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AN EVIDENCE-BASED APPROACH TO TREATMENT OF OPEN BITE AND DEEP BITE: CASE REPORTS

Aim: *Evidence-based decision making is gaining increased emphasis in medicine and dentistry. Since orthodontics is both an art and a science, not all decisions can be based solely on scientific findings. However, to the extent that orthodontics is a science and is based on the principles of scientific method, the clinician can practice evidence-based decision making. This article summarizes the results of 6 case-controlled studies on treatment changes in deep bite or open bite.* ***Material and Methods:*** *All studies used the Bolton Brush Growth Study as a source for untreated controls. Strategies for correction of deep bite included cervical pull headgear, bionator therapy, and Tweed edgewise mechanotherapy. Open-bite strategies included 4 premolar extraction, 4 first molar extraction, and active vertical corrector therapy. The changes in 6 variables involved in overlap of the incisor teeth (changes in the maxilla and mandible, as well as tipping and bodily movements of the maxillary and mandibular incisors) were summed at the occlusal plane.* ***Results:*** *Extraction of permanent teeth influences vertical facial growth, growth of the mandible is a major factor in the correction of deep bite, and tipping of the incisor teeth is an important contributor to open-bite correction. Two clinical cases that demonstrate the application of this analysis are presented. The first case involves an open bite treated with extraction of 4 premolars, and the second is a nonextraction deep-bite case treated with a Herbst appliance, followed by fixed appliances.* ***Conclusion:*** *Case-controlled studies can help practitioners decide among various treatment strategies for vertical overbite problems.* World J Orthod 2007;8:45–64.

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Clinical orthodontic treatment requires both artistic and scientific skills. However, to the extent that orthodontics is a science, the clinician can make evidence-based decisions. This article discusses the application of a series of clinical studies on overbite and open bite. To apply statistical analysis to clinical situations, the mean treatment effect can be used to represent the average expected response to a given intervention strategy. In other words, the mean change tells what is likely to occur. The range of treatment responses is an estimate of what is possible, but not necessarily likely. There are times when an orthodontist is more interested in the mean value and other times when the range of values is more pertinent to a particular clinical situation. For example, there are clinical situations when an orthodontist should not hope to achieve the mean but rather aim for getting a treatment response within the clinically satisfactory range of possible effects. One such instance is with patients who have growth irregularities that potentially require orthognathic surgery. Here, the clinician may try an orthopedic approach in hopes of eliminating an invasive surgical procedure. The orthodontist may begin orthodontic treatment nonextraction, with the option of extracting teeth later. However, the clinician will sometimes compromise the goal away from the mean values to protect a patient from the unexpected. Keeping these thoughts in mind, the clinical application of the results of scientific investigations still requires the clinician to use past experience to make the best treatment decisions for each patient. Scientific findings are an adjunct to, but not a substitute for, good judgment.

This article uses data previously published and combines the findings to create a unified approach to correction of open or deep bite. The authors also include 2 case reports to demonstrate the use of this vertical analysis.

MATERIAL AND METHODS

Samples used

Samples were culled from the finished case records of the orthodontic clinic at Case Western Reserve University, Department of Orthodontics, and from finished cases submitted by practicing orthodontists. The following inclusion criteria were used for each case: *(1)* pre- (T1) and posttreatment (T2) cephalograms of diagnostic quality; *(2)* representative of the strategy being investigated; *(3)* representative of the orthodontic condition (open bite or deep bite) being investigated. A minimum sample size of 30 was used to satisfy the requirements of the Central Limit Theorem.

Strategies investigated

Deep-bite strategies: Bionator, nonextraction; cervical pull headgear, nonextraction[1]; Tweed mechanics, extraction of 4 first premolars.[2–4]

Open-bite strategies: Sliding mechanics, extraction of 4 first premolars[5]; active vertical corrector, nonextraction[5]; sliding mechanics, extraction of 4 first molars.[2–4]

Control sample selection

All untreated controls were selected from the 4,309 subjects included in the Bolton Collection, Cleveland, OH, USA.[6] Control subjects were matched to treated subjects by age, gender, and degree of overbite or open bite. The rationale for this design is that changes in each variable in the treatment group are the result of natural growth and treatment, whereas changes in the matched control group are due only to natural growth; or

$$\Delta \text{ Variable} = [\text{Treatment } \Delta + \text{ Natural } \Delta] - \text{Natural } \Delta$$

Cephalometric analysis

All radiographs were traced on 0.003-inch matte acetate with a 0.5-mm mechanical pencil. As previously described,[1–5] the Kishiyama cephalometric analysis, which contains 6 linear and 2 angular measurements, was used. Bilateral anatomic landmarks were bisected and the midpoints calculated. This reduced landmarks to their midsagittal value, resulting in 8 landmarks (Fig 1). Six variables were then measured and the net result summed to a vertical line at the level of the occlusal plane to yield the change in overbite (OB). This analysis is unique in that it separates tipping from bodily incisor movement (Fig 2). The 6 variables measured include:

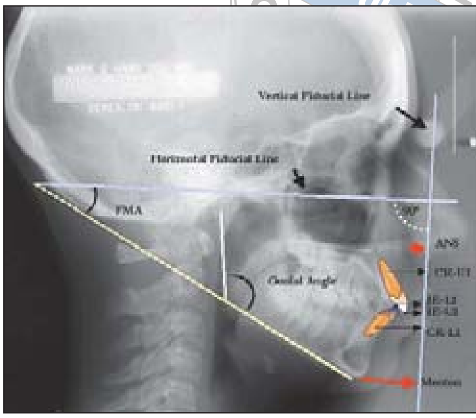

Fig 1 Landmarks used: Anterior nasal spine (ANS); center of rotation of the maxillary central incisor (CR-U1); incisal edge of the mandibular central incisor (IE-L1); incisal edge of the maxillary central incisor (IE-U1); center of rotation of the mandibular central incisor (CR-L1); most inferior point on the mandibular symphysis (menton); angle between a line tangent to the posterior border and a line tangent to the inferior border of the mandible (gonial angle); angle between the horizontal fiducial line and a line tangent to the lower border of the mandible (FMA).

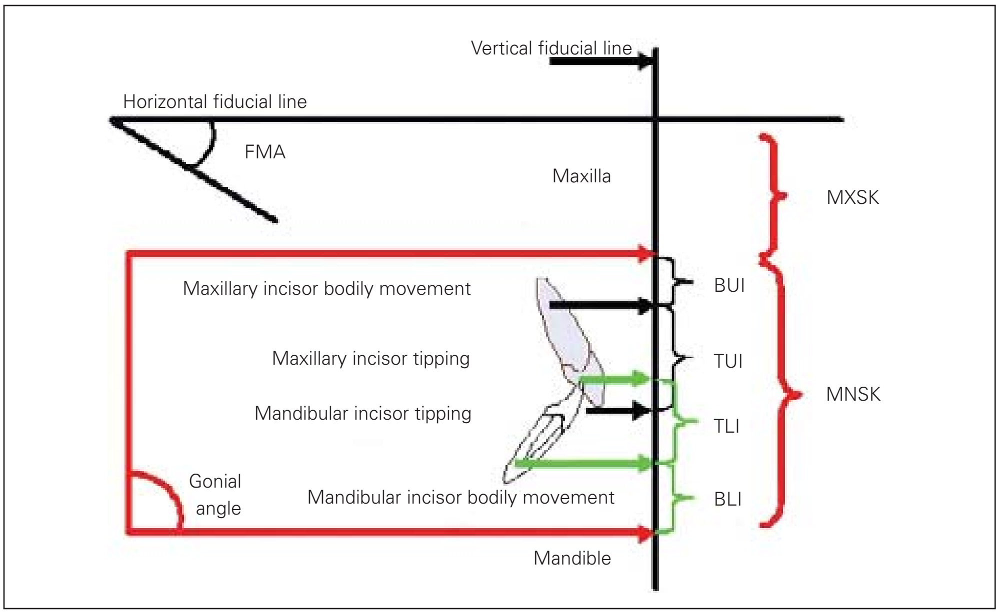

Fig 2 Schematic diagram of the skeletal, dental, and angular variables used. Vertical movement of the maxilla (MXSK); vertical movement of the mandible (MNSK); bodily movement of the maxillary incisors (BUI); tipping of the maxillary incisors (TUI); tipping of the mandibular incisors (TLI); bodily movement of the mandibular incisors (BLI).

