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Research Article

Effect of tooth hypersensitivity and caries risk on enamel electrical resistance values

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Abstract

Introduction: Tooth enamel has a high specific electrical resistance due to its mineral-rich composition. The decreased electrical resistance is associated with the low mineral content of the enamel tissue and can be used as a method for early diagnosis of incipient caries. This indicates compromised enamel protection in the absence of clinically evident enamel damage, permitting reactions to irritants without direct dentin exposure.

Aim: The study aims to investigate the relationship between reduced enamel electrical resistance measured using the CarieScanPro device and the presence of tooth hypersensitivity and varying levels of caries risk.

Materials and methods: The study involved a total of 60 patients ranging in age from 25 to 45 years, who were categorized into two distinct groups based on their caries risk and the presence or absence of tooth hypersensitivity. The risk of developing dental caries was assessed using an American Dental Association (ADA) questionnaire. This questionnaire was translated and validated in Bulgarian. A total of twenty teeth were examined for each patient, with the teeth being categorized into four groups based on their location within the oral cavity: the first group consisted of the upper central incisors, the second group consisted of the upper lateral incisors, the third group consisted of the lower central incisors, and the fourth group consisted of the lower lateral incisors. The electrical resistance of the enamel on the vestibular cervical surface was measured on each tooth. To this end, a CarieScanPro device was utilized, which shows the result as both a numerical value and a letter on a display.

Results: A statistically significant difference in the value of electrical resistance was found between patients with and without tooth hypersensitivity, but there is no such difference in patients with different degrees of caries risk.

Conclusions: Tooth hypersensitivity is significantly associated with a higher prevalence of teeth with reduced electrical resistance, regardless of caries risk level.

Keywords

clinically sound enamel, demineralization, enamel conductivity, tooth hypersensitivity

Introduction

Tooth enamel is the hardest substance in the human body. It forms a protective barrier against physical, thermal, and chemical irritants that can damage the underlying pulp. Fully formed (mature) enamel has unique morphological and biomechanical properties. The enamel has a high specific electrical resistance determined by the mineral com-

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position. It decreases when the pores created by demineralization are filled with water and soluble electrolytes.[1] The concept of detecting early damage to dental tissues and examining it using an electrical signal is not a novel one. As demonstrated in the extant literature, reports on this subject have been published since the 1950s. The journal Nature Medicine published a report in 1996 on the AC Impedance Spectroscopy Technique (ACIST), which employs alternating electrical frequencies. Devices based on this theory use a very weak alternating current circuit that is closed through the patient with a passive electrode. The cable originates at the device and terminates at a tip, which is designated as the active electrode. This electrode is positioned at the designated point of measurement.[17] CarieScan Pro is the first dental diagnostic tool to use the AC Impedance Spectroscopy Technique (ACIST). Electrical resistance measurement is important in cases where there is no clinical evidence of enamel absence or damage and no dentin surfaces are exposed. The impaired protection of the enamel makes possible the response to irritants without direct expression of the dentin. Ultrastructural changes in enamel, which are detected by measuring electrical resistance, have been shown to be associated with clinical complaints of increased sensitivity, as well as being a prerequisite for the development of carious lesions.

Aim

The present study uses the CarieScan Pro device (CarieScan Ltd., Scotland, Dundee, UK) to research a relationship between electrical resistance, tooth hypersensitivity, and caries risk.

Materials and methods

The study encompassed a total of 60 patients ranging in age from 25 to 45 years, who were divided into two groups based on their caries risk and the presence or absence of tooth hypersensitivity. The study's participants demonstrated clinically intact enamel in the cervical vestibular region. The assessment of caries risk was conducted by utilizing the American Dental Association (ADA) questionnaire, which had been translated and validated into the Bulgarian language. The ADA Caries Risk Assessment Forms are available to the public for non-commercial use, and written permission is not required (ADA Caries Risk Assessment Forms – Instructions). A total of 20 teeth were examined for each participant, with the examination focusing on teeth one through five in each of the four quadrants **(Fig. 1)**. Electrical resistance was measured on the vestibular cervical surface of each tooth using the CarieScanPro device, which provides both a numerical and letter-coded output as follows:

- 0–50 (L): Normal electrical resistance, low probability of subsurface demineralization, low risk of lesion development,
- 51–90 (M): Reduced electrical resistance, probability of initial demineralization, medium risk of lesion development,
- 91–100 (H): Low electrical resistance, advanced demineralization, high risk of lesion development.

