

EVALUATION OF FATIGUE RESISTANCE OF POST-AND-CORE SYSTEMS

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Abstract: *The aim of the present study was to evaluate the fatigue resistance of the teeth restored with different posts (carbon fibre post, zirconium post, titanium post) when subjected to a cyclic loading test. The teeth were intermittently loaded at an angle of 45 degrees to the long axis of the tooth, at a frequency of 1,3 loads per second until failure occur. The results show that the survival rate of the teeth reconstructed with carbon fibre post was higher than that of the teeth reconstructed with titanium and zirconium posts. In conclusion, the post reinforced with fibres reduces to a minimum the risk of root fractures of teeth restored with post and core systems.*

Key words: *post-and-core, fiber, zirconium, fatigue resistance*



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1. Introduction

The post-and-core systems represent an important issue in dental practice because they are the only chance to save the non-vital teeth with large coronal destructions and to avoid their extraction. The choice of an appropriate restoration for endodontically treated teeth is guided by strength and esthetics. Treatment failures caused by mechanical deficiencies of post and cores represent a problem of clinical significance and justify the researches orientated through the increasing of their performances and clinical longevity.

An “ideal” post-and-core system should fulfill a lot of requirements: the physical and mechanical characteristics (linear thermal expansion, Young modulus, Poisson ratio) and chemical (corrosion resistance) of post material, core material and crown material to be as close as possible with those of dental tissues; the post and the core must form a complex that behaves like a block under masticator forces; the construction’s rigidity to withstand the masticator forces; the post’s shape and dimensions must provide the maximum retention; to require minimal removal of tooth structures to provide resistance to fracture of the root; to have the same color with natural teeth; to have great corrosion resistance for eliminate the risk of corrosion between post, core and luting cement; to have excellent biocompatibility

The stresses distribution during masticatory function in endodontically treated teeth reconstructed with post-and-core system can cause root fractures, especially in anterior teeth. The studies performed *in vivo* (on the patient) and *in vitro* (in laboratory) showed that fracture resistance and clinical longevity of these teeth are significantly influenced by the **post characteristics**, such as **design, dimensions and material**.

Regarding the post material, controversy exists between specialists about the best choice for the longevity of the restoration: **metallic** post or **non-metallic** post?

As a result of the increasing demand from patients and clinicians for esthetic replications of the natural dentition, in the latest years there have been developed new techniques and materials for post and core systems: ceramic posts (cast or prefabricated), and composite posts reinforced with different kind of fibres: carbon, glass, quartz, silica. These new type of posts were introduced in order to replace the metallic posts which have a lot of disadvantages: poor biocompatibility (the migration of metallic ions from the post’s alloy in the oral tissues is well known), poor aesthetics (light transmission is impeded by metallic posts), high Young modulus that increase the risk of catastrophic (irreversible) root fractures followed by the tooth’s extraction (Rosentrit et al., 2000).

Ceramic posts offer mechanical properties very close to those of dental alloys and, in addition, excellent aesthetics and biocompatibility, because they eliminate the risk of corrosion, bimetallicism and allergic reactions and allow light transmission through the post structure (Mannocci et al., 1999). Ceramic posts are made of zirconium dioxide partially stabilized by the addition of yttrium (Y_2O_3) (Hochman & Zalkind, 1999).

The usage of fibre reinforced post is based on harmony between the Young modulus of the dentinal root, the post, the luting cement and the composite core

material, and on the chemical bonding between them. This result in a system that behaves like a mono-block under the masticatory forces (Bateman et al., 2003).

Even the fibre reinforced posts have many advantages: proven biocompatibility, non corrosive, an equilibrate transmission of occlusal forces, no interferences with modern techniques of investigation (RMN, scanner), easily removable to permit endodontic re-treatment, their clinical reliability must be demonstrate by passing time. Even this “in vivo” tests are the most reliable, they have the disadvantage that are time consuming because are requesting long clinical observation periods.

