CONE BEAM COMPUTED TOMOGRAPHY

AN IN DEPTH REVIEW

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INTRODUCTION

New technologies have been introduced and evolved into dentistry in recent years.

The need for 3-dimensional (3d) images has made cone beam computerized tomographies (CBCT) a valuable and popular diagnostic tool in dentistry

- Dental radiography is widely used as a diagnostic tool in daily dental practice.
- It is estimated that dentists are responsible for more than one-quarter of all medical radiographs in Europe..
- 2D imaging techniques cannot display complex 3D anatomical structures and related pathologies however CBCT technology can provide acurate 3d images while exposing the patient to a relatively low dose of radiation

FUNCTION

- Initially, medical computed tomography (CT) was used for 3d imaging in dental applications, but dental cone beam computed tomography (CBCT) quickly became the preferred option.
- This is because of cbct's ability to produce volumetric images of the jaw bone at a reasonable cost and radiation dose, as well as its compact size, affordability, and ability to be located nearby or in-office
- It was first used to evaluate impacted teeth, apical lesions, and mandibular and maxillary diseases .
- There are several models since the first one that continues to improve. Now they can rotate around the head in a single scan and get 360 pictures using only 17 seconds of accumulated exposure time .

PATIENT POSITION

- reported that 80% of the CBCT devices were either wall- or floor-mounted standing position systems (mostly with wheelchair access), while supine lying position was used only in 3% of the devices.
- While the standing position is the most used for dental CBCT scanning, it is vulnerable to patient movements especially when sufficient head fixation tools are not used.
- Some of the vendors also provide motion-correction algorithms and other solutions to improve image quality regardless of patient movement. For example, 3Shape X1 Scancomfort device (3Shape A/S, Copenhagen,Denmark) uses head-tracking technology to measure patient movement during the scanning, and reconstruction software then readjusts data for any motion to deliver sharp images.

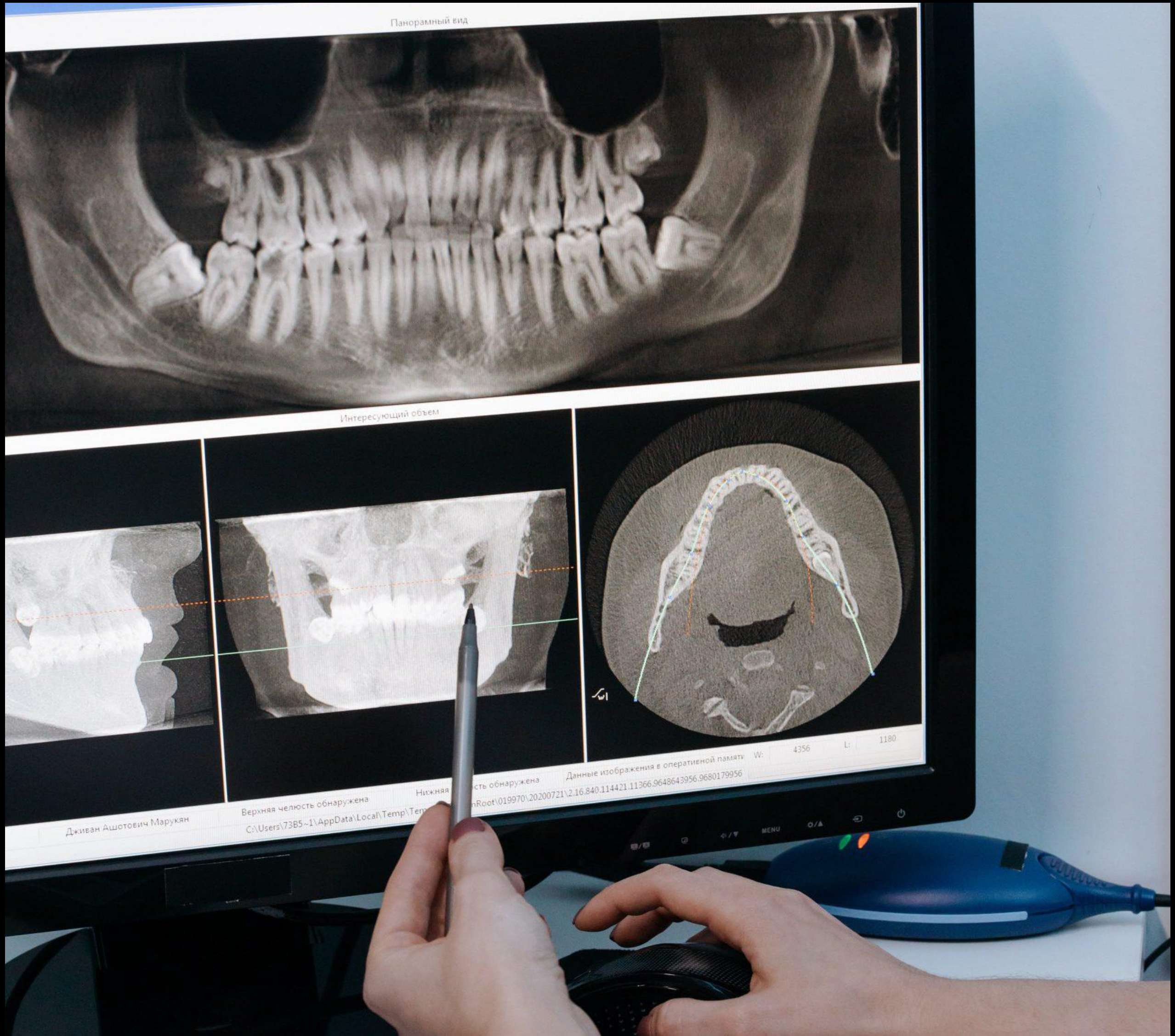
EXPOSURE DOSE

- the exposure dose amount during dental cone beam computed tomography imaging can significantly differ based on the imaging conditions.
- the effective dose from a single imaging session can range between 10 to 1000 µsv.
- the exposure dose primarily depends on the lateral area of the fov, which is the product of its height and width. therefore, selecting the smallest (fov) that fulfills the imaging objective is crucial to reduce the exposure dose.
- the field of view (fov) width can range between 4 to 20 cm, and its height can range from 3 to 20 cm.
- while the effective doses for conventional intraoral, panoramic, and cephalometric radiography range from 1-8 µsv, the exposure dose from dental cone beam computed tomography can exceed this amount by more than ten times, even under low-dose conditions. therefore, it is essential to exercise caution when using dental cone beam computed tomography imaging

