THE CUTTING EDGE

This quarterly column is compiled by JCO Technology Editor W. Ronald Redmond, DDS, MS. To help keep our readers on The Cutting Edge, Dr. Redmond will spotlight a particular area of orthodontic technology every few months. Your suggestions for future subjects or authors are welcome.

Dr. Niansong Ye and colleagues have contributed a fascinating article in which they describe the use of cone-beam computed tomography (CBCT), computer-aided design, and three-dimensional printing to produce a customized lingual appliance. The brackets are precisely positioned on the lingual surfaces by means of indirect bonding jigs produced with a 3D printer.

Their method requires a scan lasting several seconds to achieve enough accuracy (within 80 microns) for a good bracket-enamel interface. The authors admit that this amount of radiation exposure may be considered a drawback. Advantages of their system over other digital procedures for creating lingual appliances include the use of stainless steel rather than precious metals, as well as the ability to achieve root parallelism due to the visibility of the roots in CBCT scans.

If you have been following this column, you will remember my analogy to the competition between CBCT and intraoral scans as a high-stakes horse race. The race continues, with CBCT coming up fast on the inside. I, for one, am enjoying the dash to the finish! WRR

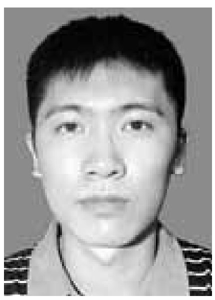
Computer-Aided Design of a Lingual Orthodontic Appliance Using Cone-Beam Computed Tomography

Although lingual orthodontics has been practiced for more than 30 years, it has never been widely accepted due to issues of patient discomfort, interference with speech, imprecise finishing, and the difficulty of rebonding brackets.[1] The Incognito* bracket introduced by Wiechmann, using digital models acquired from high-resolution three-dimensional scans of plaster casts,[2-4] has brought considerable improvement, but still has its drawbacks. For example, the lingual contours of teeth that are overlapping or partially erupted cannot be accurately scanned; in such cases, the setup can be designed only by experience, instead of using a defined tip and torque for each tooth. Furthermore, the setup software is unable to determine the labiolingual inclination of each tooth or

*Trademark of 3M Unitek, Monrovia, CA; www.3mUnitek.com.


Dr. Ye


Dr. Li


Dr. Zhang


Dr. Yang


Dr. Lai

Drs. Niansong Ye and Kefu Zhang are graduate students and Dr. Wenli Lai is Professor and Department Chair, Department of Orthodontics, and Dr. Jingtao Li is a graduate student, Department of Cleft Lip and Palate Surgery, West China College of Stomatology, Sichuan University, Chengdu 610041, China. Dr. Yimin Yang is Senior Engineer, ORJ Medical Instrument & Material Co., Ltd., Hangzhou, China. E-mail Dr. Lai at wenlilai@hotmail.com.

