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REVIEW ARTICLE

Cone-beam computed tomography of the maxillofacial region – an update

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Abstract

Background During the last few years, craniomaxillofacial diagnosis of the head has been confronted with an increasing number of innovations and improvements. The main progress occurred following the introduction of cone-beam technology in computed tomography in the 1990s. The number of manufacturers and devices using this technology for the maxillofacial region is growing rapidly and they are now becoming readily available.

Materials This article focuses on cone-beam computed tomography (CBCT) devices applied to the maxillofacial region. CBCT serves as a bridge from two dimensions (2D) to three dimensions (3D), with lower irradiation than conventional CT. Different manufacturers and models are now available to satisfy the different needs of clinicians.

Results A recent review of the manufacturers found 23 CBCT devices on the market. The specifications, applications and other issues of currently available CBCT devices are presented and discussed.

Conclusions 3D imaging is developing at a very fast pace. New technologies and machines are emerging and CBCT is becoming readily available. Due to the growing demand for the technology based on the needs of clinicians, there is now a wide and growing selection of devices on the market. Some of the new advances now mean that CBCT imaging should be a well-considered option in maxillofacial imaging. Copyright © 2009 John Wiley & Sons, Ltd.

Keywords diagnostic imaging; imaging; three-dimensional; radiography; tomography scanners; X-ray computed; cone-beam computed tomography

Introduction

Radiographic evaluation and diagnosis have undergone enormous changes in the last 20 years. New technologies are being developed and are becoming readily available to the medical and dental field. The advancements in hardware and software have allowed the development of innovative methods for facial diagnosis, treatment planning, and clinical application.

Cone-beam computed tomography (CBCT) was developed in the 1990s as an evolutionary process resulting from the demand for three-dimensional (3D) information obtained by conventional computed tomography (CT) scans. Since the first report, the technology has gained popularity in dentistry (1). The development of CBCT reduces exposure by using a lower radiation dose compared to conventional CT (2–4). Custom-built craniomaxillofacial CBCT devices have been increasing in number on the market over the last decade and a variety of applications to the facial and dental environments have been established (3).

This article gives an overview of CBCT technology and of the currently available CBCT devices applied to the maxillofacial region. Many of the data were obtained from the readily available materials from manufacturers and reported by their representatives where this was needed. The article also discusses and attempts to clarify issues regarding the use of CBCT in the clinical setting.

Materials and Methods

Conventional computed tomography (CT)

The CT was developed by Sir Godfrey Hounsfield in 1967 and there has been a gradual evolution to five generations of the system (5,6). First generation scanners consisted of a single radiation source and a single detector and information was obtained slice by slice. The second generation was introduced as an improvement and multiple detectors were incorporated within the plane of the scan. The third generation was made possible by the advancement in detector and data acquisition technology. These large detectors reduced the need for the beam to translate around the object to be measured and were often known as the 'fan-beam' CTs. Ring artifacts were often seen on the images captured distorting the 3D image and obscuring certain anatomical landmarks. The fourth generation was developed to counter this problem. A moving radiation source and a fixed detector ring were introduced. This meant that modifications to the angle of the radiation source had to be taken into account and more scattered radiation was seen. Finally the fifth (sometimes known as the sixth) generation scanners were introduced to reduce 'motion' or 'scatter' artifacts. As with the previous two generations, the detector is stationary and the electron beam is electronically swept along a semicircular tungsten strip anode. Projections of the X-rays are so rapid that even the heart beats may be captured. This has led some clinicians to hail it as a four-dimensional motion capture device (3,7). Recently presented in 2007 the Toshiba's 'dynamic volume' scanner based on 320 slices is showing the potential to significantly reduce radiation exposure by eliminating the requirement for a helical examination in both cardiac CT angiography and whole brain perfusion studies for the evaluation of stroke (6).

There are, however, limitations to the older CT systems. They are often more expensive and require a considerable amount space. The 3D reconstruction may be time consuming, therefore, less cost efficient. These machines are also not solely designed for the head and neck region. Furthermore, the irradiation exposure to the patient has limited their usage to complex craniofacial problems and for specialized diagnostic information only.

CBCT

CBCTs for dental, oral and maxillofacial surgery and orthodontic indications were designed to counter some of the limitations of the conventional CT scanning devices. The radiation source consists of a conventional low-radiation X-ray tube and the resultant beam is projected onto a Si/CsI flat panel detector (FPD) or a charge-coupled device (CCD) with an image intensifier. FPD has been shown in the literature to have a high spatial resolution (8). The cone-beam produces a more focused beam (it has a fixed area and volume on a detector) and much less radiation scatter compared to the conventional fan-shaped CT devices (9). This significantly increases the X-ray utilization and reduces the X-ray tube capacity required for volumetric scanning (10). It has been reported that the total radiation is approximately 20% of conventional CTs and equivalent to a full mouth peri-apical radiographic exposure (11). CBCT can therefore be recommended as a dose-sparing technique compared with alternative standard medical CT scans for common oral and maxillofacial radiographic imaging tasks (12). The images are comparable to the conventional CTs and may be displayed as a full head view, as a skull view or regional components.

