Leveling the curve of Spee: Comparison between continuous archwire treatment and Invisalign system: A retrospective study

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Introduction: The purpose of this study was to evaluate and compare leveling of the curve of Spee (COS) achieved by traditional fixed appliances and Invisalign clear aligners (Align Technology, Santa Clara, Calif). **Methods:** This retrospective study involved 2 groups of subjects with an increased COS depth. Patients treated with the Invisalign system (I group) and patients treated with the standard edgewise full-fixed appliance (F group). The I group included 30 subjects (13 males, 17 females; mean age, 24 years 5 months ± 19 months). The F group included 32 subjects (12 males, 20 females; mean age, 22 years 4 months ± 21 months). The 2 groups were matched for sex, age, vertical pattern, and observation period. Pretreatment (T0) and posttreatment (T1) lateral cephalograms were analyzed. COS depth was measured on digital dental casts. The intragroup variation between T0 and T1 was analyzed with a paired *t* test. The intergroup variation was evaluated using an unpaired *t* test. **Results:** The leveling of COS was statistically significant, comparing T0 and T1 within the groups. The F group presented a statistically significant extrusion of posterior teeth, with a flaring of the mandibular incisors. The I group showed a statistically significant intrusion of the mandibular incisors, with excellent control in the proclination of incisors during the intrusion movement. **Conclusions:** Traditional continuous archwire treatment and the Invisalign system effectively level the COS. (Am J Orthod Dentofacial Orthop 2022;162:645-55)

The curve of Spee (COS) is an anatomic curvature that was first described by Ferdinand Graf von Spee in 1890.[1] This anteroposterior curve is a concave line for the mandibular arch tangent to incisal edges and buccal cusp tips of premolar and molar teeth, continuing through the anterior border of the mandibular ramus and ending at the anterior-most portion of the mandibular condyle.[2]

The morphologic arrangement of teeth along this curve is linked to several anatomic and functional factors: joint inclination, overjet, the height of the molar cusp, and the quality and quantity of posterior contacts.[3] The presence of a COS of variable depth is a common finding in the occlusal arrangement.[4] Depth evaluation is essential to establish the right diagnosis and appropriate orthodontic treatment.[5-7]

Leveling of COS generally constitutes the most important preliminary clinical phase of any orthodontic treatment, and it is the sixth key of occlusion.[8] Leveling is when the incisal edges of the anterior teeth and the buccal cups of the posterior teeth are placed on the same horizontal level.[9] In orthodontics, we need to level the COS at the beginning of treatment.[10,11]

Several orthodontic mechanics have been performed to level the COS with fixed appliances: mandibular incisors intrusion,[10,12] posterior teeth extrusion,[5] or a combination of both tooth movements.[13-16] The treatment choice depends on various factors, such as incisor display and vertical dimension.[17]

The segmented archwire method, developed by Ricketts[12] and Burstone,[18] and refined by other clinicians,[19] allows for control of incisor torque in the intrusion phase

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without molar extrusion. Features of this clinical approach are wires that do not slide continuously from right to left molars and intrusive and bilateral arch springs. Anterior intrusion is the best therapeutic choice often indicated in patients with excessive maxillary incisor display at rest.[18]

The continuous archwire technique corrects deepbite through the extrusion of molars and flares out of incisors. Proponents of this technique believe that premolar and molar extrusion represent stable occlusal change, whereas mandibular incisor intrusion is an unstable movement that will almost certainly relapse in time.[20,21] In contrast, posterior extrusion is not indicated in patients with excessive mandibular anterior facial height.[18]

Tweed[10] described an arch leveling method that closely resembles the continuous archwire technique. The author introduced a continuous archwire containing a reverse COS. In this way, the leveling process was accomplished by extrusion of the premolars and molars with as little intrusion of the mandibular incisors as possible. A common disadvantage with reverse curve wires was the flaring of incisors.[22]

A review of the literature reveals a disagreement among the proponents of the various orthodontic techniques used to level deep curves of Spee.[20-25] The discussion revolves around which leveling technique produces the most effective overbite correction and the most stable long-term treatment outcomes. A study by Carcara et al[26] showed that COS could be leveled successfully within stable results when continuous archwire mechanics were used. Other authors believe those extruding posterior teeth will cause an increase in mandibular facial height. Furthermore, the orthodontically extruded buccal segments will tend to relapse after the orthodontic treatment in patients with strong muscles of mastication. This condition will lead to the recurrence of anterior deepbites.[21,27,28] Rozzi et al,[29] with their study, showed that the leveling of COS during treatment and its long-term stability was influenced by different skeletal vertical patterns.

Recently in orthodontics, the Invisalign system (Align Technology, Santa Clara, Calif) emerged as an alternative to traditional braces. The Invisalign system evolved over the last years, and numerous studies investigated the accuracy and efficiency of this technology.[30-32] Literature review showed few studies about deepbite correction by clear aligners.[33-35] The first step of this technique is to intrude incisors; therefore, teeth should be moved on the virtual treatment software to simulate the force vectors of a lower reverse COS archwire. Clear aligners level mandibular arch using a controlled proclination of mandibular incisors. According to Boyd,[36] the Invisalign system has good predictability in intrusion and leveling mechanics designed during the ClinCheck procedure. Liu and Hu[33] investigated force changes associated with different intrusion strategies for vertical correction with aligners; activation on each tooth, which is closely related to designed activation, shape, the position of the attachment, and relative movement of the adjacent teeth, influenced the final intrusion force.

Only 1 study compared the effects of Invisalign bite ramps and traditional fixed appliances to deepbite malocclusion.[35] However, the precision bite ramp is an orthodontic auxiliary with clinical limitations of use linked to an increased overjet value and patient's skeletal type.[37-39]

No studies focused on COS's changes in treatment with clear aligners.

This study aimed to compare the leveling of COS produced by fixed appliances and Invisalign clear aligners (G5 protocol) without using virtual bite ramps.

MATERIAL AND METHODS

Two groups of subjects with an increased COS were selected from files of the Departments of Orthodontics at the University of Rome "Tor Vergata" between January 1, 2017 and January 1, 2020. The first group of 30 patients (13 males, 17 females; mean age, 24 years 5 months ± 19 months) was treated with Invisalign appliance (I group). The second group of 32 patients (12 males, 20 females; mean age, 22 years 4 months ± 21 months) was treated with standard edgewise full-fixed appliances (F group). This retrospective study was approved by the ethical committee at the University of Rome "Tor Vergata" (protocol no. 152/20), and informed consent was obtained from the patients.