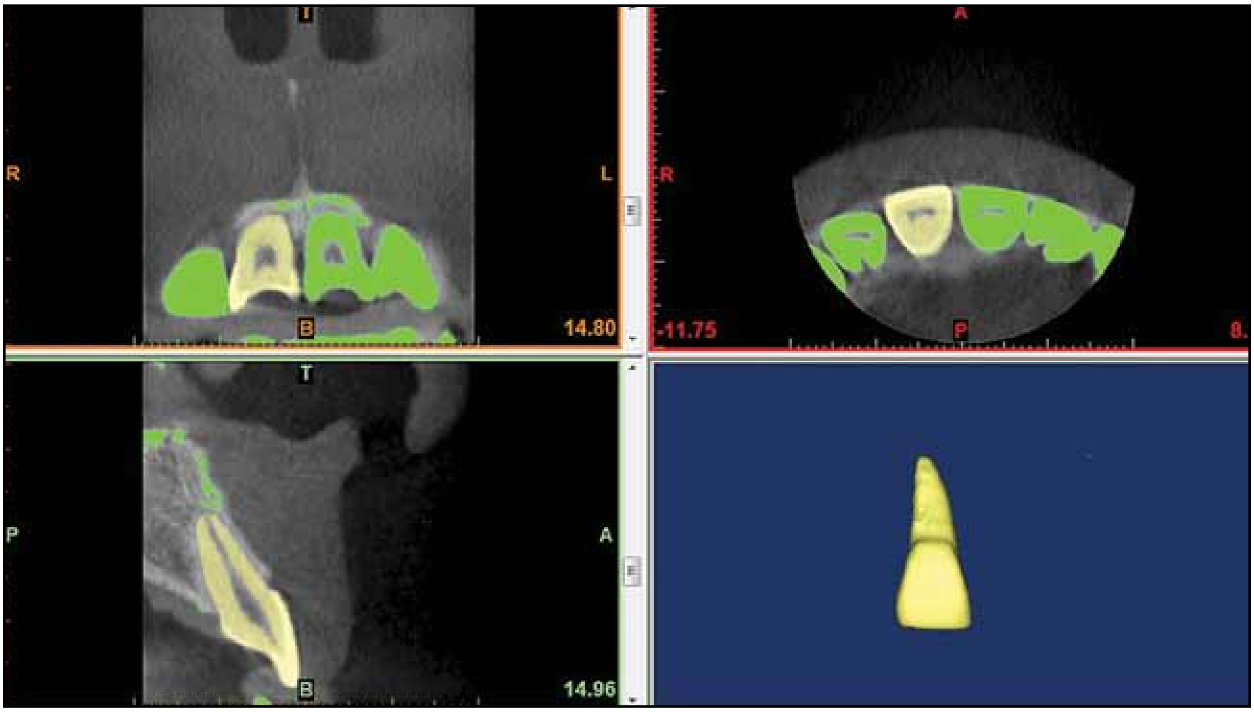


Fig. 1 Three-dimensional model for each tooth created from segmental cone-beam computed tomography (CBCT).

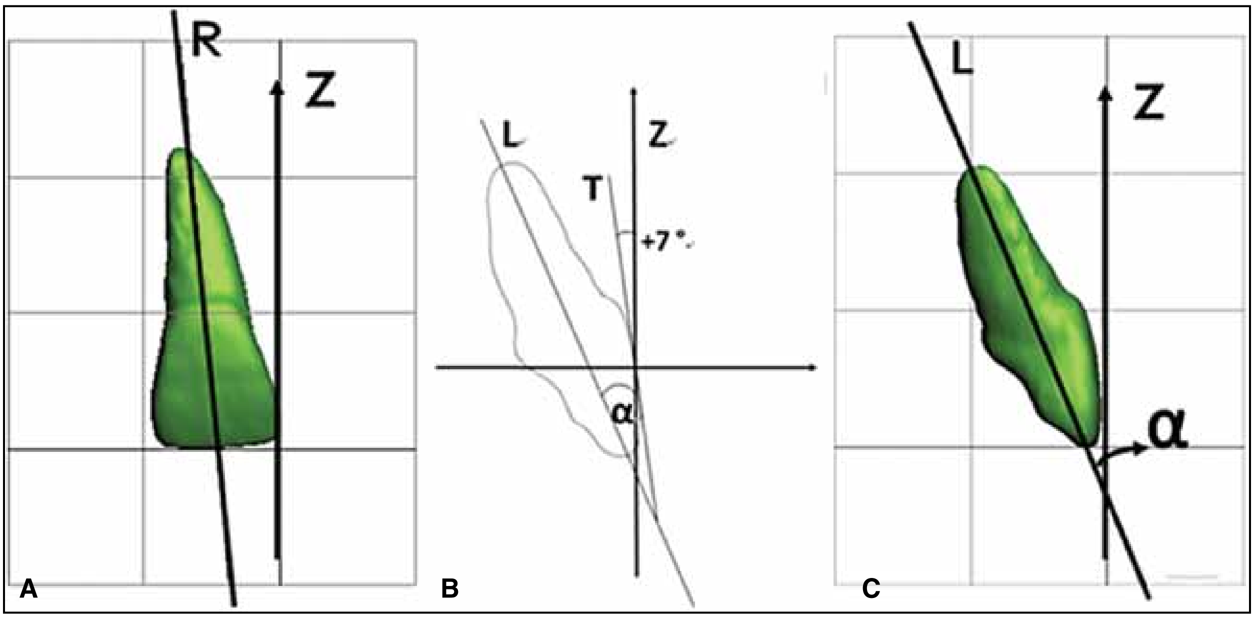


Fig. 2 A. Measurement of upper central incisor's crown angulation in 3ds Max‡ software (Z = axis perpendicular to occlusal plane; R = clinical-crown axis). B. Measurement of upper central incisor's labiolingual inclination in AutoCAD‡ software (L = long axis of tooth; T = tangent to midpoint of labial surface). Angle α (Z/L) is equivalent to labiolingual inclination (T/Z)—in this case, +7°. C. Angle α set up as labiolingual inclination in 3ds Max software.

