Original Article

Two- and Three-dimensional Orthodontic Imaging Using Limited Cone Beam–Computed Tomography

Akira Nakajima[a]; Glenn T. Sameshima[b]; Yoshinori Arai[c]; Yoshito Homme[d]; Noriyoshi Shimizu[e]; Harry Dougherty Sr.[f]

Abstract: Considerable progress has been made in diagnostic, medical imaging devices such as computed tomography (CT). However, these devices are not used routinely in dentistry and orthodontics because of high cost, large space requirements and the high amount of radiation involved. A device using computed tomography technology has been developed for dental use called a limited cone beam dental compact-CT (3DX). The aim of this article is to demonstrate the usefulness of 3DX imaging for orthodontic diagnosis and treatment planning. We present three cases: (1) one case shows delayed eruption of the upper left second premolar, (2) the second case shows severe impaction of a maxillary second bicuspid; and (3) the third case shows temporomandibular joint disorder (TMD). In the tooth impaction cases, the CT images provided more precise information than conventional radiographic images such as improved observation of the long axis of the tooth, root condition, and overlap with bone. In the TMD case, clear and detailed temporomandibular joint images were observed and pre- and posttreatment condylar positions were easily compared. We conclude that 3DX images provide useful information for orthodontic diagnosis and treatment planning. (*Angle Orthod* 2005;75:895–903.)

Key Words: Limited cone beam computed tomography; Image diagnosis; Impacted tooth; Temporomandibular joint disorder; Three-dimensional image

INTRODUCTION

We are on the verge of a great change in the way we visualize the craniofacial complex in medicine and dentistry. The impact on orthodontics will be profound. New imaging methods will replace the way we look at a variety of common diagnostic and treatment issues in daily orthodontic practice. A common example is the impacted tooth. We must obtain three-dimensional information (3D) from planar radiographic films to determine the precise location. Only then can one know in which direction to move the tooth safely and efficiently. Another problem requiring better imaging is the temporomandibular joint (TMJ). Observation of the joint on conventional TMJ radiographic images is difficult because of the superimposition of other structures located in the bone maxillary bone and the contralateral joint.

Since computed tomography (CT) was first developed,[1,2] CT image diagnosis has been used occasionally for dental diagnosis and treatment planning in 3D image diagnosis. However, conventional medical CT (helical-CT) units were not developed originally for dental diagnostic use. The problems in adapting helical-CT scans for dental use include high cost, large space requirement, long scanning time and, most important, high radiation exposure.

To resolve these problems in imaging and conventional CT, in 1997 the Department of Radiology in the Nihon University School of Dentistry developed a dental radiological unit using new technology known as limited cone beam computed tomography.[3] The origi-

[a] Assistant Professor, Department of Orthodontics, School of Dentistry, Nihon University, Tokyo, Japan.

[b] Associate Professor, Department of Orthodontics, School of Dentistry, University of Southern California, Los Angeles, Calif.

[c] Professor, Department of Hard Tissue Research, Graduate School of Oral Medicine, Matsumoto Dental University, Nagano, Japan.

[d] Research fellow, Department of Orthodontics, School of Dentistry, Nihon University, Tokyo, Japan.

[e] Professor and Chairman, Department of Orthodontics, School of Dentistry, Nihon University, Tokyo, Japan.

[f] Professor, Department of Orthodontics, School of Dentistry, University of Southern California, Los Angeles, Calif.

Corresponding author: Akira Nakajima, DDS, PhD, Department of Orthodontics, School of Dentistry, Nihon University, Tokyo 1018310, Japan
(e-mail: nakajima-a@dent.nihon-u.ac.jp)

Accepted: September 2004. Submitted: June 2004.

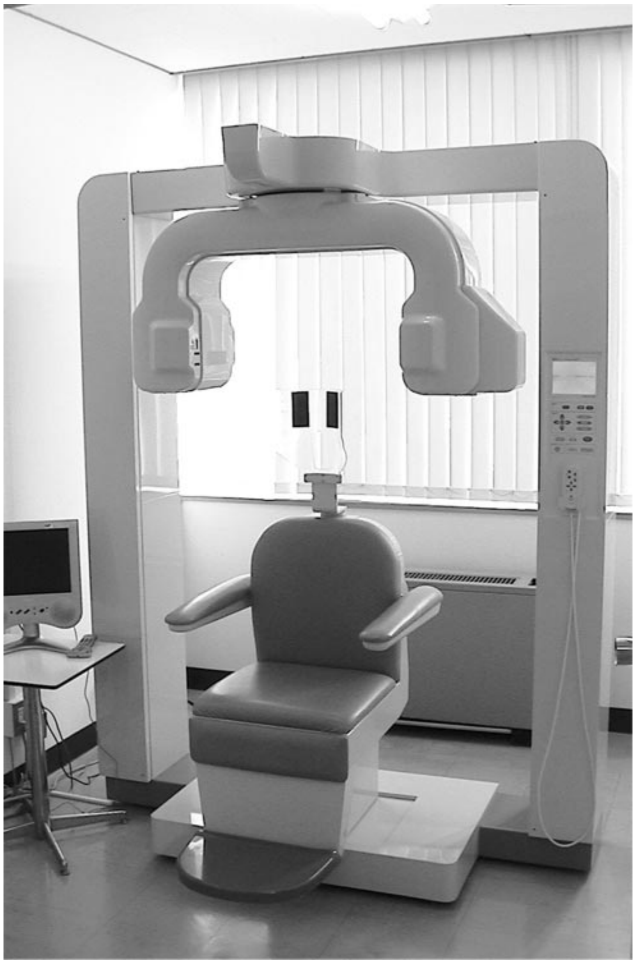

FIGURE 1. The new limited cone beam–type computed tomography apparatus (The 3DX multi-image micro-computed tomography [CT]).