SCANNING TIME

- the scanning time in cone beam computed tomography goes from 5 to 40 seconds. the exposure times are less because of the pulsing of the x-ray beam, ranging from 1 second up to 40 seconds. the times differ between scanners from a few seconds to several minutes, depending on the model.
- It is desirable to reduce CBCT scan times to as short as possible to reduce motion artifact resulting from patient movement. Decreased scanning times may be achieved by increasing the detector frame rate (number of images acquired per second), reducing the number of projections, or reducing the scan arc.
- The first method provides images of the highest quality, whereas the latter methods increase image noise

GENERAL FEATURES



- Unlike conventional CT, which utilizes fan-shaped X-ray beams in which the source must travel not only circularly around the subject but also axially along the subject's length in order to cover the entire volume of interest thus scanning one cross-sectional slice of the subject at a time, CBCT employs a cone-shaped X-ray beam and a two-dimensional detector, enabling volumetric imaging of the entire field of view (FOV) in a single rotation

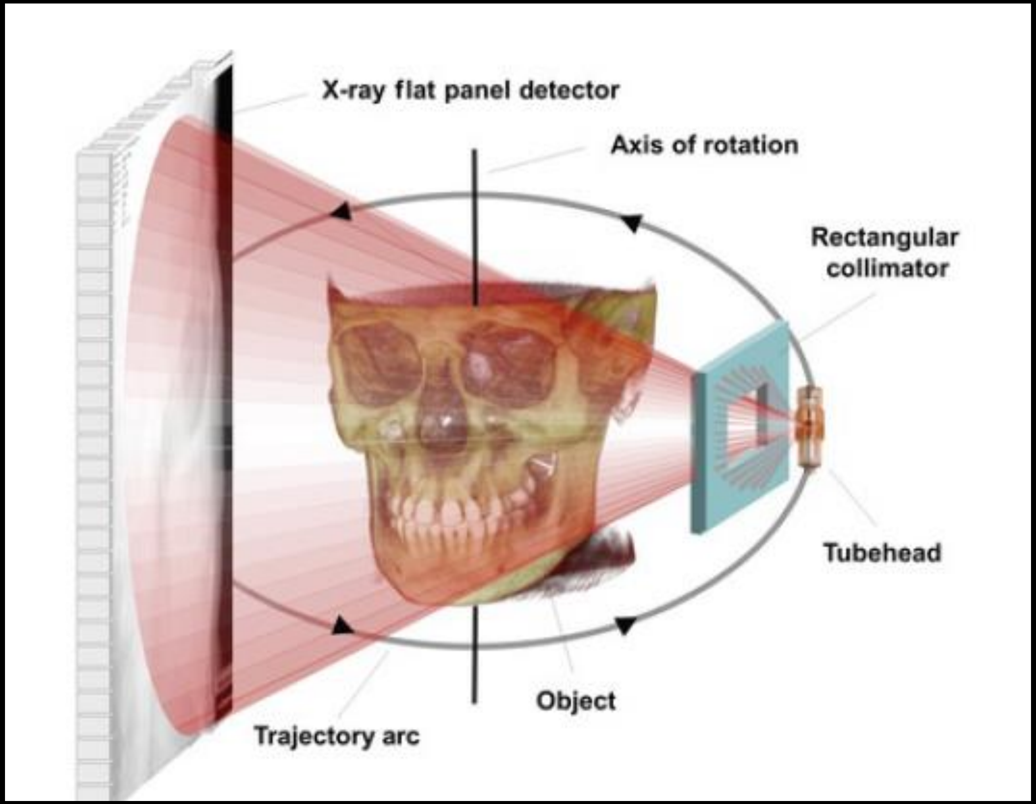
- Most of the devices also allow panoramic imaging, and with an additional arm, cephalometric imaging with the same unit.

GENERAL FEATURES

- CBCT units are available, providing fixed or variable rotation angles. Most CBCT units have fixed scan arcs. Fixed rotation angle units may be a full 360 degrees or partial trajectory arcs. Ideally, CBCT imaging should be performed with a full scan arc to acquire adequate projection data for volumetric software reconstruction
- A limited scan arc potentially reduces the scan time and patient radiation dose and is mechanically easier to perform. However, images produced by this method may have greater noise and reconstruction interpolation artifacts
- A few CBCT systems also have 3D photography capability for assisting pre-operative treatment planning and follow up.