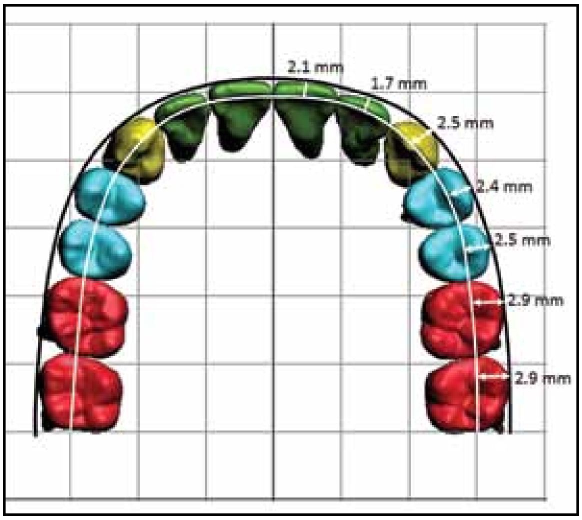


Fig. 3 Dental archform determined from standard chart, and facial prominence of crowns calculated according to Andrews.[6]

to establish root positions.

This article describes a relatively inexpensive method of producing 3D models and customized lingual brackets with cone-beam computed tomography (CBCT) and computer-aided design and manufacturing (CAD/CAM) technologies, using simplified laboratory procedures.[5]

Digital Setup

Volumetric images of the dentition and adjacent skeleton are obtained by segmental CBCT scanning** with a 40mm × 40mm field of view, a tube voltage of 90kV, a current of 5mA, a scan time of 18 seconds, and a voxel size of .08mm. The results are stored in DICOM*** format and input into Mimics† software (version 10.01) for 3D reconstruction in .stl format (Fig. 1).

The .stl file for each tooth is input into 3ds Max‡ software (version 11.0) and analyzed according to Andrews's six keys to normal occlusion,[6] as follows.

Crown angulation: The angle between the clinical-crown axis and the Z-axis (a line perpendicular to the occlusal plane) is calculated on the labial face of each tooth (Fig. 2A).

Labiolingual inclination: This is the angle formed by a tangent to the midpoint of the labial surface and the Z-axis. Because it is difficult to visualize with the current 3ds Max software, it must be measured in a different system. The projection image of each tooth in the lateral or medial plane is imported into AutoCAD‡ software, the tangent to the midpoint of the labial surface is extended, and the angle between the tangent and the tooth's long axis (the line passing through the incisal edge and the root apex for an anterior or lower posterior tooth, or the buccal cusp and furcation for an upper posterior tooth) is measured. The angle α between the long axis and the Z-axis is then calculated (Fig. 2B). In the 3ds Max software, the angle α is used to represent the labiolingual inclination of each tooth under the Andrews system (Fig. 2C).

Archform: The dental archform is determined by referring to a standard chart, and the facial prominence of the crown of each tooth is calculated according to Andrews (Fig. 3).

Occlusion: The molar relationship in neutrocclusion and the normal overbite and overjet are measured in terms of Andrews's optimal occlusion (Fig. 4).

Customized Lingual Appliances

After the setup is complete, the 3D dental model is loaded into SolidWorks†† software. A virtual .018" × .025" lingual archwire with 1st-order bends is constructed, and virtual brackets are placed at each tooth. Bracket bases (.4mm thick) are formed to adapt closely to the contours of the lingual surfaces, and the bracket bodies are then positioned on the bases at the level of the slot plane, incorporating 2nd- and 3rd-order bends

**Accuitomo 170, trademark of J. Morita Manufacturing Corporation, Kyoto, Japan; www.jmorita-mfg.com.

***NEMA, Rosslyn, VA; www.dicom.nema.org.

†Registered trademark of Materialise, Leuven, Belgium; www.materialise.com.

‡Registered trademark of Autodesk, Inc., San Rafael, CA; www.autodesk.com.

††Registered trademark of Dassault Systèmes SolidWorks Corp., Concord, MA; www.solidworks.com.