nal prototype made use of existing technology in which the film was replaced by an image intensifier. Subsequent refinements and improvements resulted in the transfer of technology to the Morita Corporation as the 3DX multi-image micro-CT (3DX).[4,5] This CT uses a cone beam with a radiation field limited to a height of 29 mm and a width of 38 mm at the center of rotation (Figure 1). This new CT unit addressed some of the aforementioned problems of conventional CTs. The 3DX has a radiological dose effect that is 1/100 of the helical-CT and is comparable with a general dental X-ray unit.[6] The exposure time for a 3DX image is a relatively short 17 seconds, which is similar to panoramic radiography.[3] The unit rotates once around the subject and compiles data from each degree in a 360° rotation. Standard imaging conditions are a tube voltage of 85 kV and a tube current of 2 mA. This new CT has been adapted specifically for 3D dental imaging.[4,5]

The purpose of this article is to demonstrate the effectiveness of the images generated by 3DX for orthodontic diagnosis and treatment planning using impacted tooth and temporomandibular disorder (TMD) orthodontic cases as illustrations.

DIAGNOSIS AND TREATMENT RESULTS

Case 1

Case 1 is a 7.2-year-old child with a Class I malocclusion and a Class I skeletal pattern with an anterior open bite (Figure 2A through C). The cephalometric analysis is shown in Table 1. We started nonextraction orthodontic treatment because of the anterior open bite. The first phase of treatment consisted of a tongue guard appliance and myofunctional therapy to eliminate the tongue habit. After a year and a half of treatment, the open bite was closed. Two years later, the upper left second deciduous molar remained, although the other three quadrants had permanent teeth (Figure 2D through F).

Phase II records (Figure 2D through F) show a delayed eruption of the upper left second premolar after the left second deciduous molar had been extracted (Figure 2E,F). The occlusal radiographs show that the crown is rotated (Figure 2G), but root development is difficult to determine from the panoramic and dental films (Figure 2H,I).

The CT images clearly show the rotation of the tooth within the bone. The sagittal and frontal view images from the scan show the condition of the tooth crown and extent of root development (more than one-third) (Figure 3A 1 through 4 and B 1 through 4). The axial views from the scan show that the crown is positioned lingually (Figure 3C 1 through 4). Therefore, we performed the surgical fenestration and retraction of the left upper premolar tooth from the lingual side (Figure 3D through F). Final records are shown in Figure 3G through I. Normal occlusion and arch form were attained in the second phase of treatment, which lasted one year and four months.

Case 2

Case 2 was diagnosed as a Class II subdivision, skeletal Class I malocclusion, with a chief complaint of bilateral, impacted maxillary second premolars (Figure 4A through C). The patient was 13 years 11 months old at the start. The cephalometric analysis is shown in Table 1. The Tweed and Steiner analyses indicated a nonextraction treatment. Standard radiographic films and 3DX examination were exposed before orthodontic treatment. Although the eruption of the second premolars was delayed, a part of a right premolar cusp was apparent in the gingival tissue (Figure 4C, single arrow).

Conventional records and clinical examination show

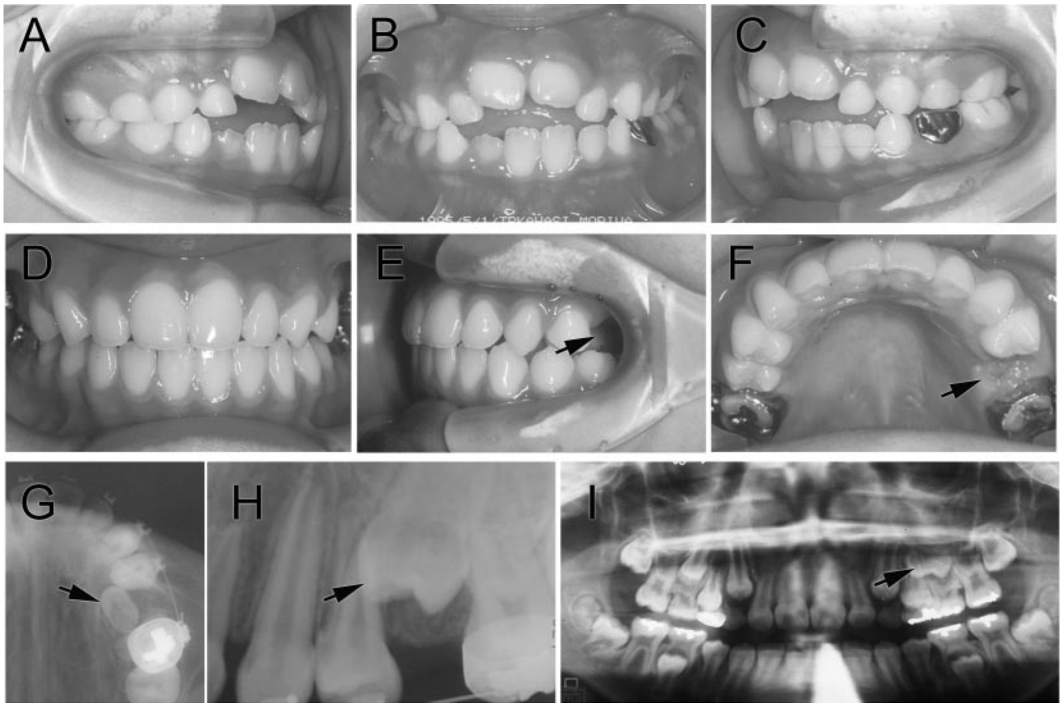

FIGURE 2. Case 1: (A,B) Oral photograph in first visit. (D–F) Oral photograph after first phase treatment. (G) Panoramic radiography. (H) Occlusal X-ray film. (I) Dental X-ray film. All single arrows indicate the impacted left second premolar.