1. Mandibular skeletal change (MNSK). Changes in the mandibular plane angle (SN-MP), as well as in the gonial angle (Go), influence the magnitude of change of MNSK.
2. Maxillary skeletal change (MXSK).
3. Bodily movement of the maxillary incisor (BUI).
4. Tipping movements of the maxillary incisor (TUI).
5. Bodily movement of the mandibular incisor (BLI).
6. Tipping of the mandibular incisor (TLI).

Linear measurements were made to the nearest 0.1 mm using an electronic digital caliper (Mitutoyo Series 550; Mitutoyo America, Aurora, IL, USA). Angular measurements were made to the nearest 0.5 degree with an orthodontic protractor (Masel Orthodontic Protractor; Masel, Bristol, PA, USA).

Sign conventions and definitions

A negative sign was given to dental and skeletal movements away from the occlusal plane, while movements toward the occlusal plane were given a positive sign. Changes in facial height were calculated using absolute values for changes and the following formula:

$$\Delta \text{ Lower face height} = \Delta \text{ MXSK} + \Delta \text{ MNSK}$$

Changes in overbite were calculated using the above sign conventions with the following formula:

$$\Delta \text{ Overbite} = \Delta \text{ MNSK} + \Delta \text{ BUI} + \Delta \text{ TUI} + \Delta \text{ TLI} + \Delta \text{ BLI}$$

Statistical analysis

All data were analyzed with the Statistical Package for the Social Sciences personal computer version (SPSS/PC). For each of the 7 linear variables (including 6 independent linear variables, MNSK, MXSK, BUI, TUI, BLI, TLI, and 1 dependent linear variable, OB changes) and 2 angular variables (FMA and gonial angle) examined, means and standard deviations were calculated for all treated and control groups. Mean changes were tested for statistical significance, using the Student *t* test; a value of $P \leq .05$ was used to assign statistical significance.

Error study

To evaluate the degree of investigator measurement error, a subset of the radiographs (usually 20 to 30) was randomly selected and measurements for the 7 linear and 2 angular variables utilized in this study were repeated. The second set of measurements was compared to the first set using intraclass correlation coefficients; tracing error was evaluated in a similar manner. Details of the error study method have been published previously.[3,4]

CASE REPORTS

Two clinical cases were selected from the Division of Pedodontics and Orthodontics at the Tri-Service General Hospital of the National Defense Medical Center, Taipei, Taiwan, ROC, to demonstrate the application of this vertical analysis.

Case 1: Open bite

Chief complaint and diagnosis. This patient was a normally developed Chinese male, 15 years 7 months of age. The patient's chief complaint was that there was not enough room for his teeth. The patient had normal facial symmetry, a convex profile, obtuse nasolabial angle, retrusive chin, 2 mm of lip incompetence at rest, and pronounced mentalis strain during lip closure (Figs 3a to 3c). The dental casts showed a Class II molar relationship with 2 buccally blocked-out maxillary canines and arch-width discrepancy. There was 0.5 mm of overjet, 1 mm of overbite, a slight curve of Spee, and a 1-mm mandibular midline shift to the right. Severe maxillary arch deficiency and moderate mandibular arch length discrepancy were present. A Bolton discrepancy analysis for tooth size revealed that there was an excess of 2.6 mm in the mandibular arch (Figs 3d to 3f).

No temporomandibular joint (TMJ) sounds or symptoms were detected clinically or reported by the patient. Panoramic radiographic analysis showed all teeth, except the third molars, had erupted. The unerupted maxillary third molars had developed normally, but the unerupted mandibular third molars were mesially inclined toward the occlusal plane. Cephalometric analysis revealed a skeletal Class II relationship, with a protrusive maxilla and downward and backward rotation of the mandible. The high mandibular plane angle (FMA, SN-GoGn), high Y-axis angle, low facial axis angle, and increased lower facial height all indicated a vertical growth pattern and open-bite tendency prior to orthodontic treatment (Fig 3g).

Treatment objectives. Treatment objectives were to: *(1)* achieve a Class I molar and canine relationship; *(2)* reduce the anterior vertical dimension; *(3)* correct the crowding and asymmetry of the maxillary and mandibular arches; *(4)* establish normal overjet and overbite, with a mutually protected occlusion; *(5)* establish good facial balance and reduce protrusive lips.

Treatment plan. A comprehensive diagnosis was made, and the patient and parents were counseled on various treatment options. The following treatment plan was used:

1. Rapid palatal expansion (RPE) for the expansion of the maxilla to coordinate the maxillary and mandibular arch forms.
2. Placement of an occipital pull headgear to maintain vertical control during leveling and alignment.
3. Extraction of maxillary and mandibular first premolars for the correction of canine and molar relationships and open bite.
4. Placement of straightwire edgewise appliances and use of light wires to level and align both arches.
5. Use of artistic bends and coordinated archwires to detail final tooth positions and finalize the occlusion.
6. Placement of a wraparound removable retainer for the maxillary arch and a bonded lingual retainer for the mandibular arch (canine to canine), both designed for long-term retention.
7. Outpatient department follow-up to evaluate the eruption pattern of the third molars.

Treatment progress. The first phase of treatment involved transverse expansion of the maxillary arch with RPE. The expansion screw was soldered bilaterally to bands on the maxillary first premolars and first molars. The RPE was activated 2 turns per day for 14 days. The screw was then fixed and left in situ for 3 months for retention. After 3 months, the RPE appliance was removed, the mandibular and maxillary first premolars were removed, and straightwire edgewise appliances (Mini-Wick brackets, 0.018 system; Ormco, Orange, CA, USA) were then placed on both arches. A high-pull headgear was attached directly to the maxillary first molar tubes. Leveling and alignment was started with 0.015-inch Tri-Flex (Rocky Mountain Orthodontics, Denver, CO, USA) archwires and later changed to larger sizes of round and rectangular wires in both arches. After 6 months, the blocked-out maxillary canines were brought into occlusion, and a magnetic vertical corrector (MVC) was delivered. The MVC was worn 24 hours per day, except during eating and brushing. After 2 months, a positive overbite was achieved and the MVC was discontinued. Archwires were then changed from 0.016-inch stainless steel to 0.017 × 0.025-inch stainless steel to retract the canines with powerchains. Space was closed within 2 months. The authors spent approximately 2 months to band the second molars on both arches sequentially and/or to reposition several brackets and first molar tubes wherever there were height discrepancies.

During the next 10 months, finishing procedures included artistic wire bending for maxillary anterior teeth, vertical and buccolingual adjustment of the buccal segment with elastics, or wire bending to improve occlusion. The final midline and buccal occlusion were established with the use of anterior diagonal elastics and posterior Class II or Class III elastics unilaterally. A maxillary circumferential retainer and a mandibular bonded lingual retainer were placed for long-term retention. Full-time wear of a maxillary retainer for at least 1 year, followed by night-time wear for another 2 years, was advised. A bonded mandibular retainer will be kept in place as long as possible.

Total treatment time was 26 months, and good results were achieved (Fig 4). Appointments were made at 2- to 4-week intervals. The patient was compliant and demonstrated good oral hygiene throughout all procedures.

Fig 3 Preoperative photographs, casts, and cephalogram of the open-bite case. **(a)** Frontal view. **(b)** Profile view. **(c)** Intraoral frontal view. **(d)** Maxillary cast, occlusal view. **(e)** Mandibular cast, occlusal view. **(f)** Lateral view of both casts. **(g)** Cephalogram.

