

## Complex Apical Anatomy Revealed Following Endodontic Treatment of a Maxillary Molar Using the GentleWave System: A Case Report

Michael W Ford<sup>\*</sup>

Endodontic Associates of Central Texas, Harker Heights, TX, USA

<sup>\*</sup>Corresponding author: Michael W Ford, DDS, MS, Endodontic Associates of Central Texas, Harker Heights, TX, USA, Tel: (254) 554-3636; Fax: (254) 519-3638; E-mail: dr.michael.ford@gmail.com

Received date: July 17, 2017; Accepted date: July 31, 2017; Published date: August 07, 2017

Copyright: © 2017 Ford MW. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

### Abstract

**Introduction:** Primary root canal treatment success depends on a number of variables, including debridement and disinfection of the root canal system to remove all bacteria and diseased pulpal and dentinal tissues. Complex root canal anatomy, such as concealed isthmuses, apical deltas and lateral canals, hinder this objective, making instrumentation of these regions nearly impossible. Recent advancements within the endodontic space have focused on improved cleaning and disinfection techniques that will enhance cleaning and debridement, even in difficult to navigate anatomy within the apical third.

**Background:** This case study explores the effectiveness of the GentleWave® Procedure in treating a maxillary second molar diagnosed with irreversible pulpitis and symptomatic apical periodontitis that also featured complex apical root canal anatomy that was undetected until obturation was completed.

**Methods:** A minimally invasive endodontic protocol was utilized to maximize preservation of tooth structure. The tooth was conservatively accessed followed by minimal instrumentation to a size 25/04 for creation of a fluid path and to facilitate future placement of root canal obturation material. Multisonic Ultracleaning™ and debridement were accomplished with the GentleWave Procedure. After obturation with gutta-percha and sealer, a final radiograph revealed a clinically significant obturation with previously unseen lateral canals and an isthmus within the apical third.

**Results:** The previously diagnosed symptomatic apical periodontitis had fully resolved by the three-week follow-up visit. This case report demonstrates a viable minimally invasive endodontic treatment for uncovering root canal systems with complex apical anatomy utilizing the GentleWave Procedure.

**Keywords:** Gentlewave Procedure; Multisonic Ultracleaning; Complex root anatomy; Minimally invasive; Apical anatomy; Preservation; Debridement

### Introduction

Successful non-surgical endodontic therapy is generally dependent on two main factors: the elimination of bacteria from the root canal system, and the prevention of reinfection. The success rate of non-surgical endodontics has been fairly consistent over the years, ranging from 67-80% [1-4]. Of the cases that do fail, a plethora of potential causes have been attributed, including untreated canals [5], the persistence of bacteria, and instrumentation errors such as the creation of perforations and ledges. The presence of complex root canal anatomy can contribute to all of these causes of failure [6,7]. Lateral and accessory canals, bifurcations, isthmuses, apical deltas, and curved roots can be both difficult to locate and to navigate, leading to bacteria being inadvertently left behind [8]. Such tortuous root canal systems contain inaccessible regions that demand a heavier reliance on debridement and irrigation techniques to disinfect the inaccessible regions prior to obturation [9].

In a review of available clinical study literature, healing rates following endodontic treatment vary when performed with different endodontic techniques [1-4]. The rate of healing after non-surgical

endodontic therapy has been reported by Murphy et al. [4], as 70.6%. In the CONSORT clinical trial, 67% of treated teeth were healed when endodontic treatment was performed with a minimum nickel-titanium rotary file size of #35 along with irrigation of 5.25% sodium hypochlorite [2]. One report by Pettiette et al. [3], showed NiTi-files were successful in 80% of the treated teeth and K-files in 43% of treated teeth. A meta-analysis performed by Ng et al. [1], demonstrated weighted-pooled success rates of 67.7% as determined by healing for endodontic treatment. These varying endodontic success rates expose the need for an endodontic technique that can provide consistent success rates achieved from effective debridement and disinfection.

