

Do thermoplastic materials improve the obturation of the root canal? Bibliographic review of the different techniques available in the market

Abstract

The root canal has a complex anatomy with irregularities, isthmuses and lateral channels among others, which contain bacteria and necrotic tissues.¹ The objectives of endodontic treatment are the proper cleaning and shaping of the duct system and its complete filling using an inert material with dimensional stability that allows us to seal and eliminate all communication channels that it has with the periodontium. The guttapercha is the most commonly used obturation material. Its physical properties allow the realization of different sealing techniques.² Although the lateral condensation technique of gutta-percha is one of the most used in endodontics, its ability to correctly reproduce the surface of the canal as well as to achieve a hermetic and peripheral seal has been questioned.³ Currently, there are different techniques to introduce such material into the duct. Techniques using thermoplasticized gutta-percha have become popular over time, although this is not without the existence of alternatives to thermoplastic materials such as Resilon.⁴

Keywords: vertical warm, root canal filing, thermoplastic injection; lateral condensation; obtura II; thermoplastic obturation techniques

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Material and methodology

For the preparation of this review work, the evidence published in the main journals of the sector was consulted, using a reference search engine such as PubMed, resulting in more than 1055 articles, which after applying the different inclusion and exclusion criteria, as a publication not greater than 10 years, index of impact 1 - 2 and the key words cited, yields a total of 65 articles, of which 15 were excluded due to methodological, technical and / or statistical errors, using therefore only 50 articles that respond to the typology of systematic reviews, clinical trials and clinical cases.

Introduction

The objective of the endodontic treatment is the complete obturation of the duct system after an adequate cleaning and conformation of the same. The conformation of the duct system allows a more effective disinfection by creating a reservoir for irrigation and medication, while creating space for the filling material. The ideal sealing material should ensure a hermetic seal of both the apical and coronal portions, adapting to the canal walls everywhere. Incomplete obturation of the canal causes the failure of the endodontic treatment.¹⁻⁴ The root canals are provided with accessory and lateral channels, bag bottoms and communications between different conduits. Some of these areas are difficult to seal using traditional techniques. The lateral filling technique has been the most widely used.³ However, with this method many irregularities occur in the final mass of the gutta-percha as well as difficulty in reproducing some channels and existing anfractuosités. In order to eliminate some of these problems, the technique of vertical condensation of tempered gutta-percha was described. From here, new methods were introduced that employ thermoplasticized gutta-percha at high or low temperature. Different studies have shown that these techniques achieve a better seal. The methods of thermoplasticized gutta-percha manage to reproduce the internal anatomy of the duct

better than the lateral condensation technique, obtaining better results in hermetic sealing. Even with great advances in endodontic technology such as rotary Ni - Ti instruments and irrigation systems, it is not possible to clean and shape each irregularity and lateral duct that appears in the root canal.

Thermoplasticity concept: advantages and disadvantages

The ideal filling material must meet a series of indispensable requirements: non-irritating, dimensional stability, absence of toxicity, radiopacity, easily manipulated, insoluble in oral fluids and the periapice itself, having good adaptation to the walls of the root canals, local biocompatibility and general, among others.⁶ Historically, the guttapercha has been the material of choice in all the techniques and before almost 100% of the treatments. It is interesting because it is one of the oldest dental materials, pseudonatural and with little evidence of allergies, incompatibilities and at a reasonable cost.⁶ In fact, its origin is believed was in 1656, by the hand of an Englishman named John Trandescant, who referred to as a material that could be heated in hot water and acquire different forms. Although it would not be until Dr. Asa Hill who finally introduced its use in dentistry.⁷ It is obtained from the sap of autochthonous trees of Malaysia, Indonesia and Brazil. In 1942, Dr. Bunn, determined that the crystalline phase of gutta-percha could exist in two forms: alpha phase and beta phase. The alpha phase is the natural form, coming directly from the tree. If it is heated above 65°, it melts and changes to an amorphous form. If the amorphous material cools very slowly (0.5°C/hour), it recrystallizes in the alpha phase, but, if instead, the amorphous material cools rapidly, it recrystallizes in the beta phase.⁸⁻¹⁰ It is the beta phase that is used in commercial preparations of dental gutta-percha for endodontic use.¹⁰⁻¹²