TABLE 1. Cephalometric Analysis of the Present Cases

Measurement	Norm	Case 1		Case 2		Case 3	
		Before Treatment	After Treatment	Before Treatment	After Treatment	Before Treatment	After Treatment
Skeletal							
SNA (°)	81.3	83.5	83.5	83.0	83.0	77.0	77.0
SNB (°)	78.75	78.5	80.5	79.0	79.0	73.5	73.5
ANB (°)	2.56	5.0	3.0	4.0	4.0	3.5	3.5
Convexity (°)	3.52	18.5	7.0	9.5	7.0	3.5	3.5
Facial angle (°)	84.04	86.5	90.0	90.0	90.0	83.5	83.0
FH to mandibular plane (°)	26.34	24.0	25.5	24.0	24.0	34.5	34.5
Y axis (°)	66.31	65.5	60.0	57.0	58.0	65.0	65.0
Occlusal plane to SN (°)	14.00	16.5	17.0	16.0	16.0	25.5	24.0
Occlusal plane to FH (°)	9.90	12.0	7.0	5.0	5.0	15.5	14.0
Wits (mm)	1.00	0.0	1.0	−2.0	−1.0	−2.5	−2.5
Dental							
FH to U1 (°)	112.08	114.0	125.0	116.0	117.0	98.0	100.0
FH to L1 (°)	56.9	66.0	55.5	66.0	58.0	58.0	56.0
Facial plane to U1 (mm)	8.55	16.0	14.0	11.5	12.5	8.0	9.0
Facial plane to L1 (mm)	5.48	11.5	11.5	8.0	10.0	6.5	7.0
Mandibular plane to L1 (°)	96.77	90.0	99.0	90.0	98.0	87.5	89.5
Interincisal angle (°)	123.54	128.5	110.0	130.0	120.0	132.5	135.0

a labially erupting maxillary right second premolar, an over-retained maxillary right second primary molar, and a high impaction of the maxillary left second premolar (Figure 4D through F). Although the occlusal and periapical films are of diagnostic quality, the precise location and condition of the high impaction is indeterminate. Note, however, that on the CT images the root can be readily distinguished from the surrounding bone structure and neighboring teeth (Figure 4G 1 through 4, H 1 through 4 and I 1 through 4). The CT images in the sagittal and axial perspectives locate the root of the second bicuspid between the first molar roots (Figure 4I-3, 4). In addition, in the axial view the impacted tooth shows approximately 45° distal-labial