Current endodontic techniques include mechanical instrumentation and irrigation. Mechanical instrumentation is required to enlarge the root canals to allow for access of irrigants [10]. Therefore, larger apical preparations and tapers have been related to improved disinfection and cleaning procedures [11,12]. The challenge with apical enlargement is the various complications it can lead to, including apical transportation, ledges, and instrument separation, as well as the removal of greater natural tooth structure, which may lead to root fractures [13]. In addition, after mechanical instrumentation up to 35-50% of the root canal system may remain untouched, regardless of the file system used for cleaning and shaping [14,15]. Irrigants that are commonly used in combination with mechanical instrumentation

include sodium hypochlorite (NaOCl) and chlorhexidine (CHX). These irrigants have traditionally been delivered into the root canal system via syringes and metal irrigation needles of various sizes. Yet historically, these irrigants have limited access to the apical 3 mm of the root canal during standard root canal treatment [16]. In addition, syringe based irrigation is reported to display weaker than optimal shear force on the canal wall than necessary for debriding biofilms [9]. This standard approach often yields less than ideal results, particularly when attempting to reach more peripheral regions, such as lateral canals, isthmuses, and the apical region [17], and therefore the need for more effective endodontic techniques has grown.

The past two decades have witnessed an explosion in advanced dental technology, some of which has taken aim at addressing shortcomings in the field of endodontics. Many of these endodontic advances have centered around improving cleaning techniques. These have included ultrasonic irrigation, negative pressure irrigation, sonic irrigation, photo-induced photo-acoustic streaming (PIPS), and laser technologies, but most have yielded disappointing study results to date [18-21]. According to the literature, the safety, effectiveness and reliability of these technologies have come into question [19,20,22,23]. Photo-induced photo-acoustic streaming and conventional needle-syringe configurations may result in extrusion of irrigants caused by positive pressure at the apex [22]. Long term success may be unsustainable due to the insufficient tissue, debris and biofilm cleaning with even contemporary techniques [1,19-20,22,23]. The EndoVac System (Discus Dental, Culver City) has been shown to have similar rates of cleaning to a conventional needle irrigation system and is not able to successfully remove all debris from complex anatomy [24,25]. Reports demonstrate long-term healing rates are hindered by increased dentin removal required to facilitate penetration of irrigants into the apical third of the root canal system using these techniques [1,26].

One of the more recent technologies aimed at improving root canal cleaning is the GentleWave® System (Sonendo, Laguna Hills, CA). The GentleWave® Procedure is completed utilizing Multisonic Ultracleaning™ where cavitation propagates multisonic acoustic waves throughout the root canal system and enhances root canal cleaning and disinfection through advanced fluid dynamics, acoustics, and tissue dissolution chemistry [27-29]. Haapasalo et al. [30], reported seven times faster tissue dissolution with the GentleWave System than standard root canal techniques, including the use of sonic and ultrasonic devices. Sodium hypochlorite penetration in the apical third was approximately four times greater with the GentleWave System than active ultrasonic activation, yet the system has been shown to cause minimal dentin erosion [27-29]. In addition, the GentleWave System has been reported to be effective in removing separated hand files from the apical and middle thirds of molar root canal systems without the need for increased canal enlargement. Clinical studies evaluating the GentleWave Procedure have demonstrated high success rates of 97% at 6 and 12-months after the GentleWave Procedure [18-32].

This present case report depicts the endodontic treatment of a maxillary second molar with complex apical root anatomy that was revealed after utilizing the GentleWave Procedure. In addition to the presence of a second mesiobuccal canal, the tooth featured multiple lateral canals and an isthmus in the apical third, which were not visualized in the initial periapical radiograph and became evident only after treatment with the GentleWave Procedure and subsequent obturation.

## Case Report

A 44-year old female with a history of hypertension was referred for endodontic evaluation. The patient presented to the clinic with a chief complaint of extreme cold sensitivity, and pressure with pain when biting. The patient reported a current pain level of 3 on a 10-point verbal pain scale.

