Periodontal and root changes after orthodontic treatment in middle-aged adults are similar to those in young adults

Jihee Han,[a] Soonshin Hwang,[a,b] Tung Nguyen,[c] William R. Proffit,[c] Kunimichi Soma,[d] Yoon Jeong Choi,[a] Kyung-Ho Kim,[a,b] and Chooryung J. Chung[a,b,c]
Seoul, Korea, Chapel Hill, NC, and Tokyo, Japan

Introduction: The goal of this study was to compare the outcomes and amount of change in periodontal health of anterior teeth in young versus middle-aged adults, who were treated to improve anterior alignment and occlusion. **Methods:** Pre- and posttreatment records including orthodontic casts, cephalograms, and standardized periapical radiographs were retrospectively collected from young adults (aged 19-30 years; n = 12) and middle-aged adults (aged ≥40 years; n = 27). Following the American Board of Orthodontics criteria, discrepancy index (DI), cast-radiograph evaluation (CRE), treatment duration (TD), marginal bone loss (MBL), and tooth length (TL) were measured, and with the use of periapical radiographs, changes in the level of marginal bone (MBC) and the amount of root resorption (RR) after orthodontic treatment were calculated. **Results:** DI, MBL, and TD were significantly higher in the middle-aged adults than in the young adults ($P < 0.05$). However, CRE and MBC after treatment were similar between the 2 groups ($P > 0.05$). The mean amount of RR following treatment was -0.6 ± 0.44 mm and -1.0 ± 0.61 mm in young and middle-aged adults, respectively. The degree of RR after compensating for treatment complexity and TD was similar between the 2 groups ($P > 0.05$). **Conclusions:** Although the initial malocclusion and periodontal conditions were unfavorable for the middle-aged adults, the overall treatment and periodontal outcomes after orthodontic treatment of the anterior teeth were similar to those for young adults. It appears that older adults tolerate orthodontics to improve the appearance of the anterior teeth as well as younger adults, with no additional burden because of their increased age. (Am J Orthod Dentofacial Orthop 2019;155:650-5)

With the gradual increase of adult orthodontic patients,[1,2] the proportion of those who are middle-aged and above is increasing as well.[3] In general, orthodontic treatment for middle-aged or elderly people is considered more complex and limited in what can be accomplished than treatment for adolescents or young adults. This is due in part to the fact that older adults have a higher risk of developing chronic periodontal disease[4,5] and respond differently owing to the aging changes of the surrounding periodontium and the dentition.[6-10]

Among adults with chronic periodontitis, about 30% indicate pathologic tooth migration resulting in occlusal changes such as flaring, diastema, rotation, and extrusion in the anterior teeth.[11] These changes in alignment and occlusion are irreversible with periodontal treatment alone but can be corrected with interdisciplinary orthodontic treatment.[12] It has been well documented that a history of periodontal disease and severe bone loss is not a contraindication to orthodontic treatment when the underlying periodontal disease is controlled and oral hygiene is maintained.[13-16] Periodontal treatment followed by orthodontic treatment has also been reported to have positive effects of increased clinical attachment and improved surrounding marginal bone height.[17-20] However, these clinical outcomes do not fully represent the impact of orthodontic treatment on middle-aged and elderly patients, because the reported data are derived from relatively young adults with or

[a]Department of Orthodontics, Institute of Craniofacial Deformity, College of Dentistry, Yonsei University, Seoul, Korea.
[b]Gangam Severance Hospital, Seoul, Korea.
[c]Department of Orthodontics, University of North Carolina School of Dentistry, Chapel Hill, NC.
[d]Orthodontic Science, Tokyo Medical and Dental University, Tokyo, Japan.
All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
Funding: Basic Science Research Program through the National Research Foundation of Korea funded by the Ministry of Science, ICT, and Future Planning (NRF-2016R1A2B4014882).
Address correspondence to: Chooryung J. Chung, Department of Orthodontics, Gangnam Severance Hospital, Yonsei University, 211 Eonjuro, Gangnam-gu, Seoul 06273, South Korea; e-mail, crchung@yuhs.ac.
Submitted, March 2018; revised and accepted, May 2018.
0889-5406/$36.00

https://doi.org/10.1016/j.ajodo.2018.05.027

without periodontal disease[13,14,21] or lack comparisons with adequate control groups.[7,15,22,23]