To overcome the difficulties of clinical studies, numerous “in vitro” (in laboratory) methods were developed to address specific properties of post and core restorations. Most of them have been focused on the determination of the mechanical resistance to a simple stress, being static tests (Maccari et al., 2003). But the experience proved that the fatigue of the restorative materials is a primordial factor in clinical failures. The **fatigue resistance tests** represent an essential research instrument because they simulate the repetitive cyclic pattern of the occlusal forces and replace the clinical tests that are time consuming and thus contribute to decrease of clinical evaluation costs and time. (Heydecke et al., 2002).

The purpose of this paper was to evaluate and to compare the fatigue resistance of teeth restored with different types of post (carbon fiber post, ceramic post and titanium post) when subjected to a cyclic loading test.

2. Material and method

2.1 Devices and equipment

The mechanical fatigue tests were performed with a machine special designed and realized for this purpose (Figure 1), based on the transmission mechanism of moving, that can apply different and cyclic forces on the teeth reconstructed with post and core systems, simulating the physiological conditions.

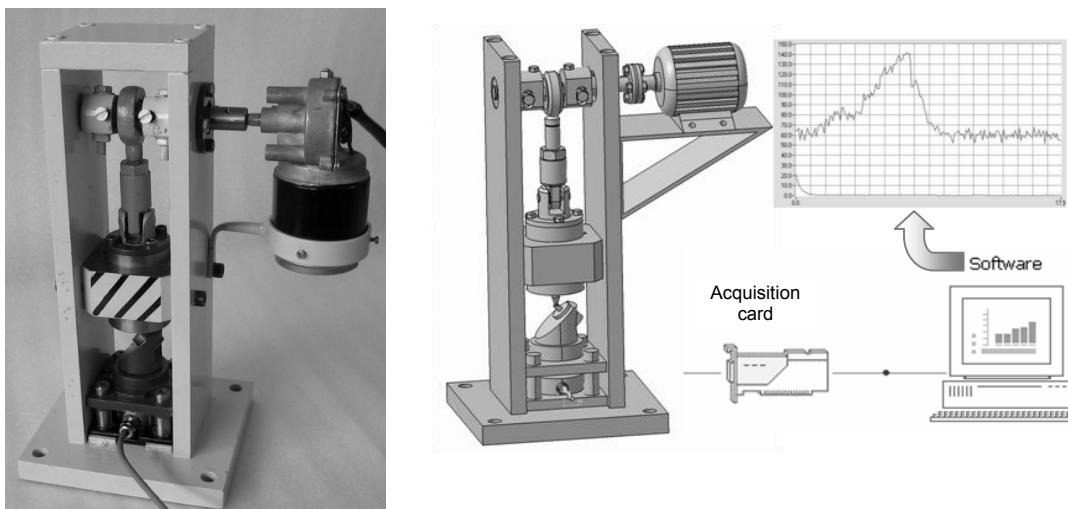


Fig. 1. The testing device and the data acquisition system: photo (left) schematic drawing (right)

Measurement system assisted by computer consists of load cell with power supply, signal conditioner, data acquisition (DAQ) device and virtual instrument software (Figure 1).

- **Load cell** type Gefran Cu1KM – Italy with nominal load of 10kN and 350Ωm strain gauges in full bridge configuration with 0.2% accuracy is connected to a stabilized 10VDC power supply;
- **Signal Conditioner** type SC 2043 SG National Instruments - USA provides both the nominal excitation voltage for load cell and the router of the conditioned strain gauge bridge signal to DAQ card;
- **DAQ Card** type PCI 6023E National Instruments - USA takes the load cell signal (with a sampling rate of 200 kS/s) via signal conditioner and displays both the graphic and numerical evolution in real time;
- **Virtual instrument VI** is the LabView application which provides the communication between DAQ device and the computer.
- **Rectilinear displacement transducer** Gefran PY2-50, with stroke up to 50mm, for displacement speed up to 10m/s and independent linearity 0,1%.