All patients were treated without extractions and were selected using the following inclusion criteria: full permanent dentition (excluding third molars, extracted or not erupted), COS >3 mm before treatment, skeletal Class I (ANB angle, 0°-4°), or moderate skeletal Class II (ANB angle, >4°) patterns, absence of posterior crossbites, postpubertal stage of skeletal maturity according to the cervical vertebral maturation method,[40] no previous orthodontic treatment, no periodontal disease or morphologic tooth anomaly, no dental restoration or crown, and no mandibular asymmetry. Patients with Skeletal Class III malocclusion were excluded because the depth of COS results was to be reduced before treatment. Only patients with complete orthodontic records were selected for this study. The records consisted of digital dental casts and lateral cephalograms before treatment (T0) and after orthodontic therapy (T1).

The I group was treated with Invisalign clear aligners (Align Technology Inc, Santa Clara, Calif). Aligners were fabricated using the Invisalign protocol.[41] The authors

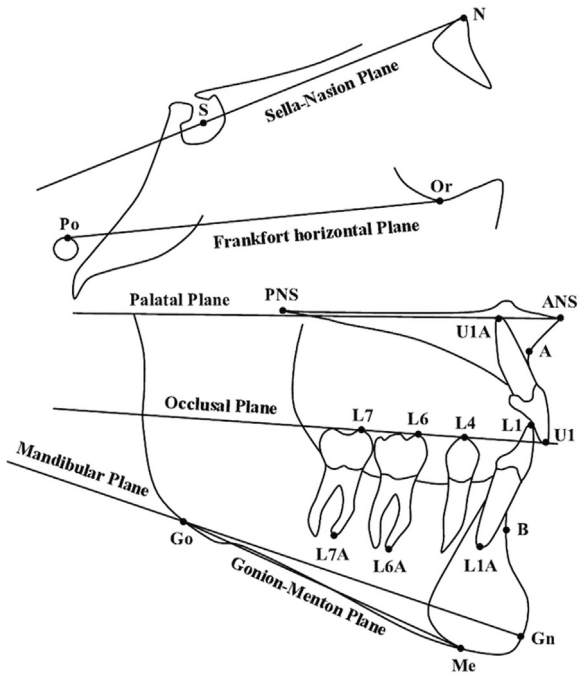

Fig 1. Landmarks and reference planes. *S*, sella; *N*, nasion; *Po*, porion; *Or*, orbitale; *PNS*, posterior nasal spine; *ANS*, anterior nasal spine; *A*, point A; *B*, point B; *U1*, most proclined incisal edge of maxillary central incisor; *U1A*, root apex of maxillary central incisor; *L1*, most proclined incisal edge of mandibular incisor; *L1A*, root apex of mandibular incisor; *L4*, most proclined cusp tip of the mandibular first premolar; *L6*, most proclined mesial cusp tip of the mandibular first permanent molar; *L6A*, mesial root apex of the mandibular first permanent molar; *L7*, most proclined mesial cusp tip of the mandibular second permanent molar; *L7A*, mesial root apex of the mandibular second permanent molar; *Gn*, gnathion; *Me*, menton; *Go*, gonion; *Sella-nasion plane*, line from S to N; *Frankfort horizontal plane*, line from Po to Or; *palatal plane*, line from PNS to ANS; *occlusal plane*, line drawn along the maximum intercuspation of the posterior teeth; *mandibular plane*, line from Go to Gn; *Go-Me plane*, line from Go to Me.

asked for intercanine width to be maintained. A number from 20 to 40 aligners were used for each arch, and a maximum of 3 revision sets of aligners were used. The molar anteroposterior occlusal relationship was not changed (eg, no Class II to Class I occlusion change), and posterior-transverse relationships were not changed significantly. No restrictions were placed on the number of attachments that could be placed. No auxiliary, elastics, or precision bite ramps were used during the treatment phases. Bite ramps, incorporated into the maxillary aligner, contact the mandibular incisors to disocclude the posterior teeth when patients bring their teeth together. This auxiliary was impossible to use in our sample of patients for an increased value of overjet.

Interproximal reduction (IPR) was completed when required using stainless steel tooth stripping blades (Tooth Stripper Kit, OrthoCare, Saltaire, West Yorkshire, United Kingdom). No restrictions were placed on the amount of IPR that could be used. A Sheridan IPR Gauge (OrthoCare) was used to calculate the amount of IPR. A conventional etch-and-bond system was used to place Transbond LR (3M Unitek, Monrovia, Calif) optimized composite attachments. The tooth movement started from the first aligner. Each patient was seen on a 6-week basis and asked to change the first 2 aligners every 2 weeks, and then the change became weekly. Patient compliance was assessed in this study through the blue compliance indicator encapsulated in the removable Invisalign clear aligners.

The F group subjects were treated by the same operator with full-fixed conventional preadjusted edgewise brackets with 0.022-in slot (Victory series; 3M, St. Paul, Minn) and MBT prescription with negative 6° torque on mandibular incisors. A standard continuous archwire sequence (0.016-in round, 0.017 × 0.025-in rectangular, 0.019 × 0.025-in rectangular martensitic active nickel-titanium alloys [3M Unitek], and 0.019 × 0.025-in stainless steel) was used in all subjects. All archwires were cinched back by the operator. Every effort was made to maintain the intercanine width by coordinating the archwires during treatment. Alignment and leveling were considered obtained when the passive engagement of a 0.019 × 0.025-in stainless steel archwire was achieved. Midtreatment checks were performed for each patient before the finishing stage. Brackets were repositioned when necessary, as required by the technique. No additional mechanics or compensation bends were made. No auxiliary, elastics, or bite turbos were used in this group too. IPR was performed identically to that used in the I group by the same orthodontist. All archwires used were uniform in arch form, and brackets were placed on all teeth from the second molar to the second molar.

The cephalometric radiographs were scanned into imaging software (version 11.0; Dolphin Imaging & Management Solutions, Chatsworth, Calif). Standard cephalometric landmarks were then identified on each radiograph; the functional occlusal plane (OP) was defined by a line intersecting the intercuspation of the posterior occlusion[42]; the palatal plane (PP) was defined by the ANS-PNS plane; the mandibular plane (MP) was defined by the Go-Gn plane.[43] These cephalometric landmarks and reference planes are shown in Figure 1. The following measurements were determined on each lateral cephalogram: SNA, SNB, ANB, SN^GoGn, FMA,

y-axis, SN^OP, OP^MP, SN^PP, IMPA, Up.Inc.^FP, overjet, overbite, and interincisal angle (Int.Inc.). The cephalometric measurements used in this study are shown in Table I and Figure 2.