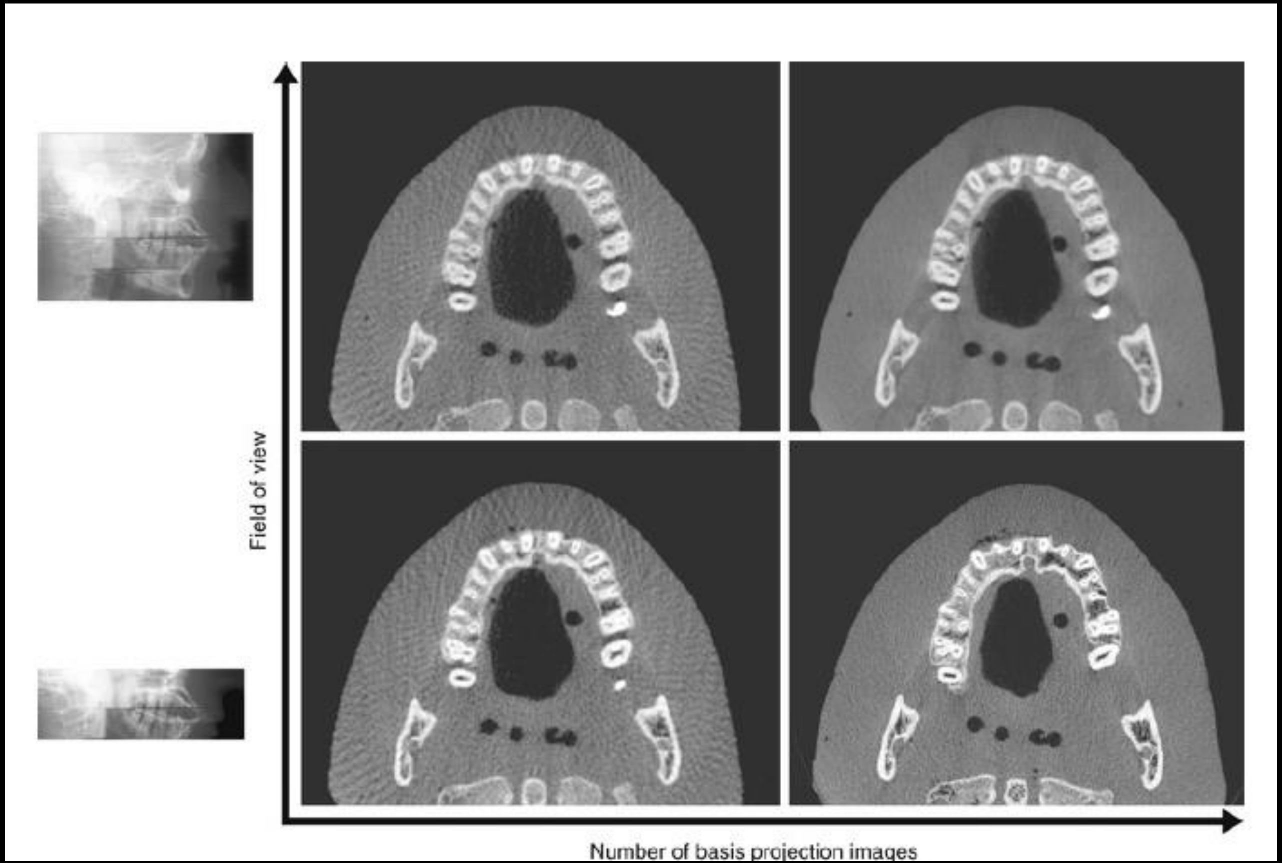
FIELD OF VIEW

- Field of view could be defined as area of interest to be covered during the scanning procedure.
- The dimensions of the FOV or scan volume primarily depend on the detector size and shape, the beam projection geometry, and the ability to collimate the beam. The shape of the scan volume can be either cylindrical or spherical.
- It is desirable to limit the field size to the smallest volume that images the ROI



FIELD OF VIEW

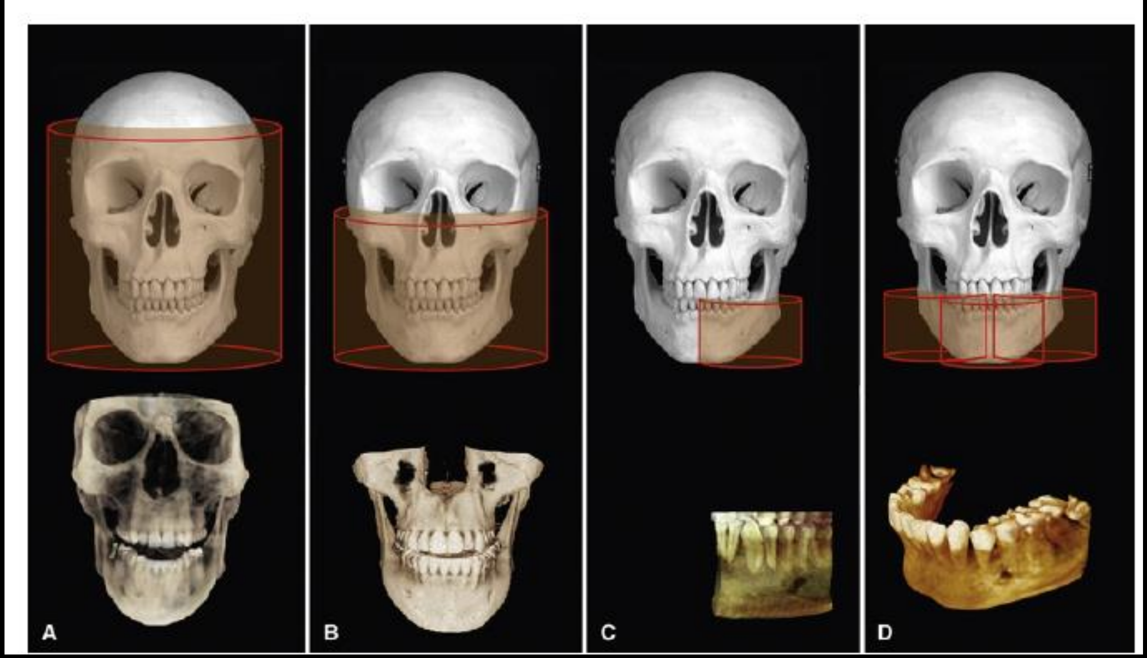
- Reduction of the FOV to the ROI improves image quality because of reduced scattered radiation. More importantly, a reduction in FOV is usually associated with patient dose reductions ranging from 25% to 66%



REDUCING FOV

- reduction in the FOV usually can be accomplished mechanically or, in some instances, electronically. mechanical reduction in the dimensions of the x-ray beam can be achieved by either pre-irradiation (reducing primary radiation dimensions) or post-irradiation (reducing the dimensions of the transmitted radiation, before it is detected) collimation.
- electronic collimation involves elimination of data recorded on the detector that are peripheral to the area of interest. electronic collimation is undesirable because it results in greater exposure of the patient to radiation than is necessary for the imaging task

- cbct systems are typically divided into three different categories according to fov size:
  1. large fov (>15 cm maximum scan volume height)
  2. medium fov (from 10 to 15 cm field height)
  3. small fov (≤10 cm field height)
- The FOVs available in dental and maxillofacial CBCT systems vary from FOVs suitable for a single jaw or a few teeth (usually 4 × 4 cm or 5 × 5 cm, or from 2× 2 cm in freely adjustable FOV systems) to full craniofacial imaging (from approximately 15 × 15 cm up to 26 × 30 cm or 17 × 32 cm).



FIELD OF VIEW

- two approaches have been introduced to enable scanning of an ROI greater than the FOV of the detector.
- one method involves obtaining data from two or more separate scans and superimposing the overlapping regions of the CBCT data volumes. software is used to fuse adjacent image volumes (“stitching” or “blending”) to create a larger volumetric data set either in the horizontal or in the vertical dimension.
- A second method to increase the height or width of the FOV using a small area detector is to offset the position of the detector, collimate the beam asymmetrically, and scan only half the patient's ROI in each of the two offset scans