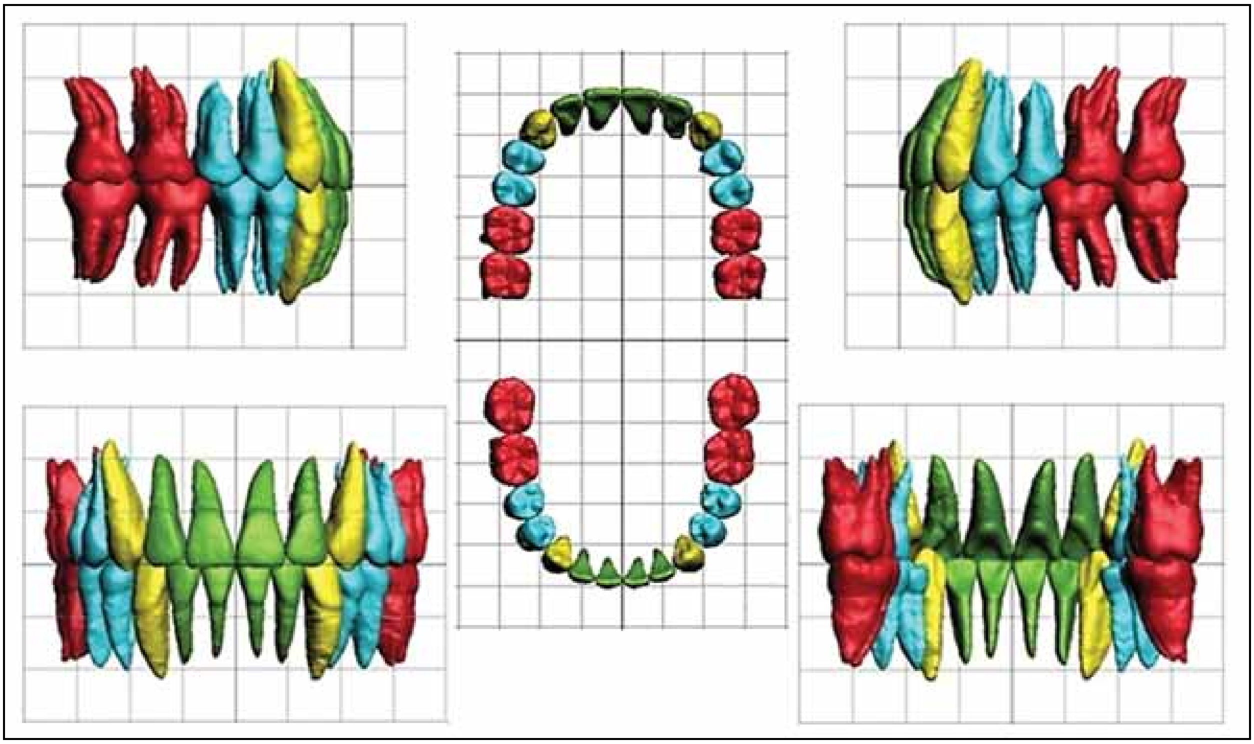


Fig. 4 Digital setup of optimal occlusion.

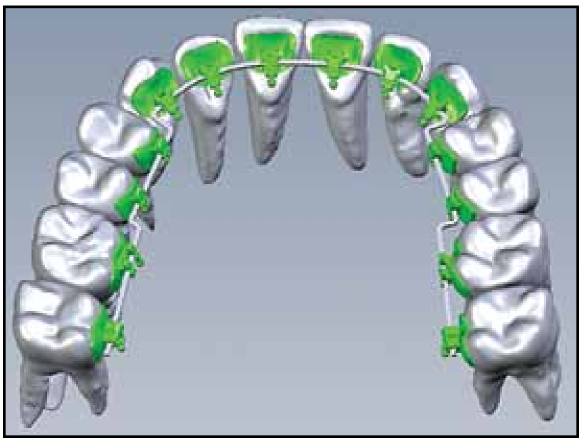


Fig. 5 Bracket bases adapted to virtual lingual contours; bracket bodies positioned on bases at level of slot plane.

(Fig. 5).