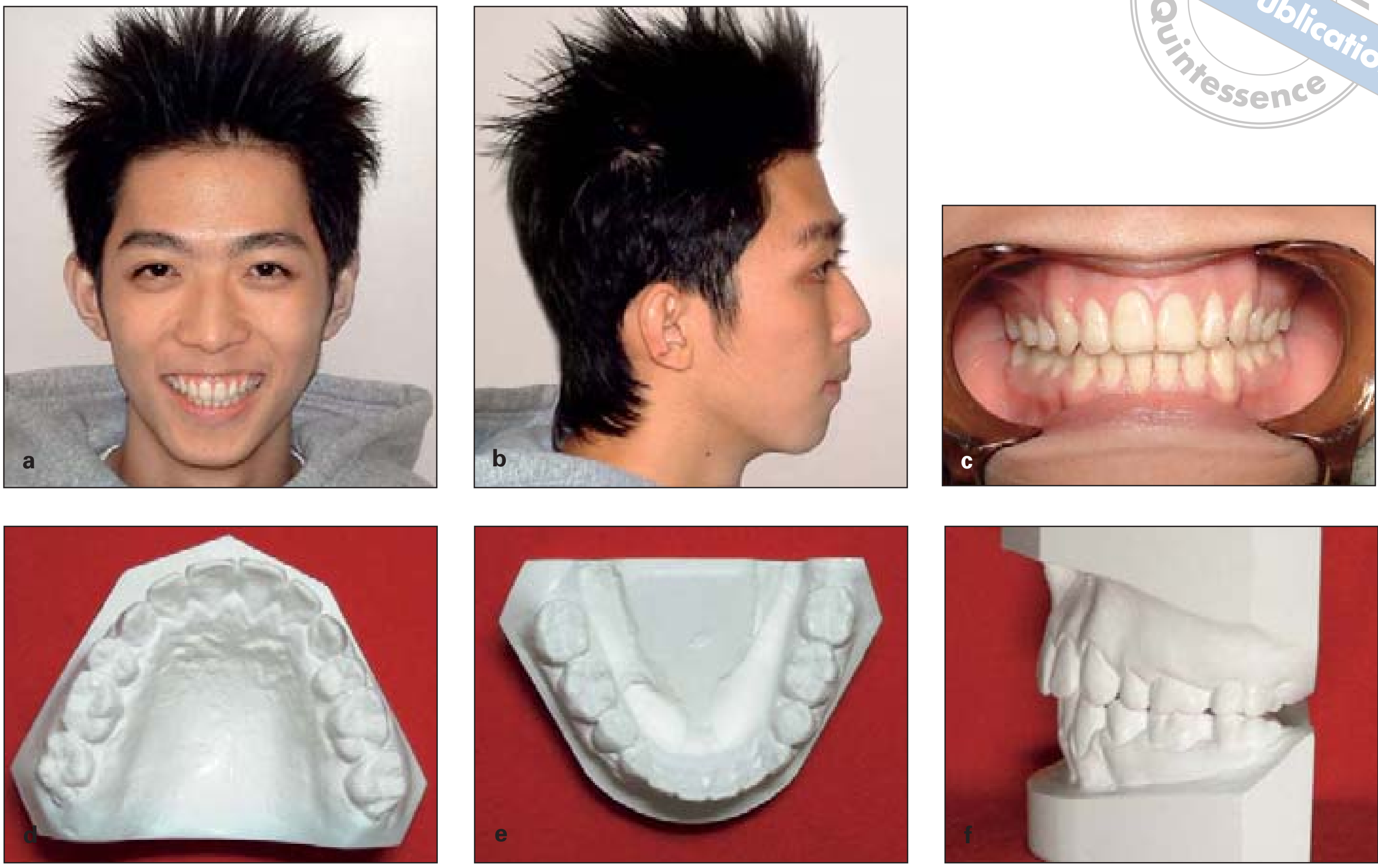

Fig 4 Postoperative photographs, casts, and cephalogram of the open-bite case. **(a)** Frontal view. **(b)** Profile view. **(c)** Intraoral frontal view. **(d)** Maxillary cast, occlusal view. **(e)** Mandibular cast, occlusal view. **(f)** Lateral view of both casts. **(g)** Cephalogram.

Fig 5 Preoperative photographs, casts, and cephalogram of the deep-bite case. **(a)** Frontal view. **(b)** Profile view. **(c)** Intraoral frontal view. **(d)** Maxillary cast, occlusal view. **(e)** Mandibular cast, occlusal view. **(f)** Lateral view of both casts. **(g)** Cephalogram.

Case 2: Deep bite

Chief complaint and diagnosis. This patient was a normally developed Chinese male, 13 years 2 months of age. The patient's chief complaint was that his "upper front teeth were too far forward." He denied any abnormal oral habits or similar occlusion in his family members. The patient had normal facial symmetry, a convex profile, acute nasolabial angle, retrusive chin, and 1 mm of lip incompetence at rest (Figs 5a to 5c). The dental casts showed a Class II molar relationship with arch width discrepancy (mandibular lingual crossbite). There was 8 mm of overjet, 5 mm of overbite, and a slight curve of Spee. Both maxillary second premolars were rotated and both mandibular second premolars

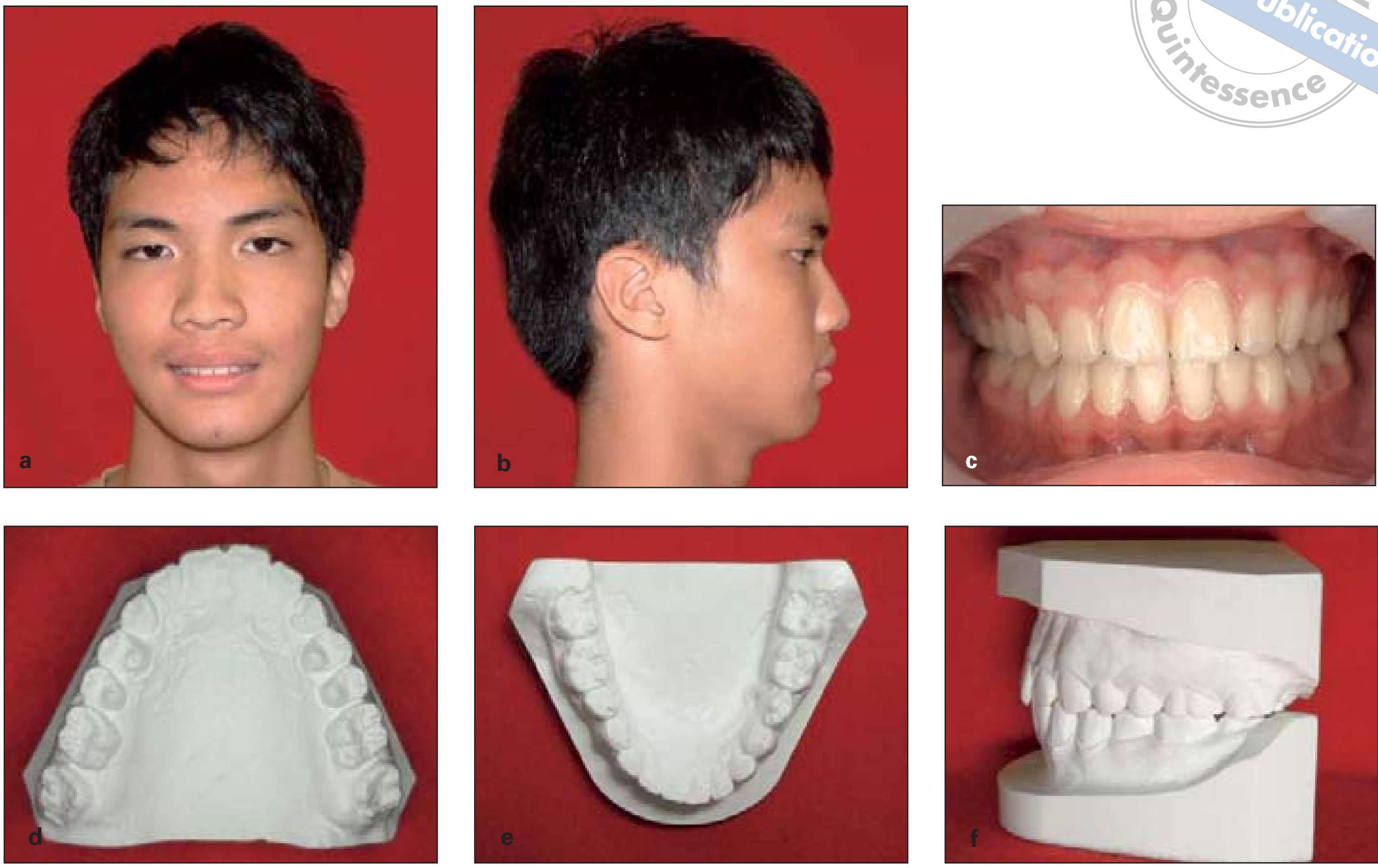

Fig 6 Postoperative photographs, casts, and cephalogram of the deep-bite case. **(a)** Frontal view. **(b)** Profile view. **(c)** Intraoral frontal view. **(d)** Maxillary cast, occlusal view. **(e)** Mandibular cast, occlusal view. **(f)** Lateral view of both casts. **(g)** Cephalogram.

were malformed. No space deficiencies were found in either arch. A Bolton discrepancy analysis for tooth size revealed an excess of 0.5 mm in the mandibular arch (Figs 5d to 5f).

