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(54) **ROOT CANAL FILLING MATERIALS AND METHODS**

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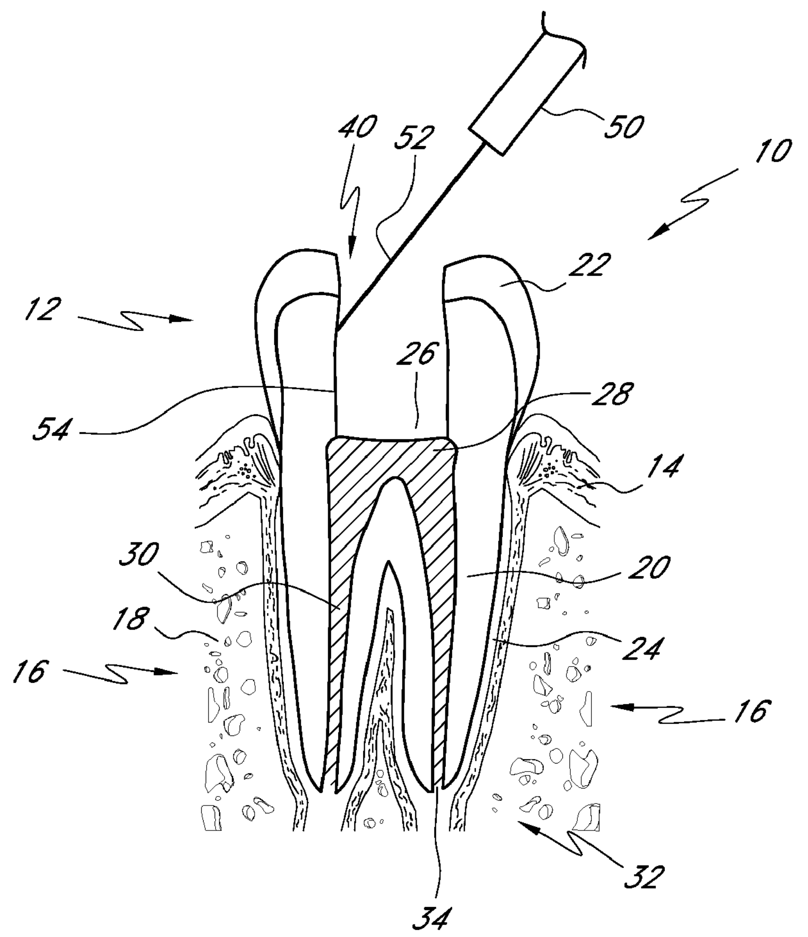
(57) **ABSTRACT**

In various embodiments of a method for filling root canal spaces, the root canal spaces are cleaned and irrigated, for example, by any suitable endodontic procedure, and the irrigating liquid is not removed from the canal spaces prior to filling. In some embodiments, a hydrophobic filler material is introduced into the root canal spaces while they are filled with liquid. As the canal spaces are filled, the hydrophobic filler material displaces the liquid and drives it out of the canal spaces, towards the crown of the tooth, where it can be removed. The hydrophobic filler material may comprise magnetically responsive particles having a hydrophobic surface coating that are compacted into the root canal spaces by application of a magnetic force field. In other embodiments, hydrophilic filler material in a flowable phase is introduced into the canal spaces where it partly displaces and partly absorbs the irrigating liquid before solidifying.



