

## Model of Tooth Enamel for Tribological Study

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### Abstract

The right selection of home hygiene products and their long-term use is an urgent issue in modern dentistry. For research of the correct combination of hardness of toothbrush and abrasiveness of toothpaste was created a model of the enamel.

In the article the following goals were solved: the microstructure and microhardness of dental hard tissues have been investigated; was studied effect of changes of the roughness of enamel surface in imitation of 1 year brushing of a hard toothbrush and paste of medium abrasivity (RDA 60); the material for creating of the tooth enamel was determined. The study of the enamel microstructure showed that an oriented structure is characteristic of the enamel. Usage a hard brush in combination with a paste of medium abrasivity (RDA 60), the optimal time for this combination can be recommended for more than a year.

A further direction of investigation is associated with the assessment of the suitability of the resulting model of tooth enamel in study of changes in the enamel surface due to use of a hard brush with a paste of varying degrees of abrasivity.

**Experimental article (J Int Dent Med Res 2023; 16(2): 619-623)**

**Keywords:** Tooth, Enamel, Tribological Study.

**Received date:** 11 October 2022

**Accept date:** 06 February 2023

### Introduction

One of the aspects of dental diseases prevention is the observance of home oral hygiene. The correct selection of home hygiene products and their long-term use is an urgent issue in modern dentistry. In order for hygiene products such as toothbrush and toothpaste to really mechanically and chemically clean the tooth surface and their long-term combination does not cause complications such as hyperesthesia, abrasion wear, abrasion<sup>1,2</sup>, it is important to choose the right home hygiene products.

Unfortunately, in the literature sources there is very little data on studies of the effect of toothbrushes of different hardness and

toothpastes of different degrees of abrasivity and their effect on the hard tissues of the teeth. According to the study by Hamza B. et al. (2020) were obtained data stating that in some toothpastes the RDA indicators were much higher than declared by the manufacturer<sup>3</sup>, which can also negatively affect the change in the roughness of the tooth enamel surface. In a study by Liljeborg A. et al. (2010) the authors concluded that the RDA parameter is not enough to accurately determine the abrasivity of the toothpaste, it is also important to carry out quantitative and qualitative measurements of changes in the tooth surface roughness to register the Ra parameter.<sup>4</sup>

According to the in vitro study, Wiegand A. et al. (2014), according to the data obtained, the authors concluded that tooth abrasion is primarily associated with the abrasivity of the toothpaste, and the toothbrush acts as a carrier, only changing the effect of the toothpaste.<sup>5</sup>

The bristles of toothbrushes, in turn, are also subject to wear, being in tribological contact with the tooth enamel. The issue of toothbrush abrasion is also poorly investigated. According to

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Fattal R.K. et al. the main defect of the bristles is delamination along the walls, this study provides a method for assessing the degree of wear of toothbrushes 3 months after use by a group of volunteers - the degree of wear of the bristles is assessed by examining them on a microscope.<sup>6</sup> Moreover, tooth enamel is used as an antagonist material in ISO testing of dental materials and restorations.<sup>7</sup> To determine the characteristics of wear resistance, the researchers Kazama T. et al. developed a device which helped to determine the coefficient of friction of the material of the toothbrush's bristles, where polymeric materials or stainless steel are used as a counterbody.<sup>8</sup>

It is not always possible to study the effect of a combination of home hygiene products on human extracted teeth or bovine teeth. Moreover, in the context of SARS CoV-2 pandemic, obtaining samples for research, as well as conducting in vivo tests, has become difficult due to the imposed restrictions. Therefore, the creation of an analogue of tooth enamel seems to be an urgent task, since the need to involve volunteers for testing toothbrushes and using human teeth for research will be eliminated.

This article is devoted to the creation of an artificial model of human tooth enamel that can serve as a replacement for the natural prototype in the listed studies. In order to achieve the set goals the following tasks were solved:

- The microstructure and microhardness of dental hard tissues have been investigated;
- On the example of abrasion year, the effect of combination of a hard toothbrush and a paste of medium abrasivity RDA 60 on changes in the surface of tooth enamel according to profilometry data was investigated;
- The material for creating tooth enamel model was determined, its physical and mechanical properties were investigated, the modes of pressing for obtaining an experimental sample were investigated.

## Materials and methods

### Investigation of the microstructure and microhardness of dental hard tissues

The objects of investigation are intact third molars (3 samples) and incisors (5 samples). The dental samples were disinfected, then stored in distilled water to prevent drying out.