Clinical examination of the second right maxillary molar (#2) revealed sensitivity to percussion, selective biting pressure on the mesiobuccal and distobuccal cusps, and buccal sensitivity to palpation. No mobility, soft tissue lesions, furcation involvement, or root resorption was noted. Vitality testing with a carbon dioxide ice stick was inconclusive; however, cold water administered via monojet syringe elicited an immediate response and duplicated the spontaneous throbbing pain the patient had reported. Radiographic examination demonstrated a minor preexisting restoration on the subject tooth (Figure 1).



**Figure 1:** Preoperative Periapical Radiograph of Tooth #2.

Based on the patient's self-reported history of symptoms and clinical findings, a pulpal diagnosis of symptomatic irreversible pulpitis, secondary to cracked tooth syndrome, and a periapical diagnosis of symptomatic apical periodontitis was made. After a review of patient options, root canal treatment was recommended in an attempt to salvage the tooth and the patient consented to treatment.

A standard anesthesia protocol was administered using 2% lidocaine (72 mg) with 1:100,000 epinephrine and 0.5% bupivacaine hydrochloride (9 mg) with 1:200,000 epinephrine via buccal and palatal infiltration (The Wand®, Single Tooth Anesthesia® System, Milestone Scientific, Inc., USA). The tooth was isolated with a dental dam and all treatment was completed under a dental operating microscope (Global™ Surgical Corporation, USA).

A minimal, straight-line, conservative endodontic access opening was created with a 245 bur (SS White®, USA). Upon entry to the pulp chamber, the 245 bur was changed to an Endo-Z™ bur (Dentsply Maillefer, Switzerland) to outline the pulpal floor and provide a file glide path. Initial examination of the pulp chamber floor revealed no catastrophic internal fracture line in the pulp chamber. There were three distinct canals noted: palatal, distobuccal, and mesiobuccal-1. Cone-beam computed tomography (CBCT) from a previous examination had revealed the radiographic presence of a mesiobuccal-2 canal. Light troughing excavation with stainless and tungsten steel burs coupled with magnification revealed the presence of the mesiobuccal-2 canal. Mechanical instrumentation began with 6 K-type files and led to a final file size of EdgeFile® X7 (EdgeEndo™, Albuquerque, NM) rotary file size 25. Instrumentation was performed to create a fluid path and enable obturation of the root canal system following the GentleWave Procedure.

In order to maintain a sealed environment for optimum Multisonic Ultracleaning during the GentleWave Procedure, a temporary build-up utilizing Kool-Dam™ (PulpDent®, Watertown, USA) was placed. The GentleWave Procedure was then completed to deliver distilled water, sodium hypochlorite and ethylenediaminetetraacetic acid (EDTA) throughout the root canal system. After drying the root canals, re-examination of the pulp chamber revealed no internal fractures. Obturation was completed with gutta-percha and AH Plus® Sealer (Danaheer, Kerr Endodontics, Orange, California), using a continuous wave warm vertical compaction technique followed by a warm vertical backfill. The access cavity was sealed with composite and final periapical radiographs were taken.

Post-operative radiographs taken at the completion of the endodontic treatment (Figure 2) revealed complex apical anatomy that was previously unrealized prior to the GentleWave® Procedure. These complex anatomies occurred within three of the four root canals of the tooth and presented as multiple lateral canals within the apical region of the palatal canal and an isthmus joining the two mesiobuccal canals. All complex anatomies were visible as clinically significant obturation.



**Figure 2:** Postoperative Periapical Radiographs of Tooth #2. The two periapical radiographic angles highlight the complex apical anatomy visualized post obturation which is most likely attributed to the cleaning and debridement ability provided by the GentleWave® Procedure.

