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MORPHOMETRIC CHARACTERIZATION OF ENAMEL AND DENTIN SURFACE MICROGEOMETRY UNDER DIFFERENT PREPARATION PROTOCOLS

Introduction. Adhesive restorations in modern dentistry require the formation of an optimal microgeometry of enamel and dentin surfaces to ensure effective micromechanical retention and long-term stability of the adhesive interface. Different preparation protocols, including rotary and air-abrasion techniques combined with acid etching, produce distinct morphological changes in hard dental tissues. However, quantitative assessment of these changes using modern surface metrology parameters in accordance with ISO 21920 standards remains insufficiently explored.

Objective. To evaluate the effect of different preparation protocols (rotary and air-abrasion, with and without acid etching) on the microgeometry of enamel and dentin surfaces based on morphometric surface parameters.

Materials and Methods. Enamel and dentin specimens were subjected to four preparation protocols: rotary preparation without etching (Group 1), rotary preparation with etching (Group 2), air-abrasion without etching (Group 3), and air-abrasion with etching (Group 4). Surface microgeometry was assessed using Ra and SDq parameters for enamel, and Slope and P95 parameters for dentin in accordance with ISO 21920 surface metrology approaches. The obtained values were analyzed comparatively across the groups.

Results. For enamel, a progressive increase in Ra and SDq values was observed from Group 1 to Group 4, with the highest values recorded after combined air-abrasion and acid etching. For dentin, Slope and P95 demonstrated a similar trend, with minimal values after rotary preparation without etching and maximal values after combined air-abrasion and etching. Acid etching enhanced the effect of mechanical treatment by forming a more developed microrelief and promoting the opening of dentinal tubules.

Conclusions. The preparation method and acid etching significantly influence the microgeometry parameters of enamel and dentin surfaces. The combination of air-abrasion and acid etching produces the most developed microgeometry of dental hard tissues, creating morphological prerequisites for improved micromechanical adhesion of restorative materials and representing a promising clinical approach for optimizing adhesive restorations.

Key words: surface microgeometry, enamel, dentin, air abrasion, acid etching, adhesion, morphometry.

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МОРФОМЕТРИЧНА ХАРАКТЕРИСТИКА МІКРОГЕОМЕТРІЇ ПОВЕРХНІ ЕМАЛІ ТА ДЕНТИНУ ЗА РІЗНИХ ПРОТОКОЛІВ ПРЕПАРУВАННЯ

Вступ. Адгезивні реставрації в сучасній стоматології потребують формування оптимальної мікрогеометрії поверхні емалі та дентину, що забезпечує реалізацію мікромеханічної ретенції та довготривалу стабільність адгезивного з'єднання. Різні протоколи препарування (роторні та повітряно-абразивні) у поєднанні з кислотним протравленням по-різному впливають на морфологію поверхні твердих тканин зуба. Водночас кількісна оцінка цих змін із використанням сучасних параметрів поверхневої метрики відповідно до стандартів ISO 21920 залишається недостатньо висвітленою.

Мета дослідження – оцінити вплив різних протоколів препарування (роторного та повітряно-абразивного, з протравленням і без нього) на формування мікрогеометрії поверхні емалі та дентину на основі морфометричних параметрів поверхні.

Матеріали та методи. Дослідження виконано на зразках емалі та дентину, підданих чотирьом протоколам обробки: роторне препарування без протравлення (1-ша група), роторне з протравленням (2-га), повітряно-абразивне без протравлення (3-тя), повітряно-абразивне з протравленням (4-та). Мікрогеометрію поверхні оцінювали за параметрами Ra та SDq для емалі, а також Slope та P95 для дентину відповідно до підходів поверхневої метрики ISO 21920. Отримані значення аналізували порівняльно між групами.

