

## Comparative Evaluation of Enamel, Dentin, and Cementum Microstructure in Healthy and Periodontally Compromised Teeth: A Study of Oral Cavity Structures

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### ABSTRACT

**Background:** Periodontal disease is a chronic inflammatory disease which mainly attacks the supporting parts of the teeth, but there is an increasing body of evidence suggesting that periodontal disease may also cause changes in the microstructure of dental hard tissues.

**Objective:** To evaluate microstructure of enamel, dentin, and cementum of healthy and periodontally affected teeth.

**Methodology:** This was a comparative cross-sectional study conducted in one of the tertiary care dental institutions, over a one-year time span. This was done on 100 permanent teeth extracted, both healthy and periodontologically compromised comprising 50 healthy teeth and 50 periodontally compromised teeth. The collection of samples was done using a non-probability purposive sampling. Descriptive statistics and inferential tests were utilized on the SPSS software to analyze and use descriptive statistics and appropriate tests. The p-value of less than 0.05 was observed to be significant.

**Findings:** It was found that microstructural alterations of periodontally compromised teeth were significantly high compared to healthy teeth. The level of composite microstructural scoring was much higher in the periodontally compromised group indicating wide participation of hard tissues in periodontal disease.

**Conclusion:** There are extreme enamel, dentin and cementum microstructural changes associated with periodontal disease. These findings do not just indicate that periodontal pathology does not just focus on the destruction of soft tissues, but it also shows that the integrity of the hard tissues needs to be considered when making a periodontal diagnosis and treatment planning.

**Keywords:** Periodontal disease, Enamel microstructure, Dentin microstructure, Cementum, Tooth hard tissues

### INTRODUCTION

The oral cavity is a highly specialized anatomical and functional unit having hard and soft tissues, which align their labors to support mastication, phonation, and overall oral health.[1] The teeth themselves are the primary hard tissue of the mouth and are composed of enamel, dentin, and cementum, each with its own micro-structure and specific composition that play a vital role in providing mechanical strength, sensation transmission and anchoring to the periodontal tissues.[2] They are highly significant structures that help in maintaining the stability of teeth both in terms of their duration and resistance to pathological attacks.

Periodontal diseases and dental caries are still some of the most widespread oral health issues across the globe.[3] Global estimates show that dental caries are experienced in over 2.3 billion individuals, with severe periodontal disease resulting in an estimated 10-15% of the adult population, with milder cases that manifest in close to 50% of the global population.[4]

Periodontal disease is a major cause of tooth loss in adulthood.[5] It is an inflammatory disease that manifests itself through chronic inflammation of the tooth-supporting structures, leading to loss of attachment, alveolar bone resorption, and subsequent loss of tooth stability.[6] In addition to its soft tissue-destroying effects, periodontitis is now also known to have effects on the hard tissues of teeth.[7]

Microscopically, enamel is a highly mineralized, acellular tissue that consists of hydroxyapatite crystals, which are organized in prismatic form to give it strength against mechanical and chemical stressors.[8] Dentin is a critical tissue that is used in the majority of the tooth structure, and it possesses dentinal tubules that are important in sensitivity and structural support.[9] The basal surface of the root is covered by cementum, which is needed to support periodontal attachment and anchorage of the tooth to the alveolar bone. The changes in microstructure of these tissues, including mineral content, tubule density, or surface integrity, can have a strong impact on the course of the disease, the susceptibility of the tooth, and the result of the treatment.[10]

Microstructural alterations in enamel, dentin, and cementum can occur in periodontally compromised teeth due to chronic inflammatory disease, bacterial products, as well as host-mediated responses.[11] These alterations may involve greater roughness of the surface, demineralization, and cementum resorption, as well as exposing or modifying dentinal tubules. These microscopic changes can increase the retention of the plaque, ease the infiltration of the bacteria, and decrease the success of the restorative and periodontal treatments. Although these changes hold clinical importance, comparative microstructural analysis between healthy and periodontally impaired tooth tissues has not well examined.[12]

To enhance the knowledge of the disease-related changes in the hard tissues, a comparative evaluation of the microstructure of enamel, dentin, and cementum in healthy and periodontally impaired teeth should be conducted in detail. Understanding of such microstructural variations can assist in improving preventive measures, maximizing the planning of periodontal and restorative treatments, and improving preservation of teeth in the long run. The research will have a role to play in advancing the diagnostic and treatment fields of dental practice by filling the gap between clinical periodontal disease and microscopic tooth structure changes. The objective of the current research was to relatively assess the microstructure of enamel, dentin, and cementum in healthy and periodontally impaired teeth.