The CarieScan Pro is a portable device based on AC Impedance Spectroscopy (ACIST), factory-calibrated and self-checked upon each start-up to ensure operational accuracy. Disposable electrodes were used for all measurements. Prior to testing, all teeth were carefully cleaned and dried. The probe's active electrode was positioned perpendicularly to the vestibular surface, and all measurements were conducted by a single operator under standardized environmental conditions. Device calibration was performed regularly between sessions. For each tooth, the average of three readings was recorded.[16] The CarieScan Pro is a diagnostic device employed for both educational and clinical purposes in the Department of Operative Dentistry and Endodontics at the Faculty of Dentistry, Medical University of Plovdiv. All participants provided written informed consent prior to undergoing any diagnostic or therapeutic procedures.

Statistical analysis

We employed the following statistical methods in the study: 1. Univariate statistical distributions were used to describe the distribution of individual variables; 2. Bivariate statistical analysis was employed to assess relationships between two variables by examining their joint distribution, which facilitates the identification of correlations, patterns, or dependencies; 3. An independent samples *t*-test was employed, with a significance level of 0.05. A *p*-value of 0.05 or less was considered statistically significant, indicating a low probability (5%) of a Type I error (false positive); 4. The Benjamini-Hochberg correction is a statistical method that we employed to control the false discovery rate (FDR) when conducting multiple comparisons; and 5. We used the Levene's test for equality of variances, which ascertains whether the variances between groups are statistically equal. This assumption is a prerequisite for conducting parametric testing.

Results

The mean age of the study participants was 35.9 years. Of the patients examined, 62.2% were female and 37.8% male. This distribution of age and sex aligns with the literature, which indicates that dentin hypersensitivity is most prevalent among individuals aged 30–40 years, particularly among women. This is likely due to dietary and oral hygiene habits. The conducted study of the electrical resistance was done on the cervical region of the teeth because tooth hypersensitivity affects this area most often. This area is characterized by a thinner enamel layer and structural vulnerability. The combined effects of erosion, abrasion, and abfraction can

