THE MEASUREMENT AND RESEARCH OF SURFACE POTENTIALS OF HUMAN TOOTH *in vitro*

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Abstract- **Previous studies have shown that there are surface potentials in the separate tooth sections and a whole tooth *in vivo*. To confirm the existence of the surface potentials in extracted tooth and research the development of the potentials, the surface potentials between mid-spots of enamel crown's buccal side and tooth root were measured with electrochemical methods. The effects of KCl concentration and acid corrosion were also examined in the present study. All the teeth developed the surface potentials, and when 0.1 mol/L KCl solution was used, the average surface potential was +20.83± 11.47mV. The potentials increased along with the ascending of KCl concentration and after being acid corroded. The results of this study suggested that there are also surface potentials in tooth as a whole tissue *in vitro*, and the potentials can be affected by the electrolyte surroundings and are developed mostly by the dental crystal structure and established in the outer layer, an electric double layer.**

Key words- tooth, surface potential, KCl, corrosion

I. INTRODUCTION

Dental caries is a chemical and electrochemical dynamical process of de- and re- mineralization. It occurs at the interfaces of dental-saliva and dental-plaque. So, studying the interface character of tooth is of great importance to discover the caries' secrets and to find effectively protection methods of tooth.

The dental hard tissue, no mater enamel, dentin or cementum, is formed mostly by the mineral, hydroxyapatite. It is soaked in the electrolyte surroundings of saliva, blood and enchyma, thus, composed an electrochemical system. Except for Miller using chemico-parasitic theory to study the caries in 1890, many scholars later focused on electrochemical fields to study the dental characters and caries. A systematic study of the dental electrochemical property made by Klein and Amberson, 1932, had suggested that the dental enamel was an electrostatic ion screen and it had permselectivity[1]. Then studies mainly about the dental permselectivity and the influence of surfactant were made[2][3] ，which concluded that the ion surroundings developed the surface potentials of tooth. A preliminary study of the dental electrochemical property *in vivo* had found that the potential of enamel lesion was lower than that of sound enamel [4]. The results affirmed the existence of surface potentials *in vivo.*

The present endeavor measured the potentials across the tooth as a whole in different conditions. This is contrast to the works of Tung, Brown [2] and Vogel *et al* [3]. In there experiments, gradient solutions were used, which can develop the potential themselves, and the teeth were made into separate sections, while the tooth in physiological condition is a whole tissue. The purpose of this study is also to explore the source of the potentials and the influence on them, which will lead to a new and convenient protection of tooth.

II. METHODOLOGY

A.Sample preparation

Fifty intact sound human permanent teeth were selected when newly extracted (the number of bicuspid was 34; molar tooth, 9; incisor, 5; canine tooth, 2). Patients aged from 13 years to 50 years, no matter what sexes are. The teeth were made clean carefully, then rinsed extensively with distilled water and immersed into fresh distilled water.

B.Apparatus and reagent

A pair of calomel electrodes (type 222, Shanghai Guangdian apparatus factory, Shanghai, P.R.China) and a high impedance electrometer (DT890/890A,10M Ω, DIGITE‹ Instrument.) were used. Two saturated KCl salt bridges like letter L were made before measurement.

The artificial saliva (1000ml) was made according to Birkland [5]. 0.46803g $Na_2HPO_4.2H_2O$ (MW=156.01,A.R.), 1.68020 g $NaHCO_3$ (MW=84.01 A.R.), 0.14703 g $CaCl_2.2H_2O$ (MW=147.03,A.R.) was dissolved with distilled water; then the PH value was adjusted to 6.8 with NaOH and lactic acid, in equilibrium with air. The KCl solutions prepared from reagent grade salts (MW=74.55,A.R., Ningbo chemical reagent fac. Zhejiang, P.R.China) and distilled water had the concentrations of 0.01, 0.05, 0.1, 0.2, 0.5and1.0mol/L.

C.lectrical circuit linkage

The tooth, dried with hydrophilic paper before being used, was hold tightly in a self-made holder. The electrodes were linked with the electrometer, and each working hand was soaked in the saturated KCl solution, together with one hand of the salt bridge respectively. The other hand of the bridge 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 fig.1.