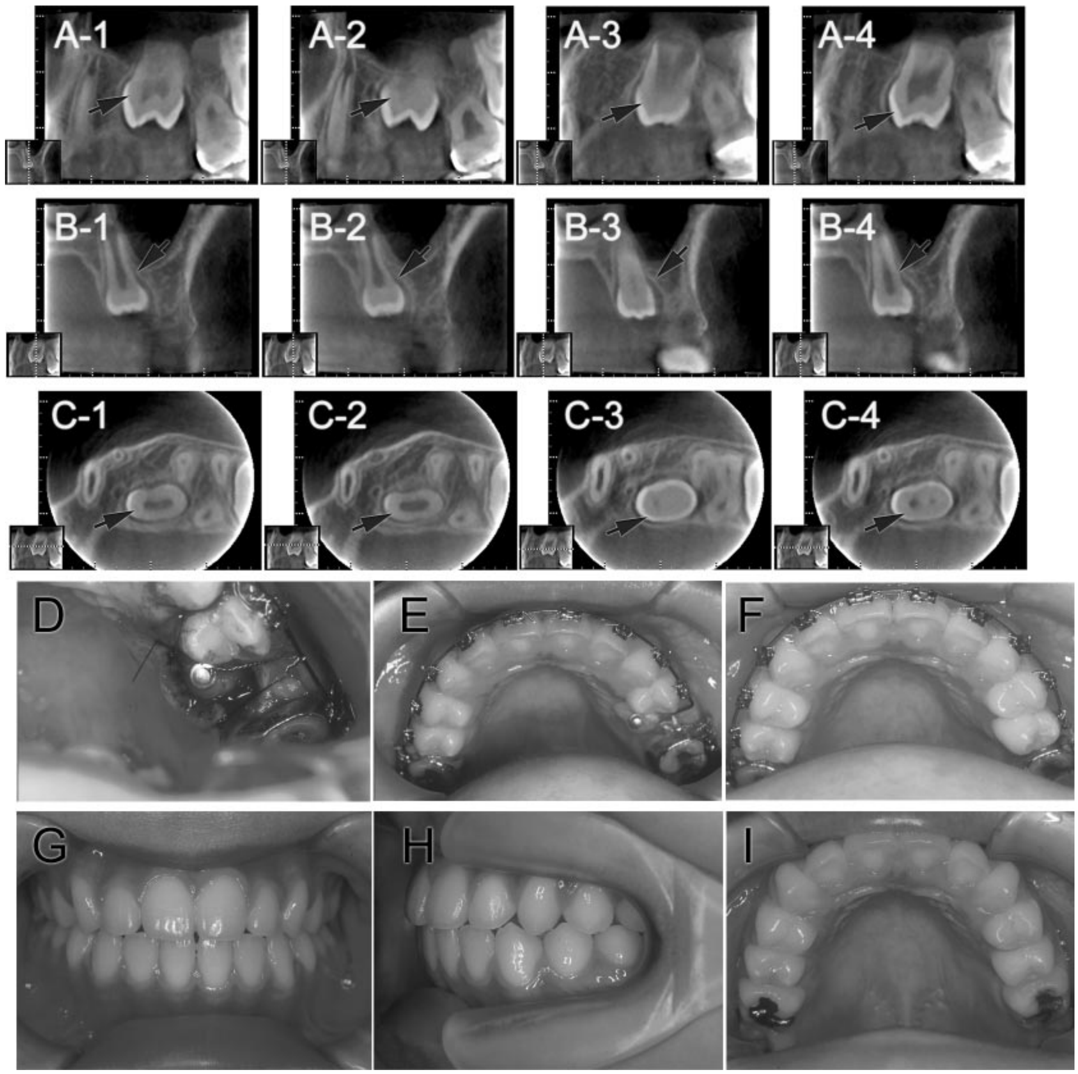

FIGURE 3. Case 1: (A 1–4) Sagittal images. (B 1–4) Frontal images. (C 1–4) Axial images. (D) The surgical fenestration and retraction of left upper premolar tooth from the lingual side. (E) Retracting of left impacted premolar. (F) After retraction. (G–I) Intraoral photograph after treatment.

tipping and is located between the first molar roots (Figure 4G 1 through 4 and I 1 through 4). The impacted bicuspid was almost in the middle of the maxillary bone (Figure 5A).

Thus, from the CT images a primary treatment plan of retraction of the left premolar tooth was selected because extraction was considered a much higher risk (of damage to the first molar and prosthesis treatment after orthodontic treatment) and the original orthodontic diagnosis was based on a nonextraction plan. The impacted tooth root was more palatal than buccal, however, the crown was located in the middle of alveolar bone between the buccal roots and the palatal root of the first molar (Figure 4H 1,2 and I 3,4; single arrows indicated). Even though the palatal cortical bone is thinner than the buccal cortical bone, the surgeon desired the superior observation of the field during the fenestration procedure, needed because of the possibility of damage to both teeth. Thus, the left upper second deciduous tooth was extracted, and the surgical fenestration was performed with retraction of the left upper premolar tooth from the labial side.

However, the impacted tooth was covered by gingival tissue soon after surgical exposure (Figure 5B). The 3D CT images showed that the orthodontic bracket remained bonded to the second premolar crown surface (Figure 5C,D). The left premolar tooth erupted after one year and six months into good occlusion and arch form (Figure 5E) without damage to the first molar roots and with completely recovered buccal cortical bone (Figure 5F).