CBCT data

The tube and the detector perform one rotation (180° or 360°) around the selected region. The resulting primary data are converted into slice data. The reconstructed slice data can be viewed in user-defined planes. The CT volume consists of a 3-D array of image elements called a voxel. Each voxel is characterized with a height, width, and depth. Since the voxel sizes are known from the acquisition, correct measurements can be performed on the images. The spatial resolution in a CT image depends on a number of factors during acquisition (e.g. focal spot, size detector element...) and reconstruction (reconstruction kernel, interpolation process, voxel size). Image noise depends on the total exposure and the reconstruction noise. Increasing the current in the X-ray tube increases the signal-to-noise ratio, thus reduces the quantum noise of the statistical nature of X-rays at the expense of patient dose. The artifacts of CT imaging are the consequence of beam hardening, photon scattering, non-linear partial volume effect, motion, stair step artifact and others.

Most machines support the Digital Imaging and Communications in Medicine (DICOM) format export. The images can therefore be used for most, if not all, the (software) applications utilized by conventional CT (13).

The following is a summary of the additions and modifications of CBCT as compared to conventional CT that make CBCT a more appealing alternative:

- Irradiation dose is lower due to the lower effective tube currently used for the CBCT. The voltage of the source is approximately the same (90–120 kV), and the current

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is roughly between 1 and 8 mA for the CBCT. On the otherhand, The CT multislice current is around 80 mA, but can also be as high as 200 mA.
- Detection systems are different (FPD or CCD with image intensifier);
- The resolution is higher; this is mainly due to lesser isotropic voxel size (14) and detector configuration.
- There is less artifacts caused by metallic structures but because of lower dose, there is more noise and detailed information about soft tissues is lost (13).
- CBCT is less expensive and smaller.

The CT scanner, however, provides better resolution to the soft tissues. For example, intracranial processes or soft tissue tumors cannot be evaluated properly using CBCT.

Results

CBCT acquisition systems

In 2005 four main CBCT devices were reported in the literature and it was expected that many companies were to enter the market (3). In July 2008, there were sixteen manufacturers of CBCT devices producing twenty-three different models. This article was written to present the most important characteristics of the available products. CBCT devices were divided to fit into four subcategories based on the need of the clinician:

- Dentoalveolar [field of view (FOV) < 8 cm].
- Maxillo-mandibular (FOV 8–15 cm).
- Skeletal (FOV 15–21 cm).
- Head and neck (FOV > 21 cm).

The important differences besides the clinical classification are the irradiation dose, size and weight, time needed for the reconstruction, voxel size, scanning time etc. The balance of benefit vs. risk is beyond the scope of the article. However, the risk of irradiating a patient should not out-weigh by the clinical information obtained. In addition, the decision to keep the machine in an in house dental setting should also be considered. Furthermore, the differences in prices, software and warranty are important considerations. The data were acquired from the readily available materials from the companies and from their employees via electronic mail. The details of the various machines have been re-classified based on possible application in the clinical scenario and based largely on the field of view. These are presented in Tables 1 to 4.

All the data were, however, not achievable: either because the manufacturers' representatives would not reply or because the data were not available at the time of writing. The most important characteristics for each device are described in the Appendix of this article.

Discussion

X-rays evaluation and diagnosis have undergone enormous changes in the last twenty years. The number of manufacturers and devices using the CBCT technology is growing rapidly. A recent overview found sixteen manufacturers and twenty-three devices using the CBCT technique applied to the maxillofacial region. The important differences between the devices are their FOV (15), the irradiation dose (16), size and weight, time needed for the reconstruction, voxel size (12,17), scanning time, price, software and warranty. In general, higher resolution images require a greater scan time. This often means that more slice images are obtained during the scanning process. The use of CBCT has many implications. The use of CBCT imaging has not been addressed in full yet. In this paper, the following distinct indications for the CBCT are proposed: (a) diagnosis; (b) clinical application; and (c) clinical evaluation of treatment outcomes.

The International Commission on Radiological Protection (ICRP) proposed a change in irradiation dosimetry which resulted in a 23–224% increase of the effective dose when compared to the 1990 guidelines (12,18). It is clearly noted where the new irradiation effective dose values were used.

Diagnosis

In the maxillofacial region, CBCT is used for the evaluation of impacted teeth (19), implant treatment planning (20), diagnostics of the temporomandibular joint (TMJ) (21), simulations for orthodontic and surgical planning, etc. (22). In complex orthodontic cases (canine impactions and clefts), in which 3D imaging is mandatory, CBCT is the method of choice. Furthermore, in cleft patients and those undergoing combined orthodontic and maxillofacial therapy, CBCT provided more information than conventional images (23). Before routine use in orthodontics, however, further studies are needed (24). It has been demonstrated that CBCT is accurate to identify apical periodontitis (25). A recently suggested CBCT-aided method for the determination of root curvature radius allows more reliable and predictable endodontic planning, which reflects directly on a more efficacious preparation of curved root canals (26). CBCT provides better diagnostic and quantitative information on periodontal bone levels in three dimensions than conventional radiography (27). CBCT can also be used for maxillofacial growth and development assessment and dental age estimation (28). A CBCT image of impacted molars is shown in Figure 1. 3D reconstruction of the mandible and maxilla is shown in Figure 2 and the TMJ is shown in Figure 3.