When the patient was contacted for a post-operative follow-up, the patient reported a pain level of zero on a 10-point verbal pain scale. At the 1-week recall, clinical examination revealed mild sensitivity to bite pressure via a cotton roll however, no sensitivity to percussion or palpation and no mobility or soft tissue lesions were noted. By the 3-week recall, the patient was asymptomatic and no further clinical signs or symptoms were present. A cast restoration was not yet placed, and the patient was reminded not to bite or chew on the tooth until protected. Apparent complete resolution of the apical periodontitis was noted.

## Discussion

According to the literature, teeth with complex root anatomy are more susceptible to endodontic treatment failure. Tabassum et al. reported the incidence of missed canals to be the main cause of failure in 42% of 1100 failed root canal treatments [7]. An analysis by Song et al. revealed the causes of failure among 493 of root canal treated teeth were due to a missing canal in 19.7% of cases and due to anatomical complexity in 8.7% of cases [6].

The naturally occurring complex root canal morphologies, such as lateral canals, isthmuses, fins, C- and S-shaped canals, and varying other canal configurations, are relatively common and present

additional challenges in cleaning, shaping, and obturation [33-35]. Studies show that 29.4% of maxillary molars have lateral canals and 20.2% of distal roots in molars exhibit isthmuses [36-39]. These lateral canals and isthmuses are nearly impossible to instrument and can only be cleaned by effective antimicrobial irrigation. Literature indicates that in the past, sealing lateral canals has only been moderately successful [40]. After endodontic instrumentation, anatomical variations typically contain tissue remnants, bacteria, and dentin shavings that inhibit the ability of irrigation fluids to reach areas of the root canal system [41,42]. Additionally, over-enlargement or excess dentin removal from instrumentation can result in perforation, root fractures or other endodontic mishaps [12,43,45]. Therefore, the need for newer, more innovative technology to enhance cleaning and irrigation for endodontic therapy has only grown as the understanding of the true complexity of the naturally occurring root canal system is understood.

An endodontic treatment, the GentleWave Procedure, was thus designed to improve cleaning and disinfection utilizing Multisonic Ultracleaning. The GentleWave Procedure delivers distilled water, sodium hypochlorite, and ethylenediaminetetraacetic acid (EDTA) throughout the root canal system using advanced fluid dynamics, acoustics, and tissue dissolution chemistry to clean and disinfect the entire root canal system, even in areas of the root canal system often untouched or undetected by standard techniques. Haapasalo, et al. [30], reported the GentleWave Procedure provides seven times faster tissue dissolution than standard root canal therapy devices, including ultrasonic based irrigation devices. Clinical study results on apical pressure testing, as published by Haapasalo et al. [45], show negative pressure being generated at the apex when utilizing the GentleWave Procedure as compared to positive apical pressures being generated when using syringe irrigation devices. A histological study of 45 endodontically treated molars compared root canal debridement efficacy of standard rotary instrumentation with needle irrigation versus minimal instrumentation with the GentleWave Procedure. Results revealed 97.2% cleaning and debridement capabilities for the GentleWave System as compared to 67.8% for standard root canal therapy [46]. A multicenter, prospective study of 75 molars treated with the GentleWave Procedure showed a 97% success rate at 12 months with 96.2% of patients being free from severe and moderate post-treatment pain in the first two postoperative days and no incidence of pain reported by day 14 [32].

As discussed, irrigants have limited access to the apical 3 mm of the root canal system during endodontic treatment [16]. The GentleWave Procedure however, shows promise for cleaning this region. Vandrangi, et al. [27], reported that sodium hypochlorite penetration in the apical third was four times more effective with the GentleWave Procedure than active ultrasonic activation, yet the GentleWave Procedure was shown to cause minimal dentin erosion [29]. When complex anatomies are successfully obturated after utilizing a minimally invasive endodontic protocol with the GentleWave Procedure, as in this case report, it implies that cleaning has occurred in the area of the root canal system untouched by the endodontic files during the procedure.