2.2 Establishing the test features

The second step in developing a fatigue test, after the construction of the fatigue device is to establish the level of load test and the precise moment of a real failure.

Due to the composition and structure, dental tissues are brittle materials. Subjected to stresses above their elastic limit, the teeth have a brittle behaviour, characterized by an increased rate of crack propagation, without any visible strain before failure.

The factors that control brittle fracture revolve around the energy that must be provided to extend the fracture by a microscopic distance and the amount of elastic strain energy that is concurrently made available by that microscopic crack extension. If the elastic strain energy being released exceeds the energy required for crack extension then we have spontaneous fracture.

The crack stops growing either when it reaches the end of the part (the part breaks), or the energy required for crack extension exceeds the strain energy being released by that same crack extension and we have crack arrest. This happens, for example when a crack grows through an area under tensile stress and then stops when it runs into an area of stress that is reduced or compressive.

Fracture mechanism described by Griffith's theory explains the failure of the brittle materials using methods of analytical solid mechanics to calculate the driving force on a crack and those of experimental solid mechanics to characterize the material's resistance to fracture. Griffith suggested that the low fracture strength observed in experiments, as well as the size-dependence of strength, was due to the presence of microscopic flaws in the bulk material. The growth of a crack requires the creation of two new surfaces and hence an increase in the surface energy.

For the fatigue test procedure it is very important to know when a real crack occurs? And by which means we can precisely determine that?! The crack relaxes the stress and hence reduces the elastic energy near the crack faces. In other words, crack

occurs when the free energy attains when the free energy attains a peak value at a critical crack length, beyond which the free energy decreases by increasing the crack length, i.e. by causing fracture. For the test, the corresponding moment of the cracking is the M point on the graph load vs. time, see Figure 2.

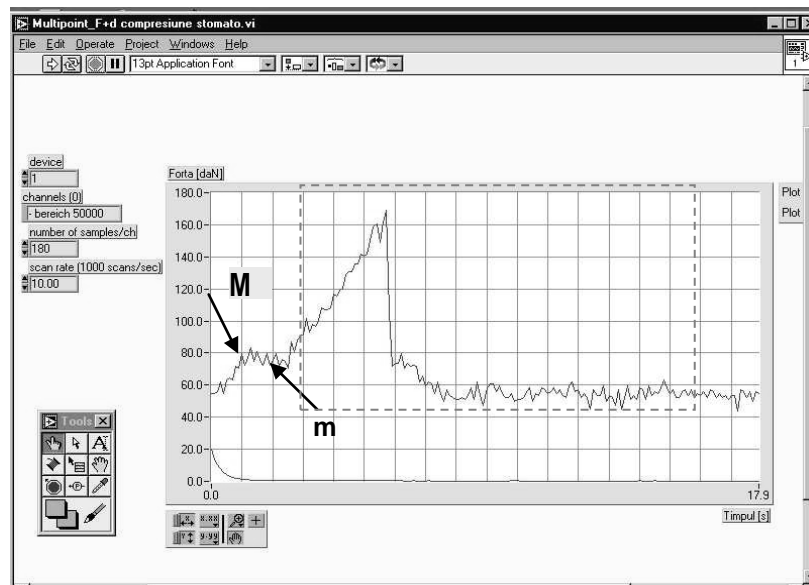


Fig. 2. The representative graph load vs. time for a brittle material with crack propagation

After the fracture, which it takes place in 10^{-2} - 10^{-3} s, the load drops down (*m* point on the graph). The specimen doesn't lose immediately its macroscopic integrity even the fracture is mechanically present. The unbroken segments still hold it together and the forces continuously increase until the catastrophic failure occurs. By smoothing the data, in Figure 3 we see more clearly all the mentioned changes in the monotony of forces values.