An .stl file for each completed virtual bracket (Fig. 6A) is loaded into a 3D printing system to produce a set of wax bracket analogs (Fig. 6B). Each bracket is then cast in stainless steel (Fig. 6C); we use conventional 17-4 (17% chromium, 4% nickel) stainless steel to make the brackets more affordable, compared with the gold alloy used in the Incognito system.[2]

Larger bracket bases can be placed and bonded directly onto the lingual surfaces of the upper anterior teeth. Teeth with more irregular lingual contours, especially the lower incisors and premolars, require customized bracket positioners to ensure accurate bonding. Using a procedure similar to the fabrication of the customized brackets, 3D models of customized positioners (Fig. 7A) are designed in SolidWorks, saved in .stl format, and printed in acrylic (Fig. 7B). The tooth number is marked on each corresponding positioner, and the positioners are then loaded with their correspond-

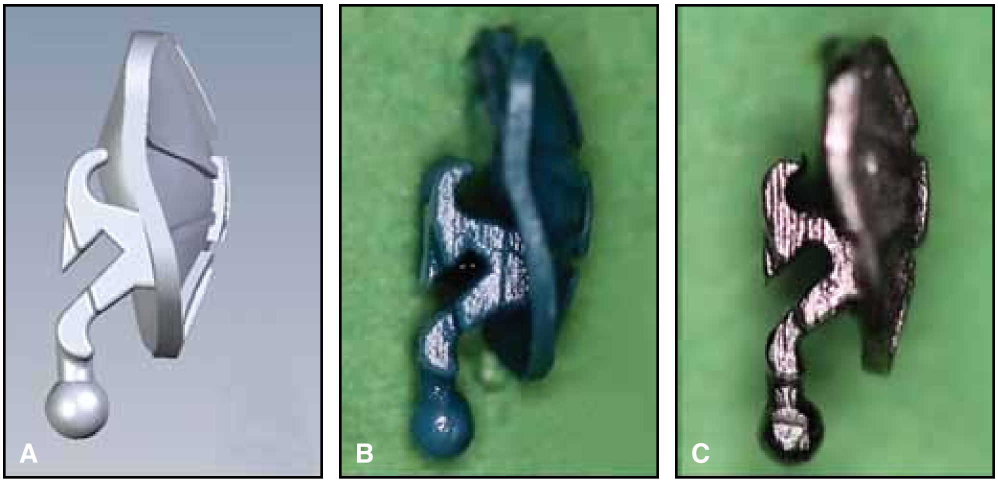


Fig. 6 A. 3D virtual model of bracket. B. Wax analog of bracket generated with 3D printer. C. Bracket cast in 17-4 stainless steel.

Fig. 7 A. 3D virtual models of customized bracket positioners. B. Customized positioners printed in acrylic.

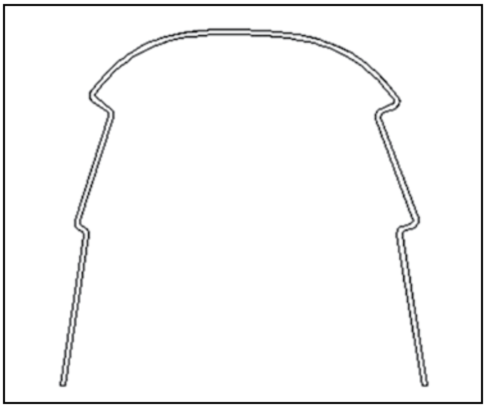


Fig. 8 Template for manual bending of customized lingual archform.

ing brackets and placed on the cast to verify that each gingival edge is pressure-free and that the positioners seat easily.

A customized lingual archwire is designed using AutoCAD software, and a template is printed at a 1:1 scale for bending of the archform (Fig. 8).

Figure 9 shows a patient bonded with customized lingual appliances.

Discussion

A manual customized setup requires separation of the teeth on a plaster cast, which can damage the proximal surfaces. Moreover, it is almost impossible to keep the contours of overlapped, crowded teeth intact during separation. These factors can have a major impact on the subsequent appliance design. Our CBCT-based digital setup not only avoids such inaccuracy, but also incorporates the dental roots, allowing the clinician to accurately plan for root parallelism at the end of treatment.

Our software is currently unable to determine the labiolingual inclination according to the angle formed by the Z-axis and a tangent to the midpoint of the labial surface, but it can analyze labiolingual inclination using AutoCAD software. The crown angulation and inclination of each tooth are thus set up digitally according to Andrews's optimal occlusion.

Repeatability can be a problem with 3D wax printing. Our system uses two types of wax—the support wax, with a melting point of 90°C, and casting wax, with a melting point of 50°C—which are separated thermally. Because constriction may occur during the process from CAD model design to wax printing to final casting, the scale of the wax printer must be finely adjusted and pretested to ensure accuracy within .0127mm.

