

The Study of the Electrochemical Deterioration of Human Teeth in Oral Cavity and the Role of Saliva

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Abstract This work is carried out to confirm the existence of the surface potentials in extracted tooth by electrochemical method. The surface potentials were measured between enamel crown's buccal side and tooth root. Surface potentials examined in all the teeth in the presence of KCl. It is found that potential increased with increasing KCl concentration and after acid corroded. The results suggest that potentials can be affected by the surrounding electrolytes and establish an electrical double layer. It is also found that on passing electric current through enamel causes degradation.

Keywords: surface potential, electrochemistry, corrosion, enamel, fluoride ion

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1. Introduction

Humans and most other mammals develop two types of teeth during lifetimes. The first teeth are deciduous or primary or milk teeth and they number 20 in humans. They erupt between the seventh month to the second year of life, and they last until the sixth to thirteenth year. After

each milk tooth is lost, a permanent tooth replaces it, and additional 8 to 12 molars appear posterior in the jaws, making the total number of teeth 28 to 32, depending on whether the four wisdom teeth finally appear, which does not occur in everyone. Some of the properties of teeth are given in the following table and as can be expected, the compression strength is higher for enamel as well the thermal expansion and conductivity [1], as shown in Table 1.

Table 1. physical property of teeth [2]

Tissue	Density (gcm ⁻³)	Modulus of elasticity (GPa)	Compressive strength (MPa)	Coefficient of thermal expansion (°C ⁻¹)	Thermal Conductivity (W/m)
Enamel	2.2	48	241	11.4×10^{-6}	0.82
Dentin	1.9	13.8	138	8.3×10^{-6}	0.59

During early childhood, the teeth begin to protrude outward from the bone through the oral epithelium into the mouth. Teeth also erupt although the cause of eruption is unknown but there are several theories attempt to explain these phenomena. The most likely theory is that growth of tooth root as well as of the bone underneath the tooth progressively shoves the tooth forward. The rate of development and the speed of eruption of teeth can be accelerated by both thyroid and growth hormones. Also the deposition of salts in the early forming teeth is affected considerably by various factors of metabolism such as the availability of calcium and phosphate in the diet. The salts of teeth, like those of bone, are composed of hydroxyapatite with adsorbed carbonates and various cations bound together in a hard crystalline substance. Also, new salts are constantly being deposited while old salts are being re-absorbed from the teeth, as occurs in bone. Deposition and re-absorption occur mainly in the dentin and cementum and to a very limited extent in the enamel [3,4,5,6].

Dental disease remains a significant problem in the world so that the vast majority of the population suffering with the consequences of this disease at some stage in their lives. It can result in acute pain, aesthetic problems and can increase the risk of tooth loss, which may have long-term effects on food intake resulting in impaired nutritional status and subsequent overall well being [7].

However, the most dominant dental disease is dental Caries, which is caused by bacterial acid production in tooth plaque, which can cause deep localized lesions if it remains near the tooth for any length of time. If left, the bacteria then may penetrate the tooth further and progress into the soft pulp tissue. Untreated dental caries can lead to incapacitating pain, potential tooth loss and loss of dental function. The development and progression of dental caries is due to a number of factors, specifically bacteria in the dental plaque (particularly *Streptococcus mutans* and *lactobacilli*) on susceptible tooth surfaces and the availability of fermentable carbohydrates [8,9,10].

Hence a trend toward explaining the physical and biological properties of dental enamel electrochemically has developed; on the basis of the permselectivity and chargeability of the enamel, attempts have been made to elucidate the ionic exchange, adsorption, and permeability of several substrates to the enamel in relation to incipient caries. Some early studies applying an electrochemical approach to enamel were made by Klein et al' and Klein [11,12]. They demonstrated experimentally that enamel had permselective properties and that in the KCl solution the isoelectric point of dog's enamel laid between pH 3.6 and pH 4.9. They further demonstrated that the enamel pore wall was positively charged in solutions on the acid side of the isoelectric point, negatively on the alkaline side [11,12].

Chick and Waters [13], also showed that, when enamel is used as a diffusion barrier between the concentration cells, enamel has permselectivity. More recently, Takaesu, Moreno, and Brudevold [3], found that synthetic hydroxyapatite membranes have cation selective properties after exposure to the intraoral environment. Kambara [14], has experimentally made a dynamic study on the permeability of dental enamel in reference to tooth surfaces, tooth age and surface subsurface enamel; he reported that enamel has amphoteric properties and that a marked change of permeable voltage was shown at pH 5.0 in deciduous teeth, at pH 4.0 in impacted teeth and at pH 3.5 in permanent teeth.