By weight, this material contains only 20% gutta-percha. The zinc oxide comprises approximately 75% and the rest of the materials are

a combination of metal sulphates (to give it radiopacity) accompanied by waxes and resins. The exact percentages of each brand are usually secret but, generalizing, usually consist of a quarter organic (gutta-percha, resin and waxes) and three quarters inorganic (zinc oxide, metal sulfates, among others).¹⁰⁻¹² The gutta-percha cannot hermetically seal a conduit by itself as a solid material that is devoid of its own adhesive properties, therefore it will require a sealant that will obliterate the interface between the conduit walls and the introduced gutta-percha, the sealing agent or cement.¹³ The interface or sealing agent must comply with the same fundamental properties as the gutta-percha itself. For this reason, a new material of the family of composites was recently introduced for the obturation of the root canals. It was developed with the aim of improving both the apical and the coronal seal. In this way, even resin sealants reinforced with glass ionomer have been developed for the bacteriostatic and preventive properties involved in the continuous and prolonged release of fluorine. The composite resins have biodegradable polymer matrices and filling of bioactive ceramics that are usually used in the field of medicine and, especially, of dentistry.¹⁴⁻¹⁷ There are therefore many combinations poetic ceramics. The proportions are usually controlled for biocompatibility, water absorption, degree of degradation and mechanical properties, making these materials can be used in a wide range of medical, dental and endodontic applications.¹⁶

Alternatives to gutta-percha: viability in the short and medium term

One of the alternatives, with better rate of result and predictability in the medium and long term is the resin. It represents an endodontic material based on a synthetic thermoplastic polymer as a drastic alternative to gutta-percha, in composition and behavior contains bioactive glass and radiopacifiers. It has the same handling and same forms of presentation as gutta-percha. For endodontic treatment, it must be dissolved with various solvents such as chloroform or, softened with heat. The assembly of the Resilon and its sealant (Epiphany Root Canal Sealant) joins the dentin to form a monoblock.¹⁴ Epiphany sealant is a dual-curing composite resin sealant. It is available in the conical shape (0.02-0.04 and 0.06) and in pellet form for use in hot compaction techniques. When this material is used, a bond is formed with the dentinal wall making the filling resistant to the penetration of bacteria and, in addition, increases the resistance of the tooth to the fracture. The resilon can also be softened by applying heat in the same systems as the thermoplasticized gutta-percha.¹⁵⁻²² It is true that the resilon shows a thermoplasticity similar to gutta-percha with a similar ability to seal the lateral ducts and depressions present in the root canals according to most of the published evidence.²⁰ In fact, the effectiveness of the vertical condensation technique, which will be discussed later, depends on the thermoplasticizing capacity of the material used. Therefore they are fully indicated for this type of technique.¹⁹ The resilon showed a better ability to seal or seal the lateral ducts with respect to other materials, especially in the apical third of the root. The resilon together with its Epiphany sealer allows a better apical seal than coronal.²¹ Some authors claim that the thermoplasticity of the resilon is higher than that of conventional thermoplastic gutta-percha.²³ This capacity is attributed to the addition of polycaprolactone to the resilon, whose melting point is 60°C, making it suitable for thermoplastic sealing techniques. The gutta-percha cones are composed of barium sulfate, zinc oxide, wax, resin and gutta-percha, but the proportions are not constant. The percentage of inorganic components in the commercialized gutta-percha formulation can affect its thermal properties. The best flow

(flow) is attributed to those cones that contain higher percentages of gutta-percha in its formulation.²⁴⁻²⁷