Clinically, middle-aged populations are frequently affected with chronic periodontal disease,[5,24] which requires continuous self-maintenance and management, and treatment planning and biomechanics for tooth movement is often complicated because of multiple tooth loss or restorations.[25,26] In contrast to the previously mentioned studies, there are reports indicating increased risks of periodontal bone loss and attachment loss because of tooth mobility after orthodontic movement in these older adults.[15,21,27] Susceptibility to root resorption has also been suggested to increase with age[7,8,28] and the presence of active periodontal disease.[29] Therefore, dental professionals may well perceive age itself as a main limiting factor for orthodontic treatment.[30,31]

The key motivating factor for adults seeking orthodontic treatment is the appearance of the anterior teeth.[32] Given the typical features of pathologic migration and aging changes associated with anterior teeth,[11,12,33] the needs and demands for orthodontic treatment in the older adult population are expected to grow.

The aim of the present study was to evaluate the influence of aging on the orthodontic and periodontal outcomes of treatment in the anterior teeth by comparing middle-aged adults and young adults.

MATERIAL AND METHODS

All patients in the Department of Orthodontics, Gangnam Severance Hospital, Yonsei University, from 2011 to 2016 who underwent orthodontic treatment to align and improve the appearance of the maxillary or mandibular anterior teeth were retrospectively evaluated (n = 51). These patients had fixed appliances on anterior teeth between the first premolars. Skeletal anchors were used if anchorage was needed in the molar regions; molars were not banded or bonded. Patients with pre- (T1) and posttreatment (T2) medical records, orthodontic casts, lateral cephalograms, and standardized anterior periapical radiographs with a 4 mm radiopaque steel ball for measurement calibration were considered to be eligible for further evaluation. Because alveolar bone loss gradually increases with age regardless of orthodontic treatment at around the age of 30,[6] the collected subjects were then divided into a young adult group aged 19-30 years (n = 12; total of 17 sites) and a middle-aged adult group aged ≥40 years (n = 27; total of 38 sites). Dental records were monitored for history of periodontal therapy before orthodontic treatment excluding periodic hygiene control. See Table I for the group characteristics. This study was approved by the Institutional Review Board (3-2017-0032).

Table I. Demographic characteristics of the subjects, n (%)

Charracteristic	*Young adults (n = 12)*	*Middle-aged adults (n = 27)*
Age (y)	22.7 ± 2.93	53.3 ± 7.93
Sex		
Male	7 (58.3%)	8 (29.6%)
Female	5 (41.7%)	19 (70.4%)
Region		
Maxilla	8 (47.1%)	20 (52.6%)
Mandible	9 (52.9%)	18 (47.4%)
Total	17 (100%)	38 (100%)
Previous history of periodontal therapy		
Male	0 (0%)	6 (22.2%)
Female	0 (0%)	11 (40.7%)
Total	0 (0%)	17 (62.9%)

The discrepancy index (DI) of the American Board of Orthodontics (ABO) was scored following the ABO criteria,[34] but it was modified to represent the degree of malocclusion and treatment complexity in the anterior teeth (canine to canine) only. In brief, anterior crowding, space, overjet, overbite, and missing anterior teeth were evaluated on the diagnostic model, and incisor–mandibular plane angle angle was evaluated on the T1 cephalograms (Supplementary Table I, available at www.ajodo.org). Skeletal criteria, such as ANB and SN-GoGn, and posterior occlusal evaluation, such as lateral open bite and buccolingual crossbite, were not included for the scoring.

To evaluate the treatment outcome, cast-radiograph evaluation (CRE) was scored following the ABO criteria,[35] with similar modification to include anterior alignment, proximal contact, overjet, and root inclination of the anterior teeth at T2 (Supplementary Table II, available at www.ajodo.org). The overall dental history and the duration of active orthodontic treatment (TD) were collected from the medical records.

To measure the change of the marginal bone height before and after treatment, standardized periapical radiographs were used (Kodak Insight, film speed F; Rochester, NY; and 70 kVp, 10 mA, Yoshida Rex 601; Tokyo, Japan). The periapical radiographs included a 4 mm radiopaque steel ball and were imaged with the use of the XCP Kit (extension cone paralleling instruments; Ran, Elgin, Ill). The magnification of the images and measurements were calibrated and standardized according to the size of the steel ball.[36] Alveolar crest (AC) was defined as the most coronal areas of

alveolar crest where periodontal space retains its normal width[22] (Fig).