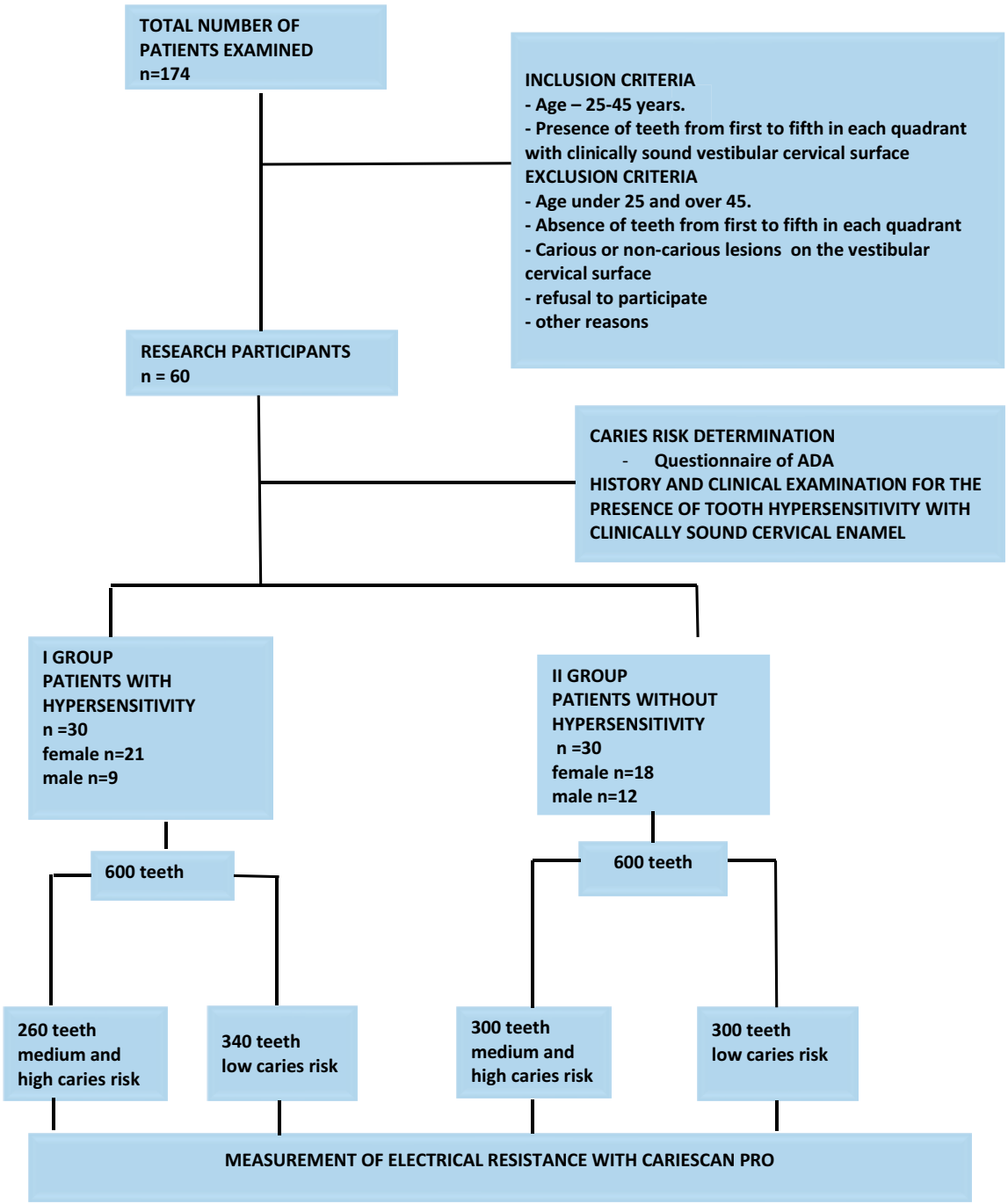

Figure 1. A PRISMA flowchart of the study.

lead to enamel loss in this region, resulting in dentin exposure.[4-6,11] Of the patients included in the study, 52.2% were assessed as having low caries risk, 37.8% were classified as having moderate risk, and 10% were designated as having high caries risk. In each patient, 20 teeth (from the first to the fifth tooth in each quadrant) were selected for evaluation. This selection corresponds to existing evidence that hypersensitivity most commonly affects canines, premolars, and incisors. All examined teeth had clinically sound cervical enamel. No statistically significant difference in electrical resistance values was observed between male and female patients—15.5% of teeth in males and 16.5% in females exhibited reduced resistance ($p>0.05$). To assess potential age-related differences, participants were divided into two age groups: 25 to 35 years and 36 to 45 years. Again, no statistically significant differences in electrical resistance values were found—15.5% in the younger group and 17% in the older group showed reduced values ($p>0.05$).

In the first study group, 30 patients with complaints of hypersensitivity and varying levels of caries risk were included. A total of 600 teeth were examined—340 from patients with low caries risk and 260 from patients with moderate to high

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caries risk. Among patients with low caries risk, 26.7% of teeth showed reduced electrical resistance, corresponding to M (medium) and H (high) values. In those with moderate and high caries risk, 29.7% of teeth showed reduced resistance. Although patients with higher caries risk exhibited a greater proportion of teeth with reduced resistance, the difference was not statistically significant ($p>0.05$) **(Fig. 2)**.