Результати. Для емалі встановлено послідовне зростання показників Ra та SDq від 1-ї до 4-ї групи з максимальними значеннями за комбінованого повітряно-абразивного препарування з протравленням. Для дентину показники Slope та P95 продемонстрували аналогічну тенденцію: мінімальні значення після роторного препарування без протравлення та максимальні в разі поєднання повітряно-абразивної обробки з протравленням. Застосування протравлення підсилювало ефект механічної обробки, формуючи більш розвинений мікрорельєф поверхні та сприяючи відкриттю дентинних канальців.

Висновки. Метод препарування й кислотне протравлення істотно впливають на параметри мікрогеометрії поверхні емалі та дентину. Поєднання повітряно-абразивного впливу з протравленням забезпечує формування найбільш розвиненої мікрогеометрії твердих тканин зуба, що створює морфологічні передумови для підвищення мікромеханічної адгезії реставраційних матеріалів і може розглядатися як перспективний клінічний підхід для оптимізації адгезивних реставрацій.

Ключові слова: мікрогеометрія поверхні, емаль, дентин, повітряно-абразивне препарування, кислотне протравлення, адгезія, морфометрія.

Introduction. Adhesive restorations are an integral component of modern minimally invasive dentistry, and their effectiveness is largely determined by the microgeometry of the surface of dental hard tissues. It is the microrelief parameters that create the conditions for micromechanical retention and the stability of the adhesive interface [1].

In clinical practice, various preparation protocols are used for enamel and dentin, including conventional rotary preparation and air-abrasion techniques, which differ in their mechanisms of interaction with dental tissues and, consequently, produce different surface morphologies [2]. Additional acid etching modifies the microstructure of both enamel and dentin by increasing microporosity and facilitating the opening of dentinal tubules [3]. Air-abrasion treatment significantly alters the microrelief architecture of dental hard tissues, intensifies the surface texture of enamel and dentin, and increases their roughness parameters. Such changes in microgeometry expand the effective contact area and optimize the conditions for adhesive fixation of restorations [4–6]. The adhesive interface of dental tissues formed after air-abrasion is characterized by pronounced microtextural heterogeneity, in contrast to the more ordered surface geometry typical of conventional rotary instrumentation [7].

Despite the considerable number of studies devoted to the adhesion of restorative materials, the quantitative assessment of enamel and dentin surface microgeometry after different preparation protocols remains insufficiently systematized. This is particularly relevant for comparative analyses based on modern surface metrology standards (ISO 21920), which allow objective evaluation of both height and gradient characteristics of the surface.

Therefore, a comprehensive investigation of enamel and dentin microgeometry following different preparation and adhesive conditioning protocols using quantitative morphometric parameters is of high relevance, as it may provide a scientific basis for selecting optimal clinical protocols to enhance the effectiveness of adhesive restorations.

Objective. The aim of the study was to evaluate the effect of different preparation protocols on the formation of enamel and dentin surface microgeometry based on morphometric surface parameters.

Materials and Methods. The surface microgeometry of enamel and dentin was investigated using five third molars extracted due to impaction in patients without signs of carious lesions. Each tooth was sectioned in the mesiodistal direction into two halves, and the specimens were allocated into four groups according to the preparation and adhesive conditioning protocols.

Specimen Preparation Protocols. In Groups 1 (n = 5) and 2 (n = 5), the surfaces were prepared using rotary instrumentation with a coarse-grit spherical diamond bur (abrasive grain size 100–125 µm) in a high-speed handpiece with water spray. New burs were used after every five specimens. The prepared cavities were rinsed with a syringe and air-dried using oil-free air.

For specimens in Groups 3 (n = 5) and 4 (n = 5), an air-abrasion technique was applied using 50 µm Al_2O_3 particles at a 45° angle, under an air pressure of 0.41 MPa, at a distance of 2 mm, using a Sandman Futura air-abrasion unit (Denmark).