This present case report features a complex apical anatomy in three of the four canals of a maxillary second molar. The palatal canal contained multiple lateral canals and the two mesiobuccal canals were joined through an isthmus, all within the apical thirds of the canals. These apical complex anatomies were not evident on the initial periapical radiographs or during the minimal shaping process,



although it should be noted that navigating these anatomies via mechanical instrumentation would not have been possible even if they had been detected. Improper cleaning and debridement of these complex anatomies would likely have resulted in residual bacteria, debris or smear layer, and would have greatly increased the chances of postoperative pain and endodontic failure. The apical cleaning and debridement within the apical third using the GentleWave Procedure allowed the subsequent obturation of these complex anatomies and likely contributed to the patient's favorable endodontic outcome.

## Conclusion

In the present case report, the lateral canals and the isthmus in the apical region were neither visible nor accessible for instrumentation or irrigation with standard endodontic techniques. Furthermore, had they been visible, any attempts to navigate such complex apical anatomies would have required excessive dentin removal to access, putting the tooth at higher risk for file separation, perforation or root fracture, and compromising the overall integrity of the tooth structure. By using the GentleWave Procedure, the complex apical anatomies were debrided and disinfected, and the canals were minimally instrumented. This report demonstrates the GentleWave Procedure as a viable endodontic treatment option for uncovering complex apical anatomies while providing the added benefit of conserving more tooth structure through minimally invasive techniques.

## Acknowledgements

The author would like to thank Dr. Stephanie Cravens for providing medical writing support.