To measure the amount of marginal bone loss (MBL), the distance from the cementoenamel junction (CEJ) to the AC was measured parallel to the long axis of the tooth at the mesial and distal aspects of the left and right central incisors before (MBL T1) and after (MBL T2) treatment. Mean change of the marginal bone was analyzed using the average measurement of the left and right central incisors. The amount of marginal bone changes from before to after treatment (MBC) was recorded as a negative value when there was an additional loss of marginal bone and as a positive value when there was an improvement of marginal bone level.

Tooth length (TL) was measured by the distance from the incisal edge to the root apex along the long axis of the tooth. Root resorption (RR) was defined as the changes of TL from before (TL T1) to after (TL T2) treatment within the individual tooth, but the changes of the left and right central incisors were averaged for the final statistical analysis.

Statistical analysis

Twenty subjects were randomly sampled and remeasured after 2-week intervals. The range of intraclass correlation coefficients was 0.785-0.995 ($P < 0.001$), indicating high reproducibility.

A paired t test was used to compare the MBL and TL between T1 and T2, and an independent t test was used to compare DI, CRE, TD, MBC, and RR between the young adults and middle-aged adults and between sexes. To reduce error caused by the difference of DI and TD, analysis of covariance (ANCOVA) was performed when comparing RR. The statistical analyses were performed with the use of SPSS 24.0 (IBM, Armonk, NY), with a significance level of $P < 0.05$.

RESULTS

DI, indicating treatment complexity, was significantly higher for the middle-aged than for the young adults ($P < 0.05$), although the posttreatment CRE was similar between the 2 groups ($P > 0.05$). The mean TD was longer for the middle-aged than for the young adults ($P < 0.05$; Table II).

The mean MBLs before (T1) and after (T2) treatment, respectively, were 1.3 ± 0.48 and 1.5 ± 0.47 mm for young adults and 3.1 ± 1.58 and 3.4 ± 1.43 mm for middle-aged adults. Both MBL T1 and T2 were significantly greater in middle-aged adults than in young adults ($P < 0.001$), but the mean change of marginal bone after treatment (MBC) was similar between the 2 groups ($P > 0.05$; Table III). A majority of subjects in both the young and middle-aged groups presented less than −1 mm of MBC after treatment (100% vs 89.5%), but 3 sites (7.9%) of the middle-aged group presented a positive MBC with improvement of MBL at T2 compared with T1 (≥0 mm; Table IV; Figure.

TL before treatment was similar between young and middle-aged adults. However, the mean amount of RR after treatment was significantly higher in the middle-aged adults than in the young adults ($P < 0.05$; Table V). RR reportedly is positively influenced by the distance of tooth movement and TD.[8,37] Given that both the initial DI and TD were higher in middle-aged adults compared with young adults, additional statistical analysis (ANCOVA) was performed to determine the influence

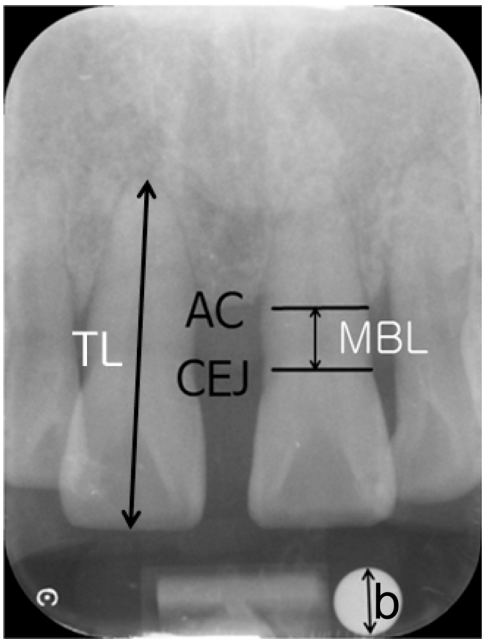

Fig. Measurement parameters with the use of a standardized periapical radiograph. *TL*, tooth length; *CEJ*, cementoenamel junction; *AC*, alveolar crest; *MBL*, marginal bone loss; *b*, diameter of the steel ball.