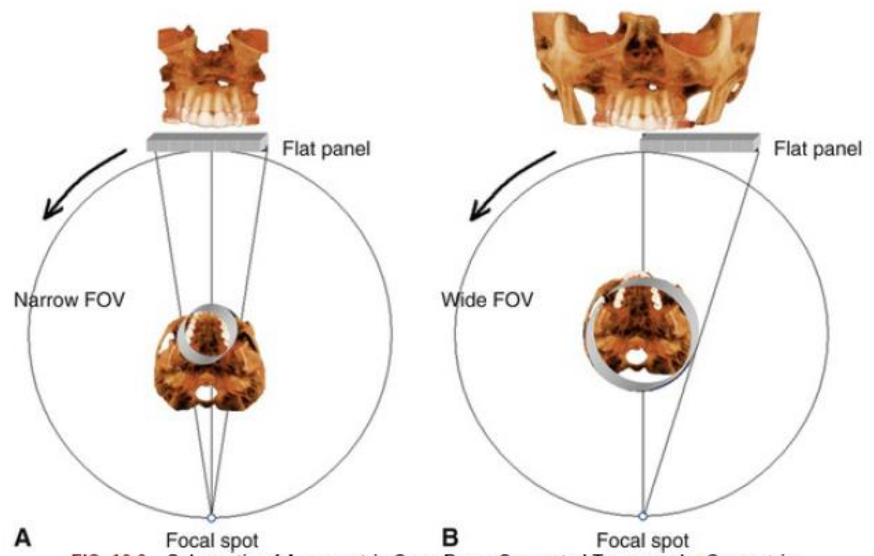


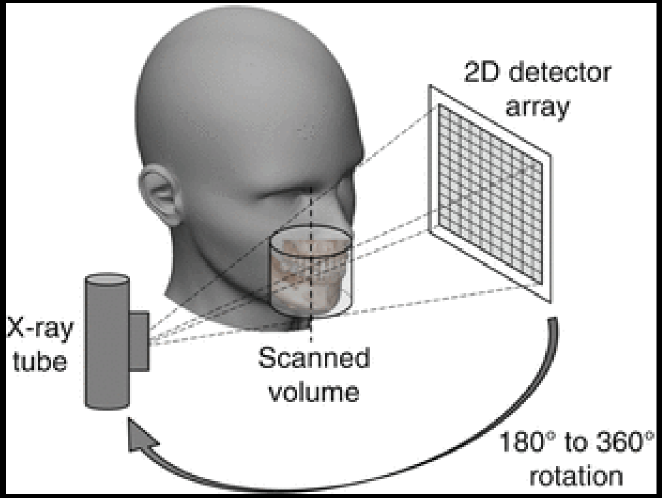
FIG. 10.6 Schematic of Asymmetric Cone Beam Computed Tomography Geometric Configuration to Increase Field of View *(FOV)* Using a Flat Panel Detector (FPD). (A) Conventional geometric arrangement whereby the central ray of the x-ray beam from the focal source is directed through the middle of the object to the center of the FPD. The resultant image is limited to the region of the detector (dentition in this case). (B) Alternative method increasing image size involves shifting the location of the flat panel imager and collimating the x-ray beam laterally to extend the FOV object. In this instance, the FPD is shifted to the opposite side of the midline halfway through the exposure. The resulting image doubles the horizontal ROI. (Adapted courtesy of SOREDEX, Tuusula, Finland.)

DATA COLLECTION DURING SCANNING

DIGITAL TIME CAPSULE

- For CBCT data reconstruction, a scan arc of at least 180◦ should be used to acquire the projection images. Most currently available dental CBCT systems use a rotation angle of 360◦ for data acquisition
- in a few devices, it is possible to select two or three different rotation angles for scanning, which allows reduced radiation exposure to the patient.
- while the lower angular range typically helps reduce patient dose, this may also reduce image quality.

- The detection system CBCT scanners is responsible for recording incident X-ray photons and converting the X-ray energy to a corresponding electrical signal. This signal is represented visually as a shade of gray on the monitor display
- CBCT technology uses a X-ray detection system that is mostly dictated by the spread of the cone beam radiation. Therefore, all CBCT units use an area detector. Two systems are currently used, image intensifiers/charge-coupled device (II/CCD) and flat panel detectors (FPDs)



DATA COLLECTION DURING SCANNING

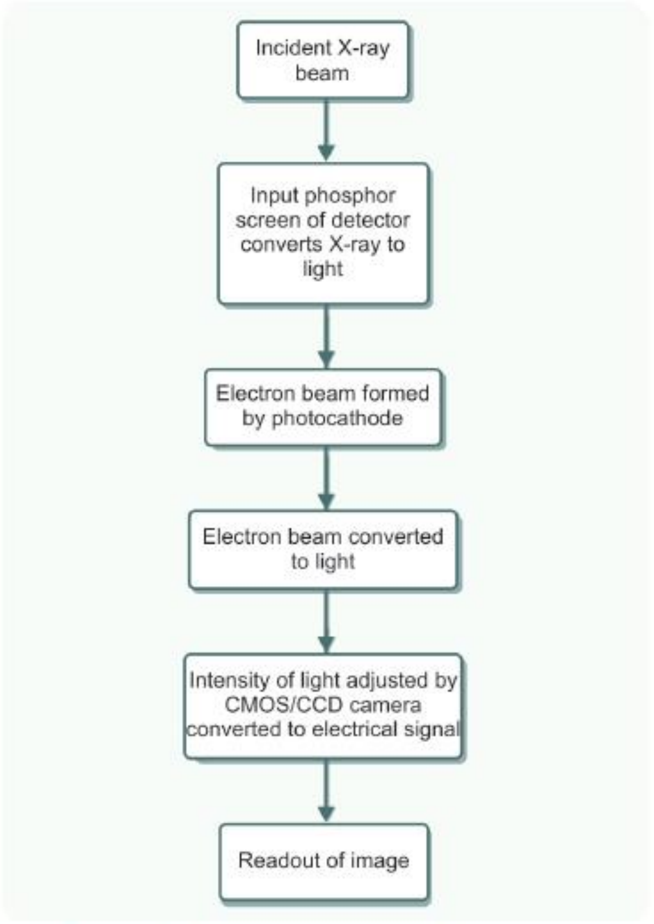


Figure 2.1: Flowchart of image intensifier/charge-coupled device (II/CCD) functioning (CMOS, complementary metal oxide semiconductor).