No TMJ sounds or symptoms were detected clinically or reported by the patient. Analysis of the panoramic radiograph showed all the teeth erupted except the third molars, and cephalometric analysis revealed a skeletal Class II relationship. A protrusive maxilla and a forward and downward position of the mandible were noted. The low mandibular plane angle (FMA, SN-GoGn), low Y-axis angle, high facial axis angle, and decreased lower facial height indicated a deep-bite tendency prior to orthodontic treatment (Fig 5g).

Treatment objectives. The treatment objectives were to: *(1)* achieve a Class I molar and canine relationship; *(2)* increase anterior vertical facial height; *(3)* correct mandibular and maxillary dental asymmetries; *(4)* establish ideal overjet and overbite with a mutually protected occlusion; *(5)* enhance forward mandibular growth and establish good facial balance.

Treatment plan. The patient and parents were presented with a comprehensive diagnosis and a list of treatment options. With the parents' consent, the following treatment plan was followed:

1. Placement of an expansion screw in the mandibular arch to coordinate the maxillary and mandibular arch forms.
2. Placement of RPE and Herbst appliances to achieve a Class I molar relationship and proper overjet.
3. Placement of straightwire edgewise appliances and the use of light wires to level and align both arches.
4. Use of artistic bends and coordinated archwires for final tooth position and occlusal adjustments.
5. Placement of a wraparound removable retainer for the maxillary arch and a bonded lingual retainer for the mandibular arch (canine to canine), both designed for long-term retention.
6. Outpatient department follow-up to evaluate the eruption pattern of the third molars.

Treatment progress. The first phase of the treatment involved transverse expansion of the mandibular arch. The expansion screw was soldered bilaterally to bands on the mandibular first premolars and first molars. The screw was activated by the slow expansion method, making 1 turn every 3 days for 3 months. The screw was then fixed and left in situ for 3 months for retention. Maxillary RPE was begun 2 weeks before the end of the mandibular arch retention and activated 2 turns per day. After 14 days of activation, the RPE was fixed and left in situ until completion of the retention of the mandibular expansion. The maxillary and mandibular expansion screws were removed after 6 months retention of each arch, and the Herbst appliance was placed immediately after screw removal. The Herbst appliance was activated from 2 mm to 6 mm bilaterally every 3 months; the total treatment time was 9 months. During the Herbst treatment, both the maxillary and mandibular anterior teeth were bonded with Mini-Wick brackets (0.018 system; Ormco), and leveling and alignment started with 0.015-inch Tri-Flex archwires and later changed to larger sizes of round and rectangular wires in both arches. After 9 months of treatment with the Herbst appliance, the initial leveling and alignment were completed and the maxillary canines were retracted to Class I; an anterior crossbite was noted. All of the teeth were banded or bonded following the removal of the Herbst appliance. Leveling and alignment was retreated with 0.015-inch Tri-Flex archwires, and the wire sizes were sequentially increased to larger sizes of round wires and 0.017 × 0.025-inch stainless steel wire. After 7 months, T-loop archwires (0.017 × 0.025-inch beta-titanium) were used to close spaces between the maxillary lateral incisor and canine bilaterally; Class III elastics were used to achieve proper overjet. The spaces were closed within 3 months.

During the next 8 months, finishing procedures included artistic wire bending for maxillary anterior teeth, and vertical and buccolingual adjustment of the buccal segment with elastics or wire bending to improve occlusion. The final midline and buccal occlusion were established with the use of diagonal elastics and posterior Class II or Class III elastics unilaterally. A maxillary circumferential retainer and mandibular bonded lingual retainer were placed for long-term retention. Full-time wear of the maxillary retainer for at least 1 year, followed by night-time wear for another 2 years, was recommended; the bonded mandibular retainer will be kept in place as long as possible.

Total treatment time was 33 months, with good results achieved (Fig 6). Appointments were at 2- to 4-week intervals. The patient was compliant and demonstrated good oral hygiene throughout all procedures.

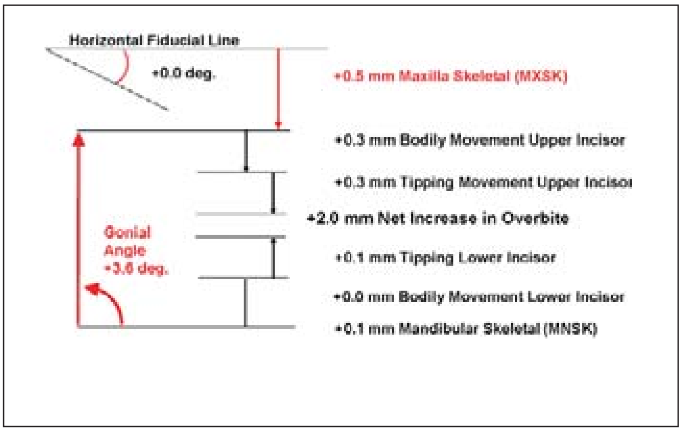

Fig 7 Schematic diagram illustrating the net change in overbite with the extraction of the 4 first molars (6×) treatment of open-bite cases.

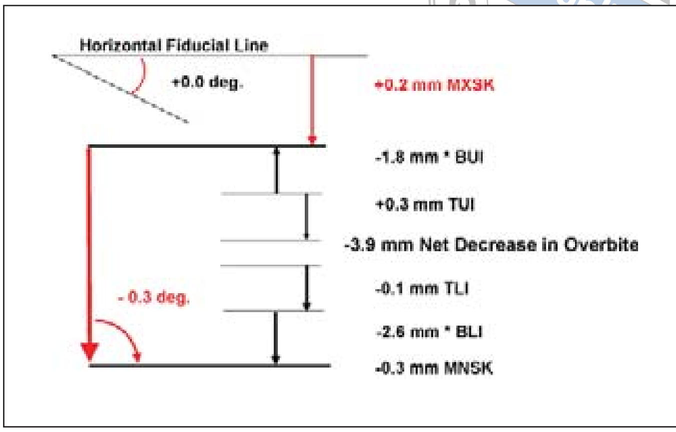

Fig 8 Schematic diagram illustrating the net change in overbite with extraction of the 4 first molars (4× Tweed) treatment of deep-bite cases. *Statistically significant changes ($P \leq .05$).

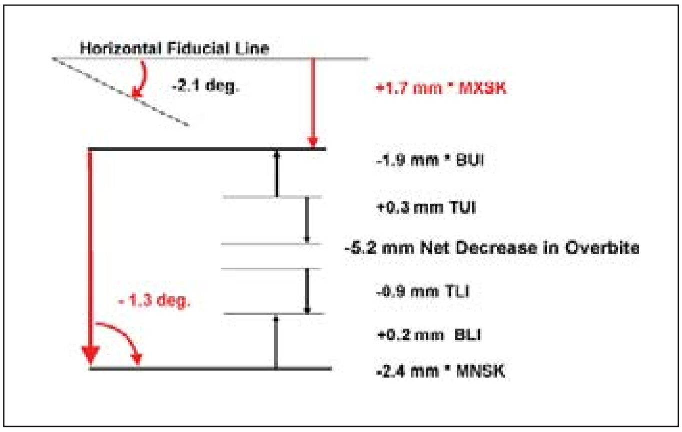

Fig 9 Schematic diagram illustrating the net changes in overbite with nonextraction, cervical-pull headgear, tandem mechanics treatment of deep-bite cases. *Statistically significant changes ($P \leq .05$).