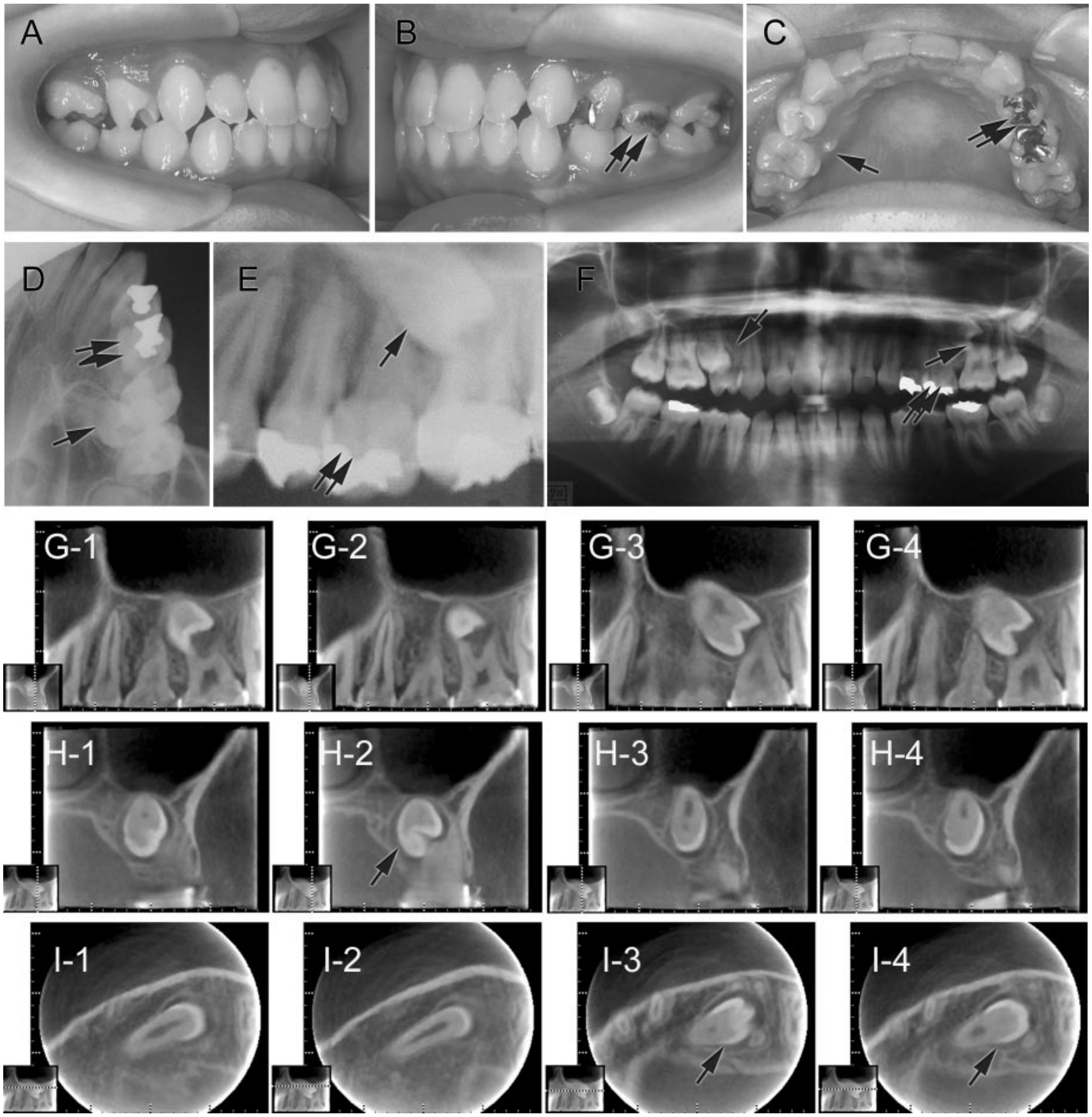

FIGURE 4. Case 2: (A–C) Oral photograph. (D) Occlusal radiograph. (E) Dental radiograph. (F) Panoramic radiography. (G 1–4) Sagittal images. (H 1–4) Frontal images. (I 1–4) Axial images. All single arrows indicate impacted second premolar and double arrows indicate the left second deciduous molar.

Case 3

Case 3 is a TMD case. This 21-year-old patient had a chief compliant of pain around the left TMJ when masticating hard and sticky foods. Case 3 was treated with a stabilization-type oral splint for approximately one year and six months under the guidance of the oral surgeon. TMJ symptoms had been resolved when this case was referred from the oral surgeon for orthodontic treatment and full-mouth reconstruction to obtain a normal occlusion. The cephalometric analysis is shown in Table 1. This case was a Class I malocclusion with a lateral open bite (Figure 6A through C, single arrows), and the Tweed and Steiner analyses suggested a nonextraction approach.

Panoramic radiography was of limited value in observing the TMJ. Note that in this case no erosion is evident on the panoramic film (Figure 6D). Because of the patient's history and symptoms, T1 and T2 magnetic resonance images (MRIs) were taken (Figure 6E,F). The T1 shows a left anterior disk displacement (Figure 6E). T2 of the same joint shows noneffusion and noninflammation at the bilaminar zone and bilateral pterygoid muscles (Figure 6F). The surface cortical bone of the TMJ was difficult to observe, even on

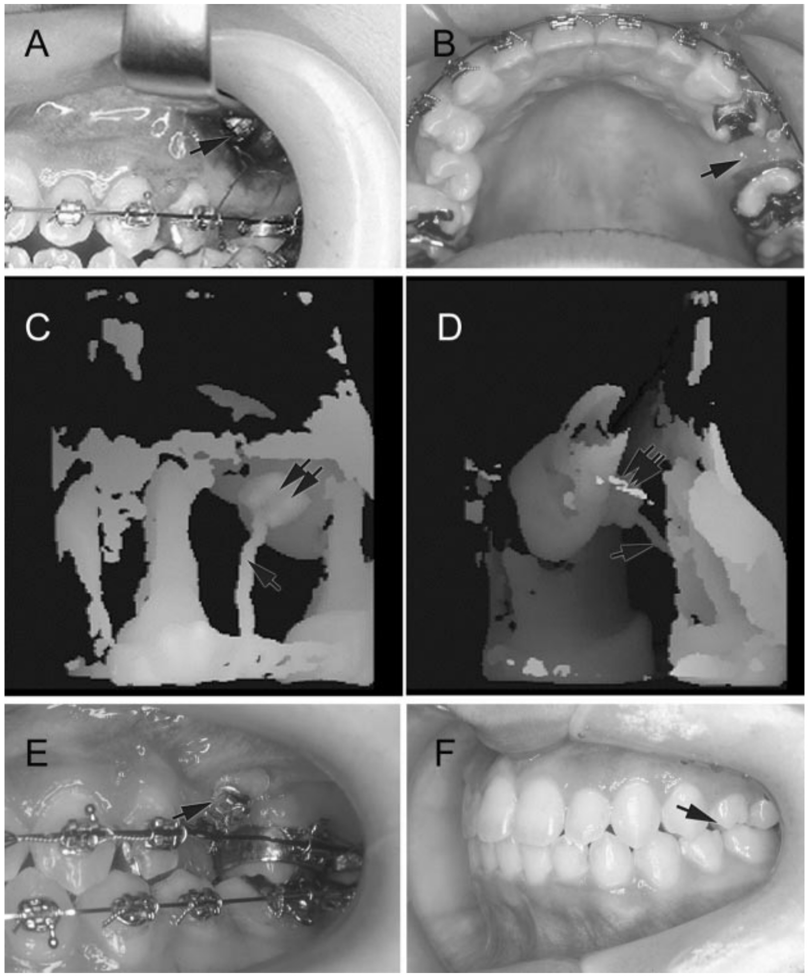

FIGURE 5. Case 2: (A) The surgical fenestration and retraction of impacted tooth. Single arrows indicate impacted tooth. (B) The impacted tooth was covered by gingival tissue. Single arrows indicate covered gingival tissue at impacted premolar. (C,D) 3D computed tomography (CT) images. Single arrows indicate ligature wire, and double arrows indicate orthodontic brackets, which are bonded on the impacted tooth surface. (E) The left premolar tooth erupted after one year and six months; single arrows indicate the left second premolar. (F) After orthodontic treatment. Single arrows indicate the left second premolar.

these standard MRIs. 3DX images were ordered and, the left TMJ clearly shows erosion in the medial-frontal aspect of the cortical bone (Figure 6G 1,2 and H 1,2). Accordingly, orthodontic treatment with a stabilizing splint was prescribed. The splint was made in a muscle relaxation position, using Dawson's technique[7] for guiding the mandible.

