The Vision for Change: 2D, 3D, and 4D Imaging in Dentistry

Today’s Agenda

- Brief overview of 2D imaging advances: Intraoral and panoramic
- Cone beam CT: technology, radiation risks, and legal responsibilities
- Cone beam CT: Clinical applications and integration into digital dentistry
- Segmentation and 4D imaging
- Intraoral digital tomosynthesis: The “new” 3D current technology and future promise
- Q & A
The Stone Age didn’t end because they ran out of stones

It ended because they discovered new technology that worked better

Brief overview of intraoral radiography advances
Available Dental Imaging Technologies

Traditional (Film)

Solid State Device (CCD or CMOS)

Photostimulable Phosphor (PSP)

Digital detectors

How a digital detector works

- Scintillator material: converts X-rays to light
- Fiber optic plate: guides light to the sensor
- CMOS sensor: light converted to an analogue signal
- Electronics: analogue signal is converted into a digital signal
- Signal is displayed on a monitor

Cable Issues…….. Not talking about cable TV

- Single largest problem with sensors
- Solutions:
  - Replaceable wire
  - 45 degree angle
  - Kevlar wrapped
  - Reinforced connect points
  - Strain relief cable
  - Swivel (novel at least)
Photostimulable Phosphor (PSP)

- 100% re-usable
- Same size as film
- Somewhat flexible
- Thin
- No wires

PSP scanner

Soredex OpTime
Direct Digital = PSP = Film

- Over 100 papers have demonstrated that there are no differences in diagnostic efficacy for any of the intraoral systems in use today
- This includes almost all forms of image processing as well
- This leads many to believe that IMAGING GEOMETRY may be the problem

No Processing Problems with Digital Imaging
What About Radiation Risks for Intraoral Radiography?
Radiation Dose for Intraoral Imaging

- Radiation for D speed film = 1
- Radiation for F speed film = ½
- Radiation for storage phosphor = ½
- Radiation for digital sensors = 1/4

Useful tools
- Contrast, Brightness
- Zoom
- Rulers

Sometimes useful
- Special filters
- Edge enhancement

Occasionally useful
- Inversion
- Color conversion (pseudo-color)
- Embossing
Special filters: “Caries detection”

Caries can be enhanced but this tool can introduce artifacts so use it only in specifically small regions.

Special filters: edge enhancements or sharpening

<table>
<thead>
<tr>
<th>Not enhanced</th>
<th>Enhanced: Careful not to overdo it False positives can be created</th>
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<tbody>
<tr>
<td><img src="image1.png" alt="Not enhanced" /></td>
<td><img src="image2.png" alt="Enhanced" /></td>
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Digital images can be enhanced by software increases the potential for greater patient understanding. Film cannot be changed. What comes out of the processor is what you get.
Task Specific Filters

- Sharpening
- General
- Endodontic
- Periodontic
- Restorative

Note: The effectiveness of some of these has yet to be scientifically demonstrated
Periodontic

Restorative
**Image Enhancement Research**

- Selected filters had no effect on the diagnostic efficacy for caries detection or for cavitation detection or for dentin penetration….more research needed
- Dual observers performed the same as single observers

**Panoramic Imaging Advances: Basically Three**

- Panoramic Bitewings
  - Great idea but not yet ready to replace intraoral imaging……..getting closer
- Panoramic Tomosynthesis
  - Choose among several image layers
  - Adjustable to correct for some positioning errors
  - Some units take 4200 pictures and stitch together the sharpest layers
- Direct X-ray detectors- no x-ray to light conversion
Five Questions to Answer

- What is 3-D cone beam computed tomography (CBCT) and how does it work?
- What do you need to consider when purchasing a CBCT system?
- What radiation doses and risks are associated with CBCT?
- What legal responsibilities come with CBCT?
- What are the current clinical applications of CBCT?
Early Dental Radiology

Basically the same as it is today....in terms of geometry
The Primary Problem with Two Dimensional Imaging:

It is the End of the Road for Improvements in Diagnosis and Treatment Planning

Where do we go from here?

