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Surface roughness and morphology of dental nanocomposites polished by four different procedures evaluated by a multifractal approach

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ABSTRACT

The objective of this study was to determine the effect of different dental polishing methods on surface texture parameters of dental nanocomposites. The 3-D surface morphology was investigated by atomic force microscopy (AFM) and multifractal analysis. Two representative dental resin-based nanocomposites were investigated: a nanofilled and a nanohybrid composite. The samples were polished by two dental polishing protocols using multi-step and one-step system. Both protocols were then followed by diamond paste polishing. The 3-D surface roughness of samples was studied by AFM on square areas of topography on the $80 \times 80\ \mu m^2$ scanning area. The multifractal spectrum theory based on computational algorithms was applied for AFM data and multifractal spectra were calculated. The generalized dimension D_q and the singularity spectrum $f(\alpha)$ provided quantitative values that characterize the local scale properties of dental nanocomposites polished by four different dental polishing protocols at nanometer scale. The results showed that the larger the spectrum width $\Delta\alpha$ ($\Delta\alpha = \alpha_{max} - \alpha_{min}$) of the multifractal spectra $f(\alpha)$, the more non-uniform was the surface morphology. Also, the 3-D surface topography was described by statistical parameters, according to ISO 25178-2:2012. The 3-D surface of samples had a multifractal nature. Nanofilled composite had lower values of height parameters than nanohybrid composites, due to its composition. Multi-step polishing protocol created a better finished surface, for both tested materials, than one-step polishing protocol, even when it was followed by diamond paste polishing. Diamond paste polishing created smooth surface and reduced roughness of tested materials.

1. Introduction

Nanotechnology deals with the physical, chemical, and biological properties of structures and their components at nanoscale dimensions. Nanotechnology is based on the concept of creating functional structures by controlling atoms and molecules on a one-by-one basis [1].

Nanotechnology has a wide range of potential applications in various fields. It has already showed its influence on creation of contemporary dental restorative nanomaterials [2]. Dental polymer-based nanocomposites are the most commonly used nanomaterials in contemporary dentistry [3].

These oxide-nanoparticles containing materials are usually divided into two groups of materials: nanofilled and nanohybrid composites [4]. Nanofills are composites filled only by particles

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in nanometer-size range, while nanohybrids possess nanofillers together with micrometer particles (0.4–5 μm) in their composition [5]. Addition of nanoparticles aimed to improve these nanostructured materials in many of their properties: mechanical strength, dimensional stability during polymerization and thermal changes, water sorption and solubility, esthetic and optical properties, wear resistance, polish ability and polish retention during the usage [2,6,7]. In all of the engineering fields of application, not only the materials characteristics are important, but also a good quality of working tools, which enable the best possible materials processing conditions.

Recently, the most of a dental professional progress depends on the materials quality progress. Hence, professional criteria for quality of restoration are rising. It is considered that dental fillings roughness below approximately 0.2 μm is a satisfying property, which can prevent some of the most common bacteria species to retain on the restoration surface [8,9].

The purpose of a dental polishing procedure is also to produce a good esthetic appearance and a gloss of a surface; lower retention possibility for discoloration and staining; and lower wear rate [10,11]. However, dental professional treatment is usually determined by the amount of time consumed, and recently, many contemporary working tools on the market are created to enable quicker dental procedures by saving clinical chair-time [12–14].

Accordingly, new “one-step” or “single-step” working tools and protocols for a restoration polishing have been released for professional dental use [9,15]. Enabling a reduction of working time spent, these procedures are supposed to become more common, pushing the multi-step polishing protocol aside. Diamond paste polishers for intraoral use also appeared on the market, enabling a simplified procedure which can reduce chair-time, and create a good final treatment of a surface [16–18].

Now a question rises, how good the surface properties of final dental restoration processed by different polishing protocols and contemporary working tools available at dental market are.

There are several possible methods to characterize the morphology of 3-D complex microstructures [19–21]. Since fractal/multifractal geometry can describe complex morphologies, there is a trend to use fractal/multifractal analysis to quantify 3-D rough surfaces [19–21].