Ideal sealing agents before thermoplastic technique

To achieve a perfect duct seal, a sealant is required next to the sealing material. Because of this, the sealant has as much or more importance than the core material.^{28,29} Currently the most accepted method for sealing the ducts that have been previously prepared includes a core of solid or semi-solid material, such as gutta-percha and a duct sealer. It has been shown that gutta-percha has no adhesion to dentin regardless of the filling technique we have used. Therefore, sealants are used as bonding agents and as a lubricant to aid the sliding of the gutta-percha cones and to seal accessory conduits. Many types of sealants have been tested according to their ability to produce a good seal in relation to their satisfactory results, such as Ah 26, Procosol, Zinc-Eugenol sealers, sealers based on Calcium Hydroxide etc.³⁰⁻³⁵

Many conduit filling techniques have been described with gutta-percha and sealants, and techniques using thermoplasticized gutta-percha have increased in the last decade.³¹ Most research has suggested that these techniques of thermoplasticized gutta-percha filling are more successful if a sealant is used, always, regardless of the type of sealant, its composition or state.³² The properties that a good duct sealer must have been listed in many cases and the ability of several of them to find one that meets all of them has been studied. The main objective is to achieve a hermetic seal, said property seems to be related to physical characteristics such as flow, solubility, working time, compression force, radiopacity and adhesiveness.³³ A study showed that there is a significant relationship between the thickness of the film and the sealing capacity: it should be expected that a lower thickness, better moisten the surface than a greater thickness and this will cause a better seal, even though the evidence does not show statistically significant data that speak of one material better than another.³⁴ The sealant component should be kept minimal due mainly to its dimensional instability and solubility over time.³⁵

Different sealing techniques based on thermoplastic materials

The lateral condensation technique of gutta-percha is one of the most commonly used in endodontics. Despite this, its capacity to reproduce the internal surface of the canal has been questioned: empty spaces, the incomplete fusion of gutta-percha cones or the lack of adaptation to the surface.³⁶ From the generalization of the technique of vertical compaction of gutta-percha (Schindler 1967) a variety of obturation techniques using thermoplasticized gutta-percha were developed. These seek to create a customized obturation for each root canal, which generates a three-dimensional obturation that accompanies its anatomy. These techniques are indicated in particular for the filling of large ducts, with irregularities in their walls, isthmuses, internal resorption, etc.³⁷⁻⁴⁰ The development of technological advances and the engineering of dental materials, new thermoplasticized gutta-percha systems have been introduced by different manufacturers together with new instruments that allow the use of different forms of gutta-percha, improve the applications and clinical results, especially in the case of irregularities Anatomical Where until only a few years ago, only silver cones could still be used, due to their great malleability.³⁸ They are most commonly used in conjunction with a vertical obturation technique to fill the middle and coronal third of the ducts.³⁹ This is so, that as in all or almost all

branches of dentistry, there is a great tangle of techniques, materials, instruments, advantages and risks etc, so we have simplified their analysis with the following classification:

1. Thermomechanical techniques¹¹⁻⁴³
2. Thermal techniques
 - a. Injectable techniques
 - b. Non-injectable techniques

Thermo mechanical techniques

McSpadden technique: in the Thermo mechanical techniques the gutta-percha is softened by the heat produced by the friction of special instruments called compactors, which are rotated at low speed in the root canal. These compactors are manufactured in stainless steel, have a design similar to that of a Hedström file but with the reversed cutting turns. They are marketed in sizes from 25 to 80, with lengths between 21 to 25mm. In this technique, after placing the sealing agent on the dentinal walls, the main cone is correctly positioned, selected in the usual way. The compactor to be used must enter without exaggerated pressure, at least until the middle third. Before inserting it into the conduit it is essential to verify the direction of rotation, the instrument rotating at low speed is introduced into the conduit up to 2mm before the working apical limit. In this way, the heat produced by friction will plasticize the gutta-percha, which at the same time will be compacted inside the duct. As the gutta-percha is compacted, the instrument tends to exit the canal. This recoil should be done slowly, always with the micromotor in motion. Once the compactor is removed it is important to immediately execute the vertical compaction, by means of attackers.

