound. Complete healing normally occurs within 8–14 days (80).

Studies on the gingival tissue response to dental materials commonly used in restorative dentistry (cast gold, gold foil, porcelain and heat-cured acrylics) indicate that they are inert. Others may cause slight acute injury, either through the leakage of specific components from the material (such as monomers) or the release of corrosion products (43). Allergic reactions of the oral mucosa (including the gingiva) to dental materials have been seen in a few patients, but most materials in use today are well tolerated by the vast majority of the patients and therefore cannot explain the destruction of the periodontal tissues adjacent to fillings, inlays and crowns.

There is now a quite voluminous material from human studies suggesting that restorations extended into the subgingival area are responsible for these pathological events and that, among margin defects, the overhangs are by far the most common type. As is the case with dental calculus, there is no indication that the sharp edges of the subgingival margins of
these restorations exert any direct injury to the local tissues but rather that the rough surfaces invite the colonization and retention of periodontal pathogens, and the detrimental effect of this is seen in the tissue response. Studies have shown that the microflora adjacent to subgingival overhangs are very similar to the bacterial composition of plaque from pathological pockets.

There are some indications that, in patients with good oral hygiene, gingival reactions to subgingival fillings and ill-fitting margins are milder than in patients who do not practice active oral self-care on a regular basis (4).

Thus, overhanging restorations appear to indirectly influence the disease in two primary ways. Areas with overhangs are difficult to clean and have repeatedly been associated with more plaque than unrestored or clinically acceptable restorations (14, 38). Overhangs may also influence plaque maturation more directly by changing the environment to promote the accumulation of certain types of bacteria (76). This has been demonstrated by studies (68) in which overhanging restorations, but not clinically acceptable restorations, allowed an increase in pigmented bacteria such as Prevotella intermedia and Porphyromonas gingivalis that are routinely detected in later stages of plaque maturation.

Gingival contours

Although early toothbrushing techniques such as the press-and-roll technique were complicated by the presence of bulky gingival contours, there is no evidence that more current techniques, if properly applied, such as the modified Bass technique, are altered in any way by such contours. The concept that gingival contours interfered with plaque removal has been used historically as one of the rationales for recontouring both bone and gingiva (42, 108, 122). It should be noted that, for current cleaning techniques, there is no evidence that gingival contours interfere with cleaning and therefore result in more plaque accumulation. On the other hand, once disease has been established, more root surface area exists to be cleaned by either the professional or the patient.

Significance of plaque accumulation

Many of the local factors that have been previously associated with periodontal disease appear to influence the disease process by affecting supragingival plaque accumulation and its removal. Although supragingival plaque is essential to the initiation of adult periodontitis, the actual correlation between supragingival plaque levels and longitudinal disease progression has been found to be rather weak (73, 74). This is to be expected, since supragingival plaque is measured but the pathogenic bacteria are localized in the subgingival plaque, which is not clinically measurable. In addition (Fig. 1), plaque accumulation does not directly result in loss of attachment but influences destruction through its effects on the presence and quantity of pathogenic bacteria, which is modulated by the nature of the host response. Therefore, simple correlations between supragingival plaque levels and loss of attachment should not be expected to be strong because of the number and complexity of intervening influences. If a population group with minimal plaque is compared with one with substantial plaque, the population that has more plaque will have substantially more disease (120, 121). These studies reaffirm the essentiality of plaque but do not address the issue of the nature of the relationship between the presence of plaque and disease initiation or progression.

The role of specific types of bacteria in adult periodontitis

Beginning in 1975 with the identification of certain bacteria associated with localized juvenile periodontitis, there has been a focus on the role of selected bacteria in periodontal disease. Although the etiological role of Actinobacillus actinomycetemcomitans in localized juvenile periodontitis has been well documented over the years (65, 107, 129, 151), the efforts to associate certain bacteria with the initiation of adult periodontitis have been both rewarding and frustrating.

Rewards and frustration

Substantial evidence exists that a limited number of bacteria (Table 1) are associated with periodontal diseases in adults on a cross-sectional basis (133, 135). In addition, if detectable levels of some of these

<table>
<thead>
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<th>Table 1. Bacteria most frequently associated with periodontal disease in adults</th>
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<tr>
<td>Actinobacillus actinomycetemcomitans</td>
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<tr>
<td>Prevotella intermedia</td>
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<tr>
<td>Campylobacter rectus</td>
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<td>Eubacterium species</td>
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species are present at an individual site, it is more likely to show disease progression (58, 150). In addition, following therapy, sites in which selected bacteria are eliminated respond better than sites in which these types of bacteria remain detectable (23, 37, 130, 131, 134).