In the second group, we assessed 30 patients (600 teeth) without complaints of hypersensitivity. Of these, 300 teeth belonged to patients with low caries risk and 300 to those with moderate to high risk. In the low-risk group, 11% of teeth showed reduced electrical resistance (M and H values), compared to 15.7% in the moderate/high-risk group. Again, this difference was not statistically significant ($p>0.05$). Further intergroup comparisons were made. Patients with hypersensitivity showed a significantly higher percentage of teeth with reduced electrical resistance (28.5%) compared to those without hypersensitivity (10.2%), with the difference being statistically significant ($p<0.05$) **(Fig. 3)**.

When comparing groups based on caries risk alone, 15.5% of teeth in the low-risk group and 17.1% in the moderate/high-risk group had reduced resistance values, with no statistically significant difference ($p>0.05$).

Among patients with moderate to high caries risk and hypersensitivity, 30% of teeth demonstrated reduced resistance. In contrast, among those without hypersensitivity but with the same caries risk, only 15.7% of teeth showed reduced resistance ($p<0.05$). Similarly, in the low caries risk group, patients with hypersensitivity had 27.4% of teeth with reduced resistance, compared to 11% in patients without hypersensitivity ($p<0.05$) **(Fig. 4)**.

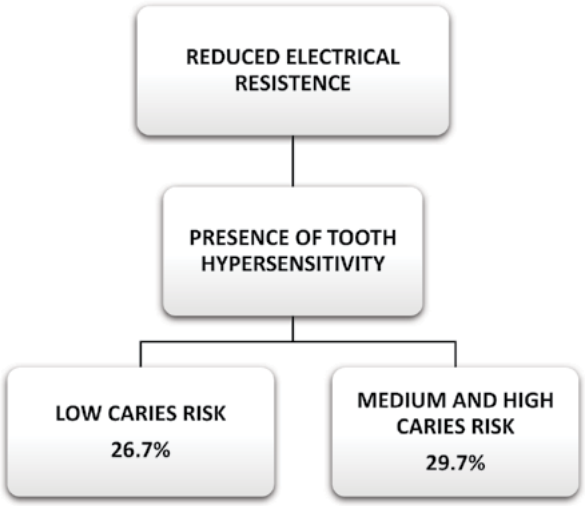

Figure 2. Teeth with reduced electrical resistance in patients with dental hypersensitivity and different caries risk.

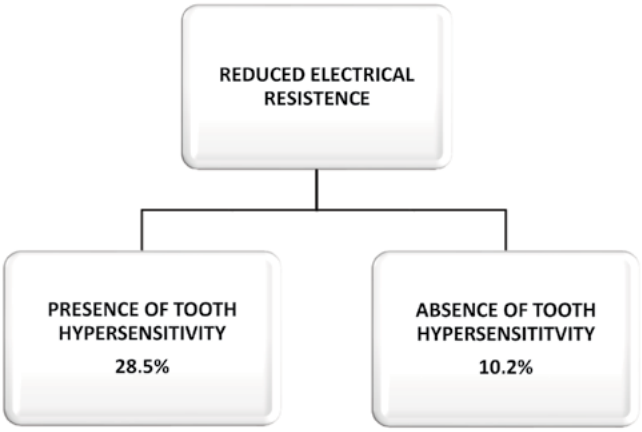

Figure 3. Effect of tooth hypersensitivity on electrical resistance.