Hybrid technique: the first steps of this technique are identical to those of lateral condensation, using an endodontic sealant, main cone and accessory cones in a quantity compatible with the dimensions of the canal. Next, a spacer creates a hollow in the cervical and middle thirds, where a gutta-percha compactor of caliber somewhat inferior to the diameter of the root canal is introduced; this instrument, which rotates clockwise, will cause softening and compaction of the gutta-percha. The use of the compactor is similar to that described in the McSpadden technique; only the depth of introduction varies. This technique combines the benefits of apical control, achieved by the technique of lateral condensation and the compaction of gutta-percha in the cervical and middle thirds, provided by the Thermo mechanical action of the compactor. It offers the best long-term results.

Quick fill technique: gutta-percha coated titanium compactors, manufactured in sizes 15 to 60, with a length of 21 to 25 mm, are used in this. The Quick - Fill to be used must be two numbers smaller than the last instrument used in the conformation of the apical portion of the canal. Once the sealant has been taken to the duct, the compactor is introduced that rotates at a variable speed, between 3000 - 6000rpm, in a clockwise direction, up to the apical limit of the preparation. While the gutta-percha is compacted, the instrument still in motion is removed.

Thermal injectable techniques

Obtura II and ultra fill: both are thermoplasticized gutta-percha injection systems that use a gun and needles of different calibers to take the gutta-percha into the root canal. They are similar techniques but they differ in some aspects. The Obtura II system uses gutta-

percha cylinders of a beta nature, needles available in two calibers and a pistol. The thinnest for conduits prepared with instruments 40 to 60 and the thickest for wider conduits. The needle is inserted in the tip of the gun and a gutta-percha cylinder in the chamber, in its upper part. When pressing with a constant tension, the gutta-percha, passes through the heater located in the front of the gun, softens and flows through the tip of the needle. The temperature varies between 180 - 200°C. On the other hand, the Ultrafill system features a heater, a metal gun and plastic cannulas that have a needle at one end. Gutta-percha is more fluid and sticky than that of the Obtura II system and is found inside plastic cannulae that come in three different colors (white, blue and green), of the same caliber, but which contain gutta-percha of different fluidity. The cannulas are placed in the heater, where the plasticization of the gutta-percha takes place, at a temperature of approximately 70°C. The cannula is placed on the gun and we apply pressure intermittently. The Obtura II system was cataloged by several authors as the one with the best capacity to adapt to the walls of the canal, fulfilling the idea of how the injectable techniques of low and high temperature were significantly better than those of lateral condensation. Optimal results evaluating working length, acceptable spaces in the obturation, excellent adaptation to the behavioral walls, hermetic sealing, etc. However, several cases of extrusion of the material through the apex were observed. It was seen as both the resilon and gutta-percha of Obtura, showed similar results when used in depression Injection needle should be prohibited in narrow and curved ducts since, the resulting obturation will have empty spaces or it will be shorter than the working length.

Non-injectable thermal techniques

Vertical gutta-percha vertical compaction technique

In this technique, the hot gutta-percha is plasticized inside the root canal with a hot instrument or by means of a special device and is compacted by attackers of different calibers. Among several different sealing techniques, it has been shown that vertical compaction produces an excellent three-dimensional seal. It was determined that the perfect adaptation of gutta-percha is obtained after softening it at 2 or 4°C above body temperature and compacting at a minimum distance of 7 mm from the apex. Even so, many studies showed that it almost never reached the proper temperature in the apical gutta-percha using heat or electricity transporters. Regarding the distance, the compaction should be made as close as possible to the apex. However, this process can produce empty spaces inside the apical gutta-percha.