Despite this very strong evidence that certain bacteria are somehow involved in the disease process of adult periodontitis, substantial questions remain and have produced frustration both for researchers and practitioners attempting to use this information. For example, attempts to associate specific bacteria with disease progression have produced conflicting results (29, 44, 52–55). It is relatively easy to demonstrate that the species present in periodontal pockets differ from those in healthy gingival sulci, but since the ecology is dramatically different in the two situations it is difficult to draw conclusions about causality just because bacterial differences exist. The more stringent challenge would be to follow gingivitis sites with and without specific putative pathogens to determine whether there is a difference in progression. In humans (150), sites with *P. intermedia, P. gingivalis* or *A. actinomycetemcomitans* show significant clinical progression in about 20% of the sites over 12 months, whereas none of the sites without detectable levels of those microorganisms exhibited progression. In animals, the implantation of *P. gingivalis* into a pre-existing gingivitis microbiota results in rapid disease progression (58). However, when one looks at the actual correlations between disease progression and certain bacteria (54, 55, 150) on a prospective basis, the correlations are rather weak. In addition, *P. intermedia*, which is one of the microorganisms most implicated in disease in adults (134), is frequently present without producing any apparent problem (150).

**Potential explanations for the role of specific bacteria**

It is of interest that individual periodontal sites are colonized by large numbers of bacteria, many of which have pathogenic potential, and yet progressive periodontal destruction occurs either rarely or at a rate at which clinical detection is infrequent. The functional relationship between individual bacteria or the composite microbiota and then destruction of the periodontium is undoubtedly complex, because the bacterial challenge is translated differently by each individual host. However, assessing the bacterial challenge by growing and biochemically identifying microbial species may produce too crude a level of specificity to properly characterize the bacterial challenge. In recent years, genetic analysis has shown both *A. actinomycetemcomitans* (56, 151) and *P. gingivalis* (87) to be very heterogeneous.

The factors that may influence both the quality and quantity of the bacterial challenge in periodontal disease were reviewed recently (134). It is important to first recognize that, with few exceptions, previous associations between bacterial species and periodontal disease have been based on species-level identification of the microorganisms. Experience in other diseases has clearly indicated that many clonal types may be contained within a single species. Most importantly, within a given species only a few clonal types appear to be pathogenic (18, 33, 105). For example, it has been known for many years that microorganisms currently classified as *P. intermedia* exhibit great genetic variability (24, 41), yet the relationship of the different genotypes to periodontal disease is essentially unknown. To understand the true correlation between certain bacteria and disease, it is essential to first determine the relative virulence potential of the various clonal types within a species suspected of being pathogenic. Several attempts have been made in recent years to evaluate the pathogenic potential of various strains within *P. gingivalis* (50, 92, 97, 106, 126, 132, 144). A diversity among *A. actinomycetemcomitans* strains relative to genetics, distribution in the population and leukotoxic activity has been observed for several years (56, 151). Although studies in animal model systems represent important first steps, the relationships between different clonal types, animal virulence models and the actual induction of periodontal disease remain essentially unexplored.

The second complicating factor in assessing the role of specific bacteria in periodontal disease is that the mere presence of a specific microorganism may have very different implications in different sites, in different hosts and in the same site at different times. Ecological factors appear to influence the impact of a particular microorganism in 3 main ways. First, the ecology directly affects the level or quantity of the bacterial challenge. In recent years, genetic analysis has shown both *A. actinomycetemcomitans* (56, 151) and *P. gingivalis* (87) to be very heterogeneous.
levels, but species that counter some of the effects of the pathogens may be altered, resulting in a change in the net bacterial challenge. Finally, it has been well documented that specific regulator genes may switch on an entire response pattern within a microorganism to allow it to cope with the specific environment (95, 101). Environmental changes that appear to be subtle at the host level may be sufficiently critical at the level of the microbiota to switch on genes that increase or decrease an entire set of virulence factors (59). Recent studies in periodontal microorganisms have observed similar phenomena (8, 17, 96).

