

# Orthodontically Induced Inflammatory Root Resorption. Part II: The Clinical Aspects

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**Abstract:** Over the past 10 years, orthodontically induced inflammatory root resorption (OIIRR) has been increasingly recognized as an iatrogenic consequence of orthodontic treatment. With this in mind, orthodontists should take all known measures to reduce the occurrence of OIIRR. The evidence that we present in this review suggests several procedures known today that can avert this phenomenon; however, none of them can be relied on to completely prevent OIIRR. We believe that future studies might clarify the exact cause and course of OIIRR and, hopefully, help eliminate it. In Part I, we discussed the basic sciences aspects of OIIRR; in Part II, we present the clinical aspects of this phenomenon. (*Angle Orthod* 2002;72:180–184.)

**Key Words:** Root resorption; Orthodontic treatment; Review

## THE CLINICAL ASPECTS OF OIIRR

Several reviews on root resorption have been published in the last 10 years.<sup>1–5</sup> During this period, significant progress in understanding the actual process has been achieved. A new term related to this phenomenon has been coined: the iatrogenic consequence<sup>1,6,7</sup> of orthodontic treatment. This expression is replacing previously used terms such as idiopathic outcome,<sup>4,5</sup> frequent complication,<sup>8–10</sup> common consequence,<sup>11,12</sup> and ubiquitous concomitant<sup>13</sup> of orthodontic treatment.

Root resorption is a universal term that describes a pathologic process for which no etiologic component is engaged in the expression. Trauma, periapical infectious lesions, and periodontal diseases are only a few of the many known etiologic factors leading to root resorption or root shortening. Although, the outcome is frequently similar, orthodontic root resorption is distinct from the other type of root resorption. Accordingly, based on the actual process, we hereby suggest a new term: *orthodontically induced inflammatory root resorption* (OIIRR).<sup>14</sup>

OIIRR is a sterile inflammatory process that is extremely complex and composed of various disparate components including forces, tooth roots, bone, cells, surrounding matrix, and certain known biologic messengers. It is therefore

not surprising to find that terms such as individual susceptibility,<sup>15,16</sup> genetics,<sup>17</sup> and systemic factors<sup>18</sup> are being discussed when damage is evident after otherwise successful orthodontic treatment.

In 1993, we reported on most published research reports on root resorption in a comprehensive review.<sup>4,5</sup> In those reviews, we listed 17 clinical considerations related to root resorption. Since orthodontists must take all known measures to try to prevent or diminish this iatrogenic phenomenon, the objective of this paper is to review, update, and summarize clinical steps that should be considered by the orthodontist as they relate to OIIRR.

## Before treatment

*General considerations.* The patient/parents must be informed about the risk of OIIRR as a consequence of orthodontic treatment. Root resorption should be discussed during consultation.<sup>5</sup> Every informed consent form signed by the patient/parents (and the orthodontist) should specifically outline the risk of OIIRR.<sup>19</sup> The rule of thumb is better to inform early than to later apologize. A well-trained orthodontist can discuss the risk and reward principle as well as the individual susceptibility to OIIRR with the patient and parents.<sup>15,16</sup> It is obvious that if the orthodontist decides to initiate treatment after reviewing all of the relevant data collected, the expected esthetic and functional benefits far outweigh the minor root changes observed in most patients.<sup>20</sup>

*Familial considerations.* A recent study<sup>20</sup> has confirmed previous results concerning the strong familial association of OIIRR. When treating a new patient whose close sibling was previously treated, orthodontists should try to obtain the final diagnostic records including the radiographs of any

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treated siblings. The need for full final diagnostic records is an ongoing, unresolved issue as many orthodontists argue that posttreatment exposure to radiation is unnecessary. Final diagnostic radiographs obviously rarely help the patient involved, but they can prove invaluable in the subsequent treatment of siblings. By adding the familial/sibling medical prevention argument to this debate, the 'pro final radiograph' view could gain the upper hand.

Sameshima and Sinclair<sup>21</sup> have recently reported that white and Hispanic patients are more vulnerable than Asian patients to OIIRR. As the actual genetic transmission presently remains unclear, further genetic study is required.