The microstructure of dental hard tissues

was studied on thin sections of intact third molars. To prepare thin sections, the samples were cut along the horizontal, vertical and diagonal planes, the resulting fragments were immersed in a fast-hardening plastic. After polymerization, the samples were ground and polished. Before the study, the surface of the thin sections was treated with an ethyl alcohol solution to remove contaminants. The study of the microstructure was carried out on Olympus BX43 microscope. The microhardness of the tooth enamel was measured on the vestibular and lingual surfaces of the incisors. The measurements were carried out on Vickers hardness testing machine (DuraScan).

### The study of changes in the enamel surface due to use of a hard brush with a paste of medium abrasivity RDA 60

The experiment was carried out on a patented device for the study of the mutual influence on the surface of dental tissues, samples of dental materials and hygiene products (utility model patent No. 205606 dated 23.04.2021).<sup>9</sup> Using this device, a study was carried out on the abrasion of the sample enamel. For the study, 3 samples were prepared, the first 3 molars were sawn with Mecatome T210 apparatus (Presi, Eybens, France) from the vestibular side. Each sample is 1×1 cm. All samples were poured into a polymer plate, so that the vestibular surface remained free. Medium abrasive paste (RDA 60) and hard brush were used. The measurements were carried out at a magnification 3D×150 at time intervals: initial condition of the tooth, 1 week, 1 month, 6 months, 1 year using the Senso neox (Sensofar) profilometer. The unit of measure for the change in surface roughness is Ra (height parameter) - this is the arithmetic mean of the absolute values of the profile deviations within the base length.

### Determination of the physical properties of experimental samples based on calcium hydroxyapatite

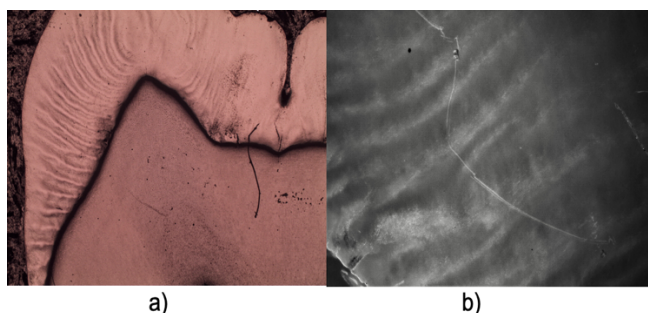
To obtain experimental samples - models of tooth enamel, calcium hydroxyapatite powder was used. The sample was obtained by cold pressing in air followed by sintering. Calcium hydroxyapatite powder was pressed on a universal testing machine IR5143 with a force of 200 kN. The physical properties of the pressed sample were investigated on DSC 404 F1 Pegasus calorimeter. In particular, DSC curve was obtained to evaluate the processes

occurring during heating, and the density of the sample was measured as a function of the temperature rise.

## Results

### Experiment 1. Investigation of the microstructure and microhardness of dental hard tissues

The study of the enamel microstructure showed that an oriented structure is characteristic of the enamel. According to the literature<sup>10</sup>, the structure of the enamel is represented by enamel prisms penetrating the interprismatic substance. In the figure (Fig. 1), the Gunther-Schroeger stripes are observed - alternating dark and light stripes arising from the unequal reflection of light from the enamel prisms cut at different angles.



**Figure 1.** Tooth enamel microstructure. a) hard tooth tissues (enamel, dentin), x100; b) Gunther-Schroeger stripes (dark-field image), x500

Vestibular surface (HV)	Lingual surface (HV)
467	322
467	449
508	292
607	467
399	283
667	358
777	431
607	399
701	312
415	322
Mean value: 561.5	Mean value: 363.5

**Table 1.** Tooth enamel surface microhardness.

During the study of the enamel surface microhardness, 10 measurements were made on the vestibular and lingual surfaces. Imprinting was carried out with a load of 0.1 N.

Results of measurements are presented in Table 1.

Total enamel surface microhardness makes 462,5 HV.

### Experiment 2. The study of changes in the enamel surface due to use of a hard brush with a paste of medium abrasivity RDA 60

Measurement data using a toothpaste of medium abrasivity (RDA 60) are presented in table 2.

According to the profilometry data, it was found that all three samples showed an increase in surface roughness *after a week* of using a hard brush and a paste of medium abrasivity. Sample No. 1 by 1.5 times; sample No. 2 and No. 3 by 1.4 times (Table 2).