No preliminary etching of dental tissues was performed in Groups 1 and 3. In Groups 2 and 4, the surfaces were etched after preparation using 37% phosphoric acid gel. Enamel was etched for 30 seconds according to the manufacturer’s instructions, and dentin for 15 seconds. The specimens were then thoroughly rinsed for 30 seconds and air-dried with oil-free air.

The surface microrelief of enamel and the microgeometry of dentin were evaluated based on digital microimages obtained after preparation of the specimens.

The primary images were processed using ImageJ software (NIH, USA) with the 3D Surface Plot function. Surface height maps were exported in text (TXT) format containing X and Y coordinates and corresponding intensity values (Z).

The obtained data were used as a numerical matrix representing the surface height profile, on the basis of which the microrelief parameters were calculated.

For enamel surface microgeometry, the parameters Ra and SDq were applied, reflecting the height and gradient characteristics of a continuous mineralized surface: Ra – the arithmetic mean surface roughness; SDq – the root mean square gradient of the surface (microrelief intensity).

For dentin surface microgeometry, which is characterized by a tubular microstructure, the parameters Slope and P95 were used to assess the degree of dentinal tubule opening and the intensity of the microrelief taking into account extreme values: Slope – the mean surface slope (gradient); P95 – the 95th percentile of microrelief amplitude.

All parameters were evaluated in accordance with ISO 21920 surface metrology standards [8].

The parameters were calculated by mathematical processing of the height matrices (X–Y–Z) using spreadsheet software and standard profilometric data processing algorithms. The microrelief parameters were derived from normalized pixel intensity values and expressed in arbitrary units (a.u.).

For each specimen, the analysis was performed on a standardized surface area of equal size. Prior to parameter calculation, the following preprocessing steps were applied: normalization of height values, removal of edge artifacts, and centering of the height profile.

The study protocol was approved by the Bioethics Committee for Experimental and Clinical Research of the Educational and Scientific Medical Institute of Sumy State University (Protocol No. 1/05 dated May 1, 2025).

Results. The morphometric analysis of the surface microgeometry of dental hard tissues demonstrated consistent changes in enamel and dentin microrelief parameters depending on the applied preparation protocol (Figs. 1a–b, 2a–b).

The enamel microrelief parameters, assessed using Ra and SDq, showed a progressive increase from Group 1 to Group 4 (Figs. 1a, 1b).

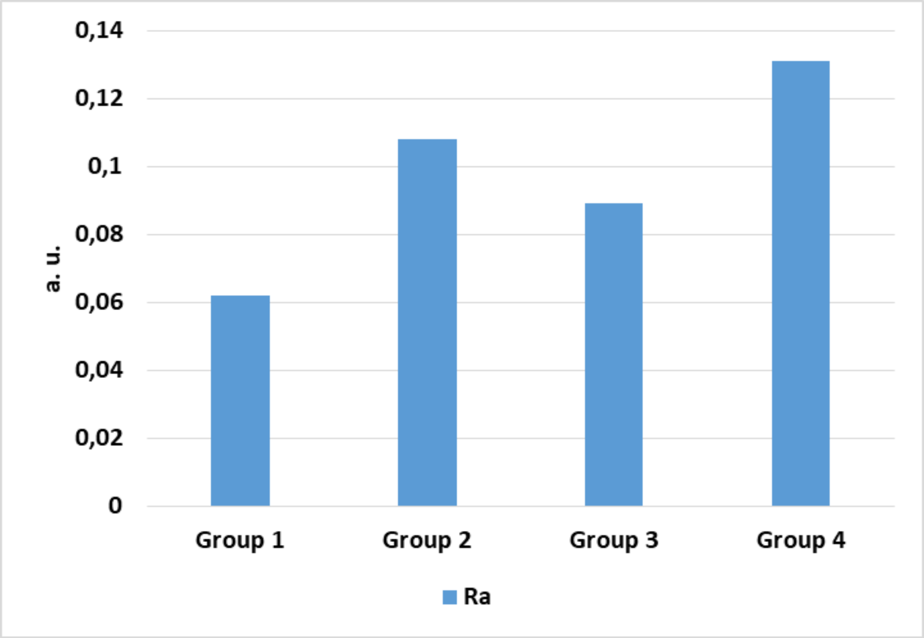

Fig. 1a. Enamel microrelief parameters (Ra) after different preparation methods

Note: Ra – arithmetic mean surface roughness (a.u.)