It was suggested that isoelectric points might correspond to the above pH. Since a layer of medium is formed at the surface of the hydroxyapatite crystal and a hydration shell of 1.9 times of its own weight (Weyl et al) [15], goes with the crystal, an electrical double layer (Helmholtz's double layer) on Zeta potential is formed

upon the surface of the crystal. The Zeta potential is thought to be related to plaque formation, the uptake mechanism of fluoride and mineralization of teeth [16].

The present study is an attempt to obtain some information about the surface potentials and other aspects that can affect the enamel of a tooth.

2. Materials and Methods

2.1. Chemicals and Apparatus

Chemical used to prepare artificial saliva by adopting Birkland procedure [7], were $\text{Na}_2\text{HPO}_4 \cdot 2\text{H}_2\text{O}$, NaHCO_3 and $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$. All these chemicals were dissolved in distilled water and then the pH adjusted around 7 by NaOH and lactic acid. KCl solution of 0.01, 0.05, 0.1, 0.2, 0.5 and 1 M concentration were also prepared. Impedance electrometer (ED205/560A, 8M Ω DIALOGAL Instrument) was used to determine potential. Electrical measurement was performed as shown in Figure 1.

2.2. Electrical Circuit Linkage

The tooth dried with hydrophilic paper before being used. It was hold tightly in a self-made two compartment paraffin wax holder. Two conducting wires were linked with the electrometer, and each working hand of these wires was connected with one hand of the other two conducting wires with crocodile teeth at the other end respectively. The other hand of the wire with crocodile teeth was connected with the tooth surface (positive hand to the mid-spot of tooth root, negative one to the mid-spot of enamel crown's buccal side) respectively, as shown in Figure 1.

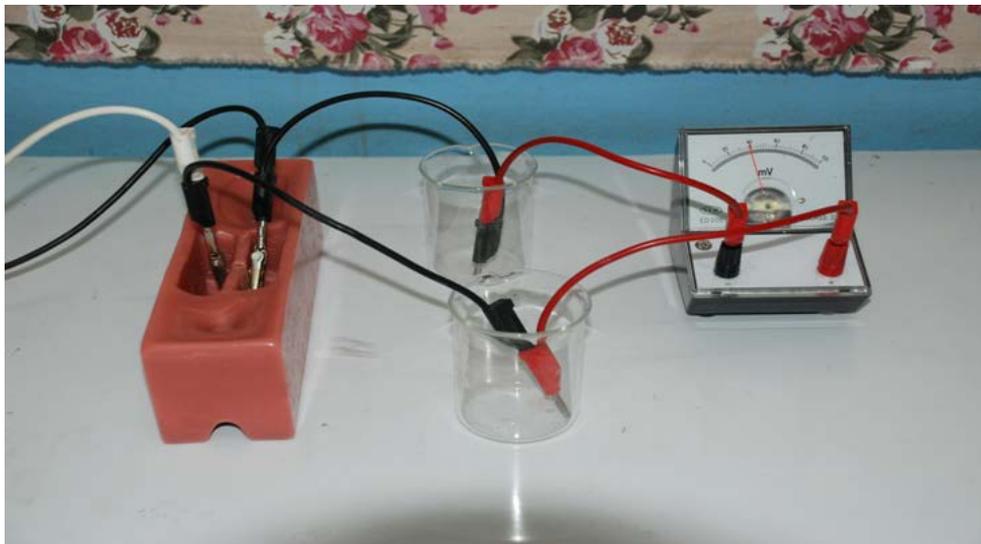


Figure 1. Illustration of apparatus for measuring electric current and the dental surface potentials



Figure 2. (a) Cleaned human permanent teeth ready to conduct an experiment. (b) A non-carious human sound incisor from which wafer was made

2.3. Sample Preparation

Twenty four human permanent teeth were selected when newly extracted. The teeth were made clean carefully, then rinsed extensively with distilled water and immersed into fresh distilled water (Figure 2).

The enamel wafer was also made from the enamel of non-carious human permanent tooth with a thickness of 200-300 μm . The surfaces of the wafers were parallel to the external surfaces of the teeth from which they were taken. This was done so that the pores that normally passed through the tooth surfaces also would pass through these wafers. To ensure that the wafers were composed of pure enamel, they were taken from enamel that was at least 0.4 mm away from the external surfaces of the tooth.