Table II. Treatment outcome based on discrepancy index (DI), cast-radiograph evaluation (CRE), and treatment duration (TD)

	Young adults		*Middle-aged adults*		
Outcome	*mean*	*SD*	*mean*	*SD*	P
DI	4.8	2.42	8.5	6.22	0.011*
CRE	−2.1	3.06	−2.5	3.14	0.69
TD (mo)	5.6	2.53	8.4	5.57	0.04*

*$P < 0.05$.

Table III. The changes of marginal bone level after orthodontic treatment

	Young adults				*Middle-aged adults*				
Measure	*T1*		*T2*		*T1*		*T2*		P
MBL	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	1.3	0.48	1.5	0.47	3.1	1.58	3.4	1.43	<0.05*
ΔMBC	Mean		SD		Mean		SD		
	−0.2		0.1		−0.3		0.38		0.06

MBL, Marginal bone loss; *ΔMBC*, Marginal bone change; *T1*, before treatment; *T2*, after treatment.
*$P < 0.05$ between young and middle-aged adults at both T1 and T2.

Table IV. Distribution of changes in marginal bone following orthodontic treatment, n (%)

Marginal bone change	*Young adults*	*Middle-aged adults*
>−1 mm to <0 mm	17 (100%)	34 (89.5%)
>−2 mm to ≤ −1 mm	0	1 (2.6%)
Improved, ≥0 mm	0	3 (7.9%)
Total sites	17 (100%)	38 (100%)

of DI and TD. Accordingly, when the 2 factors were compensated for, RRs were similar in the middle-aged adults and the young adults ($P > 0.05$; Table VI).

RR following orthodontic treatment in majority of subjects was fewer than 1 mm in both young and middle-aged adults (88.2% vs 59.5%). RR exceeding 2 mm was noted in 4 sites (10.8%) of the middle-aged adults but not in the young adults (Table VII). Sex differences were not noted for MBC and RR (data not presented).

DISCUSSION

According to this study, the middle-aged adults presented outcomes and periodontal changes after orthodontic treatment of anterior teeth similar to those of young adults, although the initial status of aged adults was relatively unfavorable owing to the complexity of malocclusion and greater marginal bone loss.

Despite the increasing needs and demands for orthodontic treatment in older adults, reports on the influence of aging on orthodontic treatment are limited and lack comparisons with young adult control subjects. Although it was difficult to set a similar degree of initial malocclusion between the 2 groups owing to the retrospective characteristics of the study, it is noteworthy that increase in chronologic age per se does not negatively affect orthodontic treatment outcomes.

After orthodontic treatment, the incisors presented an average of 0.3 mm MBL and <3 mm RR in both young and middle-aged adults. Although the amount of MBL may seem clinically insignificant, when combined with RR it may cause negative consequences in the supporting tissue owing to the changes in the crown-root ratio.[8] In general, RR limited to <2 mm reportedly does not significantly affect tooth prognosis.[38,39] However, for aged patients with preexisting attachment loss, it should be kept in mind that the effect of loss of ~3 mm apical support due to RR is estimated to be similar to the loss of 1 mm coronal support.[8,38]

Unlike young adult subjects who showed healthy periodontium with minor anterior space discrepancies, the middle-aged group had a mixture of healthy and periodontally compromised subjects with histories of pathologic migration accompanied by previous periodontal therapy (17 out of 27). To improve anterior occlusion and esthetics in these patients, alignment, space closure, and intrusion of the anterior teeth were undertaken with proper periodontal intervention and continuous hygiene control as previously recommended.[13-15,17] Importantly, an increase in marginal bone levels was noted in some of the older adults after orthodontic treatment, and MBL was limited to 0.5 mm even in those who had >1 mm of RR. Therefore, based on our results, a high-risk trait in aged adults of both severe MBL and RR was not observed.