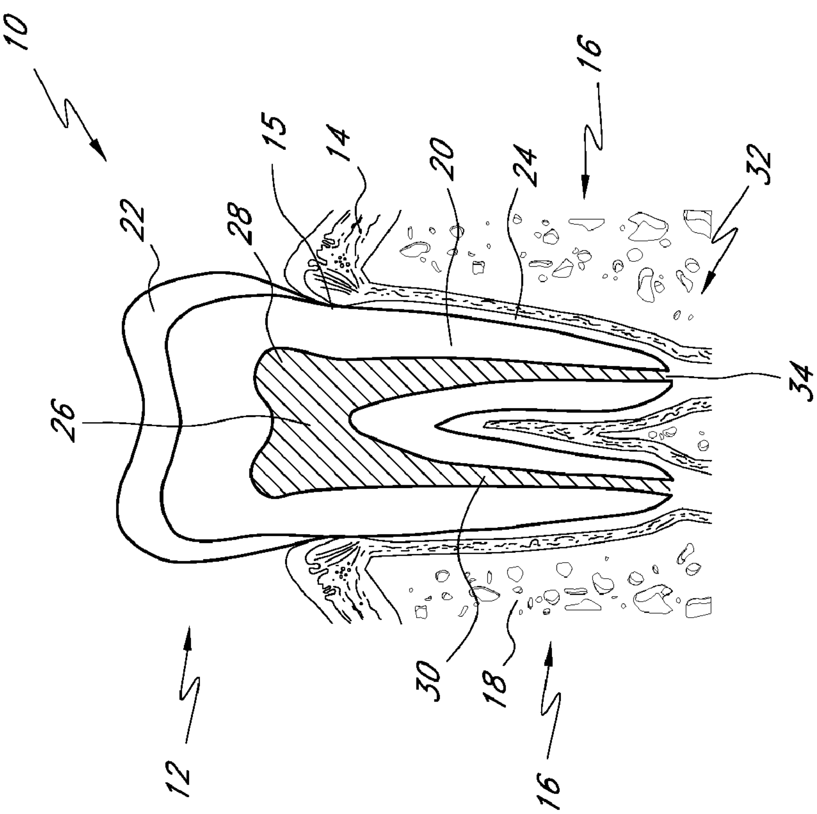


FIG. 1

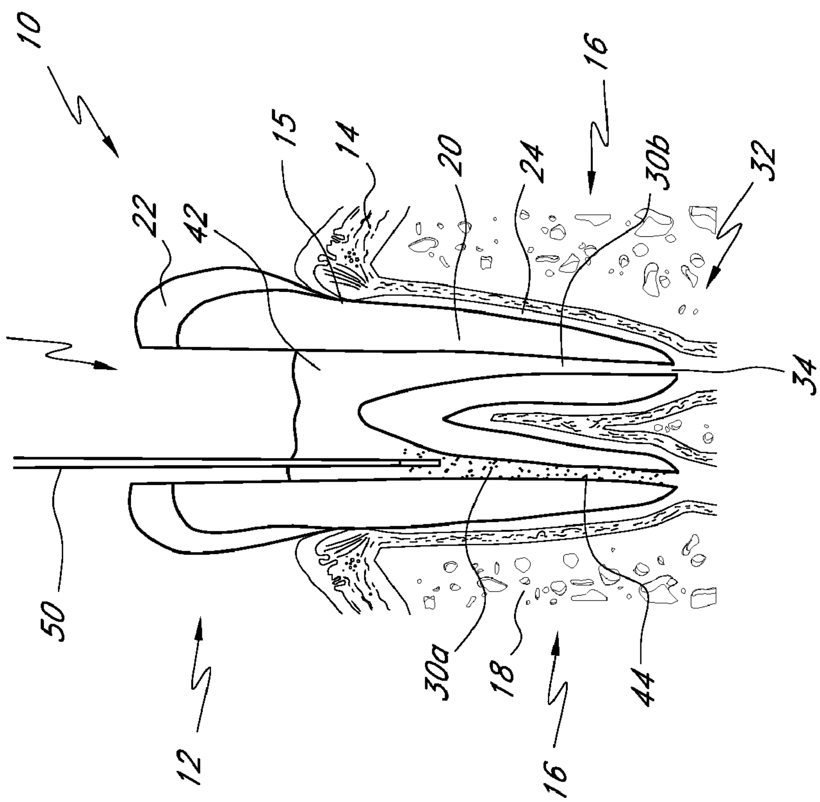


FIG. 2A

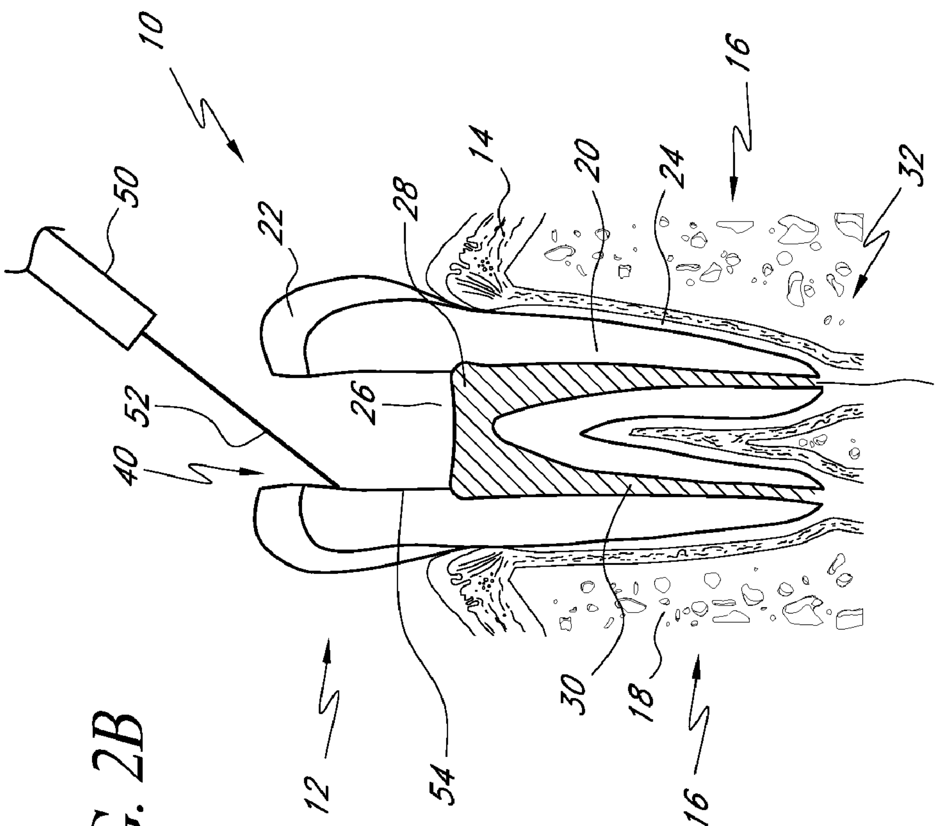


FIG. 2B

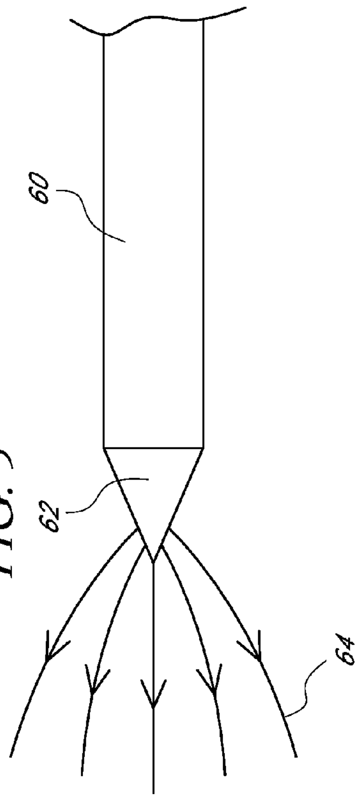


FIG. 3

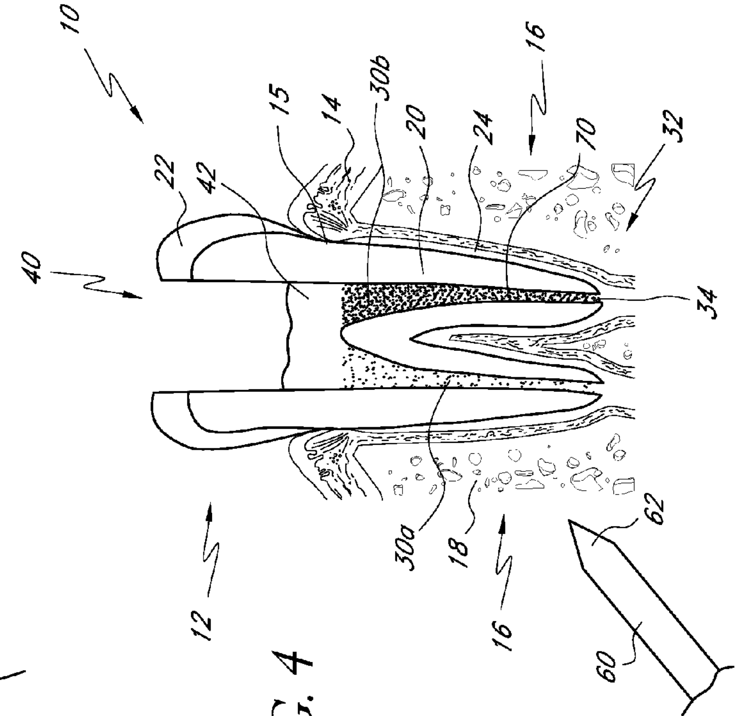


FIG. 4

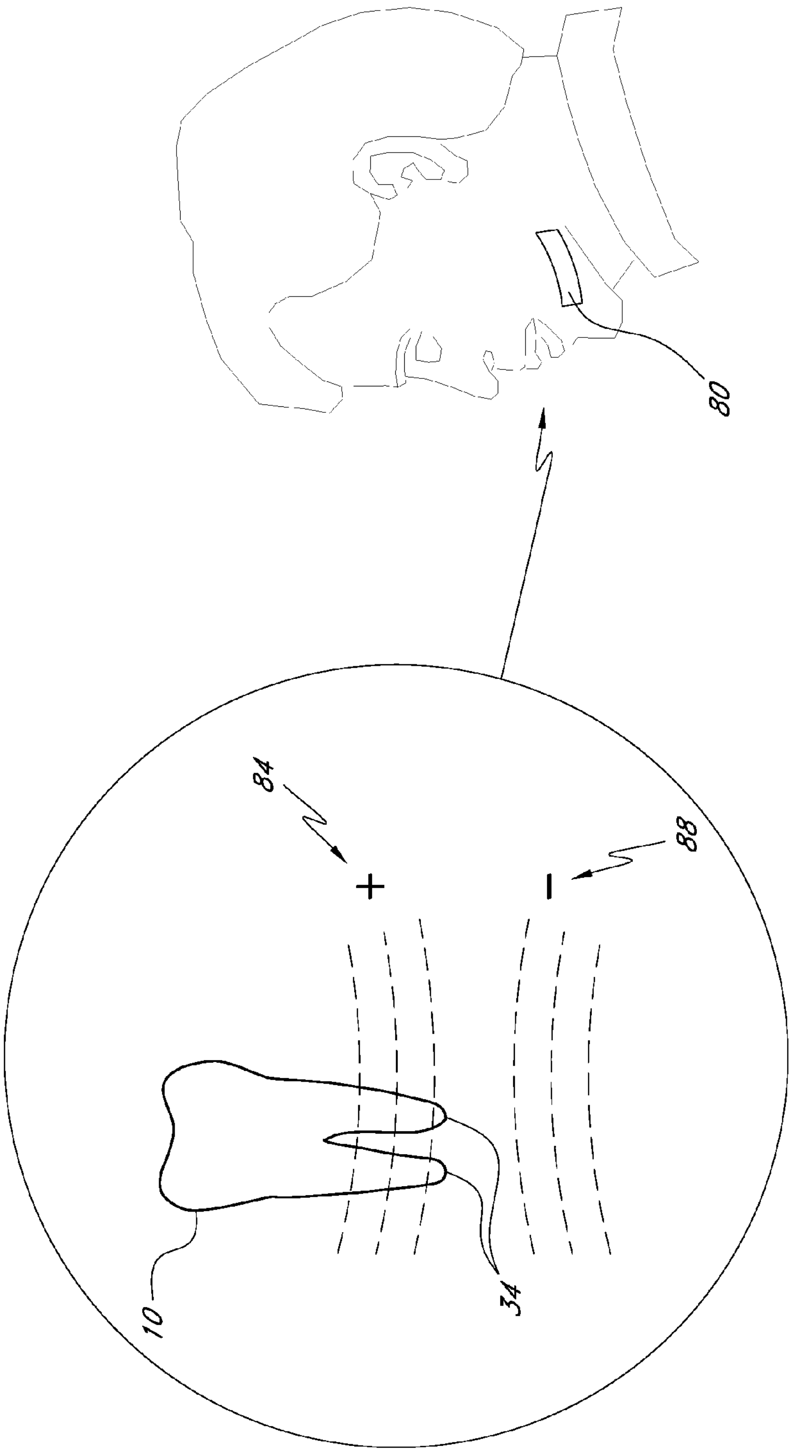


FIG. 5

ROOT CANAL FILLING MATERIALS AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit under 35 U.S.C. §120 and 35 U.S.C. §121 as a divisional application of U.S. patent application Ser. No. 11/752,812, filed May 23, 2007, entitled "ROOT CANAL FILLING MATERIALS AND METHODS," which claims the benefit under 35 U.S.C. §119 (e) of U.S. Provisional Patent Application No. 60/802,662, filed May 23, 2006, entitled "ROOT CANAL FILLING MATERIALS AND METHODS," the entire disclosure of each of which is hereby incorporated by reference herein in its entirety.

BACKGROUND

[0002] 1. Field

[0003] The present disclosure relates generally to filling spaces in a body location and more particularly to filling root canal spaces in a tooth.

[0004] 2. Description of the Related Art

[0005] Treatment of root canal spaces in a tooth typically involves removal of organic material from the root canal spaces followed by filling the spaces with a filling material. Present filling materials are hydrophobic and may include gutta-percha, polymers, calcium hydroxide ($Ca(OH)_2$), and/or zinc oxide (ZnO) liners. Prior to filling the root canal spaces with these filling materials, the canal spaces typically must be widened, which is traditionally performed with hand- or machine-driven endodontic files. To ensure proper adhesion of the filling material to tooth dentin, moisture and fluids are evacuated from the canal spaces (such as by wicking or aspirating) prior to filling. Such evacuation of fluids commonly results in sucking organic components and contaminated fluids (e.g., pus, serum, and/or blood) from the apical periodontium through one or more canal orifices, which may cause re-infection of the canal spaces. Due to these and other deficiencies, the overall success rate for the treatment is around 70 percent. Because of the uncertainty and the cost of the process, extraction of the diseased tooth is often used as a treatment alternative.