With these concepts in mind, it is very reasonable to expect to detect a suspected pathogen in many sites, but only a subset of these sites house the genotypes and environmental factors essential for virulence. Even if these stringent requirements are met at any given time, the host response at that particular time must be such that destruction occurs. This above scenario appears unusually stringent and may appear unnecessarily complicated because the contributing factors are described as independent variables. However, the probability of achieving all of the factors necessary for disease may increase substantially if many of the bacterial requirements for disease are controlled in common by an outside factor. For example, the normal maturation of the subgingival plaque and the gingival response to this maturation process may provide much of the microbial ecology and physical and biochemical factors necessary for an optimal virulence state in an ecosystem. Under such a scenario, the number of independent variables that must be aligned to achieve virulence would drop dramatically and the probability of achieving a virulent state should increase substantially. Extensive studies in the coming years will undoubtedly clarify both of these scenarios. For the moment, it seems that the important conclusion is that simplistic associations between selected bacterial species, as currently identified, and the initiation and progression of periodontal disease are not impressively strong. This should not be taken to mean that specific bacteria are unimportant in the disease process, but rather that the previous views of the relationships were most likely overly simplistic.

Factors influencing the presence and quantity of specific bacteria

The presence and level of particular bacteria in the subgingival microbiota are a function of the bacteria acquired at some point by the individual and the environmental and host factors that determine the ecological balance within the microbiota. If supragingival plaque is allowed to accumulate undisturbed, the subgingival microbiota develops in a rather predictable and consistent pattern (79, 141) that varies from site to site and individual to individual (103, 139). A variety of physical and chemical factors provided by the host and other bacteria have been described that appear to be critical to certain interactions between the bacteria during this ecological development (84). Local factors that influence certain bacteria in the subgingival area and that may be under the control of the patient or the therapist include probing depth, overhanging restorations and maturation of the plaque. The influence of overhanging restorations and of plaque maturation have been discussed above.

Pocket depth

Although there has been some confusion in recent years about the likelihood of disease progression in sites of different pocket depth, several recent studies have confirmed the longstanding clinical impression that sites with a previous history of disease are more likely to show future progression than sites with no previous disease history (1, 27, 53-55, 73, 74, 114). In untreated periodontal pockets, the most obvious influence of pre-existing disease on future disease may be the presence of substantial bacterial loads within the pocket. Previous studies (85, 86) have demonstrated that different bacterial patterns and different ecological factors may be correlated with the pocket depth. Although many specific, and as yet undefined, factors may explain this relationship, it does appear that the microbiota in untreated deeper pockets shifts towards a more anaerobic population. Nevertheless, there is no evidence that these relationships exist following therapy that has cleaned out the subgingival plaque. In other words, the critical question seems to be whether or not deeper pockets re-colonize faster following subgingival cleaning. At present there is no evidence to suggest that pocket depth is a critical determinant of disease progression following therapy.

Calculus

During the 1950s and 1960s, considerable evidence from histological and epidemiological studies indicated a close relationship between mineralized and nonmineralized deposits on teeth and the prevalence
and severity of periodontal disease (48, 78, 88, 120, 121, 146).

Clinical surveys in many parts of the world showed that dental calculus was common, although the amount and location might vary (47, 77, 88, 93, 115, 118). In general, supragingival calculus was thought to be more prevalent than subgingival calculus, and the percentage of persons with either type increased with age (123).

The role of local factors

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The natural history of calculus formation in the absence of oral care

Prospective longitudinal studies of calculus formation in tea workers in Sri Lanka, who never received dental or periodontal care and did not practice self-care during 45 years of life, have yielded new information on the natural history of calculus formation (3, 81). Under such circumstances, calculus formation starts early. At the age of 14 years, all participants had supragingival calculus. The first teeth to show calculus were mandibular incisors and maxillary first molars. The time in the life of these teeth at which calculus first formed could not be ascertained, since this had already occurred in the youngest study subjects. However, based on sequential assessments of calculus formation on other tooth types, it is clear that, without deliberate interference, supragingival calculus formation starts very soon after the tooth has erupted.

When the subjects were 25 years of age, calculus was found on most teeth, and the differences between first and second molars had disappeared. Maxillary incisors and bicuspids of both jaws might still be calculus-free, and even when the subjects were 45 years of age a few of these teeth were still without calculus, although the general calculus formation was massive.