However, the present study was conducted on subjects who underwent selective orthodontic treatment with relatively short treatment duration. Although major changes including RR can be noted and predicted during the initial phase of treatment,[40,41] it is possible that a greater degree of MBL and RR may occur in comprehensive orthodontic treatment including the whole dentition with longer treatment duration. Physiologic properties of the periodontium, such as the periodontal mechanoreceptors, also reportedly change with age, and those differences may not have been detected by our macroscopic morphologic evaluation.[9,10]

Our study was focused on the short-term treatment outcomes, but periodontal changes in the long term also are important, especially for older adults. Orthodontic treatment raises dental awareness and improves oral

Table V. Amount of root resorption following orthodontic treatment

	Young adults				*Middle-aged adults*				
Measure	*T1*		*T2*		*T1*		*T2*		P
Tooth length (mm)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
	21.7	2.34	21.1	2.27	22.4	3.09	21.4	2.93	<0.001*
Root resorption (mm)	Mean		SD		Mean		SD		
	−0.6		0.44		−1.0		0.61		0.014†

*$P < 0.001$ between young and middle-aged adults at both T1 and T2; †$P < 0.05$ between young and middle-aged adults.

Table VI. Comparison of the degree of root resorption (mm) adjusted by DI and treatment duration

Measure	*Young adults (n = 17)*		*Middle-aged adults (n = 38)*		P
Root resorption	Estimate mean	SE	Estimate mean	SE	
	−0.713	0.165	−0.909	0.108	0.346

Table VII. Distribution of root resorption severity after treatment, n (%)

Root resorption	*Young adults*	*Middle-aged adults*
<1 mm	15 (88.2%)	22 (59.5%)
≥1 mm to <2 mm	2 (11.8%)	11 (29.7%)
≥2 mm to <3 mm	0	4 (10.8%)
Total sites (%)	17 (100%)	37 (100%)

hygiene and health care behaviors,[42] and combined orthodontic-periodontic treatment shows better clinical efficacy and prognosis than basic periodontal treatment alone for periodontally compromised patients.[16] Interestingly, the level of orthodontic treatment satisfaction and intention to recommend treatment to others is higher for the middle-aged and older population than for young adults, suggesting additional psychosocial benefits of orthodontic treatment in older individuals.[39,43] Thus, proper orthodontic management in late adulthood may provide a positive psychosocial benefit in the long run for older as well as young adults.

REFERENCES

1. Keim RG, Gottlieb EL, Nelson AH, Vogels DS 3rd. 2013 JCO Orthodontic Practice Study. Part 1: trends. J Clin Orthod 2013;47:661-80.
2. American Association of Orthodontists. Smiles are in style. New study says adults are seeking orthodontic treatment in record numbers: Available at: http://www.orthodonticproductsonline.com/2013/10/aao-study-finds-adults-are-seeking-orthodontic-treatment-in-record-numbers/. Accessed May 1, 2017.
3. Piao Y, Kim SJ, Yu HS, Cha JY, Baik HS. Five-year investigation of a large orthodontic patient population at a dental hospital in South Korea. Korean J Orthod 2016;46:137-45.
4. Albandar JM, Brunelle JA, Kingman A. Destructive periodontal disease in adults 30 years of age and older in the United States, 1988-1994. J Periodontol 1999;70:13-29.
5. Eke PI, Dye BA, Wei L, Slade GD, Thornton-Evans GO, Borgnakke WS, et al. Update on prevalence of periodontitis in adults in the United States: NHANES 2009 to 2012. J Periodontol 2015;86:611-22.
6. Albandar JM, Rise J, Gjermo P, Johansen JR. Radiographic quantification of alveolar bone level changes. A 2-year longitudinal study in man. J Clin Periodontol 1986;13:195-200.
7. 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 Dentofacial Orthop 1990;98:463-9.
8. Brezniak N, Wasserstein A. Root resorption after orthodontic treatment: part 2. Literature review. Am J Orthod Dentofacial Orthop 1993;103:138-46.
9. Muramoto T, Takano Y, Soma K. Time-related changes in periodontal mechanoreceptors in rat molars after the loss of occlusal stimuli. Arch Histol Cytol 2000;63:369-80.
10. Nasution FH, Toda K, Soma K. Functional maturation of periodontal mechanoreceptors during development in rats. Brain Res Dev Brain Res 2002;139:307-12.
11. Towfighi PP, Brunsvold MA, Storey AT, Arnold RM, Willman DE, McMahan CA. Pathologic migration of anterior teeth in patients with moderate to severe periodontitis. J Periodontol 1997;68:967-72.
12. Gaumet PE, Brunsvold MI, McMahan CA. Spontaneous repositioning of pathologically migrated teeth. J Periodontol 1999;70:1177-84.
13. Thilander B. Infrabony pockets and reduced alveolar bone height in relation to orthodontic therapy. Semin Orthod 1996;2:55-61.
14. Boyd RL, Leggott PJ, Quinn RS, Eakle WS, Chambers D. Periodontal implications of orthodontic treatment in adults with reduced or normal periodontal tissues versus those of adolescents. Am J Orthod Dentofacial Orthop 1989;96:191-8.
15. Eliasson LA, Hugoson A, Kurol J, Siwe H. The effects of orthodontic treatment on periodontal tissues in patients with reduced periodontal support. Eur J Orthod 1982;4:1-9.
16. Zhang J, Zhang AM, Zhang ZM, Jia JL, Sui XX, Yu LR, et al. Efficacy of combined orthodontic-periodontic treatment for patients with periodontitis and its effect on inflammatory cytokines: a comparative study. Am J Orthod Dentofacial Orthop 2017;152:494-500.
17. Melsen B, Agerbaek N, Markenstam G. Intrusion of incisors in adult patients with marginal bone loss. Am J Orthod Dentofacial Orthop 1989;96:232-41.