No. of tooth	Number of days				
	0	7	31	183	365
1	102.5	154.9	110.3	106.7	74.346
2	179.9	244.1	86.417	107	94.753
3	144.9	206.8	155.7	46.32	29.84
	Ra, nm				

**Table 2.** Study results of using a hard toothbrush with toothpaste RDA 60.

*After a month:* The enamel surface of all 3 samples was polished. Sample No. 1 has 1.4 times decrease in roughness indicators; sample No. 2 has 2.8 times decrease; sample No. 3 has 1.3 times decrease (Table 2).

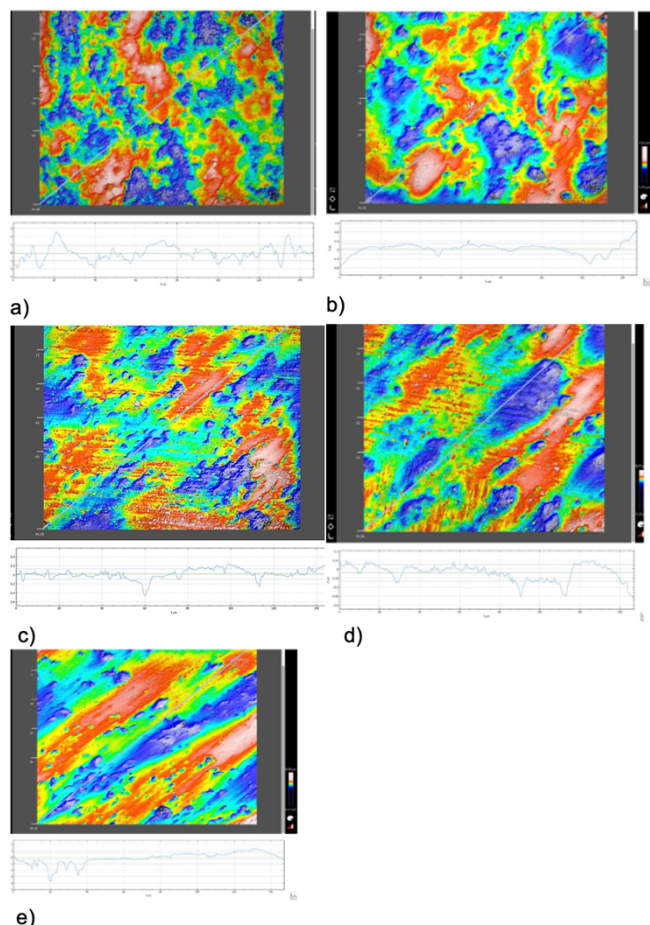
*After 6 months:* sample No. 1 had a slight decrease in surface roughness in comparison with the data at the point of the month; in sample No. 2 the surface roughness increased by 1.2 times; sample No. 3 had a decrease in the enamel surface roughness by 3.4 times (Table 2). *After 1 year:* all three samples showed a decrease in enamel surface roughness with the data at the 6 month point and with the initial condition of the tooth. Sample No. 1 - decrease in enamel roughness by 1.4 times from Ra 106.7 nm to 74.346 nm; sample No. 2 by 1.1 times from Ra 107 nm to Ra 94.753 nm; sample No. 3 by 1.6 times from Ra 46.32 nm to Ra 29.84 nm compared to the data at the point of 6 months (Table 2).

Figures 2 (a-e) show the data for sample No. 1.

Thus, profilometry data show changes in enamel relief. Increase in the enamel surface roughness in all 3 samples after a week of using a hard brush and medium abrasive paste (RDA 60). Reduction of the enamel surface roughness



in all 3 samples after a month of using this combination of hygiene products. The continuation of polishing the enamel surface at the point of 6 months, with the exception of sample No. 2, which showed a slight (1.1 times) increase in surface roughness. Moreover, all 3 samples continued to be polished in the 6 months - 1 year time segment.

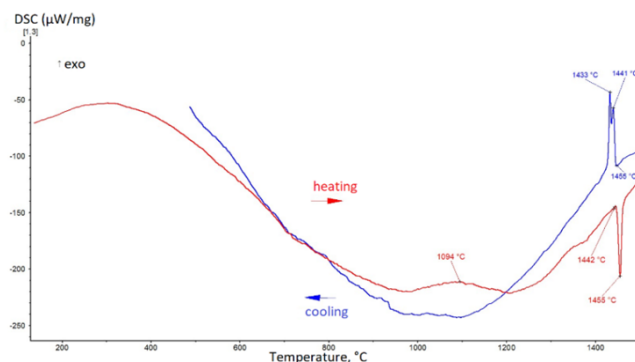


**Figure 2.** a - sample No. 1 (starting point of measurement); b - sample No. 1 (measurement after 1 week); sample No. 1 (measurement after a month); d - sample No. 1 measurement after 6 months; e - sample no. 1 (measurement after a year).