SUMMARY

[0006] An embodiment of an apparatus comprises a manipulator which produces a non-contacting force field to manipulate a filling material during filling of a root canal space of a tooth. The filling material may comprise a plurality of particles responsive to the non-contacting force field. In some embodiments, the non-contacting force field may comprise a magnetic field.

[0007] An embodiment of a method for filling a root canal space of a tooth comprises using a non-contacting force field to manipulate a filling material during filling of the root canal space. In some implementations, the non-contacting force field comprises a magnetic field, and the filling material magnetically interacts with the magnetic field.

[0008] An embodiment of a method of filling a root canal system of a tooth comprises compacting colloidally suspended discrete particles in a root canal to fill the canal with a substantially solid filling.

[0009] An embodiment of a root canal filler for a tooth comprises a multiplicity of relatively large particles sized to form a plug in a canal space proximate an apex of the tooth and a multiplicity of relatively small particles sized to at least substantially fill the remainder of the canal space.

[0010] An embodiment of a method for filling a root canal space of a tooth comprises plugging a canal space proximate an apex of the tooth and subsequently at least substantially filling remaining space of the canal with a flowable filling material.

[0011] An embodiment of a hydrophilic root canal filling material is provided. The filling material may be adapted to be introduced into a root canal space when liquid is in the canal space during filling. The liquid may provide a barrier against migration of bacteria into an apical area of the tooth. When introduced into the root canal, at least a substantial portion of the liquid may be absorbed by the hydrophilic material.