18. Melsen B, Agerbaek N, Eriksen J, Terp S. New attachment through periodontal treatment and orthodontic intrusion. Am J Orthod Dentofacial Orthop 1988;94:104-16.
19. Corrente G, Abundo R, Re S, Cardaropoli D, Cardaropoli G. Orthodontic movement into infrabony defects in patients with advanced periodontal disease: a clinical and radiological study. J Periodontol 2003;74:1104-9.
20. Cao T, Xu L, Shi J, Zhou Y. Combined orthodontic-periodontal treatment in periodontal patients with anteriorly displaced incisors. Am J Orthod Dentofacial Orthop 2015;148:805-13.
21. Bollen AM, Cunha-Cruz J, Bakko DW, Huang GJ, Hujoel PP. The effects of orthodontic therapy on periodontal health: a systematic review of controlled evidence. J Am Dent Assoc 2008;139:413-22.
22. Nelson PA, Artun J. Alveolar bone loss of maxillary anterior teeth in adult orthodontic patients. Am J Orthod Dentofacial Orthop 1997;111:328-34.
23. Lupi JE, Handelman CS, Sadowsky C. Prevalence and severity of apical root resorption and alveolar bone loss in orthodontically treated adults. Am J Orthod Dentofacial Orthop 1996;109:28-37.
24. Ong MA, Wang HL, Smith FN. Interrelationship between periodontics and adult orthodontics. J Clin Periodontol 1998;25:271-7.
25. Pinho T, Neves M, Alves C. Multidisciplinary management including periodontics, orthodontics, implants, and prosthetics for an adult. Am J Orthod Dentofacial Orthop 2012;142:235-45.
26. Geramy A. Alveolar bone resorption and the center of resistance modification (3-D analysis by means of the finite element method). Am J Orthod Dentofacial Orthop 2000;117:399-405.
27. Artun J, Urbye KS. The effect of orthodontic treatment on periodontal bone support in patients with advanced loss of marginal periodontium. Am J Orthod Dentofacial Orthop 1988;93:143-8.
28. Moyers RE. Handbook of Orthodontics. Chicago: Year Book Medical Publishers; 1988.
29. Kirschneck C, Fanghanel J, Wahlmann U, Wolf M, Roldan JC, Proff P. Interactive effects of periodontitis and orthodontic tooth movement on dental root resorption, tooth movement velocity and alveolar bone loss in a rat model. Ann Anat 2017;210:32-43.
30. Kim Y. Study on the perception of orthodontic treatment according to age: a questionnaire survey. Korean J Orthod 2017;47:215-21.
31. Buttke TM, Proffit WR. Referring adult patients for orthodontic treatment. J Am Dent Assoc 1999;130:73-9.
32. Pabari S, Moles DR, Cunningham SJ. Assessment of motivation and psychological characteristics of adult orthodontic patients. Am J Orthod Dentofacial Orthop 2011;140:e263-72.
33. Bishara SE, Treder JE, Jakobsen JR. Facial and dental changes in adulthood. Am J Orthod Dentofacial Orthop 1994;106:175-86.
34. American Board of Orthodontics. The ABO discrepancy index (DI): a measure of case complexity: Available at: https://www.americanboardortho.com/media/1189/discrepancy_index_scoring_system.pdf. Accessed May 1, 2017.
35. American Board of Orthodontics. Grading system for dental casts and panoramic radiographs: Available at: https://www.americanboardortho.com/media/1191/grading-system-casts-radiographs.pdf. Accessed May 1, 2017.
36. Akesson L, Hakansson J, Rohlin M. Comparison of panoramic and intraoral radiography and pocket probing for the measurement of the marginal bone level. J Clin Periodontol 1992;19:326-32.
37. Segal GR, Schiffman PH, Tuncay OC. Meta analysis of the treatment-related factors of external apical root resorption. Orthod Craniofac Res 2004;7:71-8.
38. Kalkwarf KL, Krejci RF, Pao YC. Effect of apical root resorption on periodontal support. J Prosthet Dent 1986;56:317-9.
39. Neely ML, Miller R, Rich SE, Will LA, Wright WG, Jones JA. Effect of malocclusion on adults seeking orthodontic treatment. Am J Orthod Dentofacial Orthop 2017;152:778-87.
40. Smale I, Artun J, Behbehani F, Doppel D, van't Hof M, Kuijpers-Jagtman AM. Apical root resorption 6 months after initiation of fixed orthodontic appliance therapy. Am J Orthod Dentofacial Orthop 2005;128:57-67.
41. Artun J, van't Hullenaar R, Doppel D, Kuijpers-Jagtman AM. Identification of orthodontic patients at risk of severe apical root resorption. Am J Orthod Dentofacial Orthop 2009;135:448-55.
42. Klages U, Bruckner A, Guld Y, Zentner A. Dental esthetics, orthodontic treatment, and oral-health attitudes in young adults. Am J Orthod Dentofacial Orthop 2005;128:442-9.
43. Lee R, Hwang S, Lim H, Cha JY, Kim KH, Chung CJ. Treatment satisfaction and its influencing factors among adult orthodontic patients. Am J Orthod Dentofacial Orthop 2018;53:808-17.