Clinical applications of the CBCT

CBCT-based implant planning has been used extensively. Many software products in the market allow clinicians to 'pre-plan' the placement of implants and even fabricate guides for implant placement.

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Table 1. Dentoalveolar field of view ($<$8 cm)

Trade Name	3D Accuitomo XYZ Slice View Tomograph	3D Accuitomo 80	3D Accuitomo FPD	Kodak 9000 3D Extraoral Imaging System	Panoramic CT
Manufacturer	J Morita Mfg Corp, Kyoto, Japan	J Morita Mfg Corp, Kyoto, Japan	J Morita Mfg Corp, Kyoto, Japan	Carestream Health (exclusive manufacturer of Kodak Dental Systems)	Asahi Roentgen Ind. Co., Ltd., Kyoto, Japan
Model	MCT-1 Type: EX-1/EX-2	MCT-1 Type EX F8 (EX-1F8/EX-2F8)	MCT-1 Type EX F (EX-1F/EX-2F)	Kodak 9000 3D	PSR9000N
Main unit dimensions	1.62 (W) 0 1.2 (D) × 2.08 m (H)	1.62 (W) × 1.2 (D) × 2.08 (H) m	1.62 (W) × 1.2 (D) × 2.08 (H) m	1.158 (W) × 1.595 (D) × 2.378 (H) m Minimum required space: 1.75 (W) × 1.9 (D) × 2.378 (H) m	1.85 (W) X 1.66 (D) X 1.94 (H) m
Weight	Approx. 400 kg	Approx. 400 kg	Approx. 400 kg	160 kg	436 kg
Input oltage	100/110/120 VAC (EX-1) 220/230/240 VAC (EX-2)	100/110/120 VAC (EX-1F8) 220/230/240 VAC (EX-2F8)	100/110/120 VAC(EX-1F) 220/230/240 VAC(EX-2F)	230–240 V, 50–60 Hz	180–220 V, 50/60 Hz
Tube voltage	60–80 kV	60–90 kV	60–80 kV	60–90 kV	60–100 kV (1 kV steps)
Tube current	1–10 mA	1–10 mA (8 mA max at 81–90 kV)	1–10 mA	2–15 mA	2, 4, 6, 8, 10 and 12 mA
Scan time	18 s	Exposure time $<$ 18 s	Exposure time $<$ 18 s	13.9 s	20 s max.
Irradiation dose	7.4 µSv	1.6 time panoramic X-ray	1.8 times panoramic X-ray	5–19 µSv* *Study from IRSN, 2008 (official French organization for radioactivity and nuclear safety)	N/A
Image detector	Image intensifier CCD	Flat panel detector	Flat panel detector	CMOS sensor with optical fibre	I.I. and CCD Camera
Grayscale	8 bit	13 bit	12 bit	14 bit	N/A

Table 1. Continued

Trade Name	3D Accuitomo XYZ Slice View Tomograph	3D Accuitomo 80	3D Accuitomo FPD	Kodak 9000 3D Extraoral Imaging System	Panoramic CT
Size of image volume	40 (D) × 30 (H) mm	40 (D) × 40 (H) mm 60 (D) × 60 (H) mm	40 (D) × 40 (H) mm 60 (D) × 60 (H) mm	50 × 37 mm	41 × 40 mm
Voxel size	0.125 mm	0.008, 0.125, 0.16 mm	0.125–2 mm	0.076 × 0.076 × 0.076 mm (isotropic)	0.15/0.1 mm
Reconstruction time	<5 min (Pentium IV 1.5 GHz)	N/A	<5 min	<2 min (but depends on the PC and system configuration)	N/A
Computer and OS specifications	Pentium IV 1.5 GHz and above, 512 MB RAM; Windows 2000 or XP professional;	N/A	PC with Pentium IV 3.8 Hz or more, Memory 4 GB	Minimum workstation image viewing requirements: CPU 2 GHz Intel Duo Core; RAM 2 GB; Windows 2000 SP4, Windows XP SP2, Windows Server 2003, Windows Vista 32 bits (Home Premium, Business, Ultimate Editions) Minimum workstation acquisition requirements: CPU 3 GHz Pentium 4; RAM 2 GB; hard disk drive, 1.2 GB for software installation/80 GB free space to use the software; Windows XP SP2	N/A
Costs	N/A	N/A	N/A	95000 USD; includes the unit with two sensors (panoramic sensor and 3D sensor), accessories, dental imaging software with 3D module	N/A

Table 2. Maxillomandibular field of view (8–15 cm)