The thin wafers allowed equilibrium potentials to be established rapidly (about eighty minutes) which was used to investigate the ionic membrane properties of dental enamel.

3. Results and Discussion

Surface potentials of all the teeth were measured between enamel crowns against tooth root. Figure 3, showing the surface potential at different KCl concentrations. As it is evident from Figure 3, increasing concentration of KCl showing increase in potential from 15.15 ± 3.16 to 39.2 ± 7.11 mV.

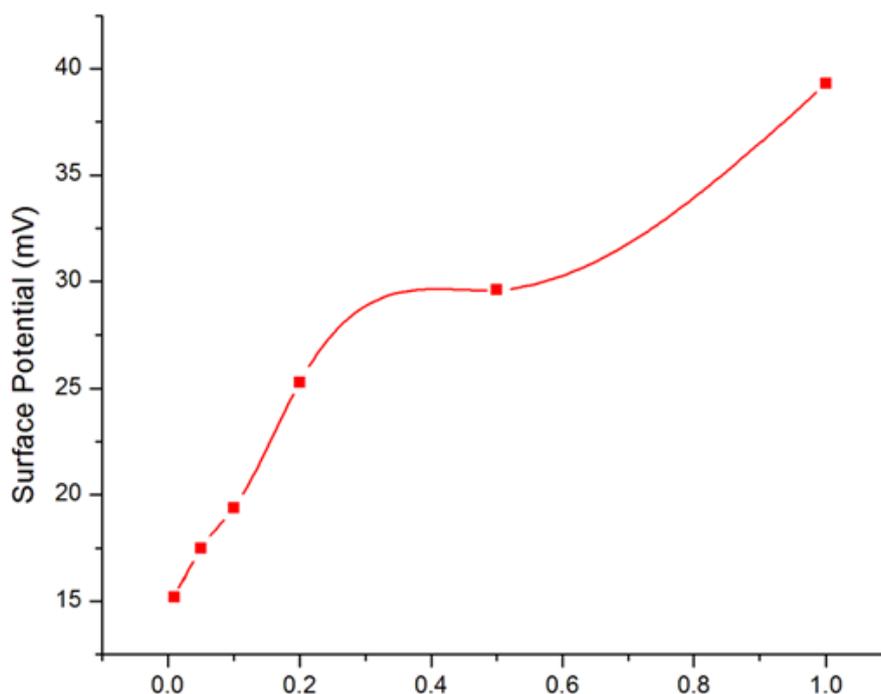


Figure 3. Effect of KCl concentration on dental surface potentials

It can be explain as since KCl solution is favorable in electrochemical investigation, for the ions K^+ and Cl^- having equal diffusion rates and activity. So the use of 0.1 mol/L KCl solution as electrolyte had similar surface potentials with the imitated physiological condition. These entire results indicate that the artificial saliva and normal saline can be replaced by 0.1 mol/L KCl solution as affective electrolyte solution in studying the tooth electrochemical characters. In the range of 0.01 to 1.0 mol/L KCl concentrations, dental surface potentials increased with increasing KCl concentration. These may owe to the density of charges attracted to the dental surface when K^+ & Cl^- were concentrated [11,12].

Also there is a stern layer, or a hydration layer of 5nm, in the enamel crystal surface, rich in attracted opposite charges. Where there's an electrical double layer, there are two layers of equivalent, opposite charges, thus, a potential must be established between the layers [2]. The surface potentials observed are all positive; which indicates that positive charges follow with the external circuit from the surface of dental root to the enamel surface.

After enamel being corroded by 30% phosphoric acid, the surface potentials rose by 39.5% compared to the

initial values got before acid treatment ($+ 29.09 \pm 5.74$ mV to $+20.83 \pm 5.70$ mV). The dental surface potentials increased surface potential after acid corrosion using the same electrolyte confirms the fact that the dental crystal structure develops the potentials. When corroded, more enamel crystals are exposed to the surrounding ions. The interaction area of crystals and surrounding ions increased and the absorbing became more tightly, which led to an increase of the potential. The ratio of concentrations on the two sides of the enamel wafer is responsible for electric ionic membrane potential differences [17].