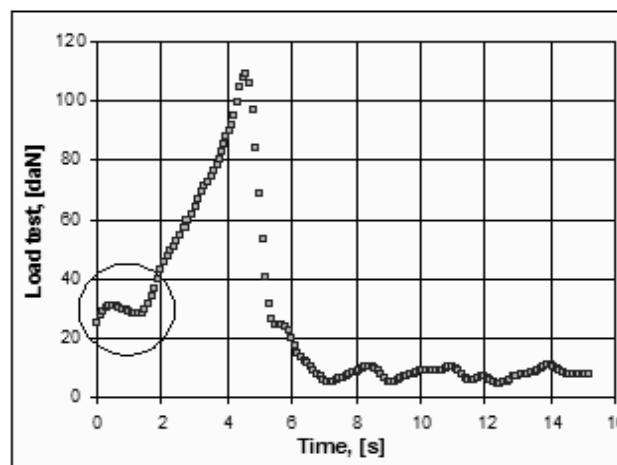


Fig. 3. Changes of the monotony of load on smooth graph load vs. time

So, when the load drops down for an imposed difference between forces values, the system stops and the digital enumerator indicates the number of cycles up to the failure.

2.3 Preparing of the samples for the test

For this experiment we used forty human maxillary incisors. To create a common base for comparison, teeth were selected on dimensional requirements (apex-cemento-enamel junction = 11÷13mm, cervical diameter = 6÷7,5mm), lack of decay, fissures, cracks, abrasion and restorations. The teeth were endodontically treated and then randomly divided into three experimental groups and one control group:

- group C – teeth restored with prefabricated carbon fibre reinforced posts
- group Z– teeth restored with prefabricated zirconium posts
- group T – teeth restored with prefabricated titanium posts
- group M (control) – endodontically treated teeth but with no posts

The crowns of the teeth from control group (M) were covered with cast metallic crowns. In experimental groups (C, Z and T) the anatomic crowns of the teeth were sectioned perpendicular to the long axis, 2mm above the cemento-enamel junction, under continuous water cooling, and then the root canals were prepared for the posts placement. The root canal filling material (gutta-percha) was removed from the roots leaving only 3 mm of it in the apical portion to ensure the apical seal of the endodontic space. The burs used to enlarge the root canals for the post hole preparation are included in the same kit with the posts, provided by the same producer, because they must have the same size and shape with the post to ensure optimal adaptation (Sorensen & Engelman, 1990).

The posts were cemented with dual-cure resin cement (Panavia F). The core build-up was performed with a light curing composite resin, applied and cured step by step until yield an abutment height of 6mm measured from cemento-enamel junction.