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Abstract

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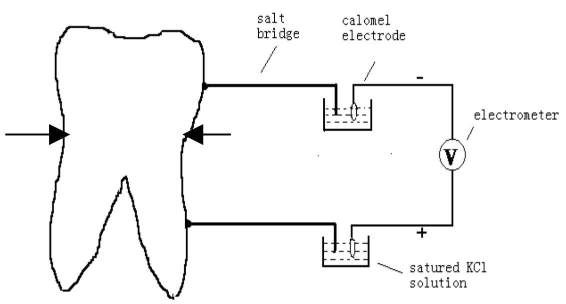

Fig.1. Illustration of apparatus for measuring the dental surface potentials:
—▶ ◀— Refers to the tooth holder

D.Measurement

Group A (imitated the physiological condition): The mid-spot of the enamel crown's buccal side was surrounded with defatted cotton saturated with artificial saliva, and the mid-spot of the root with normal saline saturated cotton (be careful enough to make the different electrolyte separately). After the electrometer gave a stable value, the potentials were recorded three times. The average potential subtracting the adjusted potential value of the electrodes got after the tooth being measured was signed as the surface potential of this tooth.

The tooth after being measured was immediately rinsed extensively with distilled water and then immersed in fresh distilled water for the next treatment.

Group B: The mid-spots of enamel crown's buccal side and tooth root were surrounded with 0.1mol/L KCl solution respectively. The procedures were the same as group A, as described above.

Effect of KCl concentration on dental surface potentials: From low concentration to high, as 0.01, 0.05, 0.1, 0.2, 0.5, 1.0mol/L successively, the KCl solution was used as the electrolyte to measured the surface potentials of the tooth. The procedures were the same as group B, and each series had a sample side of 50.

Effect of acid corrosion on dental surface potentials: The mid-spot of the enamel crown's buccal side was corroded with 30 % phosphonic acid for 1 minute, then blew dry to give creta expression. The procedures were the same as group B which using 0.1mol/L KCl as electrolyte.

E.Statistical analysis

Each series had the same sample side of 50. The data were presented as mean ± SD throughout. The significance of difference in mean's value was evaluated by student t test . The significance was defined at $p<0.05$ lever.

III. RESULTS

All the extracted teeth have surface potentials when measured between the enamel crown and tooth root (cementum). They are relatively stable direct current, along the electrochemical circuit. The data approximately normal distributes. The surface potentials in different electrolyte solutions are shown in table 1. There is no statistical significance between Group A (enamel crown to the artificial and root to normal saline) and group B (enamel crown and root both to 0.1vmol/L KCl respectively), $p>0.05$.

TABLE 1. THE DENTAL SURFACE POTANTIALS IN DIFFERENT ELECTROLYTE SOLUTION($\bar{X}$ ±s n=50)

	Surface potentials	
Group A	+22.93±12.93mV	p>0.05
Group B	+20.83±11.47mV	

Group A：Enamel crown connected with artificial saliva and tooth root with normal saline
GroupB：Enamel crown and tooth root connected with 0.1mol/LKClsolution respectively

Table 2 shows the surface potentials when using different KCl concentrations respectively in a range of 0.01 to 1.0mol/L. The ascending of the concentrations of KCl led to an increase of surface potentials from +15.17±6.32 to 39.30±14.32mV, though the inclination didn't agree with each other. The trend is shown in fig.2. Among these the 0.1mol/L KCl series had an average potential of +19.39±7.81mV, so closed to the result of group B (+20.83±11.47mV), which had the same experimental condition. They have no statistical significance ($p>0.05$), which provide parallel series and suggest the experiment have fine repeating.

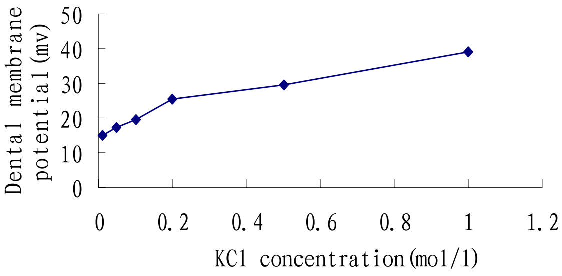

Fig. 2. Illustration of KCl concentration on dental surface potentials

30% phosphonic acid is a generally used acid in clinical practice. After enamel being corroded by the acid, the surface potentials rose 39.7% comparing to the initial values got before acid treatment (+29.09±11.51mV to +20.83±11.47mV). The change has statistical significance ($p<0.05$). Table 3 shows the results.

Table 2. Effects of KCl concentration (mol/L) on dental surface potential ($\bar{X}$ ±s mV, n=50)

Concentration	0.01	0.05	0.1	0.2	0.5	1.0
0.01	15.17 ±6.32			*	*	*
0.05		17.39 ± 7.06		*	*	*
0.1			19.39 ± 7.81	*	*	*
0.2	*	*	*	25.27± 9.79		*
0.5	*	*	*		29.62± 10.64	*
1.0	*	*	*	*	*	39.30± 14.22

* $p<0.05$

Table 3.