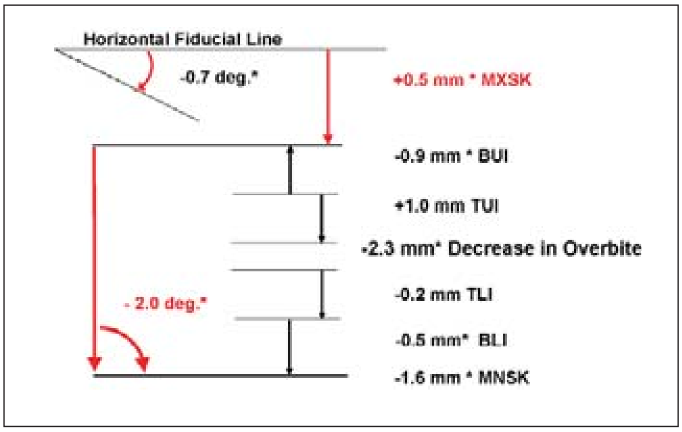

Fig 10 Schematic diagram illustrating the net change in overbite with bionator treatment of deep-bite cases. *Statistically significant changes ($P \leq .05$).

RESULTS

All results of this study are presented in summary figures and represent the net effects of the treatment strategy (Figs 7 to 13). The values listed for each variable were obtained by taking the change in the variable from the start of treatment (T1) to the end of treatment (T2) and subtracting the change in the variable from control time 1 (C1) to control time 2 (C2). The numbers in each figure represent the changes that occurred as a result of treatment only. The average net change of 2.0 mm toward the occlusal plane in overbite with extraction of the 4 first molars (6×) treatment of open-bite cases is shown in Fig. 7. The average net change of 3.9 mm away from the occlusal plane in overbite with extraction of the 4 first molars (6×, Tweed mechanics) treatment of deep-bite cases is shown in Fig 8. There are 2 statistically significant changes within this treatment group: There was a significant bodily movement of the maxillary incisor of 1.8 mm away from the occlusal plane, and there was a significant bodily movement of the mandibular incisor of 2.6 mm away from the occlusal plane (see Fig 8). The average net change of 5.2 mm away from the occlusal plane in overbite with nonextraction, cervical pull headgear, tandem mechanics treatment of deep-bite cases is shown in Fig 9. There are 3 statistically significant changes within

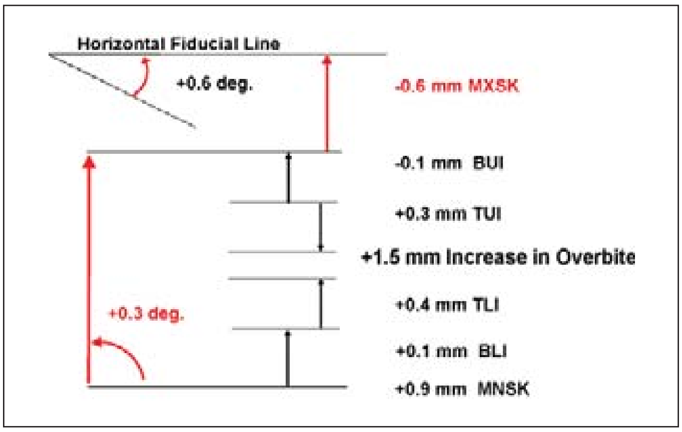

Fig 11 Schematic diagram illustrating the net change in overbite with active vertical corrector treatment of open-bite cases. *Statistically significant changes ($P \leq .05$).

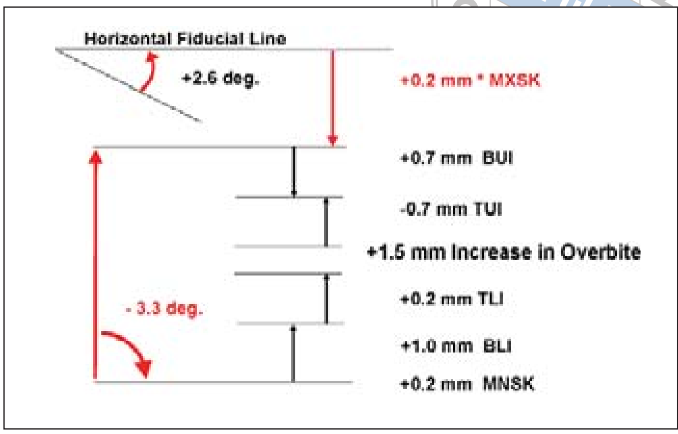

Fig 12 Schematic diagram illustrating the net change in overbite with phase 2 straightwire edgewise treatment of open-bite cases. *Statistically significant changes ($P \leq .05$)

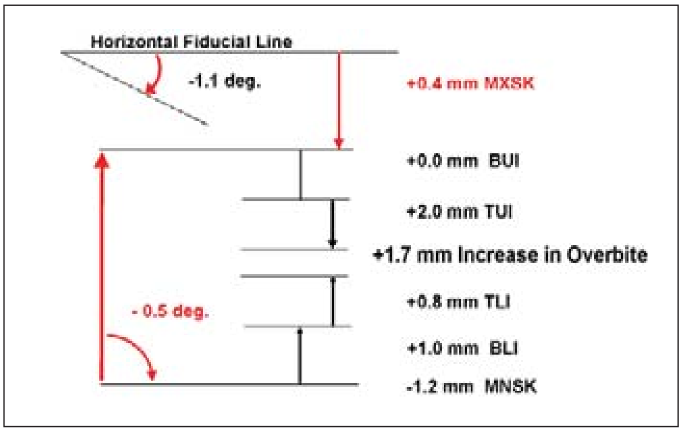

Fig 13 Schematic diagram illustrating the net change in overbite with 4 premolar extraction straightwire edgewise treatment of open-bite cases. *Statistically significant changes ($P \leq .05$)

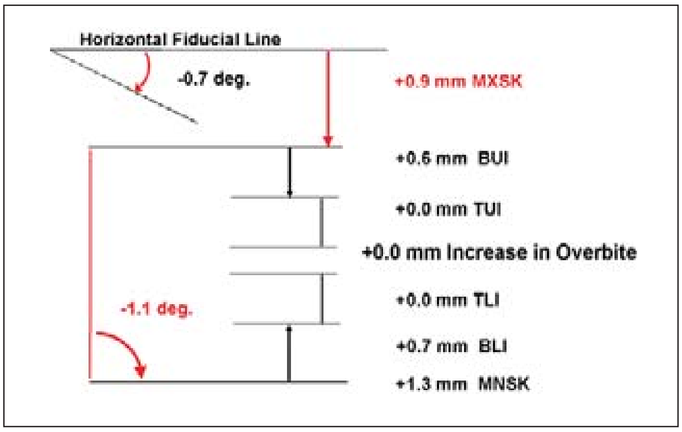

Fig 14 Schematic diagram illustrating the average change per year for each variable in untreated controls. *Statistically significant changes ($P \leq .05$).

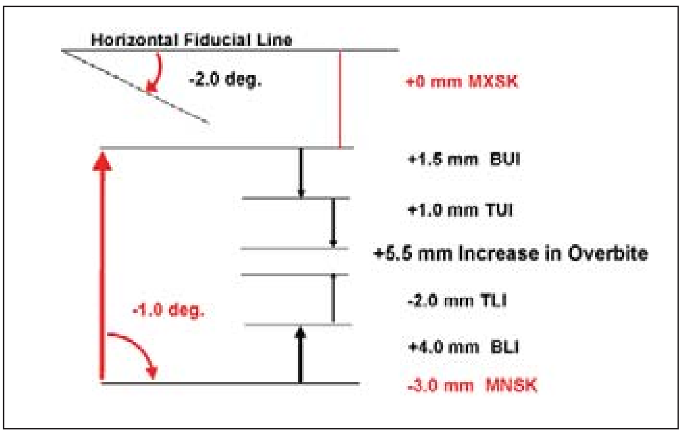

Fig 15 Schematic diagram illustrating the net change in overbite with 4 premolar extraction straightwire edgewise treatment of open-bite case at TSGH (case 1).