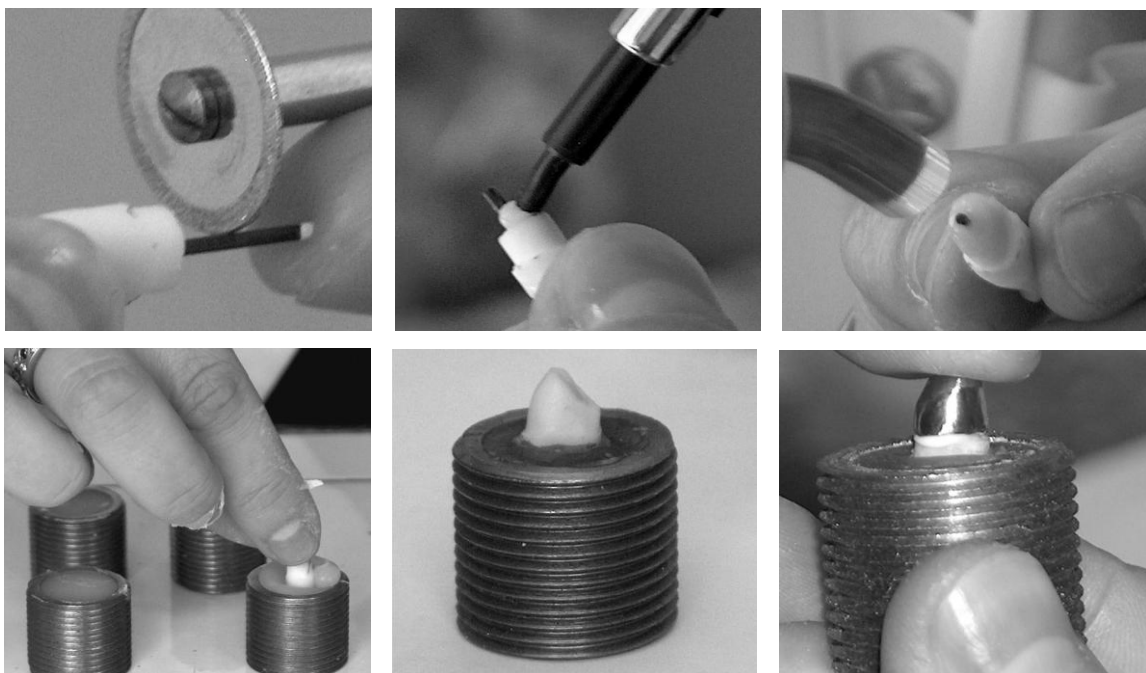


Fig. 4. Steps of preparing the samples

For the mechanical test, the teeth were mounted in stainless steel cylinders filled with self-polymerizing resin. In order to simulate the periodontal ligament, a thin layer of silicone (0.2 mm) was applied along to the root surfaces, to give stress distributions as near to clinical situation as possible. All teeth were covered with cast metallic crowns.

On the palatal surface of each metal crown, right above the cingulum, a 0.3 mm deep and 1mm-wide notch was made, in order to place there the compressive load during the test. The load was applied using a chisel-shaped steel pin, corresponding to the shape and dimension of the incisal edge of a lower incisor (Figure 5).

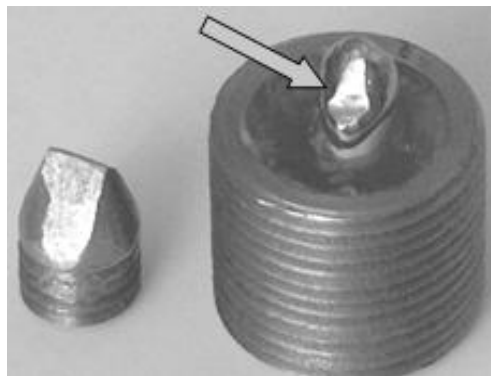


Fig. 5. The tooth mounted in acrylic block and the chisel-shape steel pin

2.4 Experimental fatigue tests of post and core systems

Each test specimen was intermittently loaded to a maximum level of 25 daN at an angle of 45 degrees to the long axis of the tooth (Figure 6), at a frequency of 1.3 Hz, until failure. The load was automatically discontinued if the sample failed or the testing device was stopped after 400 000 cyclic loads if no failure had occurred.

Root fractures, post fractures and post and crown decementation were considered causes of failure. The fractures were classified *restorable* if were located in the cervical third of the root and *catastrophic* if were located below. The survival rates of the groups were statistically compared with a Kaplan-Meier analysis.

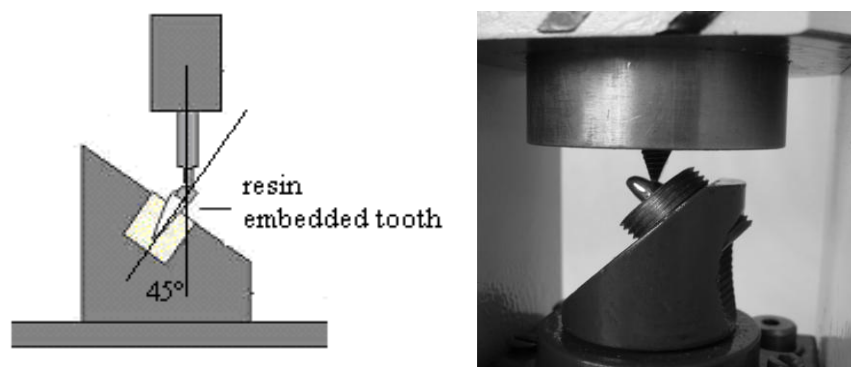


Fig. 6. The sample in the testing device: schematic drawing (left), photo (right)