[0012] An embodiment of a method of filling a root canal space of a tooth comprises introducing a hydrophobic material into a root canal space of a tooth when a liquid substantially fills the root canal space. The liquid may provide a barrier against migration of bacteria into an apical area of the tooth. The liquid may be substantially displaced from the root canal space by the hydrophobic material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. **1** is a cross section schematically illustrating a typical human tooth, which in this example is a molar.

[0014] FIG. **2**A schematically illustrates an embodiment of an endodontic treatment for filling the root canal spaces of the tooth.

[0015] FIG. **2**B is a cross-section view schematically showing an example endodontic method for cleaning a root canal system of a tooth, in which a high-velocity jet is directed toward a dentinal surface through an opening in the crown of the tooth.

[0016] FIG. **3** schematically illustrates an embodiment of a micromanipulator comprising a stylus having a magnetic tip. FIG. **3** schematically depicts example magnetic field lines near the tip.

[0017] FIG. **4** schematically illustrates a root canal filling method using the micromanipulator of FIG. **3** to magnetically guide magnetically responsive filler material into the canal spaces of a tooth.

[0018] FIG. **5** schematically illustrates another embodiment of a filling method using a matrix of electromagnetic coils to produce a magnetic field gradient near a tooth (shown in the inset).

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0019] The present disclosure describes various materials and methods for endodontic treatments that overcome possible disadvantages associated with conventional root canal treatments. In certain embodiments of a method for filling root canal spaces, the root canal spaces are cleaned and irrigated (e.g., by any suitable endodontic procedure), and the irrigating liquid is not removed from the canal spaces prior to filling. In certain such embodiments, the method comprises introducing a hydrophobic filler material into the root canal spaces while they are filled with liquid (e.g., water). As the canal spaces are filled, the hydrophobic filler material displaces the liquid and at least partially drives the filler material out of the canal spaces, towards the crown of the tooth, as will be described more fully below.

