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Mechanical properties of glass fiber-reinforced endodontic posts

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Abstract

Five types of posts from three different manufacturers (RTD, France, Carbotech, France and Ivoclar-Vivadent, Liechenstein) were subjected to three-point bending tests in order to obtain fatigue results, flexural strength and modulus. Transverse and longitudinal polished sections were examined by scanning electron microscopy and evaluated by computer-assisted image analysis. Physical parameters, including volume % of fibers, their dispersion index and coordination number, were calculated and correlated with mechanical properties. The weaker posts showed more fiber dispersion, higher resin contents, larger numbers of visible defects and reduced fatigue resistance. The flexural strength was inversely correlated with fiber diameter and the flexural modulus was weakly related to coordination number, volume % of fibers and dispersion index. The interfacial adhesion between the silica fibers and the resin matrix was observed to be of paramount importance.

Keywords: Composites; Endodontic posts; Glass fibers; Mechanical strength

1. Introduction

Wide acceptance of endodontic posts for dental root reconstructions has led to the development of new esthetic fiber posts. Practitioners have shifted from the original carbon fiber posts first described in 1990 [1] to more transparent posts reinforced with quartz, glass or silica–zirconium fibers. Different resins and manufacturing processes are used to produce fiber-reinforced posts, but unfortunately little information is available on these new materials. Previous investigations have focused on the mechanical properties [2–7], including fatigue resistance [8,9] and the influence of thermal cycling [10]. Grandini reported large variations in the response of fiber posts to a fatigue resistance test, but could not find any correlation with the observed structural characteristics [9]. Theoretically, the integrity of composite materials depends on the choice of proper matrix and fiber material combination as well as the geometry of the reinforcement and the interfacial strength and homogeneity of the final product [11,12]. Masticatory loads are transferred from the crown to the root through the core-post assembly. Endodontic posts with small diameter need high strength and modulus of elasticity to function properly in vivo [3].

In this work the in vitro flexural properties and fatigue resistance of different fiber post materials were studied and their structural characteristics observed by scanning electron microscopy (SEM) on transverse and longitudinal sections followed by computer-aided image analysis. The working hypothesis was that there exists a straightforward correlation between mechanical strength and fiber density in fiber-reinforced posts.

2. Materials and methods

2.1. Mechanical testing

Experimental posts of identical structure and composition as those in clinical use were specially made for this study by their respective manufacturers using their stan-

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dard technology. Their compositions according to their manufacturer's specifications are listed in Table 1. All posts were 2 mm in diameter and 20 mm long. Ten posts among each of the five types investigated were subjected to a three-point bending test. The three-point bending test was performed according to ISO 14125. It consists in positioning the sample on two points which define the span length of the test, and applying the load on a third point midway in the span. With reference to the standard, the span length should be 20 times the diameter of the post. The load was applied to posts with a loading angle of 90° and at a cross-head speed of 1 mm min^{-1}. All the posts were tested with a material testing machine (MTS, Eden Prairie, MN, USA). The load–deflection curves were recorded with PC software Testworks, v. 4.0. The fracture load was recorded and the flexural strength (σ) of the posts was computed using the following equation:

$$\sigma = 8\ F_{Max} l / \pi d^3,$$

where F_{Max} is the applied load (in Newtons) at the highest point of the load–deflection curve, d is the diameter of posts, and l is the span length. All tests were carried out at room temperature and humidity. The axial flexural modulus (E) for the posts was computed using the following equation:

$$E = S4l^3 / 3\pi d^4,$$

where F_{Max} is the applied load (in Newtons) at the highest point of the load–deflection curve, d is the diameter of posts (in mm), l is the span length (40 mm), $S = F/D$ is the stiffness (N m^{-1}) and D is the deflection corresponding to load F at a point in the straightline portion of the curve.

Ten posts from each group were tested in a fatigue machine (Procyon systems, Meylan, France). This device has a counter that measurers the number of cycles and stops when the specimen breaks. The load was applied perpendicularly to the long axis of the post at a frequency of 3 Hz. The load went from 25 to 100 N. The central loading anvil and the two supports had a 3 mm diameter and the distance between the two supports was 9 mm. Tests were voluntarily ended after 2 million cycles.

One-way analysis of variance (ANOVA) was computed to determine statistically significant differences at 5%. Multiple paired comparisons by the Tukey test were used to identify differences between pairs of groups. Multiple regression correlation coefficients R^2 were calculated as the ratio of the explained sum of squares divided by the total sum of squares proportional to the sample variance.

2.2. Scanning electron microscopy

Two posts of each type studied were used for SEM observations. Posts were embedded in methylmethacrylate resin inside 25 mm PTFE molds to obtain cylinders 6 mm high and 8 mm in diameter. The cylinders were cut perpendicularly to the long axis of the posts and polished with a MetaServe 3000 grinder (Buehler, Dardilly, France) using water-lubricated sandpaper following the sequence 240, 600, 1200 grit size and finishing with 6 μm diameter diamond paste. The same sequence was applied to longitudinal sections. All posts were examined at the same working distance and magnification. The broken posts were observed without polishing but following 60 s platinum sputtering with a model JFC 2300 HR sputter coater (JEOL, Tokyo, Japan). Surface topography was examined using a JEOL JSM 6700 F scanning electron microscope.

2.3. Image analysis

ImageJ software (Wayne Rasband, National Institute of Mental Health, Bethesda, MD, USA) was used to analyze the SEM micrographs. The mean diameters of the fibers and the standard deviations were calculated from measurements on more than 20 individual fibers from a randomly selected micrograph. The volume occupied by fibers was determined by summing the surface occupied by all the fibers and dividing by the total surface of the micrograph. The coordination number was obtained by considering the distance of a neighboring fiber to a central fiber for the six closest cases. Twelve measurements were averaged in order to plot distance vs. closest neighbor number. The maximum coordination number was derived where the distance rose above two standard deviations from the mean diameter of the fibers. In the ideal case where all fibers would be identical, the maximum coordination number would be 6. Lower numbers mean fewer fibers in close contact. The dispersion index evaluates the homogeneity of the distribution of fibers. This index was calculated by dividing the average distance between the centers of the six closest fibers to a central fiber by the average fiber diameter. The ideal case with the lowest possible dispersion index of 1 would mean the central fibers would have six touching surrounding

Table 1
Compositions of the experimental fiber posts provided by manufacturers.

Experimental posts ($n = 10$)	Fiber (% in vol)	Matrix (% in vol)	Manufacturer
Aestheti-Plus	Quartz (60%)	Epoxy (40%)	RTD, France
Light-Post	Quartz (59%)	Epoxy (41%)	RTD, France
Snowpost	Zircon rich glass (60%)	Epoxy (40%)	Carbotech, France
Snowlight	Zircon rich glass (64%)	Vinyl-polyestermethacrylate (36%)	Carbotech, France
FRC Postec	Glass (53%)	Urethanedimethacrylate (47%)	Ivoclar-Vivadent, Liechenstein