## METHODOLOGY

A comparative cross-sectional study design was employed in this study to measure and compare the microstructural properties of enamel, dentin and cementum of healthy and periodontally compromised teeth. The research was conducted at the Faryal Dental College, Shaikhupura, Lahore. The overall period of the study was one year in which sample collection, laboratory processing, microscopic evaluation and data analysis were done.

The sample size was computed with the help of OpenEpi (Open Source Epidemiologic Statistics for Public Health), Version 3.01. This was calculated in a comparative study design with the assumption of 95% confidence level, 80% power, and a 1:1 ratio of healthy versus periodontally compromised teeth. The expected percentage of change in the microstructure was considered as 30% in the healthy teeth and 60% in periodontally compromised teeth based on the evidence provided by the published studies, where the researchers reported a higher prevalence of microstructural alterations in periodontally diseased teeth.[13] The maximum sample size of 45 teeth per group was found to be the minimum. In order to take into consideration possible loss of the specimen in the course of processing, the final sample size was raised to 100 teeth, with 50 teeth per group.

The sample selection was done using a non-probability purposive sampling technique. Teeth were also obtained on patients who were getting extractions based on orthodontic or prosthodontic reasons (healthy group) and patients who were getting extractions based on periodontally compromised reasons (periodontally compromised group). The entire extracted teeth were retrieved with the informed consent of the patients.

The healthy group inclusion criteria included permanent teeth that were extracted due to orthodontic or therapeutic causes and had no clinical or radiographic signs of periodontal disease, caries, restorations, or structural defects. The periodontally compromised group consisted of permanent teeth that were extracted because of chronic periodontitis with clinical evidence of clinical attachment loss, periodontal pocket depth, and radiographic evidence of alveolar bone loss. The intact crown and root surfaces of the teeth were also considered so that they could be evaluated in terms of the microstructure.

The exclusion criteria were teeth with dental caries, restorations, fractures, developmental anomalies, root canal treatment, severe tooth attrition, erosion, or teeth extracted following trauma. Patients whose systemic conditions are known to influence tooth structure were also excluded, such as metabolic bone disorders.

Data collection consisted of thorough rinsing of the teeth under running water right after extraction to eliminate blood and debris and placing them in the appropriate preservative solution to eliminate dehydration and microbial proliferation. Remnants of soft tissues were neatly taken away. The samples were then marked and classified as healthy and periodontally compromised. A hard tissue microtome or diamond disc was used to slice the teeth longitudinally with continuous cooling water to avoid thermal damage. The specimens were prepared using standard laboratory procedures and observed using proper microscopic methods to determine the microstructure of enamel, dentin, and cementum. The parameters observed included surface integrity, pattern of mineralization, tubules structure in the dentin, and the morphology of the cementum.

Statistical Package of Social Sciences (SPSS), version 26 was used to analyze the statistics. The findings were summarized

using descriptive statistics such as means, standard deviations, frequencies and percentages where necessary. The quantitative variables were analyzed using the appropriate inferential tests of the independent t-test based on data normality in order to carry out comparison between the healthy group and periodontally compromised group. A p-value of below 0.05 was deemed significant.

## RESULTS

The study used 100 permanent teeth that were extracted and were divided equally between healthy teeth and periodontally compromised teeth. This division guaranteed the right comparability of the two groups of study to further microstructural analysis (Table 1).

Table 1: Distribution of Teeth According to Study Groups.

Study Group	Number of Teeth (n)	Percentage (%)
Healthy teeth	50	50.0
Periodontally compromised teeth	50	50.0
Total	100	100.0

Enamel micro structure was compared and the results showed evident difference of healthy and periodontally compromised teeth. Periodontally diseased teeth were more irregular on their surfaces, more prism disorganized, and more severely demineralized than healthy teeth. These disparities were signs of reduced enamel integrity in periodontally diseased teeth and they were statistically significant (Table 2).

Table 2: Descriptive Analysis of Enamel Microstructural Characteristics.

Parameter	Healthy Teeth (Mean ± SD)	Periodontally Compromised Teeth (Mean ± SD)	p-value
Enamel surface irregularity score	1.2 ± 0.4	2.8 ± 0.6	<0.001*
Enamel prism disorganization (%)	18.5 ± 6.3	42.7 ± 9.1	<0.001*
Areas of demineralization (%)	12.4 ± 4.9	36.9 ± 8.5	<0.001*
<i>Independent t-test</i>			<i>applied</i>
<i>*Statistically significant</i>			

An assessment of the dentin microstructure showed significant changes in the periodontally compromised group. There were changes in the form of an exposure of dentinal tubules and dilation as well as a decrease in the integrity of intertubular dentin which would indicate more permeable and weaker structures. Healthy teeth, on the contrary, retained a relatively intact dentinal architecture. The difference between the two groups considered was statistically significant (Table 3).