[0020] In some embodiments, the hydrophobic filler material comprises a colloid of coated ferromagnetic particles (and/or other material that is responsive to a magnetic field). The coating advantageously may comprise a substantially hydrophobic substance. By way of example, the coating may comprise polyorganosiloxanes, polyorganosilanes, or mixtures thereof. For convenience, the magnetically responsive particles will be referred to hereinafter as "mag-particles."

[0021] FIG. **1** is a cross section schematically illustrating a typical human tooth **10**, which comprises a crown **12** extending above the gum tissue **14** and at least one root **16** set into a socket (alveolus) within the jaw bone **18**. Although the tooth **10** schematically depicted in FIG. **1** is a molar, the material and methods described herein may be used on any type of tooth such as an incisor, a canine, a bicuspid, or a molar. The hard tissue of the tooth **10** includes dentin **20** which provides the primary structure of the tooth **10**, a very hard enamel layer **22** which covers the crown **12** to a cementoenamel junction **15** near the gum **14**, and cementum **24** which covers the dentin **20** of the tooth **10** below the cementoenamel junction **15**.

[0022] A pulp cavity **26** is defined within the dentin **20**. The pulp cavity **26** comprises a pulp chamber **28** in the crown **11** and one or more root canal spaces **30** extending toward an apex **32** of each root **16**. The pulp cavity **26** contains dental pulp, which is a soft, vascular tissue comprising nerves, blood vessels, connective tissue, odontoblasts, and other tissue and cellular components. The pulp provides innervation and sustenance to the tooth through the epithelial lining of the pulp chamber **26** and the root canal space **30**. Blood vessels and nerves enter/exit the root canal space **30** through a tiny opening, the apical foramen **34**, near a tip of the apex **32** of the root **16**.

[0023] FIG. **2**A schematically illustrates one embodiment of an endodontic treatment for filling the canal spaces **30** of the tooth **10**. A drill or grinding tool is initially used to make an opening **40** in the tooth **10**. The opening **40** may extend through the enamel **22** and the dentin **20** to expose and provide access to pulp in the pulp cavity **26**. The opening **40** may be made in a top portion of the crown **12** of the tooth **10** (as shown in FIG. **2**A) or in another portion such as a side of the crown **12** or in the root **16** below the gum **14**. The opening **40** may be sized and shaped as needed to provide suitable access to the pulp cavity **26** and/or all of the canal spaces **30**. In some treatment methods, additional openings may be formed in the tooth **10** to provide further access to the canals **30** and/or to provide dental irrigation.

[0024] The pulp cavity **26** and/or the canal spaces **30** may be cleaned and irrigated by any suitable method. For example, in some procedures, endodontic files are inserted into the root canal system to open the canal spaces **30** and remove organic material therein. An effective method for cleaning the root canal system is depicted in FIG. **2**B, which schematically illustrates a high velocity collimated jet **52** of liquid (e.g., water) directed through the opening **40** toward a dentinal surface **54** of the tooth **10**. In some embodiments, the high-velocity liquid jet may have a velocity in a range from about 50 m/s to about 300 m/s and may have a transverse size (e.g., diameter) in a range from about 1 micron to about 1000 microns.

[0025] Impact of the jet **52** causes acoustic energy to propagate from the impact site on the dentinal surface **54** through the entire tooth **10**, including the root canal system. The acoustic energy is effective at detaching substantially all organic material in the root canal system from surrounding dentinal walls. The acoustic energy may be effective at cleaning the root canal system, because the acoustic energy generates acoustic cavitation effects (e.g., cavitation bubbles, cavitation jets, acoustic streaming, entrainment, etc.), which efficiently detach and/or delaminate organic material from dentinal surfaces and tubules. The treatment time during which the high-velocity jet **52** is directed toward the tooth **10** may range from about 1 second to about 120 seconds in various cleaning methods.

[0026] In many embodiments, the detached organic material can be flushed from the root canal using an irrigation fluid (e.g., water). In some embodiments, liquid from the high-velocity jet provides the irrigation fluid. In other embodiments, a low-velocity jet or stream provides the irrigation fluid. The liquid jet **52** may be directed from a handpiece **50** that can be manipulated within a patient's mouth by a dental practitioner. In certain endodontic procedures, the high velocity liquid jet **52** is directed into the pulp cavity **26** and/or the root canal spaces **30** to excise and/or emulsify organic material therein. The liquid jet **52** may be generated by a high pressure compressor system or by a pump system in various embodiments. Further details of apparatus and methods for generating the high velocity jet **52** and using the jet **52** to clean root canal systems are found in U.S. patent application Ser. No. 11/737,710, filed Apr. 19, 2007, entitled "Apparatus and Methods for Treating Root Canals of Teeth," which is hereby incorporated by reference herein in its entirety.

[0027] In certain preferred embodiments, after cleaning the canal spaces **30**, irrigating liquid **42** (e.g., water) is not removed from the canal spaces **30** prior to filling. The irrigating liquid **42** advantageously may act as a vector for any floating particles and/or organic material and as a barrier against the influx of periapical fluid (e.g., through the apical opening **34**). Filling material **44**, such as the hydrophobic filling material described herein, may then be applied to the canal spaces **30**. As the canal spaces **30** are filled, the hydrophobic filler material **44** displaces the irrigating liquid **42** and forces the liquid **42** at least partially out of the canal spaces **30**, toward the opening **40** in the crown **12** of the tooth **10** (or toward any other suitable opening formed in the tooth **10**).