**General health.** The systemic condition of the patient should be carefully considered. Only sporadic publications concerning this issue have been reported.<sup>22</sup> It was recently reported that patients with chronic asthma, both medicated or nonmedicated, have an increased incidence of OIIRR that is confined to a slight blunting of the maxillary molars.<sup>18,23</sup> This finding might result from the close proximity of the roots to the inflamed maxillary sinus and/or the presence of inflammatory mediators in these patients.<sup>18,24</sup> An interesting study by Owman-Moll and Kurol<sup>25</sup> found that patients with allergies have an increased risk of OIIRR, although these findings were not statistically significant.

**Gender.** Most studies have not found a consistent association between gender and OIIRR.<sup>17,21,26</sup> In a group of adult (aged >20 years) orthodontic patients, Baumrind et al<sup>13</sup> found a greater prevalence of OIIRR in men than in women. In contrast, Kjar<sup>27</sup> found a greater prevalence of OIIRR in girls than in boys.

**Age.** Since all recent studies<sup>13,17,26,28–31</sup> with the exception of two studies<sup>21,32</sup> have found no relationship between OIIRR and chronological age, chronological age may not be a significant factor in the occurrence of OIIRR.

**The dentition.** Orthodontic treatment does not stop root development. Teeth with incomplete root formation at the onset of orthodontic treatment continue to develop roots during treatment, but the roots reach somewhat less than their expected root length potential.<sup>26</sup>

Two sequential orthodontic treatment procedures, one administered during adolescence and the other administered later during adulthood, not only failed to increase the extent of OIIRR, but, curiously, decreased it.<sup>32</sup> Does early treatment followed by phase II treatment serve as a protective factor limiting OIIRR?<sup>10,32</sup>

Parameters that should be evaluated from radiographs include root morphology, endodontic treatment, bone morphology, agenesis, aplasia, ectopy, and transplanted teeth. Pretreatment root shapes including root morphology should be assessed with appropriate radiographs.<sup>10,21,27,33,34</sup> Invagination and taurodontism<sup>27</sup> have been found to be risk factors for OIIRR on force induction. Normal<sup>21</sup> as well as small and peg-shaped laterals<sup>32</sup> have been reported not to be associated with a higher risk of OIIRR. Endodontically treated incisors are less vulnerable to OIIRR when com-

pared with normal teeth.<sup>29,31</sup> However, one animal study demonstrated that root-filled teeth showed greater loss of cementum after tooth movement.<sup>35</sup>

Alveolar bone width<sup>10,36</sup> and close proximity of the roots to the cortical plates<sup>33,37</sup> have been studied. Unfortunately, no conclusive results can be drawn from these studies. It is important to note that Wehrbein et al,<sup>38</sup> as a consequence of their findings, expressed grave concern relating to OIIRR. The question of whether the increased occurrence of OIIRR found in their study was due to the contact of the root with the surrounding soft tissue or with the condensed cortical bone remains to be answered.

Hypodontia or partial anodontia puts existing teeth at risk for OIIRR,<sup>27,39</sup> yet conflicting data are reported as well.<sup>34,40,41</sup> Similar controversial findings have been reported for ectopic teeth.<sup>27,34</sup>

When a patient has transplanted teeth, orthodontists are advised to wait at least three months after transplantation before exerting force on the teeth.<sup>42</sup> With regard to the risk of OIIRR, fully assimilated transplanted teeth react to orthodontic force in a way comparable to that of normal teeth.<sup>42</sup>

**The malocclusion.** Dental as well as skeletal malocclusions should be considered cautiously with respect to OIIRR. Numerous factors come to bear in the development and treatment of each malocclusion. It is therefore not surprising to find numerous conflicting and controversial conclusions in recent and past studies alike. No malocclusion is immune to OIIRR.\*