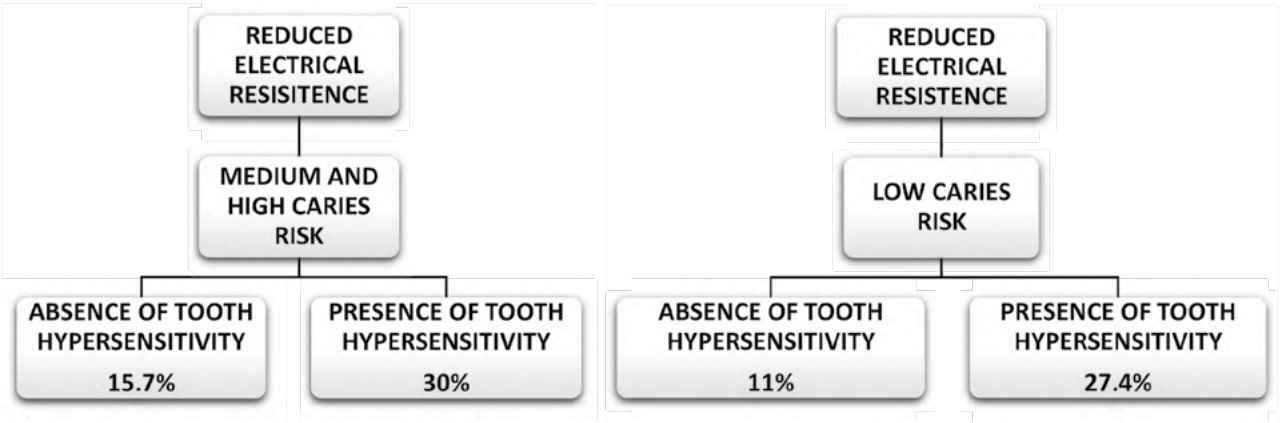

Figure 4. Correlation between reduced enamel electrical resistance, different caries risk, and tooth hypersensitivity.

Discussion

The AC Impedance Spectroscopy Technique (ACIST) operates by passing a low-amplitude, microampere-sized alternating current through tooth tissues via a sensor tip. This technique detects changes in mineral density not only at the enamel surface but also in the subsurface layers. According to the manufacturer, the diagnostic accuracy of the CarieScan Pro device is approximately 94.8%.[14] Prior research on the electrical resistance of hypersensitive teeth with clinically intact enamel yielded results consistent with the current study: hypersensitive teeth have significantly lower electrical resistance than asymptomatic teeth.[10] This phenomenon has been attributed to a reduced mineral content in the hydroxyapatite crystals of enamel, resulting in increased intercrystalline spaces, microporosities, and structural discontinuities.[13]