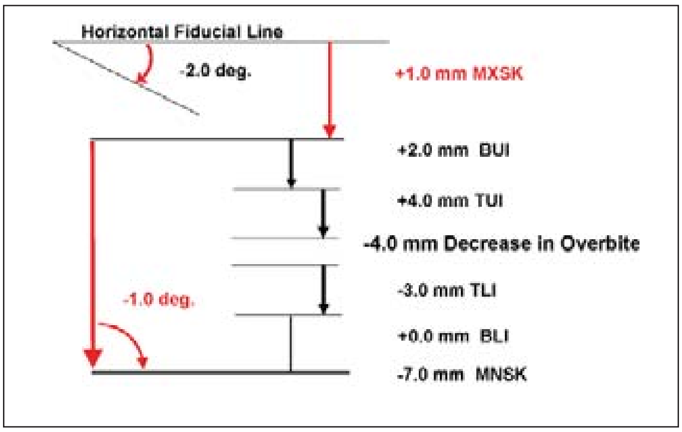

Fig 16 Schematic diagram illustrating the net change in overbite with Herbst and fixed appliance treatment of deep-bite case at TSGH (case 2).

this treatment group: There was a significant maxillary skeletal change of 1.7 mm toward the occlusal plane, a significant bodily movement of the maxillary incisor of 1.9 mm away from the occlusal plane, and a significant mandibular skeletal change of 2.4 mm away from the occlusal plane (see Fig 9). The average net change of 2.3 mm away from the occlusal plane in overbite with bionator treatment of deep-bite cases is shown in Fig 10. There were 7 statistically significant changes within this treatment group; in addition to the decrease in overbite, there was significant maxillary skeletal change of 0.5 mm toward the occlusal plane, significant bodily movement of the maxillary incisor of 0.9 mm away from the occlusal plan, significant bodily movement of the mandibular incisor of 0.5 mm away from the occlusal plane, significant mandibular skeletal change of 1.6 mm away from the occlusal plane, significant change of mandibular plane angle (SN-MP) of 0.7 degree away from the occlusal plane, and significant change of gonial angle of 2.0 degrees away from the occlusal plane (see Fig 10). The average net change of 1.5 mm toward the occlusal plane in overbite with active vertical corrector treatment of open bite is shown in Fig 11. The average net change of 1.5 mm toward the occlusal plane in overbite with phase 2 straightwire edgewise treatment of open bite is shown in Fig 12. The average net change of 1.7 mm toward the occlusal plane in overbite with 4 premolar extraction straightwire edgewise treatment of open bite is shown in Fig 13.

The numbers in each figure representing the changes due to growth (ie, mean changes found for the control groups) are shown in Fig 14. Therefore, the results as presented do not include additional maxillary skeletal changes (0.9 mm per year), mandibular skeletal changes (1.3 mm per year), bodily movement of the maxillary incisors (0.6 mm per year), and bodily movement of the mandibular incisors (0.7 mm per year). Note that there was no change in the average inclination of the maxillary or mandibular incisors in the control groups.

The 2 reported cases were treated at the Division of Pedodontics and Orthodontics, the Tri-Service General Hospital of the National Defense Medical Center, Taipei, Taiwan, ROC. One open-bite case was treated by 4 premolar extraction straightwire (see Figs 3 and 4); and a deep-bite case was treated using a Herbst appliance, followed by full bands and bonds without extraction of teeth (see Figs 5 and 6). The changes in 6 linear measurements and 2 angular measurements were calculated before and after treatment for each case. The linear measurements of the 6 variables before and after treatment for the open-bite case are summarized in Table 1. The net change of 5.5 mm toward the occlusal plane in overbite with 4 premolar extraction straightwire edgewise treatment of open-bite cases is shown in Fig 15. The linear measurements of the 6 variables before and after treatment for the deep-bite case (case 2) are summarized in Table 2. The net change of 4 mm away from the occlusal plane in overbite with Herbst and fixed appliance treatment of deep-bite cases is shown in Fig 16. The results demonstrated that there was 5.5 mm of overbite increase for the open-bite case and 4 mm of overbite decrease for the deep-bite case. The net changes support the use of the chosen treatment modalities and are consistent with evidence-based decision-making principles.

DISCUSSION

The intent of this article is to present a summary of the findings of 3 studies on deep-overbite correction and 3 studies on open-bite correction, and to construct clinically relevant evidence-based decision trees that can be used to develop rational treatment plans for patients. The data are discussed in 3 sections *(1)* what can be learned about each strategy from the data presented; *(2)* how strategies can be combined to help develop care plans for new patients; and *(3)* what the general principles are regarding the interaction of horizontal and vertical tooth movements during treatment. Two clinical cases have been presented that demonstrate the expected changes after proper orthodontic treatment.

Table 1 Linear measurement changes of the 6 variables for the open-bite case (case 1)

Variables	Pretreatment	Posttreatment	Changes (D)*
MXSK (M1)	31	31	0
BUI (M2)	46	47.5	+1.5
TUI (M3)	69	71.5	+1.0
TLI (M4)	68	65	+2.0
BLI (M5)	84.5	83.5	+4.0
MNSK (M6)	113	116	−3.0

MXSK, vertical movement of the maxilla; MNSK, vertical movement of the mandible; BUI, bodily movement of the maxillary incisors; TUI, tipping of the maxillary incisors; TLI, tipping of the mandibular incisors; BLI, bodily movement of the mandibular incisors.
*Negative number, dental and skeletal movements away from the occlusal plane; positive number, movements toward the occlusal plane.
MXSK = change in length from reference line to ANS (M1)
Δ MXSK = difference between the two M1.
Δ BUI (Δ M2) = difference between M2 − M1.
Δ TUI (Δ M3) = difference between M3 − M2.
Δ TLI (Δ M4) = difference between M5 − M4.
Δ BLI (Δ M5) = difference between M6 − M5.
Δ MNSK (Δ M6) = difference between M6 − M1.
Δ Lower face height = Δ MXSK + Δ MNSK = 0 + (−3) = −3 (the mandible moves toward the occlusal plane or there is growth-related counterclockwise rotation during treatment).
Δ Overbite = Δ MNSK+ Δ BUI + Δ TUI + Δ TLI + Δ BLI = (3.0) + (+1.5) + (+1.0) + (+2.0) + (+4.0) = +5.5 (ie, there was a 5.5-mm increase in overbite after treatment).

Table 2 Linear measurement changes of the 6 variables in the deep-bite case (case 2)

Variables	Pretreatment	Posttreatment	Changes (D)*
MXSK (M1)	28	29	+1.0
BUI (M2)	37	40	+2.0
TUI (M3)	54	61	+4.0
TLI (M4)	48	59	−3.0
BLI (M5)	66	74	+0.0
MNSK (M6)	93	101	−7.0

MXSK, vertical movement of the maxilla; MNSK, vertical movement of the mandible; BUI, bodily movement of the maxillary incisors; TUI, tipping of the maxillary incisors; TLI, tipping of the mandibular incisors; BLI, bodily movement of the mandibular incisors.
*Negative number, dental and skeletal movements away from the occlusal plane; positive number, movements toward the occlusal plane.
MXSK = change in length from reference line to ANS (M1).
Δ MXSK = difference between the two M1.
Δ BUI (Δ M2) = difference between M2 − M1.
Δ TUI (Δ M3) = difference between M3 − M2.
Δ TLI (Δ M4) = difference between M5 − M4.
Δ BLI (Δ M5) = difference between M6 − M5.
Δ MNSK (Δ M6) = difference between M6 − M1.
Δ Lower face height = Δ MXSK + Δ MNSK = 1.0 + (−7) = −6 (the mandible moves away from the occlusal plane or there is growth-related clockwise rotation during treatment).
Δ Overbite = ΔMNSK+ Δ BUI + Δ TUI + Δ TLI + Δ BLI = (−7.0) + (+2.0) + (+4.0) + (−3.0) + (+0.0) = −4.0 (ie, there was a 4-mm decrease in overbite after treatment).

Strategies for deep-overbite correction

The first major rule of deep-overbite treatment is that growth helps. If the annualized changes that occur in the control groups are examined, it is clear that facial height is increasing at a rate of almost 2 mm per year during active growth. This increase in facial height is stabilized by concomitant vertical eruption of both the maxillary and mandibular teeth toward the occlusal plane. Similar to the condylar cartilage in Johnston's "ratchet hypothesis" for horizontal mandibular growth, the teeth are the gears on the ratchet for vertical growth and maintain the increase in skeletal facial height that result from bony growth. Since Risinger and Proffit[7] have shown that teeth erupt at night, the clinician should focus on night-time wear of extraoral devices designed to promote or limit dental eruption. In the case of deep bite with decreased lower vertical facial height, the clinician should try to maximize extrusion of the dentition. Both the bionator and the cervical-pull headgear groups showed increases in facial height associated with treatment. The cervical-pull headgear was slightly more effective in increasing lower facial height. This was primarily because the headgear increased both maxillary and mandibular skeletal height, and force application was active rather than passive.