The vertical position of the maxillary (U1) and mandibular central incisors (L1), mandibular first premolar (L4), and mandibular first (L6) and second (L7) molars were measured perpendicular to the palatal and MPs, respectively. The arch leveling was measured by the changes in the measurements of the distances of those teeth to the mandibular plane. Dental casts of the I group were taken from the iTero intraoral scanner and converted into the stereolithography file format virtual casts. Dental casts of the F group were scanned by a tridimensional scanner (D800; 3Shape A/S, Copenhagen, Denmark) with a scan time of 25 seconds, resolution with 2 cameras at 5.0 megapixels, and ultra-highpoint accuracy <15 mm. Each cast was scanned from ≥ 10 views combined and rendered into 3-dimensional (3D) views with the software. The virtual 3D models were measured and analyzed with the software. COS value was measured as follows: the distobuccal cusps of the left and right second molars and the midpoint between the central incisors served as the 3 landmarks; the OP, defined by the midpoint of the center in the right and left incisor edges and the tips of the right and left second molar distobuccal cusps, was established in the mandibular dental arch. The perpendicular distances from the OP to the buccal cusp tip of each lateral tooth were measured. Measurements were obtained on the right and left sides in the deepest points of the curve. Landmarks, reference planes, and measurements used are shown in Figure 3. The premolar measuring the deepest part of the COS had to be in occlusal contact with an opposing tooth in the maxillary dentition. The COS value was the summation of the COS on the right and left sides of the dental arch, and the deepest point was used as a representative value for the COS on each side. The leveling of the COS was considered adequate when the COS depth comparison (T1 − T0) was at least 2 mm.

Statistical analysis

Data were analyzed using SPSS (version 23; IBM Corp, Chicago, Ill). A similar study proposed minimum sample size of 17 participants in each group for 80% power with a significance level of 0.05%.[37] The sample size was calculated using a 2-sample, t test power calculation. Therefore, a minimum sample size of 28 subjects in each group was established. Intraexaminer reproducibility was assessed by repeating the mandibular incisor inclination measurements, 4 weeks after the original measurements, on 15 randomly selected radiographs and models. Reliability was calculated using a paired t test. The difference was found to be nonsignificant. Interexaminer reproducibility was assessed by 2 consultant orthodontists (M.M and T.G), repeating measurements on 15 randomly selected radiographs and models. The logs of the results were compared with the lead operator's measurements using a paired t test. Again, the results were statistically insignificant. A random error was calculated using the Dahlberg equation between the first and second measures. Random errors were also clinically insignificant, with 0.7° of random error for angular measurements and 0.2 mm of random error for linear measurements. Homogeneity of variance was assessed for all variables by Levene's test. The groups were matched to T0 using the independent t test, and no statistically significant differences were found. Changes between T0 and T1 groups were analyzed with a paired t test. Differences in treatment results between the groups were analyzed using an unpaired t test.

RESULTS

The duration of treatment was similar for both groups (F group, 24 ± 8 months; I group, 24 ± 2 months). The mean number of aligners used for each patient was 30 ± 10.

T0 and T1 values of skeletal and dental measurements for each group were described in Table II. The analysis of the starting forms showed no statistically significant differences in craniofacial and dental characteristics at T0. No significant differences were found in T0 COS depth between male and female patients and between right and left sides (Table III). No significant differences were detected in the T0 COS depth between the 2 groups.

The statistical comparison of the skeletal variables between T0 and T1 in the F group (Table IV) showed a significant clockwise rotation of the occlusal plane (SNOP, 2.8°; OPMP, −1.8°) after the leveling of the dental arch.

After the flattening of the COS, the F group presented a statistically significant extrusion of posterior teeth and maxillary incisors (L6-MP, 1.5 mm; L7-MP, 1.1 mm, U1-PP, 1.3 mm).

Overjet and overbite values decreased significantly (OVJ, −1.8 mm; OVB, −2.1 mm).

The patients treated with fixed appliances evidenced a significant proclination of mandibular incisors (IMPA, 5.8°) and a decrease of the interincisal angle (Int.Inc., −6.9°) after the orthodontic treatment.

The flattening of COS was statistically significant comparing T1 and T0 (COS, −2.3 mm).

Table I. Definitions of cephalometric measurements

Measurement	*Definition*
Angular measurements (°)	
SNA	Angle between SN plane and NA plane
SNB	Angle between SN plane and NB plane
ANB	Difference between SNA and SNB
SN^GoGn	Angle between SN plane and MP
FMA	Angle between FP plane and Go-Me plane
y-axis	Angle between FP plane and line of S-Gn
SN^OP	Angle between SN plane and occlusal plane
OP^MP	Angle between occlusal plane and mandibular plane
SN^PP	Angle between SN plane and palatal plane
IMPA	Angle between MP and line of L1-L1A
Up.Inc.^FP	Angle between FP plane and line of U1-U1A
Int.Inc.	Angle between line of U1-U1A and line of L1-L1A
L6^MP	Angle between mandibular plane and line of L6-L6A
L7^MP	Angle between mandibular plane and line of L7-L7A
Linear measurements (mm)	
OVJ	Sagittal linear distance from L1 to U1
OVB	Vertical linear distance from L1 to U1
L1-MP	Linear distance from L1 to mandibular plane
L4-MP	Linear distance from L4 to mandibular plane
L6-MP	Linear distance from L6 to mandibular plane
L7-MP	Linear distance from L7 to mandibular plane
U1-PP	Linear distance from U1 to palatal plane

Note. Refer to Figures 1 and 2 for the location of each landmark.

The statistical comparison of the skeletal variables' variation between T0 and T1 in the I group (Table IV) showed a slight reduction of the angle between the sellar and MP (SNGoGn, −1.0°) with an anticlockwise rotation of the mandible.

This group of patients showed a statistically significant intrusion of the mandibular incisors (L1-MP, −2.1 mm), whereas there was no evidence of any posterior dental extrusion.

The decrease in overjet and overbite values was statistically significant (OVJ, −2.7 mm; OVB, −1.6 mm).