[0028] In certain embodiments, the filler material **44** comprises a sterile colloid comprising mag-particles. The filler material **44** may be provided to a dental practitioner in standard 1.8 milliliter dental cartridges. In a preferred embodiment schematically illustrated in FIG. **2**A, the colloid is applied to the canal spaces **30** using a standard cartridge syringe with an injection needle **50** such as, for example, a sterile disposable 30-gauge short injection needle. In some procedures, the colloid is applied into the canal spaces **30** without pressure and without binding the injection needle **50** to the walls of the canal space **30**, which advantageously may reduce application of pressure to the liquid **42** present in the canal space **30** and may allow the liquid **42** to be displaced from and escape the canal space **30**. In the example method depicted in FIG. **2**A, the needle **50** has been used to apply the filler material **44** to a portion of the canal space **30***a*. After filling the canal space **30***a*, the dental practitioner may fill other spaces in the tooth **10**, such as the canal space **30***b*. Although depicted as straight in FIG. **2**A, the needle **50** may be bent and/or curved to access portions of the canal spaces **30***a*, **30***b*. In some embodiments, portions of the needle **50** may be flexible.

[0029] In certain embodiments, a force field is used to manipulate the filler material during the filling of the canal spaces **30**. The force field advantageously may be a non-contacting force field that applies a force to the filler material without physically contacting the material. For example, the force field may comprise a magnetic force field, and the filler material may comprise a substance that is responsive to the magnetic force field.

[0030] As schematically illustrated in FIG. **3**, the magnetic force field may be applied using a micromanipulator comprising a stylus **60** having a magnetic tip **62**. FIG. **3** schematically depicts example magnetic field lines **64** near the tip **62**. In other embodiments, the magnetic field lines **64** may have a different configuration and/or polarity than shown in FIG. **3**. For example, the magnetic field lines **64** may have a configuration that includes components such as dipole, quadripole, and/or higher order multipole components. In some methods for filling root canal spaces, the magnetic tip **62** of the stylus **60** is positioned near the tooth **10** and moved toward the apex **32** adjacent to the tooth root **16**. FIG. **4** schematically illustrates application of the tip **62** of the stylus **60** to the canal space **30***a* of the tooth **10**. The magnetic tip **62** may be moved toward the apex **32** one or more times during a treatment. The magnetic field of the tip **62** may provide an attractive force that urges the mag-particles in the canal space **30***a* towards the apex **32** until substantially all the canal space **30***a* is filled, and the mag-particles are condensed in the canal space **30***a*. As the mag-particles are condensed, the liquid **42** in the canal spaces **30** is squeezed outward due to the hydrophobic surface property of the coating material of the mag-particles. This procedure may be repeated for the canal space **30** in each root **16** of the treated tooth **10**. Surplus colloid can be removed from the access opening **40** and coronal pulp chamber **28**.

[0031] In some methods, the mag-particles are also condensed in the canal spaces **30** using an endodontic spreader such as, for example, a No. 1 dental hand-spreader and/or plugger (e.g., a. Schilder spreader) so as to form a substantially solid core **70** of mag-particles in the canal spaces. The substantially solid core **70** is schematically illustrated in the canal space **30***b* shown in FIG. **4**. The resulting core **70** advantageously may be substantially bacterio-static, substantially tissue compatible, and not substantially affected by tissue metabolism. The core **70** of mag-particles also may be substantially radio-opaque. The filled canal spaces **30** may be sealed over in a conventional manner, such as with a bonded restorative material.

[0032] In certain preferred embodiments, mag-particles of different sizes are used in the filling process. In order to reduce the likelihood that mag-particles migrate through the apical opening **34** of the tooth **10** into surrounding vascularized tissue, larger mag-particles may be introduced first into the canal spaces **30**, followed by introduction of smaller mag-particles. The larger mag-particles advantageously may have a size that allows the mag-particles to migrate proximate to the apical opening **34**, but not through the apical opening **34**. The magnetic tip **62** of the stylus **60** may be used to assist condensing the larger and/or the smaller mag-particles in the canal spaces **30**. In certain embodiments, the mag-particle coating is somewhat compliant such that the coatings can deform as magnetic attraction from the stylus **60** pulls them through the root canal towards the apex **32** and into progressively smaller spaces. It is beneficial if the coating is not so compliant as to deform to a size smaller than that of the apical opening **34** (typically, 30 microns). As an example, in certain embodiments, the size of the larger mag-particles may be in a range from about 35 to about 200 microns, more preferably in a range from about 40 to 100 microns, and even more preferably in a range from about 50 to 70 microns. The larger mag-particles may thus advantageously be used to form a plug in a portion of the root canal space **30** adjacent the apex **32** of the tooth **10**. The mag-particles forming the plug may be compacted using the magnetic field of the stylus **60** and may bond to each other by diffusion of the coating material.

[0033] In certain preferred embodiments, following creation of the plug comprising the larger mag-particles, smaller size mag-particles are introduced into the canal spaces **30**. By way of example, the size of the smaller mag-particles may be in a range from about 2 to 30 microns, more preferably in a range from about 2 to 15 microns, and even more preferably in a range from about 2 to 5 microns. In certain such preferred embodiments, the mag-particles are sufficiently small to readily fill the small side canals, fins, and narrow spaces that typically extend laterally from the main root canal spaces **30**. In some methods, the smaller mag-particles are compacted by means of the magnetic field and bond to each other by diffusion of the coating materials, thereby creating a rigid volume of filling material that fills the root canal system.