Thermafill technique: In 1978, Johnson introduced a technique based on metallic stems coated with alpha gutta-percha, heated and used to seal the root canal. There are three different types of Thermafil obturators. The differences between them are found in the material of the shank. There are stems of stainless steel, titanium and plastic, coated with gutta-percha, which become part of the seal itself. The manufacturer considers that this technique will produce a dense, homogeneous and three-dimensional obturation of the root canal. The caliber of the obturator to be used is selected according to the dimensions of the root canal, with the help of special instruments called verifiers. Some authors evaluated the radiographic appearance of the fillings with the plastic shanks of Thermafill compared with the technique of lateral compaction. They determined that, in general, the density and the adaptation of the filling with Thermafil were significantly better than the lateral condensation although without many differences in the apical third of the roots. The apical extrusion

of the gutta-percha and the sealant was also significantly greater in the Thermafill fillings. There are no studies comparing the adaptation to the surface of the interior of the duct of the three different types of Thermafill obturators, so it is not known if there is any difference between using metal or plastic stems. The results of the three Thermafil obturators are among those of the Obtura II technique and the lateral condensation technique. These three showed an incomplete extension of the gutta-percha up to the working length, they left spaces between the obturator and the completion of the prepared conduit. A tendency to extrusion of the material was also observed. In general, a high incidence of space in the fillings with Thermafill is observed, perhaps due to the contraction of the gutta-percha inside the pipes sealed with stems. The molars have a much more complex access and their ducts have curvatures more frequently than in the premolars and teeth of the anterior sector. The insertion of the scions of Thermafil is much more complex and takes a long time to seal them. The extrusion of gutta-percha is very frequent and there is no difference between what is seen in teeth of one or more roots.

Microseal technique: It is a mixed filling system that simultaneously uses cones of gutta-percha, conicity 0.02 to 0.04 and thermoplasticized gutta-percha, coming from a cartridge, which is attached to a syringe and heated in an oven. Both gutta percha are homogenized inside the duct, by means of a nickel titanium compactor, McSpadden type.

The technique involved, choose the main cone that fits the dimensions of the duct. A small amount of endodontic sealant is then applied over the dentinal walls; then the main cone is placed. A digital spacer will create the space for the introduction of the compactor, which will be selected according to the size of the spacer. The compactor, previously coated with thermoplasticized gutta-percha, obtained from the syringe heated in the furnace, is introduced into the duct and when turned clockwise, it will promote the homogenization between the gutta-percha cone and the compactor, to seal the system in three-dimensional form of root canals.

System B technique: It is constituted by a hand piece, coupled to a heat generator, in which special attackers of different calibers are inserted. The obturation procedure involves locating the main cone with prior placement of a small amount of endodontic sealant. The selected attacker is then introduced into the root canal and, at the same time, the switch located on the handpiece is pressed, which will raise the temperature to around 200°C. During the maneuver of introduction of the hot attacker, the softening and compaction of the gutta-percha will take place, which has to flow and occupy the spaces in the conduit system. Once the desired depth is reached, the switch is deactivated and the heated attacker will detach from the gutta-percha, remove it from the canal and the gutta-percha from the apical portion is compacted with the appropriate instruments. In this way, the three-dimensional obturation of the apical portion of the root canal will be obtained, leaving the middle and cervical thirds devoid of obturation. Then, the middle and cervical thirds can be sealed with other gutta-percha cones or with injectable thermoplasticized gutta-percha techniques, such as the Obtura II.