Trade Name	SCANORA® 3D Cone Beam Panoramic Dental X-Ray Machine	GXCB - 500™	Ewoo Picasso	Ewoo Picasso	CB Throne™	Prexion 3D
Manufacturer	SOREDEX, Tuusula, Finland	Gendex Dental Systems, Des Plaines, IL, USA	E-Woo Technology Company Ltd, Gyeonggi-do, Republic of Korea	E-Woo Technology Company Limited., Gyeonggi-do, Republic of Korea	Hitachi Medical Corporation, Tokyo, Japan	TeraRecon Inc., San Mateo, CA, USA
Model	Scanora 3D	GXCB-500	Picasso Trio	Picasso Pro	CB Throne	Prexion 3D
Main unit dimensions	1.963 (W) × 1.543 (D) × 1.1 (H) m	1.22 (1.34) ×0.9 × 1.8 m	1.033 (W) × 1.49 (D) × 2.288 (H) m Panoramic 1.466 (W) × 1.49 (D) × 2.288 (H) m Pan+Cephalometric	1.8 (W) × 1.548 (D) × 1.836 (H) m	1.8 × 1.8 m (installation dimensions)	0.991 × 1.499 × 2.007 m
Weight	310 kg	231 kg	431 kg including packaging	400 kg including packaging	N/A	N/A
Input voltage	230/115 VAC (−10 . . . +15%) 50–60 Hz	115/200/230 V/100 V	110 V, 60 Hz	110 V, 60 Hz 220 V, 50–60 Hz	Single phase 200 V ± 10%, 7.5 kVA	N/A
Tube voltage	65–85 kV	120 kVp	40–90 kV	40–90 kV	Max.120 kV	90 kV
Tube current	0.5–8.0 mA	3–7 mA	2–10 mA	2–10 mA	15 mA	4 mA
Scan time	10, 20 s	8.9 and 23 s	15/24 s	15 s	9.6 s	19 or 37 s
Irradiation dose	Papers in process, range of 3–5 panoramic equivalents	Standard scan (8 × 8 cm, 9 s): 30–35 uSv Extended diameter scan (14 × 8 cm, 9 s): 28–33 uSv	25–60 µSv	60 µSv	N/A	N/A

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Table 2. Continued

Trade Name	SCANORA® 3D Cone Beam Panoramic Dental X-Ray Machine	GXCB - 500™	Ewoo Picasso	Ewoo Picasso	CB Throne™	Prexion 3D
Image detector	CmoS flat panel	Amorphous silicon flat panel	CsI-coated CMOS flat panel	CsI-coated CMOS flat panel	CCD camera	CsI flat panel
Greyscale	12 bit	14 bit	12 bit	12 bit	12 bit	N/A
Size of image volume	60 × 60 mm	8 0 × 80 mm	120 × 70 mm	120 × 70 mm	100 mm diameter	81 × 76 mm
	75 × 100 mm 75 × 145 mm	140 × 80 mm (D × H)			50 mm diameter	
Voxel size	0.133–0.35 mm	0.3, 0.4, 0.125, 0.25 mm	0.2 or 0.3 mm	0.2 or 0.3 mm	0.2 mm for 100 mm FOV, 0.3 mm for 50 mm FOV	N/A
Reconstruction time	1 or 2 min	<20 s and <95 s	<2 min, option 29 s; 360° (important for metal artifact compensation and true measurement of oral arch structure)	15 s, 360° (important for metal artifact compensation and true measurement of oral arch	N/A	Up to 120 s
Computer and OS specifications	Windows XP or Windows Vista > 2.4 GHZ dual core processor, 2 G RAM, PCI express bus	Minimum-Pentium 4, 3.8 gHz, 120 GB	Intel Pentium 4 950 3.4 GHz dual core, 250 GB HDD, 2 GB DDR2, 256 MB 128 bit video card – recommend NVIDIA Geforce, MS Window Vista	Intel Pentium 4 950 3.4 GHz Dual Core, 250 GB HDD, 2 GB DDR2, 256 MB 128 bit video card – recommend NVIDIA Geforce, MS Windows Vista	N/A	N/A
Costs	$169 900 in USA; varies in other countries	$129 000 (retail) USA	$185 000	N/A	N/A	N/A

Table 3. Dentoskeletal field of view (15–21 cm)

Trade Name	Ewoo Picasso	Quolis Alphard	NewTom	CB MercuRay™	NewTom	Promax	Galileos	MyRay
Manufacturer	E-Woo Technology Company Ltd, Gyeonggi-do, Republic of Korea	Belmont, Somerset, NJ, USA	Quantitative Radiology, Verona, Italy	Hitachi Medical Corporation, Tokyo, Japan	Quantitative Radiology, Verona, Italy	Planmeca Oy, Helsinki, Finland	Sirona Dental Systems Inc., Bensheim, Germany	Cefla Dental Group, Imola, Italy
Model	Picasso Master	Alphard-3030 cone-beam	NewTom 3G	MercuRay	NewTom VG*	Promax3D	Galileos	SkyView
Main unit dimensions	1.82 (W) × 1.695 (D) × 1.92 (H) m	1.981 (W) × 0.6 (D) × 1.953 (H) m	2.0 (W) × 2.413(D) × 2.0 (H) m	1.96 (W) × 1.9 (D) × 2.25 (H) m	1.13 (W) × 1.5 (D) × 2.29 (H) m	1.94 (W) × 1.23(D) × 1.53–2.43 (H) m	1.6 (W) × 1.6 (D) × 2.006 (H) m	Width: 1.45 m (11 cm detector)–1.535 m (15 cm detector) Length: 2.510 m Height: 1.68 m (11 cm detector)–1.720 m (15 cm detector)
Weight	990 kg including packaging	480 kg	363 kg	950 kg	272 kg	128 kg	140 kg	360 kg
input voltage	110 V, 60 Hz	110 V	230 V	200–240 V	100/115/200/215/230/240 V	100-240 V	230 V	115 V AC 50/60 Hz 230 V AC 50 Hz
Tube voltage	40–90 kV	60–110 kV	110 kV	60, 80, 100, 120 kV	110 kV	50-84 kV	85 kV	90 kV
Tube current	2–10 mA	2–15 mA	15 mA	10/15 mA	1-20 mA (pulse mode)	0.5–16 mA	5–7 mA	10 mA
Scan time	15/24 s	17 s	36 s	10 s	24 s	17-23 s	14 s	10, 15, 20, 30 s (default 15 s)
Irradiation dose	110 μSv	N/A	56.5 μSv according to ICRP 2007: 68 μSv	20–660 mSv; according to ICRP 2007: 569–1073 μSv	50 μSv	Effective dose according to ICRP: 189 μSv; reported, 145–841 mGy × cm^2	29 μSv; according to ICRP 2007, 70 μSv	37 μSv, typical
Image detector	Amophous silicon flat panel	Caesium scintillator flat panel detector	Image intensifier CCD	CCD camera	Amorphous silicon flat panel sensor	Image intensifier CCD	Image intensifier CCD	High resolution image intensifier, digital CCD sensor 1000 × 1000, pixel 7.4 μm
Greyscale	14 bit	256 bit	12 bit	12 bit	14 bit	12 bit	12 bit	12 bit