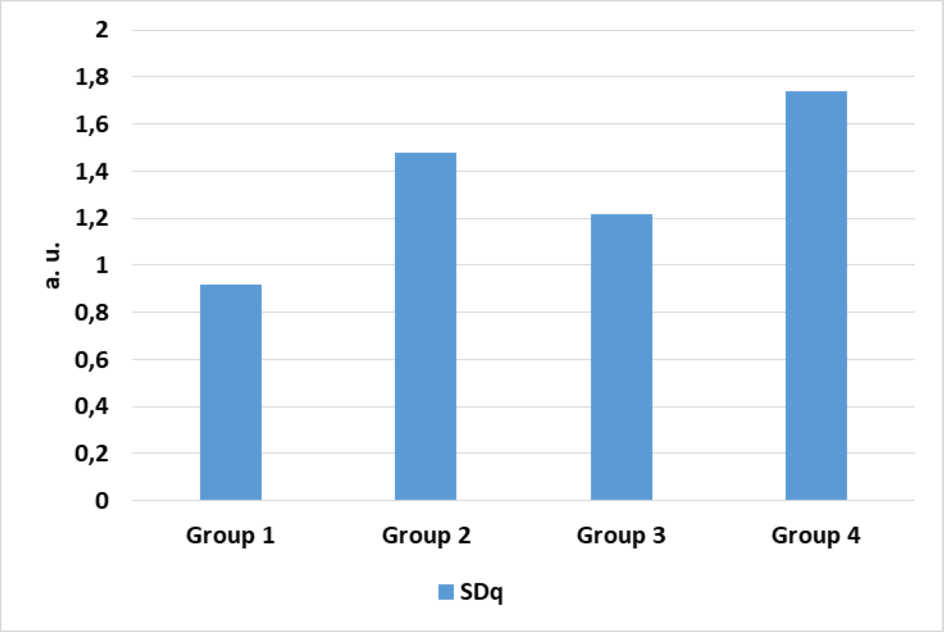

Fig. 1b. Enamel microrelief parameters (SDq) after different preparation methods

Note: SDq – root mean square surface gradient (microrelief intensity) (a.u.)

In Group 1 (rotary preparation without etching), the lowest values were observed for both the arithmetic mean surface roughness (Ra) and the root mean square surface gradient (SDq), corresponding to a relatively smooth enamel microrelief.

The application of acid etching after rotary preparation (Group 2) resulted in a pronounced increase in both parameters, indicating the formation of a more developed microrelief surface structure.

In Group 3 (air-abrasion without etching), the values of Ra and SDq also exceeded those of Group 1 but remained lower than in Group 2, reflecting the formation of a moderately expressed microrelief due to mechanical abrasive action.

The highest values of both parameters were recorded in Group 4 (air-abrasion combined with acid etching), indicating the formation of the most developed enamel surface microgeometry under the combined influence of mechanical and chemical factors.

The morphometric parameters of dentin surface microgeometry, assessed using Slope and P95, demonstrated a similar trend (Figs. 2a, 2b).

In Group 1, the lowest values were observed for both the mean surface slope (Slope) and the 95th percentile of microrelief amplitude (P95), corresponding to a less pronounced microrelief and a relatively limited opening of dentinal tubules.