3. Results

The results obtained after 400.000 impacts are shown in Table 1. Only one

fracture and one crack were observed in the control group (teeth with no post) and three fractures in carbon fibers group, while in zirconium and titanium groups were recorded six fractures in each group.

Legend ⊗ - fracture; ⊙ - intact; ▲ - crack

M (control)	Z (zirconium)	C (carbon)	T (titanium)
92.794 ⊗	26.171 ⊗	251.123 ⊗	18.763 ⊗
400.000 ▲	28.419 ⊗	258.434 ⊗	81.109 ⊗
> 400.000 ⊙	149.762 ⊗	262.257 ⊗	90.981 ⊗
> 400.000 ⊙	182.143 ⊗	> 400.000 ⊙	95.012 ⊗
> 400.000 ⊙	241.112 ⊗	> 400.000 ⊙	101.448 ⊗
> 400.000 ⊙	272.018 ⊗	> 400.000 ⊙	117.674 ⊗
> 400.000 ⊙	> 400.000 ⊙	> 400.000 ⊙	> 400.000 ⊙
> 400.000 ⊙	> 400.000 ⊙	> 400.000 ⊙	> 400.000 ⊙
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Tab. 1. The results after 400.000 cyclic loads

There were recorded three modes of fracture: **cervical** (reparable), **vertical**, and **complex** (cervical & vertical) root fracture (catastrophic, irreparable)(Figure 7). The fracture recorded in control group was cervical. In group C were recorded two cervical fractures and one vertical fracture. In group Z were recorded one cervical, two vertical and three complex fractures, and in group T were recorded two cervical and four complex fractures (in one case was recorded a bent titanium post). So, metal posts have caused a bigger number of irreparable root fractures, while the non-metallic posts produced in most cases reparable root fractures.