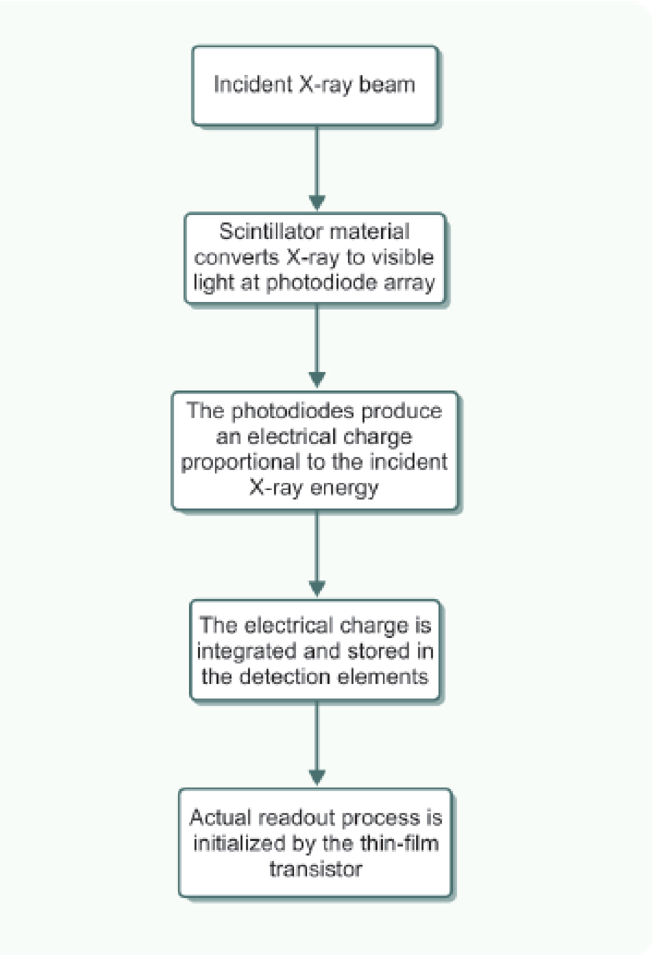


Figure 2.2: Flowchart of flat panel detector functioning

II/CCD VS FPD

- The II/CCD detectors are large and bulky and most frequently result in circular-basis image areas (spherical volumes) rather than rectangular ones (cylindrical volumes). The main disadvantages of II/CCD detectors are geometric distortion and blurring

- FPDs are less complicated, less bulky and offer greater dynamic range than II/CCD detectors. FDPs also have limitations in their performance related to the linearity of response to the radiation spectrum, the uni-formity of the response throughout the area of the detector and bad pixels, the effects of which on image quality are most noticeable at lower and higher exposures

VOXEL AND FOCAL SPOT SIZE

- The voxel sizes available in the devices have tended to be even smaller, possibly due to improved image reconstruction algorithms, image noise reduction, and patient movement correction methods.
- The smallest voxel size currently available is 50 µm, while the largest possible voxel size is 600 µm.
- The voxel size is related to spatial resolution. Therefore, smaller voxel sizes enable higher spatial resolution and delineation of smaller fine structures, such as in dental trauma cases.
- Not only voxel size but also the focal spot size affects spatial resolution. Most of the recent CBCT systems utilize a focal spot size of 0.5 mm (range 0.2 to 0.7 mm).
- The smaller the focal spot size, the smaller the penumbra at the detector, which results in a sharper image.

EXPOSURE SETTINGS

- The quality and quantity of the x-ray beam depend on tube voltage (kVp) and tube current (mA). The available ranges of exposure factors in CBCT greatly depend on the manufacturer. Some CBCT manufacturers provide units with fixed, nonadjustable exposure settings, whereas others incorporate “preset” exposure settings for different-sized individuals or specific scanning protocols and allow operator “manual” adjustment of kVp or mA or both.
- Typically, tube current values selectable for 3D imaging are between 2 and 15 mA, but the range covering all units is 1 to 120 mA. Tube voltages range from 50 to 120 kVp, with typical values between 60 and 90 kVp.
- When exposure reduction is necessary to compensate for differences in patient size, mA changes are preferable to kVp changes as the increase in noise for a given dose reduction is smaller for the former. mA adjustments affect effective dose proportionately. Similarly, a higher kVp may be considered in patients with high-density objects, such as teeth with root canal fillings or dental implants, to reduce beam-hardening artifacts from these materials.
- Adjustment of kV has an even greater effect on dose than does mA, with each increase in 10 kV approximately doubling the dose if all other parameters remain the same.