Caries risk is defined as the likelihood that an individual will develop carious lesions over a specific period. Accurate risk assessment is critical for effective treatment planning. Numerous models for Caries Risk Assessment (CRA) exist, incorporating diverse combinations of risk factors and varying methodologies for interpreting results.[8,18] A patient's clinical examination may modify the initial risk assessment based on questionnaire data and additional clinical indicators.[6] Electrical resistance measurement is emerging as a valuable tool for early detection of enamel demineralization and, consequently, early diagnosis of dental caries. Importantly, the demineralization process can occur in both carious and non-bacterial lesions associated with tooth hypersensitivity. However, the underlying mechanisms differ. The demineralization processes in the cases of caries and non-bacterial damage, which can manifest with complaints of tooth hypersensitivity, develop in a different way. Dental caries is a complex disease caused by the demineralization and remineralization of enamel in the presence of fermentable carbohydrates, saliva, and cariogenic oral flora. The greatest degree of demineralization in enamel caries occurs at the subsurface level, covered by a superficial layer that appears relatively unaffected by the attack. This means that most of the mineral loss during the initial demineralization stages occurs away from the enamel surface. By examining the optical properties of the enamel with a polarizing microscope, it is found that at this stage the subsurface enamel has a demineralized zone with a pore volume of more than 25%, while the surface enamel has a pore volume of less than 5%.[2] In cases not associated with the presence of microorganisms, the lesion develops primarily in the mantle regions of the prism, followed by dissolution of the core. Finally, the interprism areas are also affected. Non-bacterial damage to hard dental tissues can be defined as their loss through dissolution by acids unrelated to microorganisms or mechanical damage. The two chemical methods by which this can occur are either direct acid attack or chelation. Acid attack primarily affects the surface of the teeth, and studies show that in the latter case, demineralization occurs just below the surface enamel of the teeth. There are three phases of attack based on the pH of the acid. Acids with pH<1 can cause surface destruction in very short periods of time. The second phase is softening of the surface during a short exposure to pH 2–4. The third and most common form of acid attack is through weakly acidic (pH 4.5–6.9) subsurface dissolution.[14] The stability of enamel depends on its dense hydroxylapatite structure, low solubility potential, and the maintenance of mineral homeostasis through the processes of demineralization and remineralization depending on the acidity of the oral environment.[3,9,12] Although in a very small amount, the organic fraction is of great importance. The proteins are very finely dispersed in the enamel structure, and they make the tooth enamel permeable to ions, allowing the delivery of minerals in its bulk and thus regulating the surface charges of the crystal. The ability of protein molecules to change charge according to the surrounding pH is an important factor, since this organic fraction contributes to the processes of tooth surface charge regulation, protection, and remineralization.[11] Under normal conditions, any damage to the hydroxyapatite is quickly repaired by minerals and enzymes from the saliva. Saliva forms a thin coating of acquired pellicle on enamel surfaces. The pellicle is a protein layer that controls demineralization and participates in remineralization processes but may also be relevant to caries development and acid erosive processes of hard dental tissues.[15] Disruption in the composition or quantity of pellicle proteins may impair enamel's protective capacity, rendering it more susceptible to acid erosion and reducing its electrical resistance. Continued demineralization may ultimately result in enamel breakdown and dentin exposure. Whether enamel damage progresses to dental caries or non-carious lesions depends on the contributing etiological factors. It is hypothesized that the presence of cariogenic bacteria and fermentable carbohydrates promotes caries formation, while increased acidity and mechanical stress may lead to hypersensitivity or erosive lesions. However, the results of this study indicate that caries risk level does not significantly influence the proportion of teeth with reduced electrical resistance. This finding may suggest that adequate enamel protection can mitigate the impact of cariogenic factors, delaying or preventing hard tissue damage. Some patients report hypersensitivity to thermal or mechanical stimuli despite the absence of clinically visible enamel damage. This suggests that ultrastructural compromise of enamel at the dentin-enamel junction may lead to hypersensitivity through exposed or insufficiently protected dentinal tubules.

Although this study was not designed to definitively confirm or reject this hypothesis, the findings support the potential of electrical resistance measurement as a method for detecting early-stage enamel impairment.

In the reviewed literature, CarieScan Pro is mainly used for the diagnosis of early caries for the purpose of conservative treatment. Its application in dental hypersensitivity with clinically healthy enamel aims to draw attention to the possibility that ultrastructural damage to enamel can

reduce its protective function towards dentin, resulting in increased susceptibility to irritants. Our study was limited by the more difficult detection of clinical cases with hypersensitivity in clinically healthy enamel and the limited literature data in this direction. Additional factors such as sex, age, physiological characteristics, and psychosocial influences may change the processes of perception and response to irritants. The influence of certain stereotypes and expectations on the part of patients related to dental examinations and treatment may also affect the final results.[7]

Conclusions

1. No statistically significant differences in enamel electrical resistance values were observed based on sex or age.
2. Tooth hypersensitivity was associated with significantly reduced electrical resistance values, regardless of the patient's caries risk level. This suggests a potential link between hypersensitivity and impaired enamel integrity at the ultrastructural level.
3. Among patients without tooth hypersensitivity, those with moderate to high caries risk exhibited a higher proportion of teeth with reduced electrical resistance compared to those with low caries risk. However, caries risk alone did not significantly influence the overall number of teeth with reduced resistance.
4. Electrical resistance measurement is a useful method for detecting early impairment of enamel's protective function, particularly in cases of hypersensitivity where clinical signs of enamel damage are absent.

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Competing interests

The authors have declared that no competing interests exist.

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