We started upper arch leveling first to obtain normal occlusion and optimum position of the TMJ with the splint, and then we coordinated the lower arch to the upper arch for final cusp seating with the splint worn only at night (Figure 7A through C).

Two years and two months after the initial visit, good occlusion (Figure 7D through F) was achieved without TMJ pain. Also, after orthodontic treatment, we took new 3DX images to inspect the bone erosion and to compare pre- and posttreatment condylar position. The cortical bone, which before orthodontic treatment had bone erosion, no longer shows evidence of the erosion, and new cortical bone can be seen in its place (Figure 7G 1,2 and H 1,2). Comparison of the pre- and posttreatment CT images indicate no change in the muscle relaxation position (Figures 6G 1,2, H 1,2 and 7G 1,2, H 1,2). In addition, a cephalometric superimposition of pre- and posttreatment radiographs shows that the vertical dimension has not changed (Figure 7I and Table 1).

DISCUSSION

Three cases have been presented to demonstrate the improvement in diagnosis and treatment planning possible with a new imaging device such as 3DX. From a single, low-radiation scan, the clinician can easily view an impacted tooth in all three planes of space. With this ability to observe the tooth far more

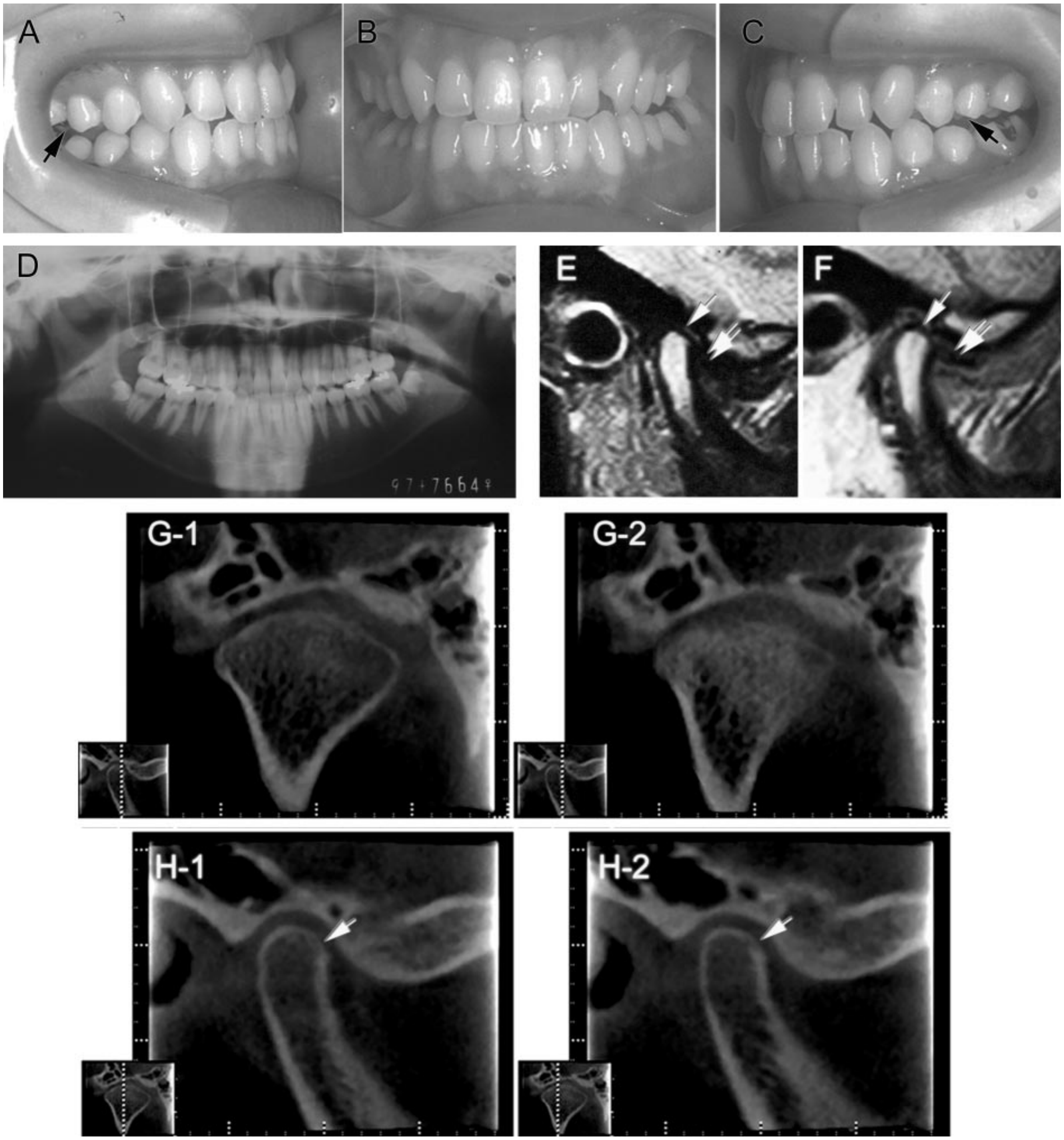

FIGURE 6. Case 3: (A–C) Oral photograph. (D) Panoramic radiography. (E) T1 magnetic resonance image (MRI) of left temporomandibular joint (TMJ). (F) T2 MRI of left TMJ. Single arrows indicate the cortical bone of TMJ, and double arrows indicate the temporomandibular disk. (G 1,2) Frontal 3DX images of left TMJ in the first visit. (H 1,2) Sagittal images; the single arrow indicates bone erosion.