The ionic membrane property of dental enamel Wafer that was used in the apparatus was 200 to 300 micrometer thick and it was made from the enamel of non-carious human tooth. The conducting wires immersed in the solution were coated with a conducting aluminum foil. Variation in the concentrations of salt solutions that bathe different sides of the tooth enamel caused significant voltages to develop. These voltages depend on concentration differences. However the thin wafer allowed equilibrium potentials to be established rapidly (45 seconds).

The effect of pH on the potentials was determined by using the same buffer in both compartments which was

found to be same within ± 0.1 pH units. The difference in potassium ion concentration caused the observed electric potentials. This difference was maintained constant and several buffering systems were used to insure that the

observed effects were caused by the pH rather than the buffer. Therefore the voltage that developed by the difference in salt concentration was considerably modified by pH variation, as shown in Figure 4 [18].

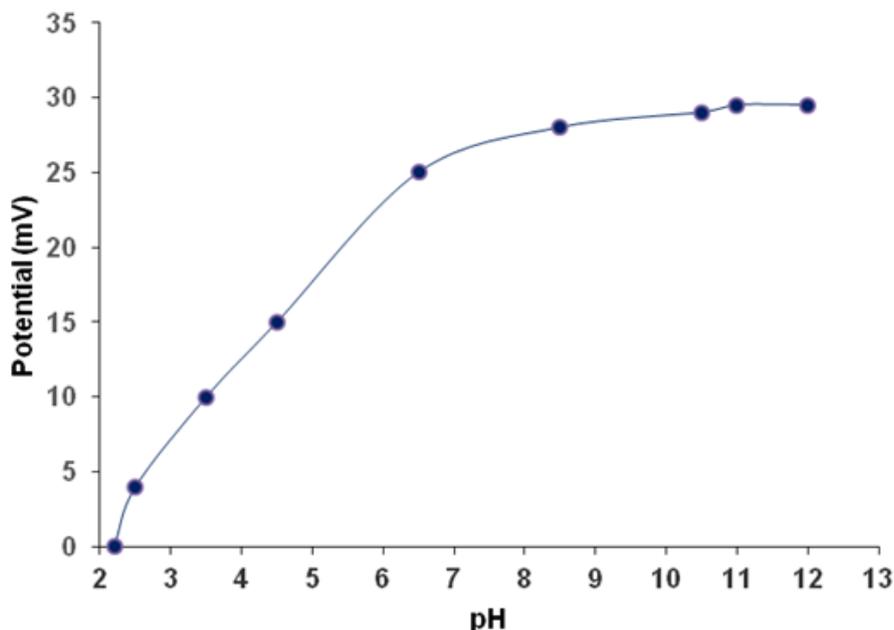


Figure 4. Effects of pH on enamel membrane potentials

When the pH was lowered to less than about six, there was significant degradation of the observed electric potential that was generated by the difference in potassium ion concentration between the two cell compartments. At a pH between two to four, the observed potential vanished.

Electric currents were passed through the dental enamel wafer to determine the extent of enamel deterioration. The

conducting wires immersed in the solution were coated with a conducting aluminum foil. With this experimental arrangement, a constant voltage that was applied to the enamel wafer gave a variation of current that was dependent on time, as is seen in Figure 5.

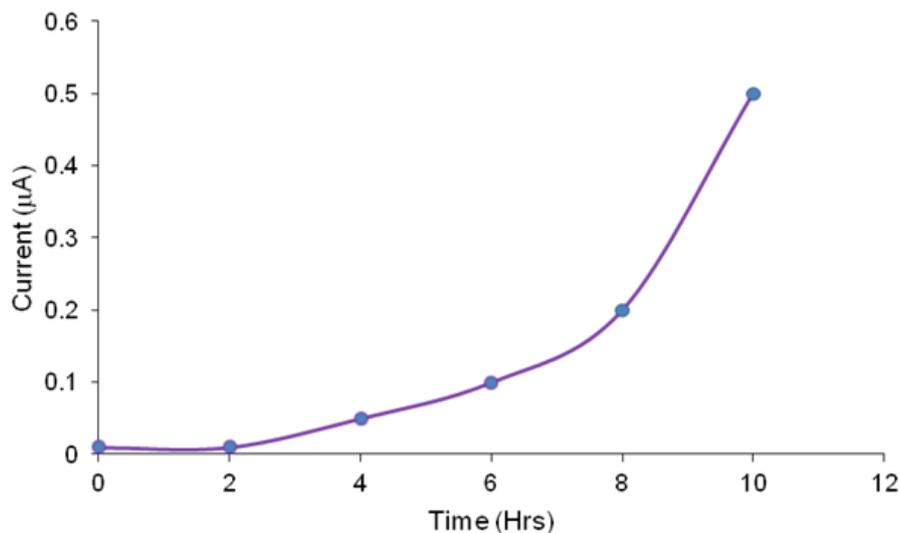


Figure 5. Time dependence of electric current through enamel wafer for 10 hours exposure