We also observed a proclination of the mandibular incisors (IMPA, 1.6°) and a lingual inclination of maxillary incisors (Up.Inc.FP, −2.0°), resulting in an increment of the interincisal angle, but with no statistical significance.

The leveling of COS was statistically significant comparing T1 and T0 (COS, −2.2 mm).

Results of the intergroup comparison were reported in Table V. The statistical comparison of skeletal measurements in the intergroup analysis showed a significant increase in clockwise rotation of the occlusal plane in the F group compared with the I group (SNOP, −3.8°; OPMP, 2.2°).

Concerning dental measurements, the F group showed a statistically significant extrusion of posterior teeth (L6-MP, −2.4 mm; L7-MP, −1.9 mm), during the leveling of the COS. Instead, the I group showed a significant intrusion of mandibular incisors (L1-MP, −1.8 mm) without any extrusion of posterior teeth. Moreover, the F group exhibited a significant extrusion of the maxillary incisor compared with the I group (U1-PP, −1.1 mm), which evidenced only a slight extrusion.

Overjet and overbite values were comparable in both groups without statistical significance.

The value of IMPA increased in the F group, with a greater dental proclination than I group (IMPA, −0.9°).

Similarly, the F group exhibited significant flaring of maxillary incisors compared with the I group (Up.Inc.FP, −3.3°).

Furthermore, the interincisal angle in the I group appeared to have significantly increased compared with the F group (Int.Inc., 9.5°), which showed a decrease in the same angle instead.

Both the systems appeared effective in the leveling of the COS. No statistically significant differences were found in the values of the COS when comparing T1-T0 changes between the 2 groups. The average correction during the leveling of the COS was 2.25 mm.

DISCUSSION

Leveling the COS generally constitutes one of the most important clinical phases of any orthodontic treatment. Although this orthodontic phase is a common goal in our orthodontic treatments, no studies compared results achieved in leveling COS with fixed appliances and clear aligners treatment.

This study aimed to compare the leveling of the COS produced by continuous archwire therapy and the Invisalign system.

Results of our study reported no statistically significant differences between sex in the mean measurements for T0 and T1 COS depth. These results agreed with those of Carter and McNamara,[44] who reported no difference in the depth of the COS between males and females by measuring from dental casts taken before treatment. In addition, Lie et al[45] showed similar trends in male and female patients after orthodontic treatment with edgewise fixed appliances with or without extractions.

Several skeletal measurements showed statistically significant intragroup and intergroup changes between T0 and T1. In particular, skeletal effects on the vertical plane were observed in both groups.

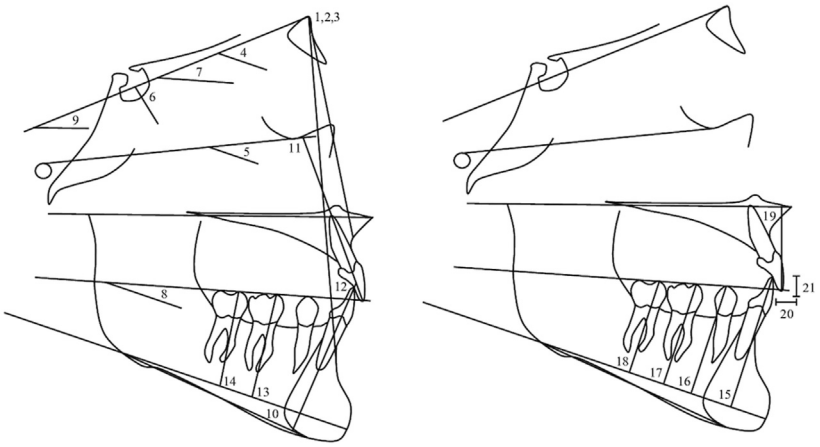

Fig 2. Cephalometric measurements. Angular measurements (°): *1*, SNA; *2*, SNB; *3*, ANB; *4*, SN^GoGn; *5*, FMA; *6*, y-axis; *7*, SN^OP; *8*, OP^MP; *9*, SN^PP; *10*, IMPA; *11*, Up.Inc.^FP; *12*, interincisal angle (Int.Inc.); *13*, L6^MP; *14*, L7^MP. Linear measurements (mm): *15*, L1-MP; *16*, L4-MP; *17*, L6-MP; *18*, L7-MP; *19*, U1-PP; *20*, overjet; *21*, overbite.

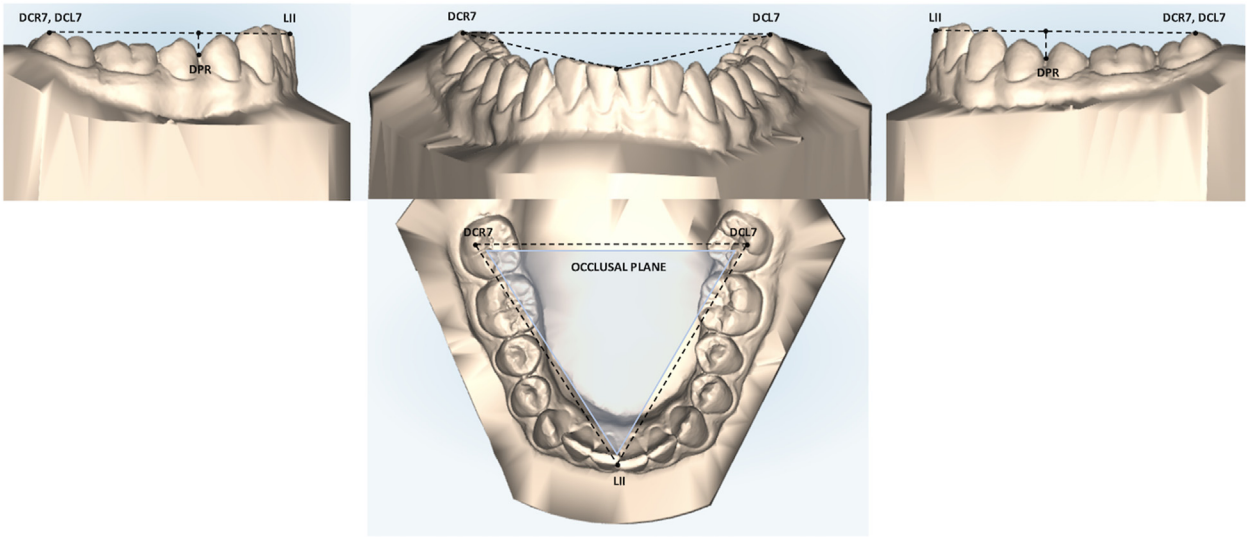

Fig 3. Digital model landmarks, reference plane, and measurement. *DCR7*, distobuccal cusps of the right second molar; *DCL7*, distobuccal cusps of the left second molar; *LII*, midpoint between the mandibular central incisors; *DPR*, the deepest point of the mandibular right arch; *DPL*, the deepest point of the mandibular left arch; *OCCLUSAL PLANE*, plane defined by DCR7, DCL7, and LII. COS is the mean value between perpendicular distances from the OP to DCR7 and DCL7.