Irrespective of age, the distribution of calculus was symmetrical by tooth type and surface. No difference in formation rates was seen between the mesial, distal and lingual surfaces. However, the mean score for the buccal surfaces was consistently the lowest. In this population the phase of supragingival calculus formation was brief, and subgingival calculus also started early, in most instances within 6 to 8 years of the eruption of the tooth. Subgingival calculus was first found on the interproximal root surfaces as a subgingival continuation of an already existing supragingival deposit or as a separate and independent subgingival entity. By the age of 30 years and beyond, however, subgingival calculus was found on virtually all root surfaces of all types of teeth without any special patterns.

Calculus formation in the presence of oral health care

The Norwegian men participating in a longitudinal investigation had received professional oral health care at regular schedules prior to and during the 20 years of the study. They all reported that they had practiced oral hygiene measures daily during most of their lives.

Of the 565 men between 16 and 34 years who participated in the first examination in 1969, only 7 individuals were completely calculus-free, and in the 558 who had either supragingival or subgingival calculus or both, the mean Calculus Index was low and the distribution within the dentition was very limited. About one third of the 16- to 17-year-olds exhibited the classical location of supragingival calculus in mandibular incisors and maxillary first molars. However, supragingival calculus was 6 times more prevalent in mandibular incisors than in maxillary molars. Supragingival calculus was rarely seen in other types of teeth. In this population supragingival calculus did not increase with age. Rather, the individual Calculus Index scores tended to change from zero to positive or from positive to zero between examinations, most likely reflecting the regularity of visits to the dental office.

Subgingival calculus was rarely observed in adolescents who received optimal dental care. In 16- to 17-year-olds, about 3% of the mandibular incisors had subgingival calculus. This increased to involve approximately 25% of these teeth as the men approached 50 years of age. The fact that subgingival calculus also first occurred on mandibular incisors and maxillary molars might suggest that the initial supragingival deposits had created the conditions for subgingival calculus formation. This is not to imply that supragingival calculus is a prerequisite for subgingival calculus formation. On the contrary, as this and other studies (123) have shown, subgingival calculus regularly forms without being preceded by the supragingival variety. However, when it occurs, it is conceivable that the initial supragingival deposit may have created conditions for subsequent formation of subgingival calculus. At any rate, subgingival calculus was rare in this group. When the men were 25 years of age, 1–2 interproximal surfaces were involved; as the men approached 50 years of age, 4–5 sites were affected.

These studies show that population groups who
do not receive professional oral health care and who essentially practice no or little oral hygiene start forming supragingival calculus shortly after tooth eruption; if left untreated, it will continue to grow, seemingly governed only by time and available space. Under such circumstances, subgingival calculus may be seen 6–8 years after eruption of individual teeth and increases in severity and extent with time. In contrast, the practice of good oral hygiene and frequent check-ups and professional care were associated with very low levels of both supra- and subgingival calculus. However, the relative contribution of professional and personal care to this outcome is still not clear.

Recent cross-sectional studies have indicated that similarly low levels of calculus are experienced by the majority of populations in which oral hygiene is actively practiced and oral health care services are provided and utilized. Approximately 50% of adults of both sexes in the United States and Denmark had no calculus (63, 100). When calculus occurred, about one third of the available tooth surfaces were affected. Studies of calculus in developing countries have reported prevalence rates ranging from moderate to extreme (5, 7, 25, 71, 136). No populations or major group of individuals have yet been seen who, in the absence of active prevention or removal, go through life without calculus.

Mechanisms of action

Supragingival calculus is almost always associated with gingivitis or periodontitis (47, 119), and subgingival calculus is invariably associated with loss of periodontal attachment and pathological pocket formation (89, 146). The longitudinal studies in Sri Lanka and Norway generally confirmed these relationships and demonstrated that, when calculus formation is allowed to occur without interruption, subgingival calculus is associated with higher rates of progression of the periodontal lesion. On the other hand, low levels of supragingival calculus are associated with high levels of gingival health, and scattered, small amounts of subgingival calculus do not seem to influence significantly the progression of the periodontal lesion (2, 3, 82).

It was long maintained that calculus caused gingival inflammation by mechanical irritation and that the rough mineralized surfaces of calculus produced ulcerations in the gingival tissues. It was shown, first microscopically (146), that the mineralized part of both supragingival and subgingival calculus are not in contact with the periodontal tissues, and that calculus is invariably covered by a soft, nonmineralized plaque that lies in immediate contact with the epithelial cells of the gingival sulcus. Subsequently, electron microscopic pictures of these relationships revealed that these soft deposits consist largely of microorganisms (140).