accurately than from conventional radiographic images, the orthodontist and surgeon can take the guesswork out of not only the surgical approach itself but also the immediate extraction decision based on the possibility that the tooth may have to be extracted after many months of presurgical orthodontic preparation. With proper location in all three planes of space, the surgeon has to remove less bone and can gain more efficient entrance into the surgical site. The orthodontist will have a better idea of the strategy in moving the tooth rapidly in the most efficient direction. The two impaction cases shown in this article demonstrate the advantages of 3D views.

Another advantage is the great tooth and bone detail that can be seen. This was shown in both case 1 and case 2 in looking at the condition of the root of the impacted bicuspid. 3DX images show that the root was more than one-third mineralized compared with the normal root in both patients. This degree of detail is representative of the vast amount of information pre-

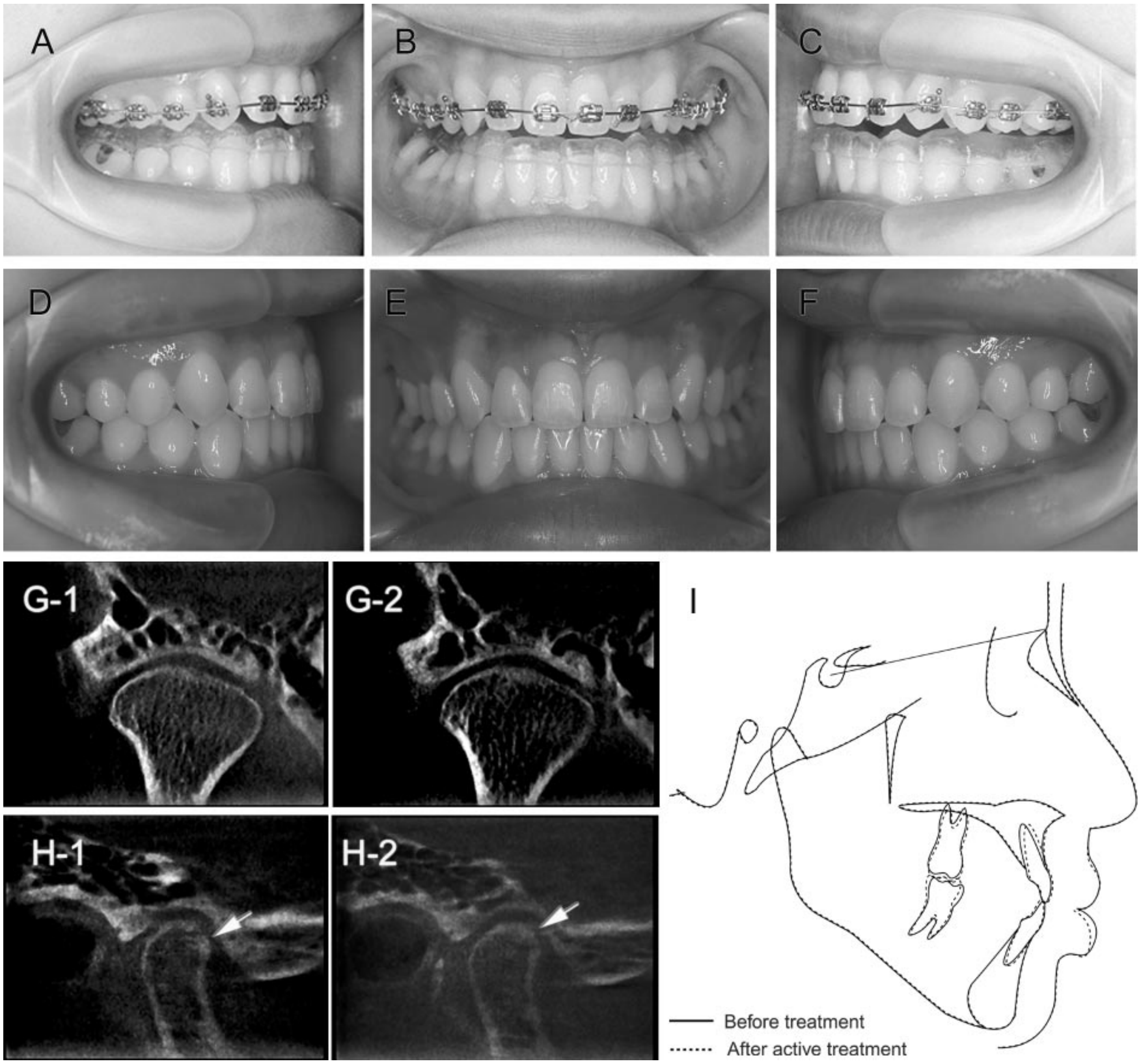

FIGURE 7. Case 3: (A–C) Oral photograph during orthodontic treatment. The patient was wearing a stabilization-type splint. (D–F) Oral photograph after orthodontic treatment. (G 1,2) Frontal 3DX images of left temporomandibular joint (TMJ) after treatment. (H 1,2) Sagittal images. The single arrow indicates the TMJ cortical bone. (I) Cephalometric superimposition in pre- and posttreatment radiographs.

sent in these scans waiting to be fully used by the clinician.