Euclidean geometry has two fundamental types of measurements: angle and distance that allow characterizing the regular, standard, geometric shapes. The natural shapes and many human artifacts are not regular geometric shapes and they can’t be represented properly by Euclidian geometry. Fractal geometry is a generalization of Euclidean geometry which allows fractal structures (fractals) to be quantitatively characterized in geometric terms [19].

A fractal is a class of complex geometric shapes exhibiting self-similarity in that small details of its structure viewed at any scale repeat elements of the overall pattern. Fractals are continuous but not differentiable geometric objects. A fractal has a fractal dimension that usually exceeds its topological dimension and may fall between the integers. The fractal dimension (D) of a surface (ranging between 2 and 3), as a quantifier of complexity, measure the degree of irregularity over multiple scales and determine how the fractal differs from Euclidean objects [19–21].

Fractal objects are either self-similar or self-affine. A self-similar object shows the same dimensions in the Z direction scale as those in the X and Y; whereas, for a self-affine object the fractal dimension of the vertical direction is different from the lateral directions [22,23]. The fractal dimension is a measure of global scaling property [20,21].

The fractal theory applied in surface science using fractal approach assumes that the surface spatial distribution can be uniquely characterized by a single fractal dimension. However, a single fractal dimension might not be sufficient to represent complex and heterogeneous behavior of surface spatial variations [20].

Multifractal theory can be considered as an extension of fractal theory and implies that a statistically self-similar measure can be represented as a combination of interwoven fractal dimensions with corresponding scaling exponents [19,20]. A multifractal structure demonstrates various self-similarities that can be described by a multifractal spectrum of dimensions and a singularity spectrum. The advantage of the multifractal approach is that the multifractal parameters can be independent of the size of the studied variable and does not require any assumption about the data following any specific distribution. Multifractality characterize the local scales properties of the object and quantify the distribution of the local singularities (local morphological multifractal exponents) [20,21].

Fractal and multifractal analyses are a collection of mathematical procedures used to determine fractal dimension (or any other fractal characteristic) or set of fractal dimensions (in the case of multifractals) with the smallest error [19].

Fractal and multifractal geometries were applied in different applications in several branches of dental practice [24–29]. In the subfield of dental materials, fractal and multifractal analyses have been applied for the quantitative description of the surfaces morphology [30–35].

The objective of this study was to examine the influence of multi-step dental polishing protocol on 3-D surface roughness of dental polymer-based nanocomposites, comparing it to the effect of single-step polishing procedure on these parameters, through multifractal analysis. The influence of diamond paste polishing following both of specified polishing procedures, was also investigated.

2. Materials and methods

2.1. Materials

Two contemporary dental resin-based nanocomposites were tested in this study: nanofilled (Filtek Ultimate Body, 3M ESPE), and nanohybrid composite (FZ550, 3M ESPE). Detailed information about materials used in the study is shown in Table 1 [36].

2.2. Procedure for preparing the specimens

Materials for testing were placed in cylindrical molds produced by a rapid prototyping technology. These filled molds were placed between two glass microscope slides and the materials for examination were polymerized through the glass using the dental LED light-curing unit by Dentsply (SmartLite® IQTM 2) in duration of 40 s to ensure good quality of polymerization. Then the specimens were released from the molds and polished by four dental polishing procedures: multi-step – MS (Super Snap, Shofu), multi-step followed by diamond paste polishing – MSD (DiamondDia, Shofu), one-step – OS (OneGloss, Shofu) and one-step followed by diamond paste polishing – OSD (see Fig. 1 and Table 2, for details).

The same dental clinician conducted all of the polishing procedures trying to simulate clinical conditions. The abrasive disks were used only for single polishing, each for 1 min, in dry or in slightly wet conditions, rotating 5000, 8000 or 10,000 revolutions per minute according to instructions for use. Two mutually perpendicular polishing directions were used during polishing. Detailed information about polishing protocols used in this study is shown in Table 2 [36].

2.3. Atomic force microscopy

Prepared specimens were tested by Veeco di CP-II Atomic Force Microscope. Contact mode with CONT20A-CP tips was used, with