Intragroup analysis of T1 − T0 changes showed a counterclockwise rotation of the mandible in the I group. The SNGoGn angle significantly decreased in the patients treated with Invisalign aligners (SNGoGn, −1.0°). We assumed that this result could be due to a potential bite-block effect given by the aligners. This finding was in contrast with Henick et al[35] probably for the use of bite ramp that maintained posterior vertical dimension, as it was also supposed by Khosravi et al.[34]

In our Invisalign group, patients had ClinCheck (Align Technology) instructions that included intrusion of mandibular incisors without using a precision bite ramp. These auxiliaries had clinical limitations, such as an increased overjet value or a skeletal type in some

Table II. Statistical comparison of cephalometric measurements between the groups at T0

Measurements	*F group*	*I group*	*Mean difference*	*Significance*
Angular measurements (°)				
SNA	80.1 ± 3.21	80.4 ± 3.03	0.3	NS
SNB	77.6 ± 4.44	77.3 ± 3.44	−0.3	NS
ANB	2.5 ± 1.73	3.1 ± 2.42	0.6	NS
SN^GoGn	32.6 ± 7.13	30.8 ± 3.01	−1.8	NS
FMA	25.2 ± 7.33	22.8 ± 4.98	−2.4	NS
y-axis	57.3 ± 4.16	57.9 ± 2.92	0.6	NS
SN^OP	18.4 ± 6.31	19.5 ± 4.52	1.1	NS
OP^MP	15.6 ± 4.80	15.1 ± 4.44	−0.5	NS
SN^PP	10.0 ± 4.29	10.1 ± 3.36	0.1	NS
IMPA	95.1 ± 8.34	97.3 ± 9.45	2.2	NS
Up.Inc.^FP	115.2 ± 9.21	113.2 ± 7.46	−2.0	NS
Int.Inc.	126.5 ± 10.86	129.0 ± 12.40	2.5	NS
L6^MP	85.4 ± 5.56	89.6 ± 5.24	4.2	NS
L7^MP	91.1 ± 6.73	94.3 ± 6.83	3.2	NS
Linear measurements (mm)				
OVJ	5.1 ± 2.14	4.5 ± 2.16	−0.6	NS
OVB	4.0 ± 1.28	4.2 ± 1.87	0.2	NS
L1-MP	33.9 ± 3.04	34.2 ± 3.65	0.3	NS
L4-MP	29.3 ± 4.50	30.1 ± 3.92	0.8	NS
L6-MP	24.2 ± 2.47	25.2 ± 3.35	1.0	NS
L7-MP	20.5 ± 3.08	22.8 ± 2.72	2.3	NS
U1-PP	24.1 ± 3.79	25.4 ± 2.78	1.3	NS
COS	3.5 ± 0.83	3.7 ± 0.82	0.2	NS

Note. Presented values are mean ± standard deviation. Refer to Table I for the definition of cephalometric measurements.
NS, not significant.

Table III. Statistical comparison of COS depths (mm) between the sex at T0

	Males			*Females*			
Group	*DX*	*SX*	*Mean DX-SX*	*DX*	*SX*	*Mean DX-SX*	*Significance*
F group	3.63 ± 0.69	3.65 ± 0.75	3.64 ± 0.84	3.49 ± 0.55	3.53 ± 0.57	3.51 ± 0.86	NS
I group	3.85 ± 0.71	3.80 ± 1.02	3.82 ± 0.97	3.68 ± 0.75	3.71 ± 0.72	3.69 ± 0.83	NS

Note. Presented values are mean ± standard deviation.
DX, COS on the right side; *SX*, COS on the left side; *NS*, not significant.

patients. Opening the bite with a possible posterior extrusion is not the ideal clinical choice in some hyperdivergent patients.

The choice of anterior incisors intrusion for flattening the COS makes the Invisalign system assimilable to the segmented archwire method in this specific phase of treatment. The potential extrusion of molars could cause an increase in mandibular facial height and a tendency to relapse after the orthodontic treatment in patients with strong muscles of mastication.[21,27,28]

In the F group, we evidenced a clockwise rotation of the occlusal plane with an increased angle between the sellar plane and occlusal plane (SNOP, 2.8°) and a decreased angle between the occlusal plane and MP (OPMP, −1.8°). The leveling of COS occurred with a significant and greater extrusion of posterior teeth in the F group. This result agreed with different authors who reported a posterior rotation of the mandible and an increased value of anterior facial height associated with extrusion of maxillary and mandibular molars during the COS leveling with continuous archwire technique.[43,46]

This outcome was significant also in the intergroup comparison. In the sample of patients treated with fixed appliances, there was a considerable clockwise rotation of the occlusal plane, which differed from the I group (SNOP, −3.8°; OPMP, 2.2°). The difference in the OP rotation could have been due to the extrusion of posterior teeth in the F group and to the potential bite-block effect in the I group.

Multiple dental measurements showed significant changes between T0 and T1 in both groups.