## Disclosure

None

## References

1. Ng YL, Mann V, Rahbaran S (2007) Outcome of Primary Root Canal Treatment: Systematic Review of the Literature-Part 1. Effects of Study Characteristics on Probability of Success. *Int Endod J* 40: 921-939.
2. Penesis VA, Fitzgerald PI, Fayad MI (2008) Outcome of One-Visit and Two-Visit Endodontic Treatment of Necrotic Teeth with Apical Periodontitis: A Randomized Controlled Trial with One-Year Evaluation. *Int Endod J* 34: 251-257.
3. Pettiette MT, Delano EO, Trope M (2001) Evaluation of Success Rate of Endodontic Treatment Performed by Students with Stainless-steel K-Files and Nickel-titanium Hand Files. *J Endod* 27:124-127.
4. Murphy WK, Kaugars GE, Collett WK, Dodds RN (1991) Healing of Periapical Radiolucencies After Nonsurgical Endodontic Therapy. *Oral Surg Oral Med Oral Pathol* 71: 620-624.
5. Weine FS, Healey HJ, Gerstein H, Evanson L (2012) Canal Configuration in the Mesio Buccal Root of the Maxillary First Molar and its Endodontic Significance. *J Endod* 38: 1305-1308.
6. Song M, Kim HC, Lee W, Kim E (2011) Analysis of the Cause of Failure in Nonsurgical Endodontic Treatment by Microscopic Inspection During Endodontic Microsurgery. *J Endod* 37: 1516-1519.
7. Tabassum S, Khan FR (2016) Failure of Endodontic Treatment: The Usual Suspects. *Eur J Dent* 10: 144-147.
8. Ricucci D, Siqueria JF (2010) Fate of the Tissue in Lateral Canals and Apical Ramifications in Response to Pathologic Conditions and Treatment Procedures. *J Endod* 36: 1-15.
9. Kishen A, Peters O, Zehnder M, Diogenes A, Nair M (2016) Advances in Endodontics: Potential Applications in Clinical Practice. *J Conserv Dent* 19: 199-206.
10. Amoroso-Silva P, Alcalde MP, Duarte MA, de Deus G, Ordinola-Zapata R, et al. (2016) Effect of Finishing Instrumentation Using Niti Hand Files on Volume, Surface Area and Uninstrumented Surfaces in C-shaped Root Canal Systems. *Int Endod J* 50: 604-611.
11. De-Deus G, Marins J, Silva EJ, Souza E, Blladonna FG (2015) Accumulated Hard Tissue Debris Produced During Reciprocating and Rotary Nickel-Titanium Canal Preparation. *J Endod* 41(5):676-681.
12. Paraskevopoulou MT, Khabbaz MG (2016) Influence of Taper of Root Canal Shape on the Intracanal Bacterial Reduction. *Open Dent J* 10: 568-574.
13. Haapasalo M, Endal U, Zandi H, Coil JM (2005) Eradication of Endodontic Infection by Instrumentation and Irrigation Solutions. *Endodontic Topics* 10: 77-102.
14. Parris J, Wilcox L, Walton R (1994) Effectiveness of Apical Clearing: Histological and Radiographical Evaluation. *J Endod* 20: 219-224.
15. Peters OA, Schöenberger K, Laib A (2001) Effects of Four Ni-Ti Preparation Techniques on Root Canal Geometry Assessed by Micro Computed Tomography. *Int Endod J* 34: 221-230.
16. Senia ES, Marshall FJ, Rosen S (1971) The Solvent Action of Sodium Hypochlorite on Pulp Tissue of Extracted Teeth. *Oral Surg Oral Med Oral Pathol* 31: 96-103.
17. Haapasalo M, Shen Y, Qian W, Gao Y (2010) Irrigation in Endodontics. *Dent Clin North Am* 54: 291-312.
18. Sigurdsson A, Le KT, Woo SM, Rassoulian SA, McLachlan K, et al. (2016) Six-month Healing Success Rates After Endodontic Treatment Using the Novel GentleWave™ System: The PURE Prospective Multi-center Clinical Study. *J Clin Exp Dent* 8: e290-e298.
19. Munoz HR, Camacho-Cuadra K (2012) In Vivo Efficacy of Three Different Endodontic Irrigation Systems for Irrigant Delivery to Working Length of Mesial Canals of Mandibular Molars. *J Endod* 38: 445-448.
20. Beus C, Safavi K, Stratton J, Kaufman B (2012) Comparison of the Effect of Two Endodontic Irrigation Protocols on the Elimination of Bacteria from Root Canal System: A Prospective, Randomized Clinical Trial. *J Endod* 38: 1479-1483.
21. Li D, Jiang S, Yin X, Wen J, Chang W, et al. (2015) Efficacy of Needle, Ultrasonic, and Endoactivator Irrigation and Photon-Induced Photoacoustic Streaming in Removing Calcium Hydroxide From the Main Canal and Isthmus: An in Vitro Micro-Computed Tomography and Scanning Electron Microscopy Study. *Photomed Laser Surg* 33: 330-337.
22. Tay FR, Gu L, Schoeffel GJ, Wimmer C, Susin L (2010) Effect of Vapor Lock On Root Canal Debridement by Using a Side-Vented Needle for Positive-Pressure Irrigant Delivery. *J Endod* 36: 745-750.
23. Yost RA, Bergeron BE, Kirkpatrick TC, Roberts MD, Roberts HW (2015) The EndoVac and EndoActivator Groups Produced Significantly Less Extrusion than PIPS Irrigation. *J Endod* 4: 1530-1534.
24. Buldur B, Kapdan A (2017) Comparison of the Antimicrobial Efficacy of the EndoVac System and Conventional Needle Irrigation in Primary Molar Root Canals. *J Clin Pediatr Dent* 41: 284-288.
25. Keleş A, Alçin H, Sousa-Neto, Versiani MA (2016) Supplemental Steps for Removing Hard Tissue Debris from Isthmus-containing Canal Systems. *J Endod* 42: 1677-1682.
26. Saini HR, Tewari S, Sangwan P, Duhan J, Gupta A (2012) Effect of Different Apical Preparation Sizes on Outcome of Primary Endodontic Treatment: A Randomized Controlled Trial. *J Endod* 38: 1309-1315.
27. Wang Z, Maezono H, Shen Y, Haapasalo M (2016) Evaluation of Root Canal Dentin Erosion after Different Irrigation Methods Using Energy-dispersive X-ray Spectroscopy. *J Endod* 42:1834-1839.
28. Charara K, Friedman S, Sherman S, Kishen A, Malkhassian G, (2016) Assessment of Apical Extrusion during Root Canal Irrigation with the Novel GentleWave System in a Simulated Apical Environment. *J Endod* 42: 135-139.