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Table 3. Continued

Trade Name	Ewoo Picasso	Quolis Alphard	NewTom	CB MercuRay™	NewTom	Promax	Galileos	MyRay
Size of image volume	200 × 190, 160 × 100, 160 × 70 mm (flexible)	200 × 179 mm	Spherical:	102.4 mm	170 (D) × 140 (H) mm	160 (D) × 130 (H) mm	150 × 150 mm	Spherical reconstruction volume
	200 × 150, 160 × 100, 160 × 70 mm (flexible)	102 × 102 mm	200 mm	150 mm				(D) 150, 110, 70 mm
		154 × 154 mm	150 mm 100 mm	190 mm				
Voxel size	0.2/0.3/0.4 mm	0.39, 0.3, 0.2 mm	0.2–0.4 mm	0.2–0.376 mm	0.3 mm cubic isometric, default and typical	0.16 mm	0.15/0.30 mm	0.16/0.23/0.33 mm (isotropic voxel)
Reconstruction time	<2 min, option 29 s, 360° (important for metal artifact compensation and true measurement of oral arch structure)	2.5 min	2 min	6 min	3 min (typical)	Under 3 min	4.5 min	2–4 min
Computer and OS specifications	Intel Pentium 4 950 3.4 GHz dual core, 250 GB HDD, 2 GB DDR2, 256 MB 128 bit video card – recommend NVIDIA Geforce, Windows Vista	Windows XP Professional SP2	Windows XP	Windows XP		Windows XP/2000/2003 or NT, Vista	Windows XP Professional SP2	Pentium Dual-QuadCore, 2 GB RAM, graphic accelerator, Windows XP
Costs	$220 000 for 200 × 190 mm	$289 000	Large FOV version: $200/190 000	$300 000	$160 000–170 000	$256 000 (only currency converted since manufacturer reported €190 000 for the European market)	Request dealer quote	$133 000 (110 mm version)
	$200 000 for 200 × 150 mm		100 and 150 mm FOV version: $140 000					$144 000 (150 mm version)

ICRP, International Commission on Radiological Protection.

Table 4. Head and neck field of view (>21 cm)

Trade Name	Kavo 3D Exam	Next Generation i-CAT®	Classic i-CAT®	Iluma™
Manufacturer	Kavo Dental GmbH, Biberach/Riss, Germany	Imaging Sciences, Hatfield, PA, USA	Imaging Sciences, Hatfield, PA, USA	IMTEC Imaging, Ardmore, OK, USA
Model	Kavo 3D Exam	Next Generation i-CAT	Classic i-CAT	ILUMA
Main unit dimensions	1.16 (W) × 1.22 (D) × 1.83 (H) m	1.219 (W) × 1.765 (H) × 0.924 m (D)	1.04(W) × 1.12 (D) × 1.83 m (H)	1.067(W) × 1.956 (D) × 2.159 m (H)
Weight	N/A	231 kg	192 kg	349 kg
Input voltage	N/A	230/110/100/200 V	230/110 V	110 V
Tube voltage	90–100 kV	120 kV	120 kV	120 kVp
Tube current	3–8 mA	5 mA (pulsed mode)	5 mA (pulsed mode)	1 or 3.8 mA
Scan time	8.5 s	5, 8.9, 18 or 26 s	10, 20, 40 s	20, 40 s
Irradiation dose	N/A	36 uSv (standard scan); according to ICRP 2007, 74 and 84 µSv	36 uSv (standard scan); according to ICRP 2007, 69 µSv	98–498 uSv (ICRP 2007)
Image detector	Amorphous silicon flat panel sensor	Amorphous silicon flat panel sensor	Amorphous silicon flat panel detector	Amorphous silicon flat panel
Greyscale	14 bit	14 bit	14 bit	14 bit
Size of image volume	230 (D) × 170 (H) mm	230 (D) × 170 (H) mm	160 (D) × 220 (H) mm	Up to 211 × 142 mm
Voxel size	0.125	0.4, 0.3, 0.25, 0.2, 0.125 mm	0.4, 0.3, 0.25, 0.2, 0.125 mm	0.09–0.4 mm
Reconstruction time	<1 min	<30 s (typical)	1.5 min	2.5–5 min
Computer and OS specifications	N/A	Windows XP	Windows XP	Windows XP
Costs	N/A	$170 000	$170 000	$189 000

ICRP, International Commission on Radiological Protection.