Effects of acid corrosion on dental surface potentials ($\overline{X}$ ±s, n=50)

	Surface potential	
Before c1orroded	+20.83±11.47mV	P<0.05
After corroded	+29.09±11.51mV	

IV. DISUSSION

For the first time we observed the surface potentials in the extracted teeth as a whole tissue. They are complex potentials between enamel, dentin and cementum. When enamel crown and the tooth root were connected to the 0.1mol/L KCl solution, the average potential was +20.83±11.47mV. Tung and Brown [2] got a potential of +15.0mV in enamel section, and Vogel *et al* [3] got average potentials of enamel: +18.9±3.2mV, dentin: +0.9±9.2mV, cementum: -0.8±8.2mV, which were similar to our results. Tooth in the *in vivo* oral environment has the similar surroundings as we imitated, so the acquired data in the extracted teeth can be useful references as the dental biological potentials *in vivo*.

KCl solution is favorable in electrochemical investigation, for the ions K^+ and Cl^- having equal diffusion rates and activity. Using 0.1mol/L KCl solution as electrolyte had similar surface potentials with the imitated physiological condition (artificial saliva to the enamel crown and the normal saline to the tooth root). These entire results certificate that the artificial saliva and normal saline can be replaced by 0.1mol/L KCl solution as affective electrolyte solution in studying the tooth electrochemical characters.

In the range of 0.01 to1.0mol/L KCl concentrations, dental surface potentials increased with the KCl concentration ascending. These may owe to the density of charges attracted to the dental surface when K^+, Cl^- concentrated. The rising trade of surface potentials is slower than the KCl concentrations, which indicated that the electrolyte surroundings affect the surface potentials in one hand, and the surface potentials is related to the tooth tissue itself in other hand.

There's a stern layer, or a hydration layer of 5nM [6][7], in the enamel crystal surface, rich of attracted opposite charges. The structure has a term of electrical double layer in electrochemistry. A surface, or an interface in precise, always has an electrical double layer. Where there's an electrical double layer, there are two layers of equivalent, opposite charges, thus, a potential must establish between the layers [8]. The surface potentials we have got are all positive; which indicates that positive charges follow with the extra circuit from the surface of dental root to the enamel surface. As using 0.1KCl as electrolyte is concerned, we can conclude that the stern layer of tooth root is full of positive ions of K^+ and the cementum itself is negatively charged, and the stern layer of enamel is full of negative ions of Cl^- and enamel itself positively charged. The dental crystal structure makes the potential possible.

The dental surface potentials increased after acid corrosion when using the same electrolyte. This experience affirmed the above view that the dental crystal structure develops the potentials. When corroded, more enamel crystals are exposed to the surroundings ions. The interaction area of crystals and surrounding ions increased and the absorbing became more tightly, which led to an increase of the potential [8].

The present endeavor offers some experimental data and pattern for exploring the electrochemical properties and ions permselectivity of tooth *in vivo*. The ion transition across the interphase is greatly modified by the surplus charges and the electrical double layer in the tooth surface, and the latter directly influent the drugs' migration and diffusion in clinical practice and experiments. According to our results, negatively charged pharmacal ions as F^- can be administrated by contained in oral cavity, and the positively charged ions such as Ca^{2+}, Sr^{2+}, prefer to the blood ways as injection or oral administration. The research on the electrochemical properties of tooth must lead to a viable convenient revolution of oral medicine.

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REFERENCES

[1] Klein H, Amberson WH, "A physical-chemical study of the structure of dental enamel," *J .Dent. Res.* vol.12, pp. 95-109, 1932.

[2] Tung and Brown, "Characterization and modification of electrochemical properties of teeth," *J. Dent. Res.* vol.62(1), pp. 60-64, 1980.

[3] Vogel GL, Mao Y, Carey CM, Chow LC, "Changes in the permselectivity of human teeth during caries attack," *J. Dent .Res.*vol.76 (2), pp. 673-681, February, 1997.

[4] Huang Lizi , " A preliminary study of biological electric phenomenon in caries lesion," *Chin. J. Stomatol* .Bejing, vol. 28, pp.297-299, 1993.

[5] Birkland JM, "The effect of pH on the interaction of fluoride and salivary ions, " *Caries. Res.* vol, 7, pp.11-18, 1973.

[6] Fan Mingwen, "Metabolism of fluoride," In *Cariology,* Guizhou publishing house of science and technology, Guizhou, P.R.China, 1993, pp. 182.

[7] Shen Mozhao, “Cell potentials and electric double layer,” In *Basic principles and application of electrochemistry,* normal university publishing house, Beijing, P.R.China, 1990, pp. 86-95.
[8] J O’M Bockis and DM Dražice , “Structure of electric double layer,” In *Electro chemistry,* translated by Xia Xi, People’s educational publishing house, Beijing, P.R.China, 1980, pp. 27-28.