29. Vandrangi P (2016) Evaluating Penetration Depth of Treatment Fluids into Dentinal Tubules Using the GentleWave® System. *Dentistry* 6: 366.
30. Haapasalo M, Wang Z, Shen Y, Curtis A, Patel P, et al. (2014) Tissue Dissolution by a Novel Multisonic Ultracleaning System and Sodium Hypochlorite. *J Endod* 40: 1178-1181.
31. Wohlgemuth P, Cuocolo D, Vandrangi P, Sigurdsson A (2015) Effectiveness of the GentleWave System in Removing Separated Instruments. *J Endod* 41:1895-1898.
32. Sigurdsson A, Garland RW, Le KT, Woo SM (2016) 12-month Healing Rates after Endodontic Therapy Using the Novel GentleWave System: A Prospective Multicenter Clinical Study. *J Endod* 42: 1040-1048.
33. Christie WH, Peikoff MD, Fogel HM (1991) Maxillary Molars with Two Palatal Roots: A Retrospective Clinical Study. *J Endod* 17: 80-84.
34. Von Arx T, Steiner RG, Tay FR (2011) Apical Surgery: Endoscopic Findings at the Resection Level of 168 Consecutively Treated Roots. *Int Endod J* 44: 290-302.
35. Vertucci FJ (2005) Root Canal Morphology and its Relationship to Endodontic Procedures. *Endodontic Topics* 10: 3-29.
36. Herbranson E (2014) The Anatomy of the Root Canal System as a Challenge to Effective Disinfection, in *Disinfection of Root Canal Systems: The Treatment of Apical Periodontitis*, John Wiley & Sons, Inc., Hoboken, NJ, USA.
37. Goel NK, Gill KS, Taneja JR (1991) Study of Root Canal Configuration in Mandibular First Permanent Molars. *J Indian Soc Pedod Prev Dent* 8: 12-14.
38. DeOliveira SH, DeMoraes LC, Faig-Leite H, Camargo SE, Camargo CH (2009) In vitro Incidence of Root Canal Bifurcation in Mandibular Incisors by Radiovisiography. *J Appl Oral Sci* 17: 234-239.
39. Hartwell G, Bellizzi R (1982) Clinical Investigation of In Vivo Endodontically Treated Mandibular and Maxillary Molars. *J Endod* 8: 555-557.
40. Carotte P (2004) Endodontics: Part 4 Morphology of the Root Canal System. *Br Dent J* 197: 379-383.
41. Gu LS, Kim JR, Ling J, Choi KK, Pashley DH, et al. (2009) Review of Contemporary Irrigant Agitation Techniques and Devices. *J Endod* 35: 791-804.
42. Khademi A, Yazdizadeh M, Feizianfard M (2006) Determination of the Minimum Instrumentation Size for Penetration of Irrigants to the Apical Third of Root Canal Systems. *J Endod* 32: 417-420.
43. Lertchirakarn V, Palamara JE, Messer HH (2003) Patterns of Vertical Root Fracture: Factors Affecting Stress Distribution in the Root Canal. *J Endod* 29: 523-528.
44. Reuben J, Velmurugan N, Vasanthi S, Priya, Vijayalakshmi (2008) Endodontic Management of a Maxillary Second Premolar with an S-shaped Root Canal. *J Conserv Dent* 11: 168-170.
45. Haapasalo M, Shen Y, Wang Z, Park E, Curtis A (2016) Apical Pressure Created During Irrigation with the GentleWave™ System Compared to Conventional Syringe Irrigation. *Clin Oral Investig* 20: 1525-1534.
46. Molina B, Glickman G, Vandrangi P, Khakpour M (2015) Evaluation of Root Canal Debridement of Human Molars Using the GentleWave System. *J Endod* 41: 1701-1705.