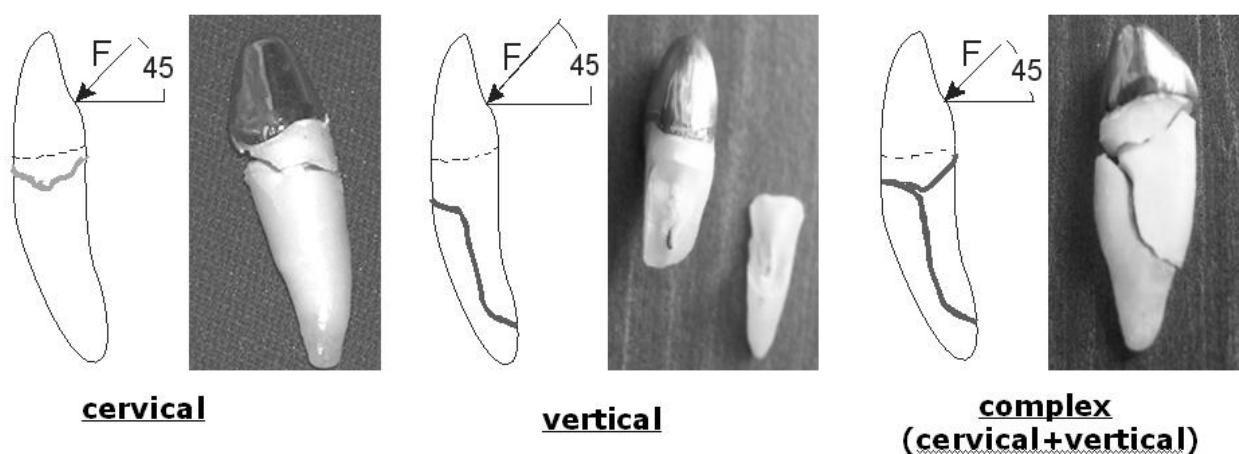


Fig. 7. The modes of failures recorded

The Kaplan-Meier analysis (Figure 8) showed that the survival rates recorded in the experimental groups (C, Z and T) were lower than that of the control group (M). The differences between the experimental groups were significant, the teeth reconstructed with posts reinforced with carbon fibers had a higher survival rates than

the teeth reconstructed with titanium and zirconium posts.

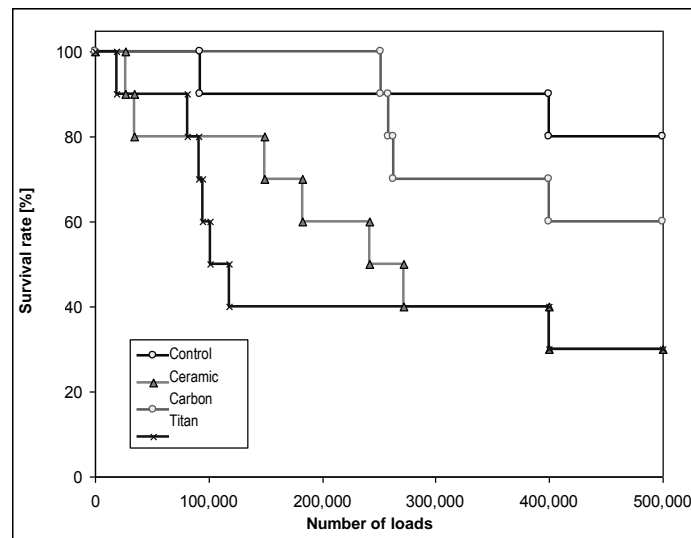


Fig. 8. Kaplan Meier curves of the experimental groups

4. Discussion

The results of this study were based on a simulation of clinical parameters, and the procedures were adopted from published recommendations on simulation of the clinical parameters of load, cycle frequency and load angle.

With rigid post systems fractures commonly occur in the apical half of the root. The results obtained can be explained due the high stiffness of the titanium and ceramic posts. It has been reported that the rigid reconstructions are unable to absorb stress and are therefore susceptible to failure (Sidoli et al., 1997, Mannocci et al., 1999, Butz et al., 2001, Strub et al., 2001). Thus, they produce the greatest stress concentration at the post-dental root interface, this behavior explaining the high frequency of the vertical root fractures recorded both in vitro (in laboratory) and in vivo (clinically).

Teeth reconstructed with fiber reinforced posts exhibit a higher fatigue resistance than teeth reconstructed with rigid posts (titanium or zirconia posts). It has been advocated that the modulus of elasticity of a post should be similar to that of the root dentin to distribute applied forces evenly along the length of the post (Assif et al., 1993, Duret et al., 1990). Because of their Young's modulus (21 GPa – on average), which is closer to dentin (18 GPa) and lower than that of zirconia and titanium posts, the non-metallic posts made from resin composite reinforced with fibers have a protective effect on the dental supporting tissues, the mode of failure recorded being more favorable to the root when compared with the metallic posts.

One shortcoming of the present study is that we simulated the clinical parameters of load value, cycle frequency, load angle and presence of periodontal ligament, but without the moisture and the temperature of the oral environment.

Even the results of the in vitro studies are promising, clinical trials are necessary to validate these observations.

5. Conclusions

Post material has a significant effect on the fatigue resistance of the endodontically treated teeth.

Fiber reinforced posts reduce the risk of root fracture and are the best choice in reconstruction of the endodontically treated teeth. Knowing the advantages and disadvantages of different types of post, the dentist will be able to avoid a post that predispose to irreparable tooth fractures.

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