Table IV. Statistical intragroup comparison (T1 − T0) in the 2 groups

	F group				*I group*			
Measurements	*T0*	*T1*	*Mean difference*	*Significance*	*T0*	*T1*	*Mean difference*	*Significance*
Angular measurements (°)								
SNA	80.1 ± 3.21	80.4 ± 3.97	0.3	NS	80.4 ± 3.03	81.0 ± 2.54	0.6	NS
SNB	77.6 ± 4.44	78.0 ± 5.23	0.4	NS	77.3 ± 3.44	78.1 ± 2.74	0.8	NS
ANB	2.5 ± 1.73	2.4 ± 1.85	−0.1	NS	3.1 ± 2.42	2.8 ± 2.28	−0.3	NS
SN^GoGn	32.6 ± 7.13	32.1 ± 8.2	−0.5	NS	30.8 ± 3.01	29.8 ± 3.88	−1.0	*
FMA	25.2 ± 7.33	25.1 ± 7.37	−0.1	NS	22.8 ± 4.98	21.6 ± 4.90	−1.2	NS
y-axis	57.3 ± 4.16	58.1 ± 4.01	0.8	NS	57.9 ± 2.92	57.8 ± 2.65	−0.1	NS
SN^OP	18.4 ± 6.31	21.2 ± 6.40	2.8	*	19.5 ± 4.52	18.5 ± 3.80	−1.0	NS
OP^MP	15.6 ± 4.80	13.8 ± 4.05	−1.8	*	15.1 ± 4.44	15.5 ± 4.55	0.4	NS
SN^PP	10.0 ± 4.29	10.6 ± 4.48	0.6	NS	10.1 ± 3.36	9.5 ± 3.13	−0.6	NS
IMPA	95.1 ± 8.34	97.6 ± 7.45	2.5	*	97.3 ± 9.45	98.9 ± 7.15	1.6	NS
Up.Inc.^FP	115.2 ± 9.21	116.5 ± 6.44	1.3	NS	113.2 ± 7.46	111.2 ± 6.30	−2.0	NS
Int.Inc.	126.5 ± 10.86	119.6 ± 5.55	−6.9	*	129.0 ± 12.40	131.6 ± 9.25	2.6	NS
L6^MP	85.4 ± 5.56	83.8 ± 7.23	−1.6	NS	89.6 ± 5.24	88.5 ± 5.23	−1.1	NS
L7^MP	91.1 ± 6.73	85.6 ± 8.42	−5.5	NS	94.3 ± 6.83	92.4 ± 7.74	−1.9	NS
Linear measurements (mm)								
OVJ	5.1 ± 2.14	3.3 ± 0.91	−1.8	*	4.5 ± 2.16	1.8 ± 1.08	−2.7	*
OVB	4.0 ± 1.28	1.90 ± 0.88	−2.1	*	4.2 ± 1.87	2.6 ± 1.37	−1.6	*
L1-MP	33.9 ± 3.04	33.6 ± 7.23	−0.3	NS	34.2 ± 3.65	32.1 ± 3.62	−2.1	*
L4-MP	29.3 ± 4.50	31.7 ± 5.76	2.4	NS	30.1 ± 3.92	29.5 ± 3.59	−0.6	NS
L6-MP	24.2 ± 2.47	25.7 ± 4.58	1.5	*	25.2 ± 3.35	24.3 ± 3.16	−0.9	NS
L7-MP	20.5 ± 3.08	21.6 ± 4.32	1.1	*	22.8 ± 2.72	22.0 ± 2.62	−0.8	NS
U1-PP	24.1 ± 3.79	25.4 ± 4.29	1.3	*	25.4 ± 2.78	25.6 ± 3.13	0.2	NS
COS	3.5 ± 0.83	1.2 ± 0.86	−2.3	*	3.7 ± 0.82	1.5 ± 1.02	−2.2	*

Note. Presented values are mean ± standard deviation. Refer to Table I for the definition of cephalometric measurements.
NS, not significant.
*$P < 0.05$.

Leveling of the COS occurred with a significant intrusion of mandibular incisors (L1-MP, −2.1 mm) and without any posterior extrusion in the I group, as it was programmed into our ClinCheck. In Henick et al,[35] there was a significant intrusion of mandibular incisors in deepbite adults treated with clear aligners (Invisalign). These results contradict the study by Khosravi et al,[34] in which mandibular incisor proclination was the primary bite opening mechanism without the intrusion of mandibular incisors in patients treated with the Invisalign system. A proper ClinCheck plan allows different teeth movements depending on individual patient requirements.

Dental intragroup findings of the F group agreed with the results of other authors. In particular, a significant extrusion of posterior teeth (L6-MP, 1.5 mm; L7-MP, 1.1 mm) and proclination of mandibular incisors (IMPA, 2.5°) were found during the leveling with the continuous archwire mechanics. Several authors noted some dental effects like extrusion of mandibular molars and flaring of mandibular incisors during the flattening of the COS.[47,48] Flare out of incisors and extrusion of molars are the first stages for deepbite correction when a continuous archwire is used[46,49,50]; 1 mm of molar extrusion effectively reduces the incisor overlap by 1.5-2.5 mm.[4,46,50,51]

Dental intergroup comparison evidenced significant differences between groups. The I group was allowed to level the COS through absolute anterior intrusion (L1-MP, −1.8 mm), with greater control of the incisal inclination when required.

Instead, flattening of COS was achieved with extrusion of mandibular molars in the group of patients treated with the fixed appliance (L6-MP, −2.4 mm; L7-MP, −1.9 mm), and proclination of mandibular incisors (IMPA, −0.9°). The slot torque prescription of mandibular incisors is negative in the straight wire appliance to prevent an excessive flaring of these teeth. Only fixed mechanics like the segmental arch technique can complete control of incisor torque during the intrusion movement. As we did not use compensation bends, mandibular incisor proclination was one of the COS leveling mechanisms.

Maxillary incisors showed a proclination in the F group (Up.Inc.FP, −3.3°) to follow the flaring of the mandibular incisors and to coordinate the dental arches.

Table V. Statistical intergroup comparison (T1 − T0) between the 2 groups

	F group	*I group*		
Measurements	*T1 − T0*	*T1 − T0*	*Intergroup comparison*	*Significance*
Angular measurements (°)				
SNA	0.3 ± 2.02	0.6 ± 1.34	0.3	NS
SNB	0.4 ± 2.03	0.8 ± 1.13	0.4	NS
ANB	−0.1 ± 0.99	−0.3 ± 0.48	−0.2	NS
SN^GoGn	−0.5 ± 2.54	−1 ± 1.41	−0.5	NS
FMA	−0.1 ± 3.45	−1.2 ± 2.57	−1.1	NS
y−axis	0.8 ± 2.44	−0.1 ± 1.59	−0.9	NS
SN^OP	2.8 ± 2.76	−1.0 ± 3.62	−3.8	*
OP^MP	−1.8 ± 2.90	0.4 ± 3.16	2.2	*
SN^PP	0.6 ± 1.88	−0.6 ± 1.17	−1.2	NS
IMPA	2.5 ± 6.16	1.6 ± 5.24	−0.9	*
Up.Inc.^FP	1.3 ± 5.95	−2.0 ± 5.36	−3.3	*
Int.Inc.	−6.9 ± 8.95	2.6 ± 4.84	9.5	*
L6^MP	−1.6 ± 3.25	−1.1 ± 3.44	0.5	NS
L7^MP	−5.5 ± 5.24	−1.9 ± 4.06	3.6	NS
Linear measurements (mm)				
OVJ	−1.8 ± 1.95	−2.7 ± 1.84	−0.9	NS
OVB	−2.1 ± 1.25	−1.6 ± 1.24	0.5	NS
L1-MP	−0.3 ± 1.12	−2.1 ± 3.48	−1.8	*
L4-MP	2.4 ± 1.62	−0.6 ± 2.85	−3.0	NS
L6-MP	1.5 ± 2.10	−0.9 ± 1.84	−2.4	*
L7-MP	1.1 ± 0.86	−0.8 ± 1.78	−1.9	*
U1-PP	1.3 ± 1.16	0.2 ± 1.55	−1.1	*
COS	−2.3 ± 1.55	−2.2 ± 1.92	0.1	NS