[0034] Various micromanipulators may be utilized to magnetically guide the mag-particles to targeted sites using magnetic force fields. Embodiments of the micromanipulator may use a magnetic force to guide the mag-particles by application of an attractive force, a repulsive force, and/or a combination thereof to pull and/or to push the mag-particles toward the targeted sites. In some embodiments, the micromanipulator is configured to provide a suitable magnetic force gradient to guide the mag-particles. By way of example, the micromanipulator may comprise a stylus (such as the stylus **60** described above) having a tip **62** that comprises one or more magnets or electromagnets. The one or more magnets may comprise rare earth (e.g., neodymium) magnets, In another embodiment, the micromanipulator comprises a plurality of coils forming a matrix of electromagnets. When suitably energized, the electromagnetic matrix of coils creates temporal and/or spatial electromagnetic field variations (statically or dynamically) to provide electromagnetic field patterns and field gradients that increase or optimize the force (and/or force gradient) applied to the mag-particles. The force gradient may be used to control the degree of mag-particle compactness and also to prevent the filler material **44** from reaching unwanted areas (e.g., the apical opening **34**).

[0035] In certain treatment embodiments, some of the mag-particles are guided by the micromanipulator to assist moving surrounding filling material into small cracks, holes, crevices, channels, and/or spaces in the root canal system. For example, movement of the mag-particles may cause some of the surrounding fluid and/or filler material to flow due to a coupling force between the mag-particles and the fluid and/or filler material. The coupling force may comprise, for example, friction, viscosity, etc. In some methods, a time varying force field (and/or force gradient) is applied to the mag-particles to cause such a flow. The fluid motions induced by the movement of the mag-particles may assist introduction of filler material into the smaller root canal spaces.

[0036] In some embodiments, the electromagnetic matrix is in the form of a strip **80** that is mounted on the head of the patient with the electromagnetic matrix in proximity to the apex of the tooth or teeth under treatment, as illustrated schematically in FIG. **5**. The matrix may be powered by a power-supply that is controlled by a computer or microprocessor. The power supply drives the matrix of coils selectively under the control of computer software to create a magnetic-field gradient in the manner of a magnetic phased array. As schematically depicted in FIG. **5**, the magnetic field gradient may be configured to provide a positive region **84** of attractive magnetic field to the root canal system, while providing a negative region **88** of zero or repulsive magnetic field near the apical openings **34** of the tooth **10** under treatment. The matrix may be spatially calibrated to the location of the apical openings **34**, so that the field gradient generated by the matrix is precisely located with respect to the tooth **10** under treatment and draws the mag-particles through the canal system, but not through the apical openings **34**. Accordingly, the electromagnetic matrix may preferably be attached to the patient in a manner that prevents or inhibits relative motion between the matrix and the tooth **10** under treatment when the magnetic field is applied. Such attachment may be accomplished by means of a helmet (e.g., for upper teeth), a jaw clamp (e.g., for lower teeth), or by clamping the matrix to one or more teeth adjacent the tooth **10** under treatment.

[0037] The matrix of coils may be used not only to move the mag-particles, but also to sense movement of the mag-particles. For example, as the mag-particles fill the root canal system, the mag-particles will cross magnetic field lines produced by the matrix, which generates a direct current (DC) in the coils. By measuring the DC current (and/or voltage) in each coil, relative movement between the mag-particles and the tooth **10** under treatment may be calculated. In some embodiments, the relative motion of the mag-particles is output on a display for viewing by the dental practitioner. In such embodiments, the dental practitioner may observe in real-time the migration of the mag-particles into the root canal system and the mag-particles' location relative to the apical openings **34**. To provide increased control over the filling treatment, the magnetic field intensity, gradient, spatial and/or temporal configuration may be altered in accordance with the sensed movement. In an alternative embodiment, the matrix of coils provides a low intensity field for sensing movement without moving the particles, and the magnetic field that moves the particles is applied by a micromanipulator such as a handheld stylus manipulated by the dental practitioner (e.g., the stylus **60** shown in FIG. **3**).

[0038] In some methods, after the filler material **44** comprising the mag-particles has sufficiently cured, energy is applied to heat the filler material **44** above the melting point to at least partially liquefy the filler material **44** and/or the mag-particles. The applied energy may comprise electric, magnetic, and/or electromagnetic energy such as, for example, from an applied electric field and/or magnetic field. In some embodiments, the applied energy comprises electromagnetic energy (e.g., ultrasound). The at least partially liquefied material may then solidify into a substantially solid core within the root canal system of the treated tooth.

[0039] In some cases, it may be desirable for the substantially solid core of mag-particles to be removed (e.g., retreatment of the tooth **10**) In some treatment methods, the core may be at least partially liquefied by application of energy to the affected tooth. As described above, the applied energy may comprise electric, magnetic, and/or electromagnetic energy. For example, ultrasound energy may be applied, e.g., with a Cavitron® instrument available from Dentsply International, York, Pa. The liquefied core material can be suctioned or irrigated out of the canal spaces **30**.

[0040] In other embodiments of methods for filling root canal spaces, the filling material may comprise a hydrophilic material such as, for example, a protein-based, reversible hydrocolloid. Protein-based reversible hydrocolloids are thermoplastics, which may liquefy in a temperature range above about 80 to 95 degrees centigrade and may solidify in a temperature range below about 40 to 45 degrees centigrade. Liquefaction and solidification temperature ranges may be different in different hydrocolloids. When in a liquid phase, reversible hydrocolloids may be able to absorb several times their volume of water. To avoid substantial changes in the physical properties of the hydrocolloid, in some methods water absorption is limited to about 30% of the volume of the hydrocolloid. Advantageously, the filling material may further comprise at least one bacterio-static substance, as well as at least one substance to provide radio-opacity. The filling material may comprise both a hydrophobic material (e.g., mag-particles) and a hydrophilic material (e.g., a reversible hydrocolloid) in some embodiments.