Failure of duct treatment

Many studies have shown a large percentage of lateral channels that are predominantly located in the middle third and the apical third of the roots. According to some authors, there is a persistent apical pathology around the untreated or obturated lateral canals.²¹ However, others argue that there is no correlation between untreated

and sealed lateral canals and failed pulp treatments. In any case, it has been affirmed that long and open lateral canals can create a double pathway for bacteria and tissue degradation between the root canal and the periodontal space.²² The filtration of the sealed ducts has been extensively in the laboratory, usually through the penetration of dye through the fillings. Despite this, it has not been able to clearly demonstrate that small soluble water molecules are a significant cause of periodontal disease. The extremely complex apical zone is the entry route for bacteria and their toxins. In order to seal the entire duct system, it is essential that the filling be three dimensional and hermetic, particularly in the last millimetres of the apical zone.¹¹⁻¹⁹ A perfect seal that seals the entire apical foramen is well condensed and adapted to the walls of the canal, and ends in the apical constriction. Due to the reabsorption of the foramen associated with apical periodontitis, the apical constriction should end as close as possible to the apical foramen.²⁰⁻²⁵

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Risk of extrusion of the sealing material

The contrasted scientific evidence has shown a higher incidence of overextension of the filling material beyond the apex when using hot gutta-percha techniques compared to the lateral compaction technique. No thermoplastic method allows controlling the sealing length of the hot gutta-percha seal. Overextension occurs in almost 35% of cases, and some authors claim up to 61%. Thermoplastic techniques require a well-defined apical barrier. Thus, an open apex, perforated or with some anatomical alteration such as an apical delta, can allow the extrusion of the filling material inside the periodontal tissues.^{41,42} Another limiting factor and even considered disadvantage, is the maximum possible magnitude of preparation of the channel when using injectable techniques and very especially, the negative conditioner that this symbolizes of face to the later rehabilitation with the use of complementary elements or auxiliary of retention¹⁴. When we use the vertical sealing technique, the length and the amount that we introduce the heat tip inside the tooth influence the degree of extrusion of the material. In this study it is determined that the tips should be introduced at 3-5 mm of the working length. According to previous works, the mother gutta-percha cone will only be plasticized

if the heat tip is inserted a minimum of 2mm, taking as reference the working length. There are certain factors that influence the potential risks of exit of the sealing material, such as the anatomy of the conduit or hydrostatic pressure, the latter regardless of the technique, material and even the operator's skill.¹ The presence or absence of preoperative apical periodontitis, density and extension of the obturation, as well as the quality of the coronal restoration also influence⁵. In cases of vital teeth, the extrusion of the material does not limit the long-term prognosis. Many studies have shown that gutta-percha is well tolerated by tissues, thanks to fulfilling one of the required properties of all behavioral obturation materials, such as local and general biocompatibility.^{6,7} If it is true, that there is an adverse effect on teeth with apical periodontitis due to the overinstrumentation that normally precedes the over-sealing of the root canal. The passage of the material to the region is related to inflammation and inflammatory processes that can damage the reparative processes.^{10,11}

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Conflicts of interest

The author declares that there is no conflict of interest.