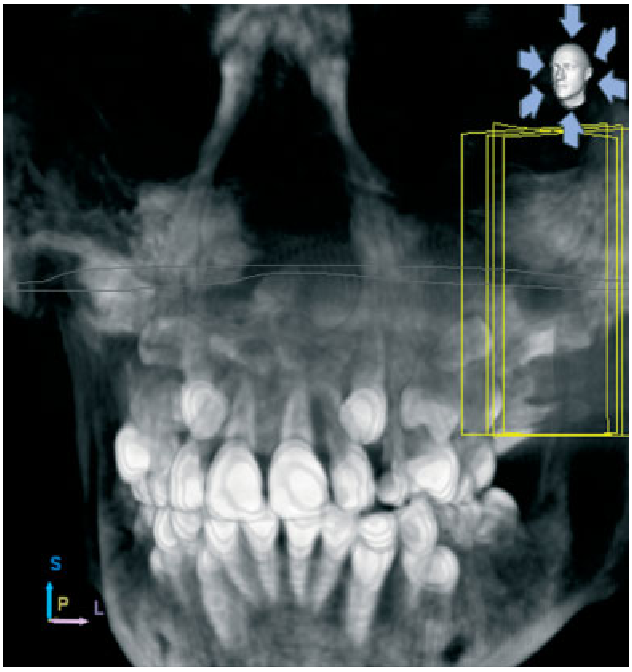

Figure 1. 3D volume-rendered views showing ectopic cuspids

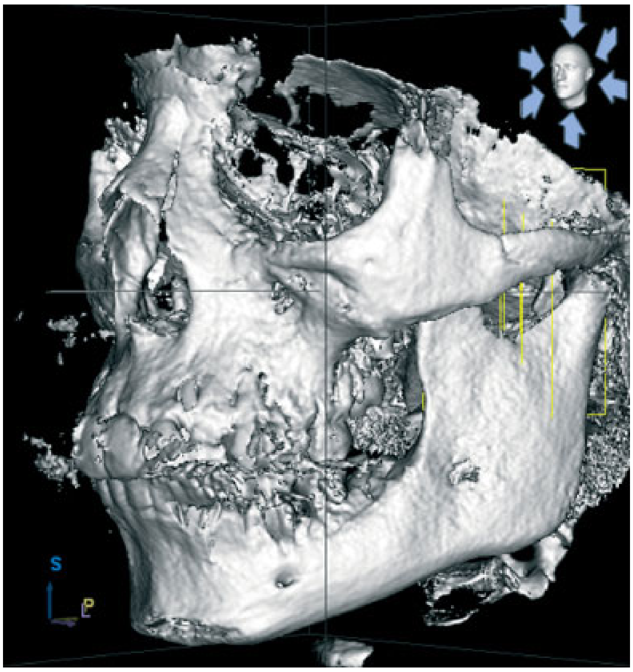

Figure 2. 3D volume rendering of the maxillofacial skeleton

CBCT provides information for 3D models made by rapid prototyping. The obtained 3D models can serve as a matrix that enables precise planning of operations such as for mini-implant positions in anatomically complex sites (29). A recent study that included phantoms and human cadavers showed that intra-operative CBCT quantifiably improved surgical performance in all excision tasks and significantly increased surgical confidence. Such intra-operative imaging in combination with real-time tracking and navigation should be of great benefit in delicate procedures in which excision must be executed in close proximity to critical structures (30). Another study included 179 patients undergoing facial surgery and intra-operative CBCT was used. The acquisition of the datasets was uncomplicated, and image quality was sufficient to assess the postoperative result in all cases (31).

CBCT also has a role in navigational surgical procedures. These allow for mirroring of the contralateral

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Figure 3. Coronal section view of the temporomandibular joints (TMJ)

normative side onto the defective side. Navigational procedures allow for reconstructions to be created in the virtual environment.

Late evaluation with CBCT

CBCT is also a tool for the evaluation of surgical and orthodontic treatment. There have not been a lot of papers published but they are increasing in their number as CBCT is becoming more readily available. CBCT was successfully used to compare the anteroposterior positions of the cleft-side piriform margin and alar base with those of the non-cleft side in 52 postoperative unilateral cleft lip patients with no alveolar bone graft (32). CBCT can be used in combination with 3D soft tissue data obtained with stereophotogrammetry, structured light systems and laser acquisition systems for diagnostic, treatment planning and post-treatment evaluation purposes (33).

Conclusions

Imaging diagnosing is developing at a very fast pace. New technologies and machines are emerging and CBCT is becoming readily available. There is an increasing number of manufacturers and models of CBCT devices for the maxillofacial region on the market. A recent overview of CBCT devices is presented. The diagnostic, clinical and research possibilities of employing the CBCT technique seem to be wide and growing. In view of the irradiation dose compared to conventional CT imaging, the decision to perform CBCT imaging should be a well-considered action.