### Treatment of choice

Is there a preferable appliance or force system for preventing OIIRR? Numerous studies comparing alternative treatment systems have been performed over the years. Previously, no study could demonstrate a clear advantage of one system over the others. Although several studies have been published in the last decade, it is still impossible to point out a system that will reduce or eliminate the OIIRR phenomenon with a degree of certainty (S. Geron and N. Brezniak, personal communication).<sup>6,12,33,39,45–51</sup> In this section, we include studies that addressed both the bracket type (SE, SW, Begg, SPEED, Lingual in different slot sizes, and other known names) and the methods (continuous vs segmental wires<sup>12</sup>; the use of rectangular wires<sup>33,39</sup>; different rapid maxillary expansion systems<sup>47,51</sup>; type of orthodontic movement<sup>13,31,36,42,45,46</sup>; continuous vs intermittent<sup>9</sup>/interrupted<sup>15</sup>/discontinuous<sup>52</sup> forces; and amount or extent of tooth movement<sup>12,13,16,33</sup>).

No orthodontic force can imitate the natural harmless physiologic force.<sup>53</sup> Although no difference in OIIRR has been found at low and high force levels (50 g to 200 g),<sup>54,55</sup> it is still recommended not to overload the teeth with high force levels. High levels of force will tend to increase the

\*References 10, 13, 17, 21, 33, 36, 37, 43, 44.

damaged areas in the periodontal ligament, which may lead to more extensive OIIRR.<sup>56,57</sup> The literature agrees that jiggling<sup>13,58</sup> and movement caused by application of intermaxillary elastics<sup>33,39</sup> are two kinds of movement likely to increase the risk of OIIRR.

### During treatment

1. The new light-force rectangular wires that are used in treatment as initial wires have become very popular in the last decade. According to Proffit and Fields,<sup>58</sup> use of these wires might increase the jiggling movements during the first stage of treatment, exposing the root to more OIIRR. We therefore suggested proceeding with this initial step with caution, until more definitive data are published.
2. Longer intervals between activations remain strongly recommended.<sup>53,59,60</sup>
3. Do extractions of teeth serve as an important factor in the occurrence of OIIRR? Unfortunately, no definitive conclusion has been drawn in reference to this controversial issue.<sup>6,13,26,48,51</sup>
4. A possible correlation between the duration of active treatment and the incidence and extent of OIIRR is an open controversy.<sup>†</sup> Most conclusions have been obtained from clinical studies, whereas a single short-term animal-based study rejected the association between the duration of active treatment and OIIRR.<sup>59</sup>
5. After 6 months of treatment, periapical radiographs of the teeth involved in this treatment should be obtained.<sup>9,61,62</sup> Since, in most published papers, the incisors are the teeth that tend to be most affected,<sup>1,5</sup> the changes in their root shape might project on the overall phenomenon. When OIIRR is detected in the six-month periapical radiograph, treatment should be halted for two to three months with passive archwires.<sup>9</sup> This suggestion can actually be applied to any extensive orthodontic procedure on a mandatory basis. Halting treatment for three months in one arch while working on the other is a practical solution that can be implemented without changing the treatment protocol.
6. When the treatment is durable, periapical radiographs should be obtained, with the following consideration. When minimal OIIRR is present, the aforementioned procedure<sup>60</sup> is sufficient. However, when severe resorption is identified, the treatment goals should be reassessed with the patient; for example, alternative options might include prosthetic solutions to close spaces, releasing teeth from active arches if possible, stripping instead of extracting, and early fixation of resorbed teeth.<sup>20</sup> Orthognathic surgery can also be considered in extreme cases, yet it cannot be relied on to prevent OIIRR.<sup>33,36</sup>

### After treatment

1. Final records including radiographs are recommended and are even mandatory. If OIIRR is present on the final radiographs, the patient/parents should be informed. Final records and radiographs will be useful for the future orthodontic treatment of siblings.<sup>17</sup>
2. For teeth with severe resorption, follow-up radiographic examinations are recommended until OIIRR is no longer evident.<sup>61</sup> In cases of extreme resorption, endodontic treatment may be considered as well.<sup>5,63</sup> It should be noted that cemental repair or termination of the active processes of OIIRR occurs naturally after the removal of bands and brackets.<sup>29,30</sup>
3. Several anecdotal reports<sup>64,65</sup> have demonstrated the stability of teeth with severe resorption over the years. However, the use of teeth with severe resorption as abutment teeth should be reconsidered.<sup>61</sup>
4. Retaining the teeth with fixed appliances should be done with caution. Occlusal trauma of the fixed teeth or segments might lead to extreme OIIRR.<sup>66</sup>