References

- Schilder H. Filling root canals in three dimensions. *Dent Clin North Am*. 1967;723–744.
- Orstavik D. Materials used for root canal obturation: technical, biological and clinical testing. *Endod Topics*. 2005;12(1):25–38.
- Tanomaru-Filho M, Sant'Anna Júnior A, Bosso R, et al. Effectiveness of gutta-percha and Resilon in filling lateral root canals using the Obtura II system. *Braz Oral Res*. 2011;25(3):205–209.
- Schäfer E, Nelius B, Bürklein S. A comparative evaluation of gutta-percha filled areas in curved root canals obturated with different techniques. *Clin Oral Investig*. 2012;16(1):225–230.
- Tanomaru-Filho M, Sant'Anna Júnior A, Berbert FL, et al. Ability of gutta-percha and Resilon to fill simulated lateral canals by using the Obtura II system. *J Endod*. 2012;38(5):676–679.
- Fracassi LD, Ferraz EG, Albergaria SJ, et al. Evaluation of the quality of different endodontic obturation techniques by digital radiography. *Clin Oral Investig*. 2013;17(1):97–103.
- Zogheib C, Naaman A, Sigurdsson A, et al. Comparative micro-computed tomographic evaluation of two carrier-based obturation systems. *Clin Oral Investig*. 2013;17(8):1879–1883.
- Marciano J, Michalesco P, Abadie MJM. Stereochemical structure characterization of dental gutta-percha. *J Endod*. 1993;19(1):31–34.
- Silver GK, Love RM, Purton DG. Comparison of two vertical condensation obturation techniques: Touch'n Heat modified and System B. *Int Endod J*. 1999;32(4):287–295.
- Venturi M, Di Lenarda R, Prati C, et al. An *in vitro* model to investigate filling of lateral canals. *J Endod*. 2005;31(12):877–881.
- Shipper G, Orstavik D, Teixeira FB, et al. An evaluation of microbial leakage in roots filled with a thermoplastic synthetic polymer-based root canal filling material (Resilon). *J Endod*. 2004;30(5):342–347.
- Miner MR, Berzins DW, Bahcall JK. A comparison of thermal properties between gutta-percha and a synthetic polymer based root canal filling material (Resilon). *J Endod*. 2006;32(7):683–686.
- Karr NA, Baumgartner JC, Marshall JG. A comparison of gutta-percha and Resilon in the obturation of lateral grooves and depressions. *J Endod*. 2007;33(6):749–752.
- Gurgel-Filho ED, Feitosa JPA, Gomes BPFA, et al. Assessment of different gutta-percha brands during the filling of simulated lateral canals. *Int Endod J*. 2006;39(2):113–118.
- Karabucak B, Kim A, Chen V, et al. The comparison of gutta-percha and Resilon penetration into lateral canals with different thermoplastic delivery systems. *J Endod*. 2008;34(7):847–849.
- Goldberg F, Artaza LP, Silvio A. Effectiveness of different obturation techniques in the filling of simulated lateral canals. *J Endod*. 2001;27(5):362–364.
- Almeida JFA, Gomes BPFA, Ferraz CCR, et al. Filling of artificial lateral canals and microleakage and flow of five endodontic sealers. *Int Endod J*. 2007;40(9):692–699.
- Venturi M, Prati C, Capelli G, et al. A preliminary analysis of the morphology of lateral canals after root canal filling using a tooth-clearing technique. *Int Endod J*. 2003;36(1):54–63.
- Tanomaru-Filho M, Silveira GF, Tanomaru JMG, et al. Evaluation of the thermoplasticity of different gutta-percha cones and Resilon. *Aust Endod J*. 2007;33(1):23–26.
- Sant'Anna-Júnior A, Tanomaru-Filho M, Duarte MAH, et al. Temperature changes in gutta-percha and Resilon cones induced by a thermomechanical compaction technique. *J Endod*. 2009;35(6):879–882.
- Ricucci D, Siqueira JF. Anatomic and microbiologic challenges to achieving success with endodontic treatment: a case report. *J Endod*. 2008;34(10):1249–1254.
- Clark DS, El Deeb ME. Apical sealing ability of metal versus plastic carrier Therafil obturators. *J Endod*. 1993;19(1):4–9.
- Venturi M. An *ex vivo* evaluation of a gutta-percha filling technique when used with two endodontic sealers: analysis of the filling of main and lateral canals. *J Endod*. 2008;34(9):1105–1110.
- Tennert C, Jungbäck IL, Wråbas KT. Comparison between two thermoplastic root canal obturation techniques regarding extrusion of root canal filling-a retrospective *in vivo* study. *Clin Oral Investig*. 2013;17(2):449–454.
- Wolf M, Küpper K, Reimann S, et al. 3D analyses of interface voids in root canals filled with different sealer materials in combination with warm gutta-percha technique. *Clin Oral Investig*. 2014;18(1):155–1561.
- Keleş A, Alcin H, Kamalak A, et al. Micro-CT evaluation of root filling quality in oval-shaped canals. *Int Endod J*. 2014;47(12):1177–1184.
- Oddoni PG, Mello I, Coil JM, et al. Coronal and apical leakage analysis of two different root canal obturation systems. *Braz Oral Res*. 2008;22(3):211–215.
- Tay FR, Pashley DH, Williams MC, et al. Susceptibility of a polycaprolactone-based root canal filling material to degradation. I. Alkaline hydrolysis. *J Endod*. 2005;31(8):593–598.
- Marciano J, Michalesco P, Charpentier E, et al. Thermomechanical analysis of dental gutta-percha. *J Endod*. 1992;18(6):263–270.
- Maniglia-Ferreira C, Silva Júnior JB, Paula RC, et al. Brazilian gutta-percha points. Part I: chemical composition and X-ray diffraction analysis. *Braz Oral Res*. 2005;19(3):193–197.