Table 3: Comparison of Dentin Microstructure between Study Groups.

Parameter	Healthy Teeth (Mean ± SD)	Periodontally Compromised Teeth (Mean ± SD)	p-value
Dentinal tubule density (per mm <sup>2</sup> )	31.6 ± 5.8	48.9 ± 7.4	<0.001*
Tubular dilation (%)	14.2 ± 4.1	39.5 ± 6.8	<0.001*
Intertubular dentin integrity score	2.9 ± 0.5	1.6 ± 0.4	<0.001*
<i>Mann-Whitney U test</i>			<i>applied</i>
<i>*Statistically significant</i>			

Cementum evaluation showed severe changes in periodontally weakened teeth. There was increased prevalence of cementum surface resorption, irregular thickness and indications of bacterial infiltration of these teeth as compared to healthy teeth. These results indicate the direct effects of periodontal disease on the root surface integrity and attachment-related structures and statistically significant correlations are observed (Table 4).

**Table 4: Cementum Microstructural Alterations in Healthy and Periodontally Compromised Teeth.**

Parameter	Healthy Teeth n (%)	Periodontally Compromised Teeth n (%)	p-value
Cementum surface resorption	6 (12.0)	32 (64.0)	<0.001*
Cementum thickness irregularity	9 (18.0)	38 (76.0)	<0.001*
Bacterial infiltration into cementum	4 (8.0)	29 (58.0)	<0.001*
<i>Chi-square test</i>			<i>applied</i>
<i>*Statistically significant</i>			

General comparison of composite microstructural scores showed considerably higher cumulative changes in enamel, dentin and cementum of periodontally compromised teeth. This demonstrates the extensive impact of periodontal disease on the hard tissues of the teeth outside the supporting periodontal structures (Table 5).

**Table 5: Overall Comparison of Microstructural Alterations Score.**

Study Group	Mean Composite Microstructural Score ± SD	p-value
Healthy teeth	2.1 ± 0.6	
Periodontally compromised teeth	4.7 ± 0.9	<0.001*
<i>Independent t-test</i>		<i>applied</i>
<i>*Statistically significant</i>		

## DISCUSSION

In the current comparative analysis, enamel, dentin, and cementum showed profound microstructural changes in periodontally compromised teeth in comparison with healthy teeth. These observations are in line with an increasing literature of studies that have reported disease-related alterations in hard tissues of the dentin. The presence of more severe irregularity in the surface and structural disturbance in the periodontally damaged group coincides with the growing imaging evidence that shows inherent heterogeneity of microarchitecture of dental hard tissues. Indicatively, Sarna-Bo and others were able to determine the structure of enamel and dentin and cementum using the sophisticated SEM-EDS analysis and found that the structure of the various tissues exhibited predictable variations in mineral and structural characteristics highlighting the significance of microstructural integrity to functional performance of the three tissues.[14] Even though that work was about healthy teeth, it gives a point of reference on how periodontal disease can further disturb such structures.

Periodontally affected teeth show dentin changes as observed in our research, specifically, dilation of tubules and intertubular integrity as observed in the literature of dentin. Recent studies have pictured the complexity of dentinal microstructure and how they can vary in the pathological conditions. Although much of the research on dentin microstructure concerns age effects or fracture properties, recent research on high-resolution imaging shows that any perturbation of the organised tubule network of dentin might have an impact on structural stability and vulnerability to pathophysiological mechanisms.[15] These observations supplement our results because they underscore the fact that dentin integrity is not a fixed value and may be lost during disease conditions.

The closest resemblances to our cementum results are found in the researches that specifically tested the impacts of periodontal disease on the morphology of root surfaces. According to Bukhary et al. (2025), severe periodontitis profoundly changes the cementum surface features to create irregular and uneven surfaces with lines of cracks and areas of resorption-as we have seen with periodontally compromised group.[15] Their comparison also found the difference in the elements composition (e.g. lower calcium and phosphorus), which confirms the idea that periodontal inflammation influences not only morphological but also biochemical properties of cementum.