### Diagnostic tools

Radiographs are the most popular tool in the diagnosis procedure. Because of their limitations, regular periapical radiographs might obscure major defects on the root surfaces. More modern imaging technologies such as computed tomography (CT) are currently used strictly for research. Their advantage over conventional radiographs as a diagnostic tool is significant, but CT is a costly procedure and demands special equipment. Buccal and lingual root resorption defects are not visible with currently used imaging technologies. Additional mesial or distal periapical views might increase the accuracy of the diagnosis of OIIRR.<sup>67,68</sup> Digital reconstruction using computer software may also enable more accurate analyses of the extent of root resorption.<sup>69-71</sup>

The sensitivity of conventional and digital radiographs has been found to be similar<sup>62,71</sup>; however, digital systems enable earlier quantification of small alterations in root length. This constitutes a practical advantage over conventional radiographs.<sup>62</sup>

Recent reports by Ericson and Kuroi<sup>72,73</sup> point out the limitations of conventional diagnostic tools used to analyze the damage sustained by the roots. Although periapical, panoramic films and lateral head films might demonstrate normal root morphology, CT can reveal that real damage exists. This confirms Graber's comment in the introduction to Wehrbein's<sup>24</sup> paper, ". . . what we do not see does not mean it does not exist." The future use of sophisticated imaging techniques may change some basic and common ideas concerning OIIRR.

The development of an inexpensive and safe three-di-

<sup>†</sup>References 10, 13, 16, 26, 33, 37, 45, 49, 51.

mensional imaging tool and its routine use for diagnosis in orthodontic patients should be discussed.

### SUMMARY

OIIRR is an iatrogenic consequence of orthodontic treatment. Keeping this in mind, orthodontists should take all known measures to reduce its occurrence. Although several protective procedures have been suggested, none of them can actually prevent OIIRR with any degree of certainty.

We believe that future, more genetically based studies, as well as other basic science research, might clarify the exact nature of OIIRR and hopefully help to prevent or even eliminate this phenomenon.