Precise bracket placement has been difficult to achieve with both lingual and labial orthodontic appliances. For this reason, various indirect-bonding systems have been introduced, including rapid prototyping trays (RPT),[7] the Custom Lingual Appliance Setup Service (CLASS),[8] the Hiro system,[9] and the Transfer Optimized Positioning (TOP) system.[10] Our method uses CAD/CAM software and 3D printing to produce a customized positioner for each tooth, thus ensuring accurate bonding. The acrylic positioners can be saved so that brackets can be properly reseated in the event of bond failures.

Current methods of creating digital models include laser scanning of plaster casts, CBCT imaging of orthodontic impressions or plaster casts, and direct intraoral laser scanning of the dental arches or plaster casts.[11] With either laser or CBCT scanning, the accuracy of the resulting 3D model can be affected by material distortion during impression taking or shrinkage during shipment to a service center. Intraoral laser scanning is inconvenient and time-consuming.[12] None of these scanning techniques can capture the full tooth contours in a patient with overlapping contacts or partially erupted or impacted teeth. A previously described technique merged CT-scanned roots and laser-scanned crowns to produce a complete 3D model, but the procedures were complex and time-consuming.[13] Our method directly reproduces the entire crown-and-root setup and requires less scanning time.

Although CBCT is not as precise in measuring dental morphology as surface-scanning methods, which reach an accuracy of 1 micron,[14] it is now accurate to a minimum voxel size of 80 microns, and research has confirmed a 1:1 image-to-reality ratio.[15,16] Still, in a study by Liu and colleagues, CBCT tooth volumes deviated from the actual physical measurements by –4% to 7%, with subjective aspects of virtual tooth segmentation affecting the volumetric measurements.[17] A high-resolution CBCT scan takes several seconds,

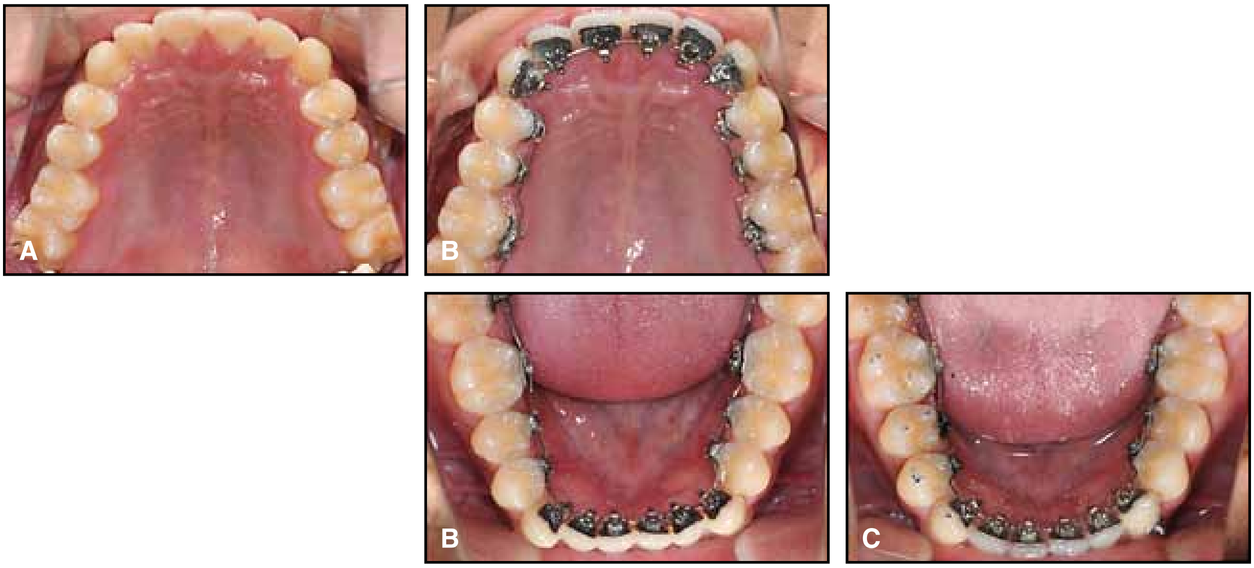


Fig. 9 A. Maxillary arch before treatment. B. After bonding with customized stainless steel brackets. C. Mandibular crowding resolved in six weeks using .014" nickel titanium archwire.

during which any motion of the patient's head could reduce accuracy; scanning accuracy may also be degraded by metal objects such as brackets and crowns.[18] Concerns about radiation dosage continue to be raised as well.