[0041] In certain method embodiments, the hydrophilic filling material is supplied in sealed 1.8 ml dental cartridges suitable for use in dental syringes. To liquefy the filling material, the cartridges may be placed in a heated liquid (e.g., hot or boiling water) for a liquefaction time that is about 10 minutes for some hydrocolloids. After the filling material is sufficiently liquefied, the cartridge can be placed in a cartridge syringe fitted with a suitable needle, for example, a 30 gauge short needle.

[0042] To deliver the filling material to the root canal system, the needle may be curved and/or bent to access the canal spaces **30** in the tooth **10** under treatment In certain preferred embodiments, the needle is placed without binding into the canal space **30**, and a suitable amount of liquefied filling material is injected into the space **30** to partially absorb and/or partially displace liquid in the canal space **30**. It may be desirable in some embodiments for enough water from the canals **30** to be displaced such that no more than about 30% of the water is absorbed by the hydrocolloid filler (e.g., at least about 70% of the water is displaced). By introducing a suitable amount of liquid reversible hydrocolloid into the canal spaces **30**, the hydrocolloid may help maintain the liquid stage of filler material previously introduced into the canal spaces **30**, may help maintain application of pressure, and thereby may help transport the filler material to the apex **32** and to substantially all the canal spaces **30** before the filler material solidifies. The filled canal spaces **30** may be sealed over in a conventional manner with a bonded restorative material.

[0043] As described above, in some methods, after the filler material has sufficiently cured, energy is applied to heat the filler material toward or above the melting point to at least partially liquefy the filler material (and/or mag-particles if used). The at least partially liquefied material may help fill the canal spaces **30** and may help provide a substantially uniform core of material in the root canal system. The applied energy may comprise electric, magnetic, and/or electromagnetic energy such as, for example, from an applied electric and/or magnetic field. In some embodiments, the applied energy comprises electromagnetic energy (e.g., ultrasound). The at least partially liquefied material may then solidify into a substantially solid core within the root canal system of the treated tooth.

[0044] Although the tooth **10** depicted in the figures is a molar, one of ordinary skill in the art will appreciate that the procedures may be performed on any type of tooth such as an incisor, a canine, a bicuspid, or a molar. Also, the disclosed methods are capable of filling root canal spaces having a wide range of morphologies, including highly curved root canal spaces which are difficult to fill using conventional dental techniques. Moreover, the disclosed methods may be performed on human teeth (including children's teeth) and/or on animal teeth.

[0045] The foregoing description sets forth various preferred embodiments and other illustrative but non-limiting embodiments of the inventions disclosed herein. The description provides details regarding combinations, modes, and uses of the disclosed inventions. Other variations, combinations, modifications, equivalents, modes, uses, implementations, and/or applications of the disclosed features and aspects of the embodiments are also within the scope of this disclosure, including those that become apparent to those of skill in the art upon reading this specification. Additionally, certain objects and advantages of the inventions are described herein. It is to be understood that not necessarily all such objects or advantages may be achieved in any particular embodiment. Thus, for example, those skilled in the art will recognize that the inventions may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other objects or advantages as may be taught or suggested herein. Also, in any method or process disclosed herein, the acts or operations making up the method/process may be performed in any suitable sequence and are not necessarily limited to any particular disclosed sequence. Accordingly, the scope of each of the inventions disclosed herein is to be determined according to the following claims and their equivalents.

1. (canceled)

2. A root canal filler for a tooth, comprising:

a multiplicity of relatively large particles sized to form a plug in a canal space proximate an apex of the tooth; and

a multiplicity of relatively small particles sized to at least substantially fill the remainder of the canal space.

3. The root canal filler of claim **2**, wherein sizes of the relatively large particles are in a range from about 35 microns to about 200 microns.

4. The root canal filler of claim **2**, wherein sizes of the relatively small particles are in a range from about 2 microns to about 30 microns.

5. The root canal filler of claim **2**, wherein at least some of the relatively large particles or the relatively small particles comprise a ferromagnetic core substantially surrounded with a hydrophobic coating.

6. The root canal filler of claim **5**, wherein the hydrophobic coating comprises polyorganosiloxanes, polyorganosilanes, or a mixture thereof.

7. The root canal filler of claim **2**, wherein the multiplicity of relatively small particles is sized to at least substantially fill side canals and other canal spaces extending laterally from the canal space.

8. (canceled)

9. (canceled)

10. (canceled)

11. (canceled)

12. A system comprising:

a filling material comprising a plurality of particles responsive to a non-contacting energy field, said filling material configured to at least partially fill a root canal space of a tooth; and

a manipulator configured to produce the non-contacting energy field and to manipulate the filling material without physically contacting the filling material during filling of the root canal space of the tooth, the non-contacting energy field comprising electric energy or ultrasound energy, the manipulator configured to be positionable near the tooth and to provide sufficient non-contacting energy to at least partially liquefy at least some of the filling material in the root canal space.

13. A method for filling a root canal space of a tooth, comprising:

using a non-contacting energy field to at least partially liquefy a filling material in a root canal space during filling of the root canal space,

wherein the non-contacting energy field comprises electric energy or ultrasound energy.

14. The root canal filler of claim **2**, further comprising a hydrophilic material.

15. The root canal filler of claim **14**, wherein the hydrophilic material comprises a reversible hydrocolloid.

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