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### REFERENCES

- Harris EF. Root resorption during orthodontic therapy. *Semin Orthod.* 2000;6:183–194.
- Killiany DM. Root resorption caused by orthodontic treatment: an evidence-based review of literature. *Semin Orthod.* 1999;5:128–133.
- Vlaskalic V, Boyd RL, Baumrind S. Etiology and sequelae of root resorption. *Semin Orthod.* 1998;4:124–131.
- Brezniak N, Wasserstein A. Root resorption after orthodontic treatment: Part 2. Literature review. *Am J Orthod Dentofac Orthop.* 1993;103:138–146.
- Brezniak N, Wasserstein A. Root resorption after orthodontic treatment: Part 1. Literature review. *Am J Orthod Dentofac Orthop.* 1993;103:62–66.
- Blake M, Woodside DJ, Pharoah MJ. A radiographic comparison of apical root resorption after orthodontic treatment with the edge-wise and speed appliances. *Am J Orthod Dentofac Orthop.* 1995;108:76–84.
- Ghafari JG. Emerging paradigms in orthodontics—an essay. *Am J Orthod Dentofac Orthop.* 1997;111:573–580.
- Poumpros E, Loberg E, Engstrom C. Thyroid function and root resorption. *Angle Orthod.* 1994;64:389–393.
- Levander E, Malmgren O, Eliasson S. Evaluation of root resorption in relation to two orthodontic treatment regimes. A clinical experimental study. *Eur J Orthod.* 1994;16:223–228.
- Taithongchai R, Sookorn K, Killany DM. Facial and dentoalveolar structures and the prediction of apical root shortening. *Am J Orthod Dentofac Orthop.* 1996;110:296–302.
- Igarashi K, Adachi H, Mitani H, Shinoda H. Inhibitory effect of topical administration of a biphosphonate (risedronate) on root resorption incident to orthodontic tooth movements in rats. *J Dent Res.* 1996;75:1644–1649.
- Alexander SA. Levels of root resorption associated with continuous arch and sectional arch mechanics. *Am J Orthod Dentofac Orthop.* 1996;110:321–324.
- Baumrind S, Korn EL, Boyd RL. Apical root resorption in orthodontically treated adults. *Am J Orthod Dentofac Orthop.* 1996;110:311–320.
- Brezniak N, Wasserstein A. Orthodontically induced inflammatory root resorption. Part I: the basic science aspects. *Angle Orthod* 2002;72:.
- Owman-Moll P, Kurol J, Lundgren D. Continuous versus interrupted continuous orthodontic force related to early tooth movement and root resorption. *Angle Orthod.* 1995;65:395–401.
- Kurol J, Owman Moll P, Lundgren D. Time related root resorption after application of controlled continuous orthodontic force. *Am J Orthod Dentofac Orthop.* 1996;110:303–310.
- Harris EF, Kineret SE, Tolley EA. A heritable component for external apical root resorption in patients treated orthodontically. *Am J Orthod Dentofac Orthop.* 1997;111:301–309.
- McNab S, Battistutta D, Taverne A, Symons AL. External apical root resorption of posterior teeth in asthmatics after orthodontic treatment. *Am J Orthod Dentofac Orthop.* 1999;116:545–551.
- Machen DE. Risk management concept. *Am J Orthod Dentofac Orthop.* 1989;95:267–268.
- Bednar JR, Wise RJ. A practical clinical approach to the treatment and management of patients experiencing root resorption during and after orthodontic therapy. In: Davidovitch Z, Mah J, eds. *Biological Mechanisms of Tooth Eruption, Resorption and Replacement by Implants.* Boston, Mass: Harvard Society for the Advancement of Orthodontics; 1998:425–437.
- Sameshima GT, Sinclair PM. Predicting and preventing root resorption: Part I. Diagnostic factors. *Am J Orthod Dentofac Orthop.* 2001;119:505–510.
- Runge ME, Edwards DL. Orthodontic treatment for an adolescent with a history of acute lymphoblastic leukemia. *Pediatr Dent.* 2000;22:494–498.
- Davidovitch Z, Godwin S, Young-Guk P, Taverne AAR, Dobeck JM, DeSanctis GT. The etiology of root resorption. In: McNamara JA, Trotman CA, eds. *Orthodontic Treatment: Management of Unfavorable Sequelae.* Ann Arbor, Mich: Center of Human Growth and Development, University of Michigan; 1996:93–117.
- Wehrbein H, Fuhrmann RA, Diedrich PR. Human histologic tissue response after long-term orthodontic tooth movement. *Am J Orthod Dentofac Orthop.* 1995;107:360–371.
- Owman-Moll P, Kurol J. Root resorption after orthodontic treatment in high- and low-risk patients: analysis of allergy as a possible predisposing factor. *Eur J Orthod.* 2000;22:657–663.
- Hendrix I, Carels C, Kuijpers-Jagtman AM, Van 'T Hof M. A radiographic study of posterior apical root resorption in orthodontic patients. *Am J Orthod Dentofac Orthop.* 1994;105:345–349.
- Kjar I. Morphological characteristics of dentitions developing excessive root resorption during orthodontic treatment. *Eur J Orthod.* 1995;16:25–34.
- Harris EF, Baker WC. Loss of root length and crestal bone height before and during treatment in adolescent and adult orthodontic patients. *Am J Orthod Dentofac Orthop.* 1990;98:463–469.
- Owman-Moll P, Kurol J, Lundgren D. Repair of orthodontically induced root resorption in adolescents. *Angle Orthod.* 1995;65(6):403–408.
- Owman-Moll P, Kurol J. The early reparative process of orthodontically induced root resorption in adolescents—location and type of tissue. *Eur J Orthod.* 1998;20:727–732.
- Costopoulos G, Nanda R. An evaluation of root resorption incident to orthodontic intrusion. *Am J Orthod Dentofac Orthop.* 1996;109:543–548.
- Mirabella AD, Artun J. Prevalence and severity of apical root resorption of maxillary anterior teeth in adult orthodontic patients. *Eur J Orthod.* 1995;17:93–99.
- Mirabella AD, Artun J. Risk factors for apical root resorption of maxillary anterior teeth in adult orthodontic patients. *Am J Orthod Dentofac Orthop.* 1995;108:48–55.
- Lee RY, Artun J, Alonzo TA. Are dental anomalies risk factors for root resorption in orthodontic patients? *Am J Orthod Dentofac Orthop.* 1999;116:187–194.
- Mah R, Holland GR, Pehowich E. Periapical changes after ortho-