Conclusion

Our streamlined technique of 3D model acquisition, virtual setup, and CAD/CAM manufacturing of customized lingual brackets and positioners can be easily applied in the office to make customized lingual orthodontic appliances more acceptable to both patients and orthodontists.

REFERENCES

1. Mujagic, M.; Fauquet, C.; Galletti, C.; Palot, C.; Wiechmann, D.; and Mah, J.: Digital design and manufacturing of the Lingualcare bracket system, J. Clin. Orthod. 39:375-382, 2005.
2. Wiechmann, D.; Rummel, V.; Thalheim, A.; Simon, J.S.; and Wiechmann, L.: Customized brackets and archwires for lingual orthodontic treatment, Am. J. Orthod. 124:593-599, 2003.
3. Wiechmann, D.: A new bracket system for lingual orthodontic treatment, Part 2: First clinical experiences and further development, J. Orofac. Orthop. 64:372-388, 2003.
4. Wiechmann, D.: A new bracket system for lingual orthodontic treatment, Part 1: Theoretical background and development, J. Orofac. Orthop. 63:234-245, 2002.
5. McCrostie, H.S.: Lingual orthodontics: The future, Semin. Orthod. 12:211-214, 2006.
6. Andrews, L.F.: The six keys to normal occlusion, Am. J. Orthod. 62:296-309, 1972.
7. Ciuffolo, F.; Epifania, E.; Duranti, G.; De Luca, V.; Raviglia, D.; and Rezza, S.: Rapid prototyping: A new method of preparing trays for indirect bonding, Am. J. Orthod. 129:75-77, 2006.
8. Buso-Frost, L. and Fillion, D.: An overall view of the different laboratory procedures used in conjunction with lingual orthodontics, Semin. Orthod. 12:203-210, 2006.
9. Hiro, T.; Iglesia, F.; and Andreu, P.: Indirect bonding technique in lingual orthodontics: The HIRO system, Prog. Orthod. 9:34-45, 2008.
10. Wiechmann, D.: Lingual orthodontics (Part 3): Intraoral sandblasting and indirect bonding, J. Orofac. Orthop. 61:280-291, 2000.
11. White, A.J.; Fallis, D.W.; and Vandewalle, K.S.: Analysis of intra-arch and interarch measurements from digital models with 2 impression materials and a modeling process based on cone-beam computed tomography, Am. J. Orthod. 137:456 (e451-459), 2010.
12. Torassian, G.; Kau, C.H.; English, J.D.; Powers, J.; Bussa, H.I.; Salas-Lopez A., M.; and Corbett, J.A.: Digital models vs. plaster models using alginate and alginate substitute materials, Angle Orthod. 80:474-481, 2010.
13. Macchi, A.; Carrafiello, G.; Cacciafesta, V.; and Norcini, A.: Three-dimensional digital modeling and setup, Am. J. Orthod. 129:605-610, 2006.
14. Hajeer, M.Y.; Millett, D.T.; Ayoub, A.F.; and Siebert, J.P.: Applications of 3D imaging in orthodontics: Part I, J. Orthod. 31:62-70, 2004.
15. Maret, D.; Molinier, F.; Braga, J.; Peters, O.A.; Telmon, N.; and Treil, J.: Accuracy of 3D reconstructions based on cone beam computed tomography, J. Dent. Res. 89:1465-1469, 2010.
16. Lagravere, M.O.; Carey, J.; Toogood, R.W.; and Major, P.W.: Three-dimensional accuracy of measurements made with software on cone-beam computed tomography images, Am. J. Orthod. 134:112-116, 2008.
17. Liu, Y.; Olszewski, R.; Alexandroni, E.S.; Enciso, R.; Xu, T.; and Mah, J.K.: The validity of in vivo tooth volume determinations from cone-beam computed tomography, Angle Orthod. 80:160-166, 2010.
18. De Vos, W.; Casselman, J.; and Swennen, G.R.: Cone-beam computerized tomography (CBCT) imaging of the oral and maxillofacial region: A systematic review of the literature, Int. J. Oral Maxillofac. Surg. 38:609-625, 2009.