Bodily movement of the maxillary and mandibular incisors contributed to correction of the deep bite in all of the samples studied. This makes sense since, in the absence of treatment, the maxillary and mandibular incisors tend to erupt toward the occlusal plane to maintain the dental occlusion as the maxilla and mandible grow. Since teeth are suspended within each bone by the periodontal ligament, they are displaced along with the bone during periods of rapid growth; however, they can erupt independently toward the occlusal plane. An interesting combination of movements between bone and teeth occurs with the maxillary compared to the mandibular jaw. Since the eruption of both the maxillary and mandibular incisors is toward the occlusal plane, eruption of teeth in the maxilla is synergistic with the growth changes in this bone; in the mandible, eruption of the teeth is in the direction opposite of bone growth. In the absence of treatment (see Fig 14), the eruption of the maxillary and mandibular incisors equals the vertical change in the mandible. Therefore, the effective clinical working range for dental changes in overbite is the sum total of the skeletal changes. The clinical implications of this statement indicate that if a patient has both a deep bite and decreased lower facial height then an effective treatment strategy would be to stimulate vertical facial growth during treatment. The data suggest that most treatment strategies result in an increase in lower facial height. From greatest increase to least, potential strategies include cervical-pull headgear, bionator, nonextraction straightwire, and 4 premolar extraction straightwire. Within these strategies, the clinician must also consider the relationship of the maxillary incisors to the upper lip.

Clinically, the orthodontist must answer the question of whether or not to intrude the maxillary incisor. If the answer is yes, then the best clinical choice to intrude the maxillary incisors and increase the lower face height is nonextraction, cervical-pull headgear, with a maxillary utility arch. Using this therapeutic combination and planning on the average treatment response, a 9-mm increase in facial height can be expected for a teenager during an average 2-year treatment interval. This 9 mm includes 4 mm of natural vertical growth and 5 mm of increased facial height due to treatment. Since maxillary skeletal changes occur toward the occlusal plane, the effective working range that can be used by the clinician to improve the deep bite is the mandibular skeletal change. In the case of the cervical-pull headgear strategy, the average mandibular skeletal change is about 5 mm (2.4 mm from treatment, 2.6 mm from natural growth). The observed change in overbite is 5.2 mm, with about half of this change due to intrusion of the maxillary incisors. Therefore, on average the clinician used all of the working range to achieve the results. More intrusion of the maxillary incisors would require extrusion of the mandibular incisors to maintain incisor contact. If the average crown height of the maxillary lateral incisor is about 7 mm and normal overbite is about 1 mm, then the maximum change in deep overbite would be about 6 mm. Therefore, this combination of intraoral and extraoral mechanics produces a change in overbite that is close to the maximum.

What about changes in dental overbite without an increase in facial height? If the treatment goal is to correct a deep overbite without increasing lower vertical facial height, then only 2 of the strategies examined here are viable choices. Interestingly, both strategies involve removing permanent teeth. The more common choice is extraction of 4 first premolars. In this study, 2 groups received this treatment strategy; 1 was a deep-bite sample and the other an open-bite sample. The other difference between the 2 groups was in treatment mechanics, with 1 group treated with Tweed mechanics and the other with sliding mechanics. It appears that extraction of premolars alone is not enough to control an increase in lower facial height normally associated with orthodontic treatment of growing patients. Since 1 group was an open-bite sample, only the deep-overbite changes in the Tweed sample can be examined. Here, the overall increase in lower face height over a 2.5-year period would be about 5.5 mm (5 mm from normal growth and 0.5 mm due to treatment). Since only the mandibular skeletal change is available to correct deep overbite, the working range is about 3 mm. The change in overbite observed was 3.9 mm, resulting from 1.7-mm intrusion of the maxillary incisors, on average, and about 2.1 mm change in the mandibular incisors. The change in the maxillary incisors is similar to that seen with the cervical-pull headgear. However, since vertical facial height (maxillary skeletal change plus mandibular skeletal change) was not increased, the impact of the intrusion of the maxillary incisors relative to the maxilla was greater. This group did not approach the theoretical maximum of 6 mm overbite change. There are 2 reasons for this finding, the first is that the pretreatment overbites were not as deep as those in the cervical-pull headgear group and the second is that the overbite in the finished cases was deeper in the Tweed sample. Since 4 premolars were removed in the Tweed group, it is most likely that the bites were slightly deeper in the headgear sample.

Strategies for open-bite correction

The first rule of open-bite correction is that mandibular growth hurts. Of the 6 strategies examined, 3 showed increases in lower facial height, 2 showed no change from normal growth, and 1 showed a moderate, yet statistically insignificant, decrease in mandibular growth. It is important to note that since maxillary growth occurs toward the occlusal plane, relative intrusion of posterior maxillary teeth as the maxilla remodels downward is a potential source of open-bite correction. This relative intrusion is the most likely explanation for the small decrease in mandibular vertical growth seen with the active vertical corrector group. The reason the 1 mm decrease in vertical mandibular growth was not statistically significant is probably because of the large range of values associated with the active vertical corrector response. It is not clear if this variability in response is due to variations in patient compliance or due to biologic variability in response to this mechanical force system. However, the mean mandibular skeletal change in 1 year, due to normal growth, was 1.3 mm, so the treatment effect of 1 mm was close to the potential maximum relative intrusion of the posterior teeth during the average 12-month treatment with the active vertical corrector.

The 2 other strategies that showed no additional vertical facial growth during treatment both involved removal of permanent teeth. In the first molar extraction sample, the most likely explanation of the mechanism of response is that removal of the largest posterior tooth redistributed posterior occlusal forces and pressure exerted by the muscles of the pterygomasseteric sling and may have prevented the mandibular skeletal increase usually associated with orthodontic tooth movement. In the case of the Tweed 4-premolar extraction group, it is likely that the combination of extraoral forces of the high-pull J-hook headgear and intraoral vertical elastic traction extrusive forces on the dentition produced the change. Since this was a deepbite sample, it is not clear if a similar response would be observed in higher angle open-bite patients. The fact that mandibular growth is usually increased by many orthodontic interventions suggests that open-bite treatment approaches that do not involve attempts at relative mandibular molar intrusion should not be used during periods of rapid facial growth. This general recommendation would also apply to the noncompliant patient who is unlikely to wear an active vertical corrector or high-pull headgear to counteract the natural extrusive effects of orthodontic tooth movements.

Examination of the 4-premolar extraction group demonstrates the importance of tipping of the anterior teeth lingually to achieve incisor contact in open-bite patients. It is worth noting that in the untreated controls there was virtually no change in incisor angulation in the absence of orthodontic treatment. Although only the changes in maxillary and mandibular incisor tipping associated with 4-premolar extraction were statistically significant, changes in angulation of the maxillary and mandibular incisor teeth were observed in all of the open-bite correction groups. This difference in tipping among groups is understandable, since the decision to extract first premolars is often made when the orthodontist wants to resolve dental problems in anterior teeth. The old maxim, to extract as close as possible to the problem, is justified by the results of these controlled studies. In the case of open bite, premolar extraction allows maximum retraction of the anterior teeth and, since tipping is under operator control, the orthodontist can adjust the angulation of the teeth to achieve the desired result. One should also note that natural dental eruption occurs toward the occlusal plane and thus favors open-bite correction. This factor is often considered in the correction of open bites that are the result of thumb- or digit-sucking habits. In the young child, the natural forces of dental eruption will often correct an anterior open bite if the child can stop the habit. This natural tendency for spontaneous correction often clouds findings of early intervention strategies for open bite, since at least some of the treated patients would have improved without treatment. That is one of the main problems when studying early intervention strategies. By definition, all early intervention strategies that are really unnecessary, because naturally occurring processes such as dental eruption would correct the problem, get counted as treatment successes when they should be considered failures. This fact points to the need for untreated controls in all scientific investigations of treatment strategies.