A constant potential difference of 10 V was applied. The electric current increased with time in an exponential manner; this indicates a continual degradation of the enamel wafer that is proportional in rate to the current at any given time. When the enamel samples were removed from the apparatus illustrated in Figure 2, physical deterioration was noted. The region of the wafer that was exposed to electric current had the same white, opaque appearance that is associated usually with carious lesions.

Control wafers that were subjected to identical circumstances, except for the flow of electric current had no physical deteriorations [19].

The right hand side solution of the compartment of Figure 2 was diluted from 0.1 N KCl to 0.05 N KCl plus 0.05 N KF under the applied potential of 10 V. This is used to test the effect of fluoride ion on electric current. The result of this experiment is shown in Figure 6.

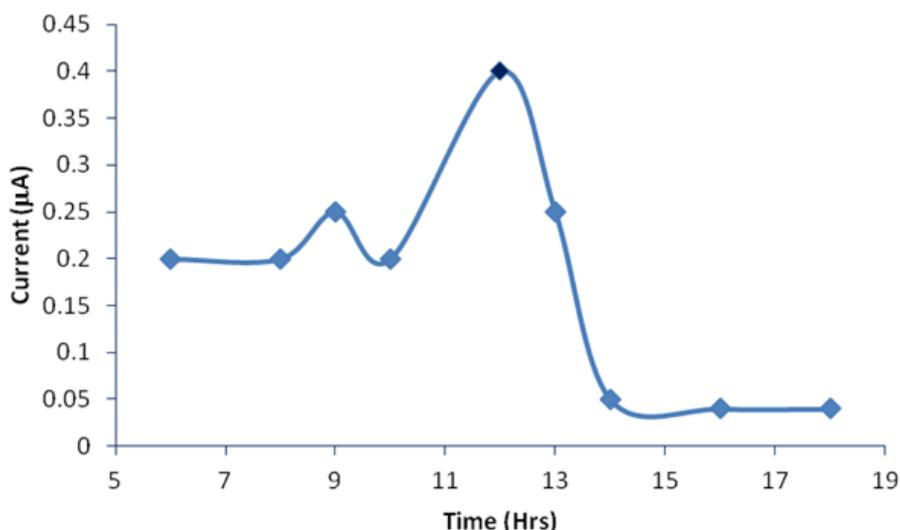
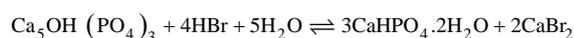
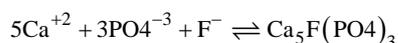


Figure 6. Effect of fluoride addition on electric current through enamel wafer

After an electric current flowed through an enamel wafer for several hours, the 0.1 N KCl solution in the electrically positive compartment of the cell was diluted with an equal volume of 0.1 N KF. The polarity of this compartment of the cell was such that the fluoride ion was driven electrically into the enamel wafer. As is shown in Figure 6, the addition of fluoride ultimately caused the electric current to drop by a factor of about four.



When the enamel dissolves



This drop in current indicates a significant increase in the electric resistance of the enamel as a result of contact with fluoride. An increase in electric resistance should be beneficial if caries are formed by an electric mechanism.

Hence the present endeavor offers some experimental data and pattern to determine the electrochemical properties and ions permselectivity of tooth. The ion transition across the interphase is greatly modified by the surplus charges and the electrical double layer in the tooth surface [20].

4. Conclusions

All teeth have surface potentials when measured between the enamel crown and tooth root. There is relatively stable direct current, along the electrochemical circuit. The existence of oral electric potentials, their possible short circuiting by regions of low pH or poor enamel quality, and the degradation of enamel by an electric current indicates that an electrochemical mechanism for caries formation is a possibility. The effect of fluoride could help to eliminate these short circuits of the oral electric potentials that are caused by local regions of low quality enamel. The elimination of local short circuits would minimize the incidence of tooth deterioration if the electric current that is associated with the short circuits causes their formation. The experimental evidence suggests that electrochemical phenomena play an important role in the mechanism of tooth deterioration.

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