According to profilometry data, we see the effect of home hygiene products on the change in the enamel surface roughness. When using a hard brush in combination with a paste of medium abrasivity (RDA 60), the optimal time for this combination can be recommended for more than a year. According to profilometry data at the 1-year point (Fig. 2, e), the enamel surface is polished.

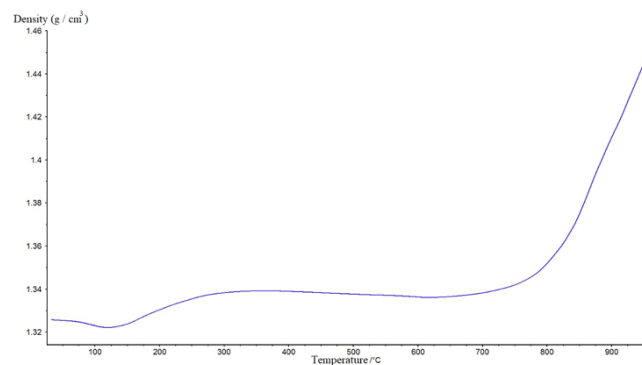
### Experiment 3. Determination of the physical properties of experimental samples based on calcium hydroxyapatite

Experimental samples were obtained by cold pressing of calcium hydroxyapatite powder on air. Investigation of the pressing modes showed that the sample, pressed at  $P=250$  MPa and subjected to further heat treatment at  $t = 1100^{\circ}\text{C}$  for 2 h, exfoliates. The sample pressed at  $P=500$  MPa and subjected to further heating has a hardness of 460 HV, which complies with the microhardness of the incisor enamel surface. The figure (Fig. 3) shows DSC curves during heating and cooling of the sample after pressing at 500 MPa.



**Figure 3.** DSC curves of heating and cooling of a hydroxyapatite sample after pressing at 500 MPa. The DSC heating curve shows one exothermic peak ( $1094^{\circ}\text{C}$ ) associated with sintering process. The reversible transformation in the  $1433-1455^{\circ}\text{C}$  temperature range is associated with the decomposition of hydroxyapatite to  $\alpha$ -TCP and TTCP.<sup>11</sup>

The change in the density of the sample depending on temperature was also investigated. The results are shown in Fig. 4.



**Figure 4.** Change in the density of the experimental sample during sintering.

## Discussion

Unfortunately, there are not a lot of studies of combination toothbrush with different hardness and toothpaste with different RDA level. In research of Razumova S.N. et al. (2022) in combination soft toothbrush and low abrasiveness of toothpaste during one year of usage smoothen the surface of the enamel.<sup>12</sup> Regarding study Razumova S.N. et al. (2021) the combination of hard toothpaste and high abrasiveness toothpaste couldn't be used more than 6 months.<sup>13</sup> In pilot study of Kozlova Y.S. et al. (2021) concluded that combination of medium toothbrush and medium abrasiveness toothpaste during one year of using doesn't change the enamel surface.<sup>14</sup>

More research is needed on various combinations of toothpaste and toothbrush.

## Conclusions

The study investigated the effect of the combination of a hard toothbrush and a medium abrasive paste RDA 60 on the change in the roughness of the tooth enamel surface according to profilometry data. It is shown that over time the tooth enamel roughness changes, therefore, the toothbrush, toothpaste and tooth enamel upon contact have a mutual effect, changing the relief of the contacting surfaces. Since the use of real teeth in tribological studies of dental materials and toothbrushes is difficult, especially in the context of the Covid-19 pandemic, it becomes necessary to create an artificial model of human tooth enamel. According to the results of investigations performed in the study, the microstructure and microhardness of dental hard tissues were determined. Based on the results obtained, it was determined that the most suitable material for creating an analogue of tooth enamel is calcium hydroxyapatite. An experimental sample was created by pressing at  $P = 500$  MPa followed by sintering, and its physical and mechanical properties were investigated. A further direction of investigation is associated with the assessment of the suitability of the resulting model of tooth enamel in study of changes in the enamel surface due to use of a hard brush with a paste of varying degrees of abrasiveness.

## Declaration of Interest

The authors report no conflict of interest.

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