General vertical principles

Figure 17 schematically illustrates the impact of overbite changes in angulation of the anterior teeth. As can be seen in the drawing, as the maxillary and mandibular incisors are retracted around their center of rotation (estimated to be about two-thirds of the root length), the effective size of the crown in a vertical dimension increases. For an average crown height of 8 mm, a 15-degree change in angulation results in about a 2-mm increase in effective crown height, which translates to about a 2-mm increase in overbite. Similarly, in the mandibular arch, changing the mandibular incisor angulation by 15 degrees results in an additional 2 mm of effective incisor length and an additional 2 mm of incisor overbite. Although some maxillary and mandibular incisor retraction could probably be achieved in nonextraction cases, especially if there were large diastemas present, extraction of the first

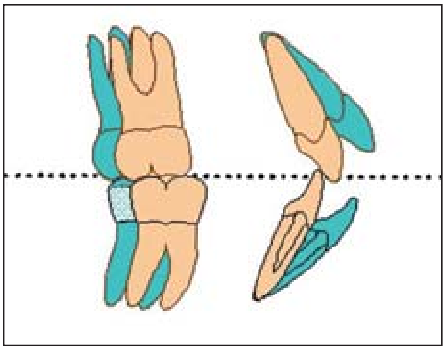

Fig 17 Schematic diagram illustrating the effect of incisor retraction/uprighting on overbite (before treatment, blue; after treatment, tan).

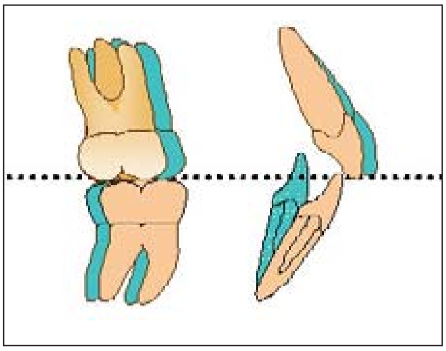

Fig 18 Schematic diagram illustrating the relationship between horizontal and vertical incisor relationships during Class II Division 1 molar correction with advancement of the mandibular incisors (before treatment, blue; after treatment, tan).

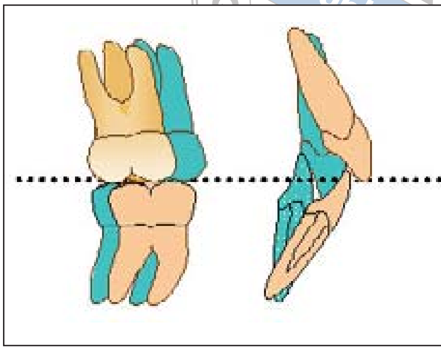

Fig 19 Schematic diagram illustrating overbite and overjet changes in Class II Division 2 deep-bite malocclusion, showing the effect of tipping the incisors forward on the overbite (before treatment, blue; after treatment, tan).

Table 3 Evidence-based decision matrix for deep-bite cases

Strategy	MXSK	MNSK	Lower face height	BUI	TUI	BLI	TLI
CPHG NonX utility arch	Hurts ++	Helps +++	Increased +++	Helps	Neutral	Neutral	Helps
Bionator	Hurts +	Helps	Increased ++	Helps	Hurts	Helps	Neutral
4× Tweed	Neutral	Neutral	Same	Helps +++	Neutral	Helps +++	Neutral

MXSK, vertical movement of the maxilla; MNSK, vertical movement of the mandible; BUI, bodily movement of the maxillary incisors; TUI, tipping of the maxillary incisors; TLI, tipping of the mandibular incisors; BLI, bodily movement of the mandibular incisors; Helps, changes in this variable help correction of the overbite; Hurts, changes in this variable are in the direction opposite that needed for correction of the overbite; Neutral, minimal changes observed in this variable compared to normal growth; CPHG NonX, cervical-pull headgear, nonextraction; 4× Tweed, extraction of 4 premolars, Tweed mechanics; +, subjective estimate of effect size.

Table 4 Evidence-based decision matrix for open-bite cases

Strategy	MXSK	MNSK	Lower face height	BUI	TUI	BLI	TLI
AVC–Phase 1	Helps	Neutral	Neutral	Neutral	Helps	Hurts	Helps
SW–Phase 2 NonX	Helps	Hurts	Neutral	Helps	Hurts	Helps	Hurts
4× SW	Helps	Hurts	Increased +	Neutral	Helps ++	Neutral	Helps ++
6× SW	Helps	Neutral	Neutral	Neutral	Helps	Neutral	Helps

MXSK, vertical movement of the maxilla; MNSK, vertical movement of the mandible; BUI, bodily movement of the maxillary incisors; TUI, tipping of the maxillary incisors; TLI, tipping of the mandibular incisors; BLI, bodily movement of the mandibular incisors; Helps, changes in this variable help correction of the overbite; Hurts, changes in this variable are in the direction opposite that needed for correction of the overbite; Neutral, minimal changes observed in this variable compared to normal growth; AVC, active vertical corrector; 6× SW, extraction of 4 first molars, straightwire mechanics; +, subjective estimate of effect size.

premolars is likely the most efficient strategy to create large amounts of space to retract and upright incisors (Table 3). For this reason, a general principle of open-bite treatment in the permanent dentition should be "if in doubt, take them out" (Table 4).

Figure 18 illustrates the relationship between overjet and overbite in Class II correction. In the Class II Division 1 malocclusion, there is usually a degree of dental protrusion. This dental protrusion must be eliminated if orthodontic correction of the overjet is to be successful. However, there are at least 3 approaches to reducing this protrusion. The first is to remodel the maxillary dentition using headgear applied to the maxillary first molars. The vertical effects of this approach will be to increase mandibular vertical growth. A second alternative is to expand the maxilla. Again, the effects of expansion will likely result in an increase in vertical facial height. The third approach combines bodily and tipping retraction of the anterior teeth, which is operator-controlled. However, retraction of teeth requires space and therefore often requires the extraction of permanent teeth. In these cases, attention should be paid to the vertical dimension. Ideally, the orthodontist should try to limit additional increases in vertical facial height during overjet correction since vertical increases negatively impact overjet correction. The authors suggest that Tweed mechanics might be a good approach to use for Class II correction when reduction in maxillary dental protrusion without increasing mandibular vertical height is a treatment goal. In the mandibular arch, the interaction of vertical and horizontal incisor movements is also worth considering. As shown in Fig 18, tipping the mandibular incisors around the center of rotation results in forward and downward movement of the incisal edge. In fact, for each millimeter of anterior movement, there is about 0.5 mm of vertical change and a gain of about 1.5 mm in arch length. This combination of vertical and horizontal changes favors overjet correction in cases of deep bite with mandibular anterior crowding, using a nonextraction approach in the mandibular arch. Therefore, in Class II Division 1 cases associated with mandibular crowding and maxillary dental protrusion, a treatment plan involving extraction of first premolars in the maxillary arch without extraction in the mandibular arch makes sense. In Class II Division 1 cases with decreased lower facial height and minimal mandibular crowding, nonextraction with application of a headgear is a reasonable treatment approach to achieve dental correction and improve facial balance.

The last general consideration of vertical and horizontal interactions concerns the patient with a Class II Division 2 anterior dental appearance. These cases often have bimaxillary dental retrusion, in addition to deep overbite and a Class II molar relationship. In these cases, tipping both the maxillary and mandibular incisors forward around the center of rotation creates a favorable interaction of vertical and horizontal dental changes (Fig 19). As was seen in the previous example, for every millimeter of forward movement of the incisal edge, there is a gain of about 1.5 mm in arch length in both arches. For each millimeter of movement forward around the rotational center, the overbite is reduced by about 0.75 mm in the maxillary arch and by about 0.5 mm in the mandibular arch. The synergistic effect of these movements effectively resolves crowding and deep bite. In fact, in Class II Division 2 cases that do not share the characteristics of crowding and deep bite, treatment is usually more difficult.

CONCLUSIONS

To the degree that orthodontics is a science and not an art, evidence-based decisions are possible. This article reviewed the results of 6 case-controlled studies; 3 studies addressed the problem of deep overbite and 3 studies considered the problem of open bite. The net changes reported for the 2 clinical cases presented were consistent with the evidence-based decision-making principles for vertical correction outlined here.

Based on the combined results of these studies, the authors suggest the following 4 principles of vertical overbite correction:

1. Treat deep bite during periods of active growth.
2. Treat deep bite more often with nonextraction.
3. Treat open bite after growth has slowed.
4. Treat open bite more often with extraction of permanent teeth.

Of course, these principles are not to be considered inviolate rules for treatment. Diagnosis and treatment planning in orthodontics must be individualized for each patient. There is no substitute for good clinical judgment by an experienced orthodontist. Orthodontic treatment is both a science and an art, and successful patient care requires the application of both.

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