It was also demonstrated that rough surfaces on teeth do not per se cause injury to the gingival epithelium (148) but primarily serve as retention sites for oral microorganisms. This was confirmed in a 2-year clinical trial of daily oral use of an antibacterial agent (chlorhexidine). Under these experimental conditions supragingival calculus formed, but due to the antibacterial action of chlorhexidine, its surface was not covered by live bacteria and the gingiva remained healthy (81). Others (75) have reported that, in monkeys treated with chlorhexidine, histological studies revealed a normal junctional epithelium attached to subgingival calculus.

Although calculus may not directly influence periodontitis, it would be reasonable to expect that subgingival calculus would influence the physical chemical environment and therefore the microbial ecology of the subgingival region. Since calculus has the potential to concentrate both nutrients and toxins, (116) one might expect substantial influences on the bacterial ecosystem. Although this may be the case, it is truly speculative.

Connective tissue destruction

The accumulation of a bacterial load and specific bacteria and associated gingival inflammation appear to be essential for adult periodontitis, but the transition from gingivitis to periodontitis is unlikely to be a simple function of whether or not the inflammation has extended into the supporting structures (49). Inflammation is a composite term that includes many redundant pathways that together produce clinical signs and symptoms (112). The process involved in destroying supporting tissues rather than just the changes involved in gingivitis is not known. Although it is well established that certain inflammatory pathways contribute to bone destruction (104, 112), the key question is what factors shift the balance from a chronic gingivitis state to one of destructive periodontitis.

Current thought implies that pathogenic bacteria and the host response to these bacteria determine whether or not the inflammation results in connective tissue and bone destruction. Although this relationship is to some extent speculative, it is consist-
ent with the observation that gingivitis may be stable for years without evidence of progression to periodontitis (21, 72) and that bacterial changes (58) and host changes, such as in some individuals with human immunodeficiency virus infection, may result in progressive destruction.

Other factors (Fig. 2) are potential secondary influences on the destructive process. For example, smoking (see Genco & Löe in this volume) is known to alter the inflammatory process (16, 125, 143), but the influence of these effects on periodontal disease has not yet been defined. Studies (32) have shown that smokers have more calculus, deeper pockets and more bone loss but less clinical inflammation and supragingival plaque than nonsmokers. Even when adjusted for age and calculus, the smokers were found to have less inflammation and more bone loss than the nonsmokers. Multiple studies have demonstrated that smoking does not alter the clinical levels of plaque accumulation but results in less gingival inflammation than observed in nonsmokers (11, 13, 26, 32, 89). If one were to substantially reduce the bacterial challenge in both smokers and nonsmokers, it would undoubtedly be found that smoking by itself is not a primary factor in connective tissue destruction. However, even in subjects with good oral hygiene, smokers had significantly more bone loss than nonsmokers (12), and smoking alters the clinical response to therapy (117). These studies suggest that smoking may have a substantial modifying effect on the process of connective tissue destruction once it has been initiated.

In addition to the role of calculus in altering the bacterial ecosystem as discussed above, calculus may influence the connective tissue destructive process. One means is by concentrating bacterial toxins (116) in such a way that calculus actually increases the net bacterial challenge presented to the host, above and beyond the challenge expected from the plaque alone. In addition, by calcifying successive layers of plaque, calculus formation extends the bacterial front and may therefore be one mechanism for shifting the bacterial challenge and the zone of destruction (111) more apically.

### Conclusion

The following conclusions on the role of local factors in the initiation and progression of periodontal disease appear to be appropriate at this time:

- The definition of a local factor has become increasingly complex as the understanding of host responses in periodontal disease and in inflammation in general has increased.
- It is now recognized that local factors other than bacterial plaque may play important modifying roles in specific individuals. Unfortunately, until recently, study designs and analytical techniques have limited the ability to assess the complex interactions necessary to evaluate the true role of some of these factors in periodontal disease and therapy. This process of understanding the role of modifiers of disease is complicated even more by the fact that, as multiple factors become involved, the influence on disease outcome may involve a complex function that is not linear and may change at different stages of the disease process.

We therefore enter a relative new phase where we hope to clarify more specifically not only the role of bacterial plaque and certain pathogenic bacteria in the initiation and progression of periodontitis but also the role of systemic and local modifying factors and their magnitude of influence in individual patients.

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### References

The role of local factors


Korman & Löe


The role of local factors


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