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Appendix

Kavo 3D Exam

The Kavo 3D Exam was recently introduced by KaVo Dental GmbH (Biberach/Riss, Germany). It has a wide FOV up to 23 cm (diameter) × 17 cm (height). The scan time is 8.5 s, or 26 s for high resolution. The primary reconstruction takes < 1 min; the voxel size can be as low as 0.125 for the high-resolution images and the greyscale is 14 bits. The device has a small footprint (1.2 × 1.1 m). The imaging is performed with the patient in the upright position. The estimated dose of irradiation was not yet available at the time of writing.

Next generation i-CAT

The next generation i-CAT produced by Imaging Sciences International (Hatfield, PA, USA) is offering a 14 bit greyscale with a short scanning time (5, 8.9 and 26.9 s), a short time of reconstruction (<30 s) and an adjustable sensor orientation. The FOV standard size is 17 × 13 cm (diameter × height) with the possibility of an extended view of 23 × 17 cm (diameter × height). This is sufficient to capture a standard facial image equivalent to that of a 3D lateral cephalogram. The effective irradiation dose according to International Commission on Radiological Protection (ICRP) 2007 for the standard settings is estimated at 74 μSv (three times dental panoramic tomogram) for the portrait mode and 84 μSv for the landscape mode (18).

Classic i-CAT

The Classic i-CAT cone-beam 3D imaging system was also developed by Imaging Sciences International. The image is captured with the patient sitting upright and a varying scan time (20–40 s). The reconstruction time for the standard 20 s scan is < 1 min. The voxel size of down to 0.125 mm offers high resolution. The greyscale is 14 bits. Beam collimation can be adjusted and allows full height and targeted FOV scans, providing the ability to further minimize patient radiation. The FOV is 17 × 13 cm (diameter × height) with the possibility of extended FOV being 17 × 22 cm. The effective irradiation dose according to ICRP 2007 for the standard settings is estimated at 69 μSv for the standard settings (18).

Iluma

The Iluma is produced by Imtec Co. (Ardmore, OK, USA) and is currently marketed by Kodak Dental Systems and GE Healthcare. The machine delivers a 120 kV tube voltage and tube current of 1 or 3.8 mA. The minimum voxel size is down to 0.09 mm, the standard being 0.4 mm, and the greyscale is 14 bits. The reconstruction time for the resolution of 0.4 mm voxels is 2.5 min, and 5 min for the 0.3 mm voxel size. The scan time for image acquisition is approximately 10–40 s. The machine occupies a footprint of 1.1 × 1.4 m. The irradiation dose according to ICRP 2007 for standard settings is 98 μSv, and 498 μSv for the ultra-high-resolution scan (18).

Quolis Alphard: Alphard-3030 cone-beam

This device is produced by Belmont Equipment (Somerset, NJ, USA). The Alphard 3030 CBCT has a FOV of 20 × 17.9 cm. The voxel size is down to 0.2 mm, the greyscale according to the manufacturer is 256 bits. The scanning time is 17 s and the time of reconstruction is 2.5 min.

E-Woo Picasso

E-Woo Technology Co. Ltd (Gyeonggi-do, Republic of Korea) offers three different CBCT machines regarding the need for a bigger FOV. They are called Trio, Pro and Master:

- *Trio* combines panoramic, cephalometric and CBCT functions in one device. The scanning time for the cephalogram is 12 s, 13 s for the panoramic and 15 s for the CT scan. The FOV is 12 × 7 cm and the reconstruction time is < 2 min.
- *Pro* has the same FOV (12 × 7 cm) and does not include the panoramic and cephalometric options.
- *Master* has an FOV of 20 × 19 cm and a scanning time of 24 s. It is offered as a standard and superior variant. The superior has a special design allowing the patient to be standing or seated during the scan and comes with additional software, direct DICOM printer option and PACS interface.

Newtom VG

The Newtom VG is a newer device from Quantitative Radiology (Verona, Italy), acquired by AFP Imaging Corporation (USA) in 2007. It captures the volume of 16 × 14 cm (diameter × height) and is an upright scanning system. The system has a small footprint (1.13 × 1.52 m) and is interestingly also available as a mobile, NewTom VG Flex. Newtom VG utilizes a 14 bit greyscale and the estimated dose of irradiation is 50 μSv. The scan time is 24 s and the typical reconstruction time is 3 min.

Newtom 3G

The family of Newtom 3G devices was introduced as part of an evolutionary process from its predecessor, the Newtom 9000, and is developed by Quantitative Radiology. The Newtom 9000 was the first device in the dental market to use CBCT technology. The imaging positioning of the patient in the Newtom 3G is with the patient lying supine on a custom-built table. 3D scans of the head and neck are completed within 36 s and the system is able to obtain three different FOVs, depending on the device specification and clinical information needed: 20, 15 and 10 cm diameter, respectively. The voxel resolution is 0.2–0.4 mm and the greyscale is 12 bits. Custom-built software allows volumetric and surface area analysis of soft and hard tissues. The effective irradiation dose according to ICRP 2007 for the standard settings and the large FOV is estimated at 68 μSv (18).