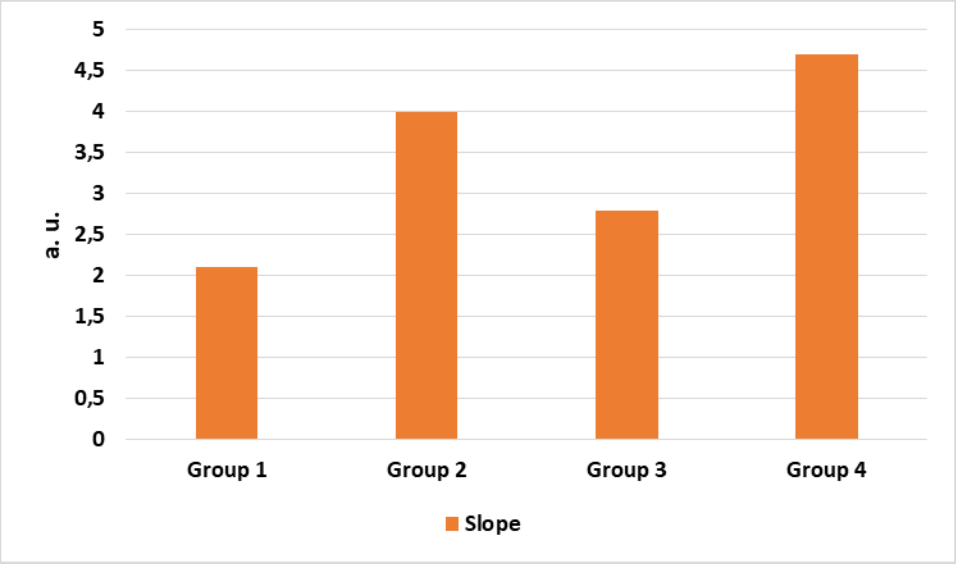

Fig. 2a. Dentin microrelief parameters (Slope) after different preparation methods

Note: Slope – mean surface slope (gradient) (a.u.)

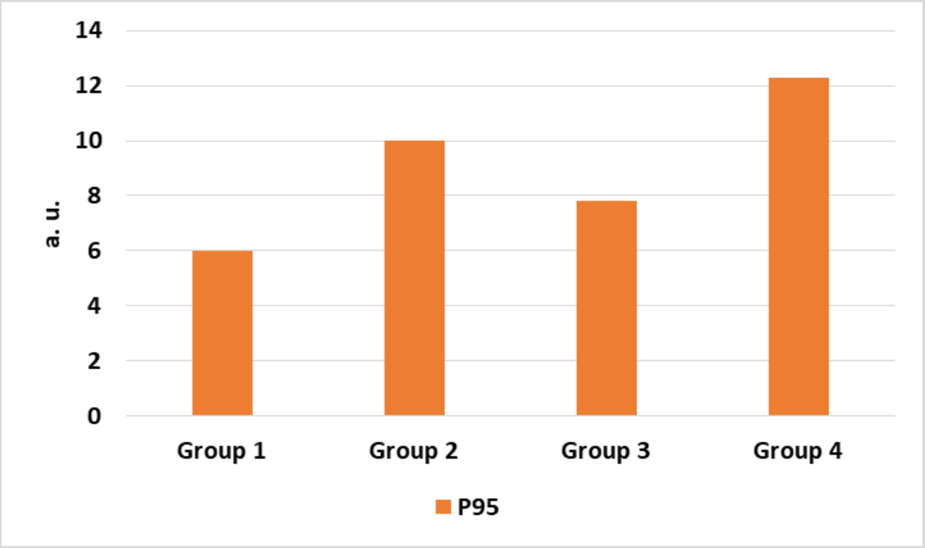

Fig. 2b. Dentin microrelief parameters (P95) after different preparation methods

Note: P95 – 95th percentile of microrelief amplitude (a.u.)

In Group 2 (rotary preparation with etching), both parameters increased markedly, indicating intensification of surface microgeometry and a greater degree of exposure of tubular structures.

Air-abrasion without etching (Group 3) resulted in a moderate increase in Slope and P95 compared with Group 1; however, these values remained lower than those in Group 2.