Supplementary Table I. Modified discrepancy index (DI) to measure orthodontic case complexity

Measure	*Criteria*	*Scoring*
Overjet	≥0 to <1 mm	1 point
	≥1 to ≤3 mm	0 point
	>3 to ≤5 mm	2 points
	>5 to ≤7 mm	3 points
	>7 to ≤9 mm	4 points
	>9 mm	5 points
	Negative overjet	1 point per mm
Overbite	>0 to ≤3 mm	0 point
	>3 to ≤5 mm	2 points
	>5 to ≤7 mm	3 points
	100% overbite	5 points
	0 mm(edge to edge)	1 point
	Open bite	2 points per mm for each maxillary tooth involved from canine to canine
Crowding	≥1 to ≤3 mm	1 point
	>3 to ≤5 mm	2 points
	>5 to ≤7 mm	4 points
	>7 mm	7 points
IMPA	≥99°	1 point
	Each full degree >99°	Add 1 point
Impaction (except third molars)		2 points per tooth
Missing teeth (except third molars)	Noncongenital	1 point per tooth
	Congenital	2 points per tooth
Spacing	Diastema ≥2 mm	2 points
	≥0.5 mm space on both sides of any 4 teeth or more	2 points

IMPA, incisor–mandibular plane angle.

Supplementary Table II. Modified dental cast and radiograph evaluation (CRE) to evaluate treatment outcome

Measure	*Criteria*	*Scoring*
Deviated alignment	≥0.5 to ≤1 mm	1 point for each tooth
	>1 mm	2 points for each tooth
Interproximal space	>0.5 to ≤1 mm	1 point for each contact
	>1 mm	2 points for each contact
Overjet	If the mandibular canines or incisors are not contacting lingual surfaces of maxillary teeth, and the distance is ≤ 1 mm	1 point for each maxillary tooth
	>1 mm	2 points for each maxillary tooth
Root angulation	Not parallel	1 point for each occurrence
	Root contacting adjacent root	2 points for each occurrence
	Omit scoring the canine relationship with adjacent tooth root	