- dontic movement of root-filled ferret canines. *J Endod.* 1996;22:298–303.
36. Horiuchi A, Hotokezaka H, Kobayashi K. Correlation between cortical plate proximity and apical root resorption. *Am J Orthod Dentofac Orthop.* 1998;114:311–318.
  37. Kaley J, Phillips C. Factors related to root resorption in edgewise practice. *Angle Orthod.* 1991;61:125–132.
  38. Wehrbein H, Bauer W, Diedrich PR. Gingival invagination area after space closure: a histologic study. *Am J Orthod Dentofac Orthop.* 1995;108:593–598.
  39. Levander E, Malmgren O, Stenback K. Apical root resorption during orthodontic treatment of patients with multiple aplasia: a study of maxillary incisors. *Eur J Orthod.* 1998;20:427–434.
  40. Kjaer I. Revisiting root resorption. *Am J Orthod Dentofac Orthop.* 2000;117:23A letter to the editor.
  41. Artun J. Revisiting root resorption. *Am J Orthod Dentofac Orthop.* 2000;118:14A letter to the editor.
  42. Paulsen HU, Andreasen JO, Schwartz O. Pulp and periodontal healing, root development and root resorption subsequent to transplantation and orthodontic rotation: a long-term study of auto-transplanted premolars. *Am J Orthod Dentofac Orthop.* 1995;108:630–640.
  43. Taner T, Ciger S, Sencift Y. Evaluation of apical root resorption following extraction therapy in subjects with Class I and Class II malocclusions. *Eur J Orthod.* 1999;21:491–496.
  44. Harris EF, Butler ML. Patterns of incisor root resorption before and after orthodontic treatment in cases with anterior open bites. *Am J Orthod Dentofac Orthop.* 1992;101:112–119.
  45. Beck BW, Harris EF. Apical root resorption in orthodontically treated subjects: analysis of edgewise and light wire mechanics. *Am J Orthod Dentofac Orthop.* 1994;105:350–361.
  46. Parker RJ, Harris EF. Directions of orthodontic tooth movements associated with apical root resorption of the maxillary central incisor. *Am J Orthod Dentofac Orthop.* 1998;114:677–683.
  47. Everdi N, Okar I, Kucukkeles N, Arbak S. A comparison of two different rapid palatal expansion techniques from the point of root resorption. *Am J Orthod Dentofac Orthop.* 1994;106:47–51.
  48. McNab S, Battistutta D, Taverne A, Symons AL. External apical root resorption following orthodontic treatment. *Angle Orthod.* 2000;70:227–232.
  49. Janson GR, De Luca Canto G, Martins DR, Henriques JF, De Freitas MR. A radiographic comparison of apical root resorption after orthodontic treatment with 3 different fixed appliance techniques. *Am J Orthod Dentofac Orthop.* 2000;118:262–273.
  50. Mavragani M, Vergari A, Selliseth NJ, Boe OE, Wisth PJ. *Eur J Orthod.* 2000;22:665–674.
  51. Sameshima GT, Sinclair PM. Predicting and preventing root resorption: part II. Treatment factors. *Am J Orthod Dentofac Orthop.* 2001;119:511–515.
  52. Acar A, Canyurek U, Kocaaga M, Erverdi N. Continuous versus discontinuous force application and root resorption. *Angle Orthod.* 1999;69:159–164.
  53. Oppenheim A. Human tissue response to orthodontic intervention of short and long duration. *Am J Orthod Dentofac Orthop.* 1942;28:263–301.
  54. Owman-Moll P, Kurol J, Lundgren D. Effects of doubled orthodontic force magnitude on tooth movement and root resorption. An inter-individual study. *Eur J Orthod.* 1996;18:141–150.