31. Simon S, Rilliard F, Berdal A, et al. The use of mineral trioxide aggregate in one-visit apexification treatment: A prospective study. *Int Endod J*. 2007;40(3):186–197.
32. Güneş B, Aydinbelge HA. Mineral trioxide aggregate apical plug method for the treatment of nonvital immature permanent maxillary incisors: Three case reports. *J Conserv Dent*. 2012;15(1):73–76.
33. Bakland LK, Andreasen JO. Will mineral trioxide aggregate replace calcium hydroxide in treating pulpal and periodontal healing complications subsequent to dental trauma? A review. *Dent Traumatol*. 2012;28(1):25–32.
34. Holden DT, Schwartz SA, Kirkpatrick TC, et al. Clinical outcomes of artificial root-end barriers with mineral trioxide aggregate in teeth with immature apices. *J Endod*. 2008;34(7):812–817.
35. Sundqvist G, Figdor D. Endodontic treatment of apical periodontitis. In: Orstavik D, Pitt Ford TR, editors. *Essential Endodontology. Prevention and Treatment of Apical Periodontitis*. Blackwell; 1998:242–277.
36. Wu MK, Fan B, Wesselink PR. Diminished leakage along root canals filled with gutta-percha without sealer over time: A laboratory study. *Int Endod J*. 2000;33(2):121–125.
37. Patil SA, Dodwad PK, Patil AA. An *in vitro* comparison of bond strengths of Gutta-percha/AH Plus, Resilon/Epiphany self-etch and EndoREZ obturation system to intraradicular dentin using a push-out test design. *J Conserv Dent*. 2013;16(3):238–242.
38. Mushtaq M, Farooq R, Ibrahim M, et al. Dissolving efficacy of different organic solvents on gutta-percha and resilon root canal obturating materials at different immersion time intervals. *J Conserv Dent*. 2012;15(2):141–145.
39. Dhaded N, Uppin VM, Dhaded S, et al. Evaluation of immediate and delayed post space preparation on sealing ability of Resilon-Epiphany and Gutta percha-AH plus sealer. *J Conserv Dent*. 2013;16(6):514–517.
40. Cecchin D, Souza M, Carlini-Junior B, et al. Bond strength of Resilon/Epiphany compared with Gutta-percha and sealers Sealer 26 and Endo Fill. *Aust Endod J*. 2012;38(1):21–25.
41. Tanomaru-Filho M, Pinto RV, Bosso R, et al. Evaluation of the thermoplasticity of Gutta percha and Resilon using the Obtura II system at different temperature setting. *Int Endod J*. 2011;44(8):764–768.
42. Gesi A, Raffaelli O, Goracci C, et al. Interfacial strength of Resilon and Gutta-Percha to intraradicular dentin. *J Endod*. 2005;31(11):809–813.
43. Kim YK, Grandini S, Ames JM, et al. Critical review on methacrylate resin-based root canal sealers. *J Endod*. 2009;36(3):383–399.