Promax 3D

The Promax 3D is developed by Planmeca (Helsinki, Finland). It has a tube voltage of 50–84 kV and a scan time of 18 s. The image volume is up to 8 × 8 cm, greyscale is 12 bits and voxel size is 0.16 mm. The reconstruction time of the images is typically < 3 min. The irradiation for the standard settings is 189 μSv according to ICRP 2007 (18).

CB MercuRay

The CB MercuRay imaging CBCT is developed by Hitachi Corporation (Tokyo, Japan). The X-ray source is made of a low-energy fixed anode tube producing a cone-shaped X-ray beam that is captured on an image intensifier and a solid-state charge-coupled device (CCD). The manufacturers claim a scan time of 10 s through a rotation of 360° that provides 288 views that can be seen either 2D or 3D. The greyscale is 12 bits and the FOV is spherical, 20, 15 and 10 cm, respectively. The 3D volume reconstruction time is 6 min. The export to DICOM and other formats is possible. According to ICRP 2007, the effective irradiation dose for the standard quality is 569 μSv, and 1073 μSv for the highest quality images (18).

Sirona Galileos

The Sirona Galileos is produced in Bensheim, Germany. It has a scan time of 14 s. The effective irradiation exposure for the standard settings is 70 μSv, according to ICRP 2007 (18). The field of view is 16 × 16 cm. The voxel size is 0.15–0.30 mm and the greyscale is 12 bits. The image reconstruction time is 4.5 min.

Scanora 3D cone-beam panoramic dental X-ray machine

Scanora (Soredex, Tuusula, Finland) is a CBCT device with an FOV of 7.5 × 14.5 cm, a 12 bit greyscale, 0.133–0.35 mm voxel size and it needs 1–2 minutes for the reconstruction. The irradiation is in the range of three to five panoramic tomograms, as claimed by the company.

GXCB-500

The GXCB-500 (Gendex Dental Systems, Des Plaines, IL, USA) is a scanner with a 14 bit greyscale with 8.9 and 23 s scanning time. The FOV is up to 14 × 8 cm. The voxel size is down to 0.125 mm and the reconstruction time is short −<20 s, and <95 s for the high-resolution. It is powered by the i-CAT software. The reported irradiation dose is 28–35 μSv.

CB Throne

CB Throne™ CBCT is developed by Hitachi Corporation (Tokyo, Japan). Its FOV is 5 or 10 cm in diameter and the voxel resolution is 0.2 and 0.3 mm, respectively. At the time of writing it was only available for the Japanese market.

Skyview

Skyview Myray (Cefla Dental Group, Imola, Italy) is another system where the manufacturer recommends lying down as the best position for obtaining consistently sharp images. The image size can be up to 11 × 11 × 11 cm, it has a 12 bit greyscale and the reconstruction time is < 4 min. The reported effective dose of irradiation is 37 μSv.

3D Accuitomo

The XYZ Slice View Tomograph was developed as collaboration between the School of Dentistry, Nihon University. and J Morita MfG Corporation, Kyoto, Japan. The device allows specific anatomical investigation, since the FOV is 4 × 3 cm (diameter × height). Consequently the irradiation dose is lower (7.4 μSv). The voxel size is 0.125 mm and the greyscale is 8 bits. The time of reconstruction is < 5 min, using a Pentium IV with 1.5 GHz processor. This unit requires a space of 1.62 × 1.20 m.

3D Accuitomo 80

The 3D Accuitomo 80 is also produced by J Morita MfG Corporation, Kyoto, Japan. It has a voxel size as low as 0.8 mm and a 13 bit greyscale. It captures an FOV of 4 × 4 cm or 6 × 6 cm (diameter × height). The irradiation dose claimed by the manufacturer is 1.6 multiples of a dental panoramic tomogram.

3D Accuitomo FPD

The 3D Accuitomo FPD, also produced by J Morita MfG Corporation (Kyoto, Japan), has a 12 bit greyscale, irradiation dose estimated at 1.8 times dental panoramic

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tomogram and a voxel size down to 0.125 mm. The FOV is also 4 × 4 cm or 6 × 6 cm.

Prexion 3D

The CBCT Prexion (TeraRecon Inc., San Mateo, CA, USA) performs a 360° scan in 19 s, and 37 s for the high-resolution scan. It uses a CsI flat panel detector and has an FOV of 8.1 × 7.6 cm. The reconstruction time is up to 120 s and the system is compatible with the DICOM 3.0 and third-party systems.

Kodak 9000 3D Extraoral Imaging System

The Kodak 9000 3D Extraoral Imaging System [Carestream Health (exclusive manufacturer of Kodak Dental Systems), Rochester, NY, USA) is another device with the smaller FOV (5 × 3.7 cm) with a voxel size down to 0.076 mm, a 14 bit greyscale and a low dose (5–19 μSv) of irradiation according to L'institut de Radioprotection et de Sûreté Nucléaire (IRSA), 2008.

Panoramic CT PSR9000N

The PSR9000N from Asahi Roentgen Ind. Co. Ltd (Kyoto, Japan) is one of the smaller FOV scanners, with a cylindrical area of up to 4.1 × 4 cm. It has a high resolution (voxel size 0.1 mm). The time of exposure is 20–30 s and the manufacturer offers different modes of imaging: Panoramic CT, Dental CT, Block CT, Digital Panorama and 3D image display.