The highest values of both parameters were recorded in Group 4 (air-abrasion combined with acid etching), indicating the most pronounced microgeometric transformation of the dentin surface and the greatest degree of dentinal tubule opening.

Discussion. The results of the present study demonstrate a clear pattern in the influence of preparation method and acid etching on the formation of the microrelief of dental hard tissues. For both enamel and dentin, a progressive increase in surface microgeometry parameters was observed when moving from rotary preparation without etching to air-abrasion combined with acid etching.

The increase in Ra and SDq values following acid etching and air-abrasion reflects the formation of a more developed microporous enamel surface structure. This finding is consistent with established concepts of selective dissolution of prismatic and interprismatic enamel substance under acid etching, leading to the formation of a micromechanically retentive surface [9]. Air-abrasion preparation, in turn, creates microroughness through mechanical microchipping and surface erosion [10]. The combined action of these factors explains the maximal microrelief parameter values observed when air-abrasion is combined with acid etching.

In contrast to enamel, dentin has a more complex structural organization, including dentinal tubules, an organic matrix, and variable mineralization [11]. The present results showed that Slope and P95 values increased markedly with the use of acid etching and air-abrasion technology, indicating the formation of deeper and steeper microstructural features.

This effect is likely associated with the removal of the smear layer, opening of dentinal tubule orifices, and partial demineralization of peritubular dentin [12]. Air-abrasion additionally enhances these effects through mechanical cleaning and microerosion of the surface [1; 13].

Different morphometric parameters were used taking into account the differences in the structural organization of enamel and dentin. Despite their distinct histological structure, both tissues demonstrated a similar trend – an increase in microrelief parameters under the combined influence of mechanical and chemical treatment. This indicates the universality of the mechanisms responsible for the formation of a retentive microrelief for adhesive technologies.

At the same time, the magnitude of changes was more pronounced for dentin, which can be explained by its lower degree of mineralization and the presence of an organic matrix sensitive to acid conditioning.

An increase in surface microrelief parameters of dental hard tissues is directly associated with an enhanced potential for micromechanical adhesion of restorative materials. The obtained data allow the following practical conclusions to be drawn: acid etching is a critical step in the formation of an adhesive surface for both enamel and dentin; air-abrasion preparation provides a more developed surface microgeometry compared with conventional rotary instrumentation; and the combination of air-abrasion with acid etching creates the most favorable conditions for adhesion. These findings are consistent with previous studies demonstrating that surface microrelief is a key factor in establishing adhesive contact between dental hard tissues and composite materials [2].

At the same time, certain limitations of the study should be acknowledged. The obtained microrelief parameters are based on digital image analysis and do not include direct evaluation of adhesive bond strength. In addition, the results were obtained under laboratory (in vitro) conditions and do not account for biological factors present in the oral environment. Further research should be aimed at integrating morphometric surface analysis with mechanical testing of adhesive strength and long-term clinical observations.

Conclusions. It was established that the preparation method and the use of acid etching significantly influence the microgeometry parameters of dental hard tissues.

For enamel, a progressive increase in the arithmetic mean surface roughness (Ra) and the surface gradient (SDq) was observed in the following order: rotary preparation without etching, air-abrasion without etching, rotary preparation with etching, and air-abrasion combined with etching.

For dentin, a similar pattern was found: the values of mean surface slope (Slope) and the 95th percentile of microrelief amplitude (P95) were minimal after rotary preparation without etching and maximal when air-abrasion was combined with acid etching.

The combination of mechanical (air-abrasion) and chemical (acid etching) effects provides the formation of the most developed surface microgeometry of both enamel and dentin.

An increase in the microrelief parameters of dental hard tissues creates morphological prerequisites for enhanced micromechanical adhesion of restorative materials.

The obtained results substantiate the feasibility and clinical relevance of using air-abrasion preparation combined with acid etching as a promising approach for optimizing adhesive restorations.

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