Note. Presented values are mean ± standard deviation. Refer to Table I for the definition of cephalometric measurements.
NS, not significant.
*$P < 0.05$.

Instead, there was a lingual inclination of maxillary incisors in the I group to correct the overjet's value. These results affected the interincisal angle with a statistically significant difference between groups at T1 through an increased value in the I group compared with the F group (Int.Inc., 9.5°).

A fundamental difference between groups is that a bracket and wire system pull on teeth, whereas clear aligners push on teeth. The method by which the fixed and the invisible appliances apply their forces influenced our results. According to Isaacson et al,[52] fixed appliances apply a coronal and buccal force to the center of resistance of a tooth, determining tipping and proclination of the mandibular labial segment. Differently, clear aligners place a force along the complete length of the crown, creating forces closer to the center of resistance of the tooth and minimizing the amount of proclination. Therefore, mandibular incisor angulation was greater in the F group than in the I group.

Overjet and overbite values were significantly decreased at the end of treatment in both groups of patients. However, there were no significant differences in the correction of these 2 variables comparing the 2 groups.

After treatment, the 2-sample of patients showed similar average modifications of the COS, as evidenced by our measurements on digital dental casts. Both systems appeared effective in leveling COS, but the dental movements were different.

The leveling of COS was obtained through anterior intrusion in the I group; teeth's movement was calibrated and gradual; it allowed us to maintain vertical control without unwanted movements.[34]

Flattening of the COS occurred through posterior extrusion in the F group, and overbite reduction was mainly because of molars extrusion and the mandibular incisors flaring.[46,53]

In clear aligner treatment, entire teeth segments may be intruded successfully, or selective intrusion of individual teeth may also be programmed to level the COS. This can be performed without concurrent extrusion of the posterior segments when desired. We can decide, following different protocols, such as the one used by Henick et al,[35] using bite ramps, to have a COS correction with posterior extrusion or even using the Khosravi protocol to have a leveling of the COS by proclination of mandibular incisors.[34] As the Invisalign group had a

significant increase in the amount of mandibular incisor intrusion with minimal proclination, it can be concluded that the G5 pressure areas were effective in intrusion mechanics.[39] It is important to note that the success of any Invisalign treatment ultimately depends on the proper formulation of the ClinCheck plan.

Through the continuous archwire system, leveling of the COS can be achieved only with posterior molars extrusion and mandibular incisors flaring, without the same control that we can get with the Invisalign system. We should resort to more complex fixed mechanics, such as the segmented archwire method for major control.

CONCLUSIONS

1. Traditional continuous archwire therapy and Invisalign treatment effectively level the COS.
2. The leveling of COS was achieved through anterior intrusion in the I group, with good control in the proclination of the incisors during the intrusion movement.
3. Flattening of the curve occurred mainly through posterior extrusion in the F group, with a flaring of the mandibular incisors.