Case 2 CT images also show that, even though the impacted tooth had been hidden by periodontal tissue, the orthodontic bracket remained bonded to the tooth. This suggests that these images can not only identify the tooth condition and location in high resolution but the images also provide important information during retraction of an impacted tooth.

In case 3, the TMJ images not only demonstrate accurate condylar cortical bone information but also comparable TMJ position between pre- and postorthodontic treatment for TMD. The views shown are superior to the MRI scans used at present. According to a previous study,[8,9] 3DX had significantly lower risk in radiation exposure compared with conventional TMJ images. This case supports their conclusion that these scans are an improvement for TMD image diagnosis. In particular, we demonstrated that condylar position between pre- and posttreatment was unchanged in a symptomatic orthodontic patient.

Cone beam CT machines are being introduced to orthodontists. These wide-range cone beam CT machines have been developed specifically for orthodontics and take much larger volumes to cover the craniofacial complex.[10–12] The NewTom 9000, for example, has an effective dose for imaging a maxillomandibular volume of 50.3 μSv. The author of one report concluded that this is significantly less than that detected with conventional medical CT.[12] Note, however, that the radiological dose in 3DX for the upper molar, lower molar, and TMJ is 6.3, 11.7, and 7.4 μSv.[6] Although the NewTom 9000 can take 3D images for the whole maxillofacial region of similar quality as a medical conventional CT, the radiological dose is approximately 2.5–5 times higher than 3DX. The NewTom 9000 and similar units are much larger and have longer exposure times than the limited type reported here. In addition, 3DX provided higher resolution images rather than the other CTs, such as NewTom 9000. Because of the radiological dose effect and higher resolution, it concentrates focus on dental use, which area is 29 mm (240 voxels) × 38 mm (320 voxels) and each voxel is 0.125 mm.[3] Again, it should be emphasized that the two types have essentially different purposes in dentistry. Resolution is higher in 3DX images, but certain soft tissue areas such as the TMJ disk are hard to observe. The concept of 3DX was originally for general dental use with a similar range of dental X-ray film.[3]

CONCLUSIONS

The 3DX images greatly improve the clinician's ability to diagnose and plan treatment for impacted teeth. The precise location of the object can be seen easily in all three planes of space after minimal experience with the unit's software.

The resolution of the 3D images in 3DX is very high—high enough to see the condition of the bone on the condyle, and the conformation of the developing root, as shown in the cases.

The 3DX images can be used to compare pre- and postorthodontic treatment condylar position with relatively less radiation than currently accepted methods.

ACKNOWLEDGMENTS

The authors thank Dr Shinkichi Namura, Dr Kohji Shinoda, Dr Yoshito Homme, and our colleagues at the Department of Orthodontics and Radiology, School of Dentistry, Nihon University, for their continuous strong support. This work was supported by a grant from the Ministry of Education, Culture, Sports, Science and Technology to promote multidisciplinary research projects.

REFERENCES

1. Hounsfield G. Computerized transverse axial scanning (tomography) part 1. Description of system. *Br J Radiol.* 1973;46:1016–1022.
2. Ambrose J. Computerized transverse axial scanning (tomography) part 2. Clinical application. *Br J Radiol.* 1973;46:1023–1047.
3. Arai Y, Tammisalo E, Iwai K, Hashimoto K, Shinoda K. Development of a compact computed tomographic apparatus for dental use. *Dentomaxillofac Radiol.* 1999;28:245–248.
4. Arai Y, Hashimoto K, Iwai K, Shinoda K. Fundamental efficiency of limited cone-beam X-ray CT (3DX multi image micro CT) for practical use. *Dent Radiol.* 2000;40:145–154.
5. Hashimoto K, Arai Y, Iwai K, Araki M, Kawashima S, Terakado M. A comparison of a new limited cone beam computed tomography machine for dental use with a multidetector row helical CT machine. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2003;95:371–377.
6. Iwai K, Arai Y, Hashimoto K, Nishizawa K. Estimation of effective dose from limited cone beam X-ray CT examination. *Dent Radiol.* 2000;40:251–259.
7. Dawson PE. *Evaluation, Diagnosis, and Treatment of Occlusal Problem.* 1st ed. St. Louis, Mo: Mosby; 1989:41–47.
8. Terakado M, Hashimoto K, Arai Y, Honda M, Sekiwa T, Sato H. Diagnostic imaging with newly developed ortho cubic super high resolution CT (ortho-CT). *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2000;89:509–518.
9. Honda K, Larheim TA, Johannessen S, Arai Y, Shinoda K, Westesson PL. Ortho cubic super-high resolution computed tomography: a new radiographic technique with application to the temporomandibular joint. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2001;91:239–243.
10. Maki K, Inou N, Takanishi A, Miller AJ. Computer-assisted simulations in orthodontic diagnosis and the application of a new cone beam X-ray computed tomography. *Orthod Craniofac Res.* 2003;6:95–101.
11. Ludlow JB, Davies-Ludlow LE, Brooks SL. Dosimetry of two extraoral direct digital imaging devices: NewTom cone beam CT and Orthophos Plus DS panoramic unit. *Dentomaxillofac Radiol.* 2003;32:229–234.
12. Mah JK, Danforth RA, Bumann A, Hatcher D. Radiation absorbed in maxillofacial imaging with a new dental computed tomography device. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2003;96:508–513.