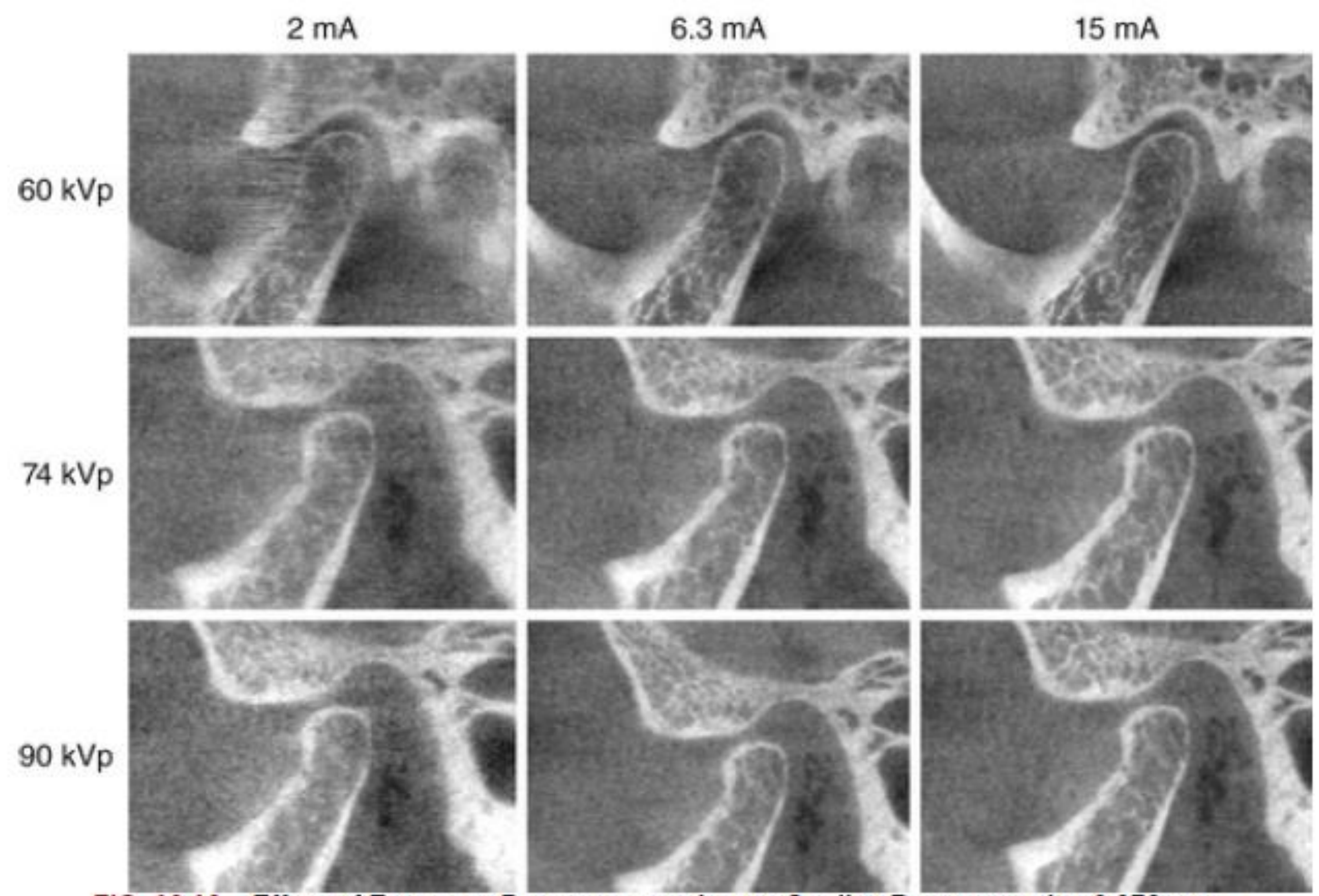


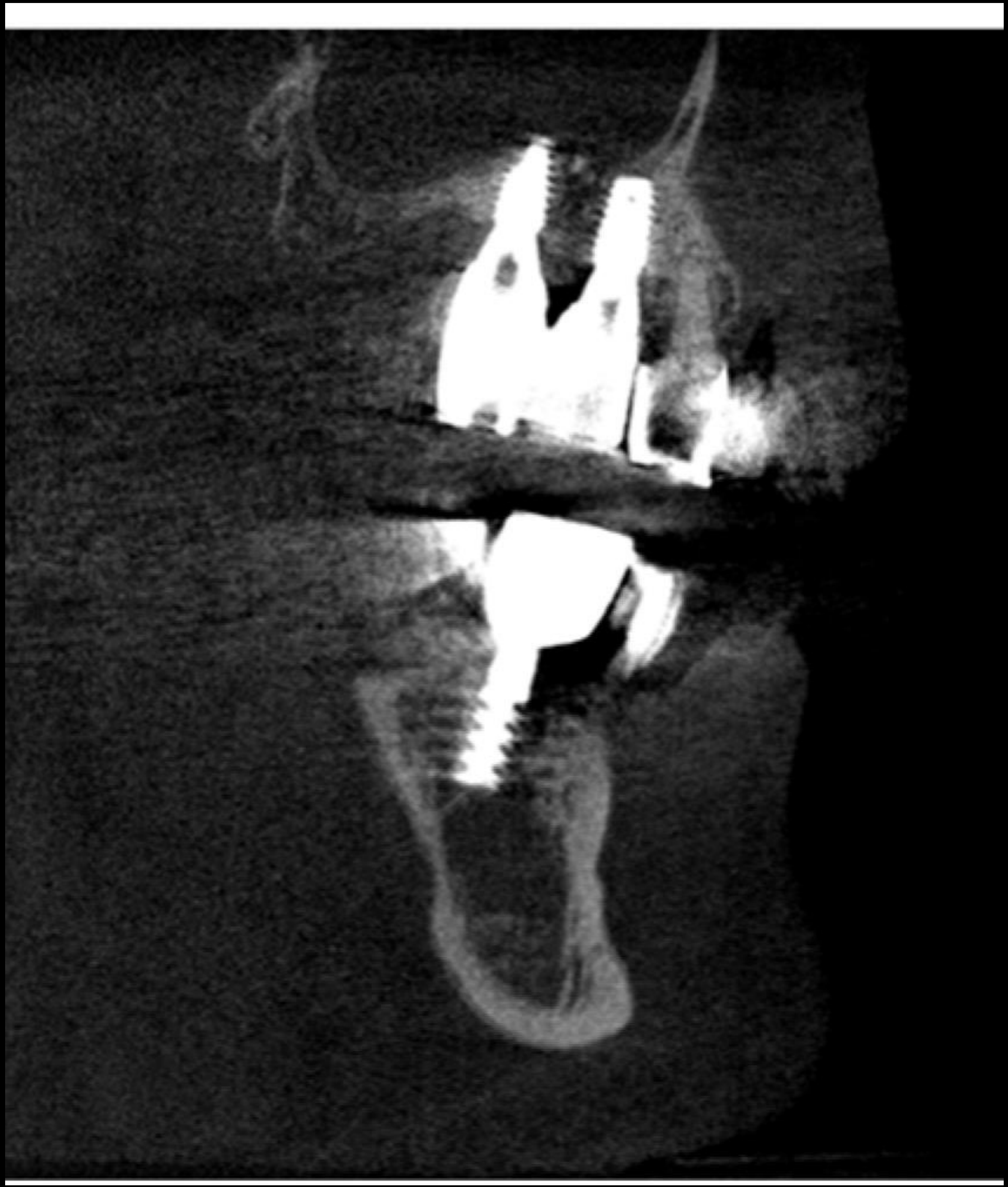
FIG. 10.10 Effect of Exposure Parameters on Image Quality. Representative 0.076-mm

EXPOSURE SETTINGS

- a recent CBCT innovation is incorporation of automatic exposure control (AEC) as a dose reduction strategy to optimize patient doses. AEC attempts to adjust and customize tube current (ma) specifically for each patient according to the radiation intensity recorded by the detector by using a short pre-examination (scout) exposure or using an exposure modulation during the rotation. it is anticipated that widespread implementation of AEC in CBCT will avoid the need for manual adaptation of exposure parameters based on patient size.

IMAGE RECONSTRUCTION TECHNIQUE

- the reconstruction technique still mostly used in dental cbct systems utilizes 3d filtered back projection (fbp) by feldkamp-davis-kress (fdk) algorithm due to its simplicity and rapid reconstruction times.
- recently, some cbct models have been introduced that use iterative reconstruction methods or dl-based reconstruction methods.
- the reconstruction times differ between the scanners from almost real-time reconstructions up to a few minutes, depending on the acquisition parameters (fov, voxel size, number of projections, rotation angle), hardware (processing speed, data transfer from acquisition to reconstruction computer), and software (reconstruction algorithms) used.