REFERENCES

1. Spee FG, Beidenbach MA, Hotz M, Hitchcock HP. The gliding path of the mandible along the skull. Ferdinand Graf Spee (1855-1937), prosector at the Anatomy Institute of Kiel. J Am Dent Assoc 1980; 100:670-5.
2. The glossary of prosthodontic terms. J Prosthet Dent 2005;94:10-92.
3. Ramfjord SP, Ash MM. Occlusion. 3rd ed. Philadelphia: WB Saunders Co Ltd; 1983.
4. Dhiman S. Curve of Spee - from orthodontic perspective. Indian J Dent 2015;6:199-202.
5. Braun S, Hnat WP, Johnson BE. The curve of Spee revisited. Am J Orthod Dentofacial Orthop 1996;110:206-10.
6. Germane N, Staggers JA, Rubenstein L, Revere JT. Arch length considerations due to the curve of Spee: a mathematical model. Am J Orthod Dentofacial Orthop 1992;102:251-5.
7. Farella M, Michelotti A, van Eijden TM, Martina R. The curve of Spee and craniofacial morphology: A multiple regression analysis. Eur J Oral Sci 2002;110:277-81.
8. Andrews LF. The six keys to normal occlusion. Am J Orthod 1972; 62:296-309.
9. Baldridge DW. Leveling the curve of Spee: its effect on mandibular arch lengths. J Clin Orthod 1969;3:26-41.
10. Tweed CH. Clinical Orthodontics. St Louis: CV Mosby; 1966. p. 461-547.
11. Halimi A, Benyahia H, Azeroual MF, Bahije L, Zaoui F. Relations entre la divergence faciale et les parametres de la DDM. Int Orthod 2017;15:698-707.
12. Ricketts RM. Bioprogressive therapy as an answer to orthodontic needs. Part I. Am J Orthod 1976;70:241-68.
13. Shioya S, Arai K. Dentoskeletal morphology of adult Class II Division 1 and 2 severe deep overbite malocclusions. Orthod Waves 2017;76:97-104.
14. Salehi P, Gerami A, Najafi A, Torkan S. Evaluating stress distribution pattern in periodontal ligament of maxillary incisors during intrusion assessed by the finite element method. J Dent (Shiraz) 2015;16:314-22.
15. Veli I, Ozturk MA, Uysal T. Curve of Spee and its relationship to vertical eruption of teeth among different malocclusion groups. Am J Orthod Dentofacial Orthop 2015;147:305-12.
16. Nayar S, Dinakarsamy V, Santhosh S. Evaluation depth of the curve of Spee in Class I, Class II, and Class III malocclusion: a cross sectional study. J Pharm Bioallied Sci 2015;7(Suppl 1):S92-4.
17. Nanda R. The differential diagnosis and treatment of excessive overbite. Dent Clin North Am 1981;25:69-84.
18. Burstone CR. Deep overbite correction by intrusion. Am J Orthod 1977;72:1-22.
19. Mulligan TF. Common sense mechanics. J Clin Orthod 1979;13: 676-83.
20. Wylie WL. Overbite and vertical facial dimensions in terms of muscle balance. Angle Orthod 1944;14:13-7.
21. Bench RW, Gugino CF, Hilgers JJ. Bio-progressive therapy. Part 2. J Clin Orthod 1977;11:661-82.
22. Kumar KP, Tamizharasi S. Significance of curve of Spee: an orthodontic review. J Pharm Bioallied Sci 2012;4:S323-8.
23. Merritt J. A cephalometric study of the treatment and retention of deep overbite cases [thesis]. Houston: University of Texas; 1964.
24. Schudy FF. The association of anatomical entities as applied to clinical orthodontics. Angle Orthod 1966;36:190-203.
25. Graber TM. Orthodontics: Principles and Practice. Philadelphia: WB Saunders; 1969.
26. Carcara S, Preston CB, Jureyda O. The relationship between the curve of Spee, relapse, and the Alexander discipline. Semin Orthod 2001;7:90-9.
27. Klineberg I. Occlusion: Principles and Assessment. Oxford; Boston: Wright; 1991.
28. Otto RL, Anholm JM, Engel GA. A comparative analysis of intrusion of incisor teeth achieved in adults and children according to facial types. Am J Orthod 1980;77:437-46.
29. Rozzi M, Mucedero M, Pezzuto C, Lione R, Cozza P. Long-term stability of curve of Spee levelled with continuous archwires in subjects with different vertical patterns: a retrospective study. Eur J Orthod 2019;41:286-93.
30. Kravitz ND, Kusnoto B, BeGole E, Obrez A, Agran B. How well does Invisalign work? A prospective clinical study evaluating the efficacy of tooth movement with Invisalign. Am J Orthod Dentofacial Orthop 2009;135:27-35.
31. Grünheid T, Loh C, Larson BE. How accurate is Invisalign in nonextraction cases? Are predicted tooth positions achieved? Angle Orthod 2017;87:809-15.
32. Sheridan JJ. The readers' corner. 2. What percentage of your patients are being treated with Invisalign appliances? J Clin Orthod 2004;38:544-5.
33. Liu Y, Hu W. Force changes associated with different intrusion strategies for deep-bite correction by clear aligners. Angle Orthod 2018;88:771-8.
34. Khosravi R, Cohanim B, Hujoel P, Daher S, Neal M, Liu W, et al. Management of overbite with the Invisalign appliance. Am J Orthod Dentofacial Orthop 2017;151:691-9.e2.
35. Henick D, Dayan W, Dunford R, Warunek S, Al-Jewair T. Effects of Invisalign (G5) with virtual bite ramps for skeletal deep overbite malocclusion correction in adults. Angle Orthod 2021;91: 164-70.
36. Boyd RL. Complex orthodontic treatment using a new protocol for the Invisalign appliance. J Clin Orthod 2007;41:525-47: quiz 523.

37. Hennessy J, Garvey T, Al-Awadhi EA. A randomized clinical trial comparing mandibular incisor proclination produced by fixed labial appliances and clear aligners. Angle Orthod 2016;86:706-12.
38. Morton J, Derakhshan M, Kaza S, Li C. Design of the Invisalign system performance. Semin Orthod 2017;23:3-11.
39. Invisalign. Invisalign G5 Innovations for Deep Bite. San Jose, CA: Align Technology, Inc.; 2013. Align Technology, Inc. https://investor.aligntech.com/static-files/c2024ea9-93c7-4d42-b1ec-e3ffc783eec1. Accessed April 1 2020.
40. Baccetti T, Franchi L, McNamara JA Jr. The cervical vertebral maturation (CVM) method for the assessment of optimal treatment timing in dentofacial orthopedics. Semin Orthod 2005;11:119-29.
41. Wong BH. Invisalign A to Z. Am J Orthod Dentofacial Orthop 2002;121:540-1.
42. Bimler HP. Bimler therapy. Part 1. Bimler cephalometric analysis. J Clin Orthod 1985;19:501-23.
43. Bernstein RL, Preston CB, Lampasso J. Leveling the curve of Spee with a continuous archwire technique: a long term cephalometric study. Am J Orthod Dentofacial Orthop 2007;131:363-71.
44. Carter GA, McNamara JA Jr. Longitudinal dental arch changes in adults. Am J Orthod Dentofacial Orthop 1998;114:88-99.
45. Lie F, Kuitert R, Zentner A. Post-treatment development of the curve of Spee. Eur J Orthod 2006;28:262-8.
46. Weiland FJ, Bantleon HP, Droschl H. Evaluation of continuous arch and segmented arch leveling techniques in adult patients–a clinical study. Am J Orthod Dentofacial Orthop 1996;110:647-52.
47. Baydaş B, Yavuz I, Atasaral N, Ceylan I, Dağsuyu IM. Investigation of the changes in the positions of upper and lower incisors, overjet, overbite, and irregularity index in subjects with different depths of curve of Spee. Angle Orthod 2004;74:349-55.
48. Pollard D, Akyalcin S, Wiltshire WA, Rody WJ Jr. Relapse of orthodontically corrected deepbites in accordance with growth pattern. Am J Orthod Dentofacial Orthop 2012;141:477-83.
49. Ball JV, Hunt NP. The effect of Andresen, Harvold, and Begg treatment on overbite and molar eruption. Eur J Orthod 1991;13:53-8.
50. Dake ML, Sinclair PM. A comparison of the Ricketts and Tweed-type arch leveling techniques. Am J Orthod Dentofacial Orthop 1989;95:72-8.
51. De Praeter J, Dermaut L, Martens G, Kuijpers-Jagtman AM. Long-term stability of the leveling of the curve of Spee. Am J Orthod Dentofacial Orthop 2002;121:266-72.
52. Isaacson RJ, Lindauer SJ, Davidovitch M. On tooth movement. Angle Orthod 1993;63:305-9.
53. McDowell EH, Baker IM. The skeletodental adaptations in deepbite correction. Am J Orthod Dentofacial Orthop 1991;100:370-5.