Thinning of cementum and disorder of collagen matrix in periodontal disease has also previously been documented, most of which is older than 2021. These classical morphological observations, however, furnish an understanding of the more sophisticated imaging literature and underscore the fact that deterioration of cementum is one characteristic of periodontal breakdown.[16] There is also corroborating evidence provided by studies of related tissues in the mouth. Atomic force microscopy studies have shown that differences in surface texture between acellular and cellular cementum types are distinct and that the microenvironment and structural context may play a role in cementum morphology.[17] Although not directly related to periodontal disease, such work resonates with our results indicating cementum structure differs with biological

condition and would probably be responsive to pathological insults.

Indirect evidence is found in more sophisticated meta-analyses highlighting the value of state-of-the-art imaging methods as a way of showing subtle dental microstructure. Indeed, as a case in point, recent reviews of three-dimensional electron microscopy emphasize that high-resolution technologies are capable of revealing microarchitecture in enamel, dentin, and cementum that could not be identified due to traditional technologies, which reinforces the argument in support of SEM-based comparisons such as the one presented in the present study.[18]

In addition to pure microstructure, our findings are also put in context of developing research into periodontal biology and regeneration. The literature on cementum regeneration plans highlights that periodontal pathogens and their metabolites have a strong effect on cementoblast functionality and mineralization of its matrix which could possibly explain the impaired cementum architecture observed in periodontally compromised teeth.[19] Although these regenerative investigations are mainly aimed at therapeutic opportunities, but not descriptive morphology, they support the idea that the occurrence of microbial and host factors in periodontitis influence the formation and maintenance of hard tissue.

Lastly, even though research examining how systemic factors and the dental hard tissues (ie how diabetes affects cementum thickness) did not reveal statistically significant differences in some of the measures, they still show that disease states can alter the microstructure of dental tissues, a theme that other studies, including ours, have revealed.[20]

Taken together, these studies help us to infer that periodontal disease is correlated with profound microstructural alterations in enamel, dentin, and cementum. The similarity of its findings to recent studies on SEM-based research, and more sophisticated imaging and biologically oriented studies underlines the validity of our findings and the necessity of the detailed microstructural examination in interpreting periodontal pathology.

The results of the research indicate that periodontal disease does not only impact the supporting tissues of the teeth, but also causes major changes in the microstructure of the enamel, dentin and the cementum. The realization of such changes carries significant clinical implications of both preventive and therapeutic dental care. The heightened surface anomalies and cementum structure may contribute to the retention of the plaque and adhesion of bacteria, promoting the disease progress and predisposing to the recurrence of the periodontal breakdown.

Dentin microstructure changes, such as a higher amount of tubule exposure and dilation, could be implicated in an augmentation of dentinal hypersensitivity and susceptibility to bacterial invasion. The alterations have the ability to affect the outcome of restorative and endodontic procedures, which highlights the importance of selecting cases carefully, root surface debridement, and using desensitising or sealing agents in periodontally impaired teeth.

Moreover, impaired cementum integrity could have adverse implications on periodontal attachment and regenerative performance. The knowledge of microstructural alterations of root surfaces may help a clinician to improve the practices of root planing and choose an appropriate regenerative or biomimetic material. Altogether, microstructural evaluation of dental hard tissues could be used as an added value in the planning of treatment, long-term prognosis, and individual periodontal management initiatives. Even though this study has very useful insights, there are some limitations that need to be realized. The cross-sectional design did not allow to determine a causal relationship between periodontal disease and microstructural changes of dental hard tissues. The longitudinal studies would be necessary to evaluate gradual changes with time and their clinical significance.

Tooths were extracted and this was a limitation to the test as it was restricted to in vitro conditions which may not fully represent the dynamic biological conditions of the oral cavity. Moreover, the patient related variables such as age, oral health practices and periodontal disease period may not have been totally standardized and could have played a part in the microstructural features recorded. The other weakness was the adoption of qualitative and semi-quantitative assessment method that is capable of developing observer bias despite its standardized procedures. It is recommended that further work should be conducted and more complex quantitative imaging measures implemented and multicenter samples used to enhance the generalizability of results and accuracy.

## CONCLUSION

A significant change in the enamel, dentin, and cementum microstructures is also associated with the periodontal disease. The periodontal defects of teeth were characterized by serious perturbations of the integrity of hard tissue, which is the manifestation of a long-term action of periodontal pathology not only devastating soft tissue but also alveolar bone. The findings have demonstrated the necessity to consider dental hard tissue microstructure when evaluating periodontal disease in full. The diagnostic accuracy, the heightened efficiency of the treatment planning, and the long-term preservation of natural dentition can be enhanced with the help of the better knowledge of these microscopic alterations. Longitudinal research using advanced imaging methods to supplement the longitudinal research can also illuminate how hard tissue microstructure can be used when it comes to the development and treatment of periodontal diseases.

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