METAL ARTIFACTS REDUCTION TECHNIQUES

- metal restorative materials (e.g. dental implants, metal fillings and crowns, fixed orthodontic appliances) and related artifacts are common in dental imaging
- metal implants result in streaking and beam-hardening artifacts in the cbct images that can be seen as dark table shading and bright streaks, especially around highly attenuating metallic objects within the image volume
- however, many dental cbct systems currently have noise/scatter correction and metal-artifact reduction algorithms to overcome the decreased image quality due to highly attenuating metal implants

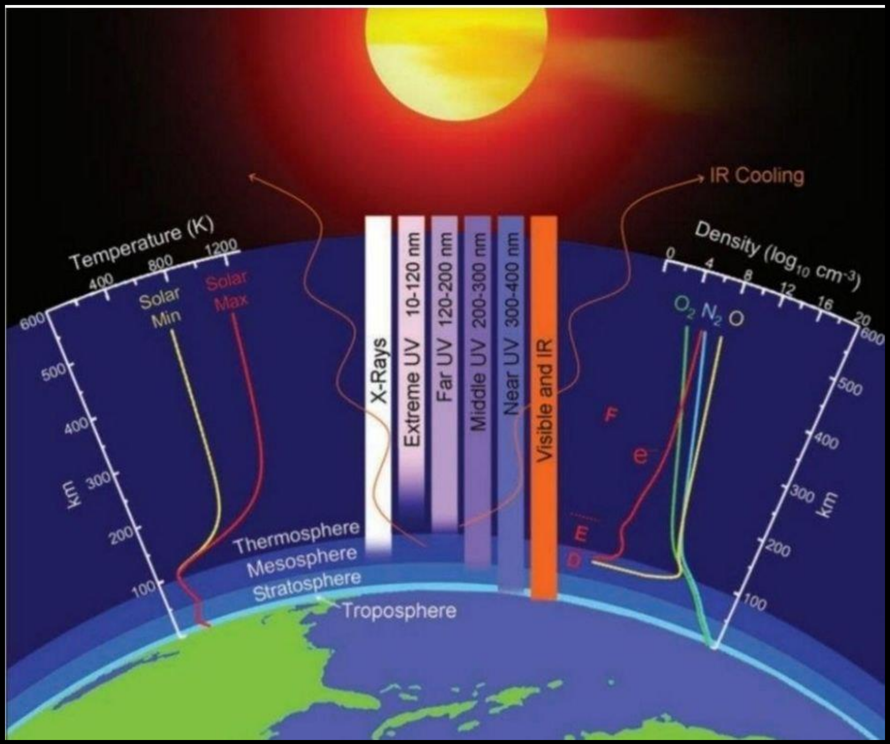
STITCHING VOLUMES

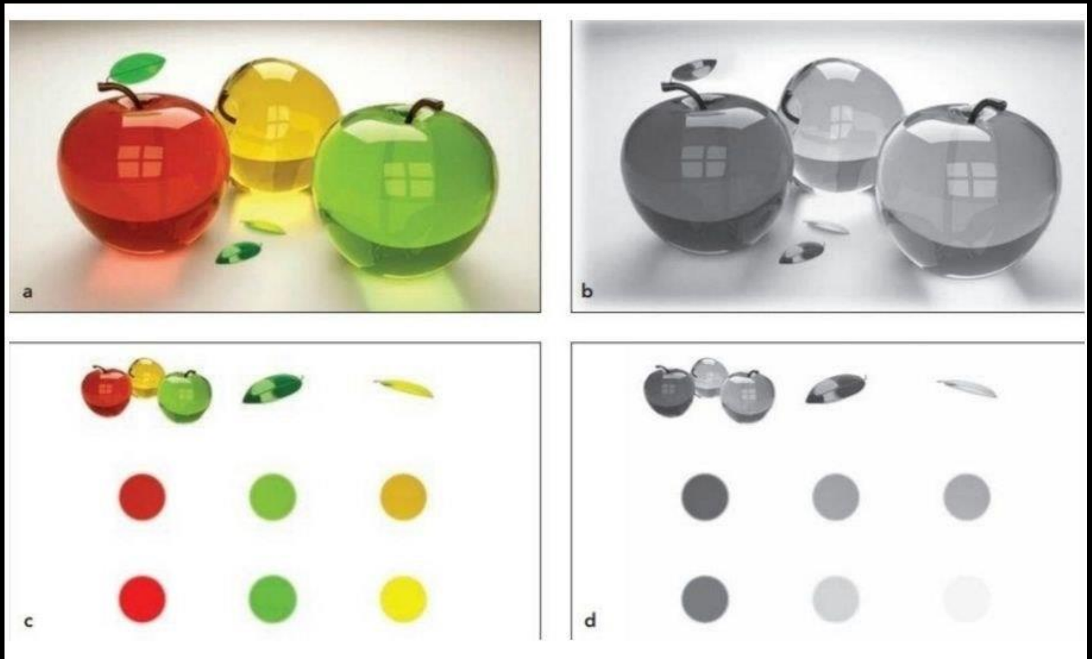
- In some cases, the single FOV does not have enough coverage for the clinical volume of interest. Thus, separate scans producing FOVs adjacent to and partly overlapping each other may be stitched together to provide a larger effective field of view. This stitching may be used to combine horizontal or vertical image volumes to compile a larger image volume. The stitching process itself may utilize exact information on patient positions between the separate original scans or automatic matching of the images using image registration.

- However, with the field-of-view (FOV) of a single 3D volume, it is not possible to freely explore within a large anatomical region (e.g., a third trimester fetus), which is an essential skill to be learned for diagnosing patients. The acquired simulation volume needs to ideally span, for example, the entire abdomen to provide a realistic scene for training. Large-FOV ultrasound volumes are also potentially beneficial for diagnostic applications. For instance, standardized, large-FOV ultrasound volumes of the breast can now be acquired using ABUS and ABVS platforms.

BEAMHARDENING AND ARTEFACT

- An X-ray tube produces a beam with a continuous spectrum of energies . When the poly energetic beam is attenuated and scattered in the patient, the mean energy of the remaining primary photons becomes higher. To better appreciate beam hardening artifact and its cause, we will develop another model to gain better insight into how the CBCT detector responds to the incident photons. When considering attenuation, we must think in terms of distributions. As Fig 2-39 shows, sunlight is composed of a very wide distribution of energy, only a small portion of which we respond to and see as visible “white” light. Visible white light is itself composed of a distribution of energies. Our optical system is able to distinguish these different energies of light, which we perceive as color ,as well as their intensity, which we perceive as brightness. The detector of the CBCT machine is not able to distinguish these different energies of the x-ray beam, detecting only the intensity of the beam. A useful way of thinking about it might be that the CBCT detector only sees things in grayscale.10 This will require us to investigate some of the counterintuitive issues surrounding the transformation of energy-dependent attenuation to intensity-only information that normally escape
- attention due to the nature of the human visual system.