  55. Owman-Moll P, Kurol J, Lundgren D. The effect of four-fold increased orthodontic force magnitude on tooth movement and root resorption. An intra-individual study. *Eur J Orthod.* 1996;18:287–294.
  56. Brudvik P, Rygh P. Non-clast cells start orthodontic root resorption in the periphery of hyalinized zones. *Eur J Orthod.* 1993;15:467–480.
  57. Brudvik P, Rygh P. Root resorption beneath the main hyalinized zone. *Eur J Orthod.* 1994;16:249–263.
  58. Proffit WR, Fields HW. The first stage of comprehensive treatment: alignment and leveling. In: *Contemporary Orthodontics*. 3rd ed. St Louis, Mo: CV Mosby; 2000:527–529.
  59. King GJ. Effect of timing of orthodontic appliance reactivation on osteoclast and root resorption. In: Davidovitch Z, Mah J, eds. *Biological Mechanisms of Tooth Eruption, Resorption and Replacement by Implants*. Boston, Mass: Harvard Society for the Advancement of Orthodontics; 1998:451–458.
  60. Reitan K. Some factors determining the evaluation of forces in orthodontics. *Am J Orthod.* 1957;43:32–47.
  61. Levander E, Malmgren O. Long term follow-up of maxillary incisors with severe apical root resorption. *Eur J Orthod.* 2000;22:85–92.
  62. Levander E, Malmgren O. Early radiographic diagnosis of apical root resorption during orthodontic treatment: a study of maxillary incisors. *Eur J Orthod.* 1998;20:57–63.
  63. Gholston L, Mattison G. An endodontic-orthodontic technique for esthetic stabilization of externally resorbed teeth. *Am J Orthod.* 1983;83:435–440.
  64. Parker WS. Root resorption—long-term outcome. *Am J Orthod Dentofac Orthop.* 1997;112:119–123.
  65. Desai HM. Root resorption: another long-term outcome. *Am J Orthod Dentofac Orthop.* 1999;116:184–186.
  66. Roberts WE. Bone physiology, metabolism, and biomechanics in orthodontic practice. In: Graber TM, Vanarsdall RL, eds. *Orthodontics: Current Principles and Techniques*. St Louis, Mo: CV Mosby; 2000:231–234.
  67. Andreasen FM, Sewerin I, Mandel U, Andreasen JO. Radiographic assessment of simulated root resorption cavities. *Endod Dent Traumatol.* 1987;3:21–27.
  68. Goldberg F, De Silvio A, Dreyer C. Radiographic assessment of simulated external root resorption cavities in maxillary incisors. *Endod Dent Traumatol.* 1998;14:133–136.
  69. Reukers EA, Sanderink GC, Kuijpers-Jagtman AM, Van 't Hof M. Radiographic evaluation of apical root resorption with 2 different types of edgewise appliances. Results of a randomized clinical trial. *J Orofac Orthop.* 1998;59:100–109.
  70. Reukers EA, Sanderink GC, Kuijpers-Jagtman AM, Van 't Hof M. Assessment of apical root resorption using digital reconstruction. *Dentomaxillofac Radiol.* 1998;27:25–29.
  71. Heo MS, Lee SS, Lee KH, Choi HM, Park TW. Quantitative analysis of apical root resorption by means of digital subtraction radiology. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2001;91(3):369–373.
  72. Ericson S, Kurol J. Incisor root resorptions due to ectopic maxillary canines imaged by computerized tomography: a comparative study in extracted teeth. *Angle Orthod.* 2000;70:276–283.
  73. Ericson S, Kurol J. Resorption of incisors after ectopic eruption of maxillary canines: a CT study. *Angle Orthod.* 2000;70:415–423.