- Figure 2-40a shows three glass apples. As humans, we can see that the leaves are green, and we can also readily appreciate the differences in color between the three apples.11 Further, the apples all appear to have approximately the same brightness or intensity. However, once they are transformed to grayscale, the differences in their intensity become obvious (Fig 2-40b). The grayscale version of the red apple appears much darker, and the grayscale versions of the green and yellow apples appear to have approximately the same intensity. In this model, the glass apples are not only attenuating the beam of white light as evidenced by their shadows, but they are also changin the mean energy of the beam of light as evidenced by the color of their shadows. The yellow apple attenuates all colors that are not yellow and allows only yellow light to pass through (see Fig 2-40a) . Thus, the green leaf that is in the yellow apple's shadow, being illuminated by the light that has already passed through the yellow apple, looks more yellow that it actually

- What we see as humans is a function of how it is illuminated. In this respect, the CBCT detector is no different. However, the detector of the CBCT only sees the shadow, not the color. It is this combination of the wavelength-dependent attenuation of the photon-matter interaction with the inability of the CBCT detector to discriminate wavelength/energy information in the incident beam that gives rise to beam hardening artifact

GREYSCALE VALUES AND HU CALIBRATION

- The intrinsic greyscale values in MSCT image data are calibrated to the Hounsfield unit (HU) scale which describes the relative X-ray attenuation in a voxel in relation to the attenuation of air (−1000 in HU range) and water (zero in HU range). The applicability of the HU scale in CBCT image data is limited due to several physical factors including, most of all, X-ray scatter due to the cone beam geometry, and projection data truncation, which bring uncertainty and inconsistency to the claimed HU values and ultimately limit low-contrast (soft-tissue) resolution. Therefore, the exact quantitative greyscale values (or pseudo HU-scale) should be used with caution in clinical CBCT applications.

PATIENT DOSE

- Estimated the radiation risk for dental CBCT imaging and concluded the need for justification and optimization of CBCT exposure with a specific focus on children The presented lifetime attributable radiation induced cancer risk was between 2.7 and 9.8 per million examinations. , the organ doses for children are higher compared to adults due to the decreased attenuation and relatively larger tissue volumes in the primary beam. Furthermore, radiogenic tumour incidence in children is more variable than in adults and depends on the tumour type, age and gender.

PATIENT DOSE

- For about 25% of cancer types, including leukaemia and thyroid, skin, breast and brain cancer, children are more radiosensitive than adults. The tube voltage settings should be adopted according to the patient’s size, although adjustment of the tube voltage is often limited with dental CBCTs. The filtration usually cannot be modified by the user, although it might have a remarkable impact on dose, indicating that the manufacturers’ role is essential. Adding a new 0.5 mm copper filter and modulating the tube current on the Promax 3D CBCT scanner (Planmeca, Helsinki, Finland) decreased the effective dose from 674 μSv to 153 μSv between older and newer models.

FROM GUIDELINES TO CLINICAL USE

- The decision to order a CBCT scan must be based on the patient's history and clinical examination, and justified on an individual basis by demonstrating that the benefits to the patient outweigh the potential risks of exposure to X-rays, especially in the of children young adults. CBCT should only be used when the question for which imaging is required cannot be answered adequately by lower dose conventional dental radiography or alternate imaging modalities. can improve the endodontist's performance and facilitate better patient management. But if a CBCT study is ordered for every patient and thus partially becomes a screening instrument, many patients may be exposed unnecessarily to ionizing radiation.

FROM GUIDELINES TO CLINICAL USE

- In addition, some incidental findings will be identified as pathology with potential further workup or even treated unneces The AAE/AAOMR statement suggests that the risk-benefit ratio is too high for CBCT to be used as a screening tool, even though the radiation levels are quite low with focused-field imagers. We must remember, however, that these recommendations partially stem from a more medical model of imaging where the radiologist is not involved with patient care. In general, the authors all clinicians involved in patient care-recommend ordering a CBCT study in situations where it is likely to inform, influence, or alter decisions with regard to diagnosis, prognosis, and management strategies .

FROM GUIDELINES TO CLINICAL USE

- CBCT scans may also be appropriate for diagnosing and treatment planning a variety of endodontic, implant, periodontal, orthodontic, and oral and maxillofacial surgical cases. Additionally, because there is considerable overlap between different areas of dentistry, a CBCT scanner can aid in identifying the reason some complications occur when traditional radiographic evaluation is inconclusive .

TRAINING ASPECTS

- EADMFR has prepared a position paper on basic training requirements for the use of dental CBCT by dentists. The aim of this position paper was to recommend a minimum level and core content of training for dentists involved in CBCT imaging in dental practice in Europe. DMFR is a registered specialty in only five European countries - Finland, Norway, UK, Sweden and Turkey - and there is obvious need for CBCT training for dentists. However, these guidelines are suggestions made by an expert group and they are not legally binding, nor do they replace national regulations. have also paid attention to the need for dental educators to incorporate the most updated information on CBCT technology into their curricula. They also pointed out the need to conduct studies meeting methodological standards to demonstrate the diagnostic efficacy of CBCT in dentistry

- The indications for the use of CBCT imaging in DMFR have been presented in the SEDENTEXCT guidelines. The ALARA principle has to be followed, and no routine use of CBCT or other radiological method is allowed. The referring dentist must supply sufficient clinical information, including results of earlier examinations to allow the CBCT practitioner to perform the justification process. Also, the previous images have to be available before CBCT imaging takes place. Having all this information available, the use of CBCT can be considered justified if 2D radiographs do not or are not expected to answer the diagnostic question and it is expected that CBCT will add new relevant information.

QUALITY ASSURANCE

- Quality assurance (QA) is an important part of the clinical use of any radiological modality, including CBCT, meant to assure that the technical specifications and performance level of the scanner are maintained during its life cycle. The manufacturer typically performs quality assurance procedures during the original installation. However, the user organization should also pay attention to the performance of regular QA tests, related to further constancy and maintenance testing,
- and ensure that QA phantoms and guidelines are in place and implemented during the clinical use of the device. This approach was also an essential part of the SEDENTEXCT project, including the formulation of a quality assurance programme. From the practical point of view, it should be emphasized that the staff performing dental imaging must have competence in dental imaging quality assurance issue[32].

CONCLUSION

- The dental profession has a long history of using the most current technology to provide improved care to patients. The CBCT scanner is becoming the standard of care for many procedures, and CBCT manufacturers continue to make great advances toward expanding the applicability of this technology to dental practices. The newer CBCT scanners feature settings for bitewing radiographs, as well as dual-sensor set- ups for either CBCT or panoramic radiographs. Current CBCT devices enable temporomandibular joint lateral or axial views, as well as a variety of settings for different areas of interest, thereby limiting radiation exposure to a small area. However, it is ultimately the responsibility of the clinician to use CBCT technology responsibly, supporting its application based on an evaluation of reasonable degree of risk versus reward. Through education and a commitment