Into the Third and Fourth Dimension
The First CBCT System: The Dynamic Spatial Reconstructor

Early 1980s

3-D Cone Beam CT Imaging:
Three Advantages

- Diagnosis and treatment planning
- Foundation for digital dentistry
- Patient education
Cone beam CT: A combination of three technologies

- C-arm fluoroscopy with image intensifiers or flat panel detectors
- Computed Tomography: The algorithm for constructing the volumes
- Panoramic radiography as a platform for the CBCT unit

Image Acquisition:
A series of skull projections (a video)
Back Projection Image Reconstruction

CT Image Reconstruction

Courtesy of Dr. John Ludlow
CT Image Reconstruction

CT Development and the Beatles

Electrical and Musical Industries Records
How is CBCT different from conventional medical CT?

CONVENTIONAL CT
- Fan-beam
- Multiple revolutions
- Unlimited scan volume
- Little scatter; soft tissue detail
- Higher costs
- Higher Dose

CONE BEAM CT
- Cone-beam
- One revolution
- Limited scan volume
- Lots of scatter; hard tissue only
- Lower Costs
- Lower Dose

Representative Fields of View
Fields of View

15.5 by 15.5 cm
What About Radiation Risks?
**CBCT Effective Doses (2007 ICRP) Adults**

*NOTE: Keep in mind that these are always changing and are dependent on multiple factors. These data were based on 167 adult exposure combinations.*

- **Large FOV CBCT scans for all protocols**
  - 46 - 1073 µSv
  - For standard protocols the mean is **212 µSv**

- **Medium FOV CBCT scans**
  - 9 - 560 µSv
  - For standard protocols the mean is **177 µSv**

- **Small FOV CBCT scans**
  - 5 - 652 µSv
  - For standard protocols the mean is **84 µSv**

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**Stochastic vs Deterministic Effects**

**Stochastic effects**
- Effects where the *risk* is *proportional* to the dose
- Implies that there is no threshold
- e.g. cancer, mutations (genetic effects)
- Severity of the effect is independent of the dose

**Deterministic effects**
- Effects where the *severity* is *proportional* to the dose
- Implies a threshold
- e.g. sunburn, *in-utero* birth defects, cataracts, radiation burns
- Dose threshold for birth defects **100-250 mSv** (note effective dose for dental radiographs is in microsieverts)
Reference from the Health Physics Society

- Most diagnostic procedures expose the embryo to less than 50 mSv.¹
- This level of radiation exposure will not increase reproductive risks (either birth defects or miscarriage).
- According to published information, the reported dose of radiation to result in an increased incidence of birth defects or miscarriage is above 200 mSv.
- Note in dentistry we measure dose in **microsieverts**

- Robert Brent, MD, PhD

https://hps.org/hpspublications/articles/pregnancyandradiationexposureinfosheet.html

Radiological Responsibility

Who is responsible for reading CBCT data?
Radiological Responsibility

Someone is

Ethical and Legal Responsibilities

- The entire scanned volume should be examined
- Recognition of abnormal and appropriate referral
- Training is offered by most manufacturers
- There are oral and maxillofacial radiologists that can help
Radiographic Signs: these do not change much for CBCT Imaging

1. Radiographic density
2. Margin characteristics
3. Shape
4. Location and distribution
5. Size
6. Internal architecture
7. Effect on surrounding tissue

Current Applications for Cone Beam CT Imaging
3D vs 2D: General Principle.
1. 2D underestimates bone loss
2. 2D overestimates bone gain
3. 3D is free of angulation artifacts

CBCT for Implant Site Assessment: A major reason for CBCT purchases
A case performed without 3D treatment planning

- 2D periapical radiograph seems to indicate that the implant was successfully placed
- It did osseointegrate (about 90% do)
- ..........but

All is not as it seems....
Furcation lesion induced by failed implant

Immediate post-op | 1 month post-op | 6 weeks post-op

Note that implant was placed in a mucous retention cyst
Implant placement without a CBCT volume

Don’t try this at home….or without a CBCT scan

Recommendations for Implant Imaging

Specifically, the AAOMR recommends that cross-sectional imaging be used for the assessment of all dental implant sites and that CBCT is the imaging method of choice for gaining this information.
One of the best reasons for a CBCT system

Why guided surgery is a good idea

The Plan

The Result
2. Developmental Abnormalities

Impacted teeth

An unusual dental anomaly
A supernumerary attached to the second molar

Lateral incisor did not respond to endodontic therapy
A secondary root was found

Identification of ankylosed teeth
Possible paramolars adjacent to the maxillary third molars?

Paramolar location revealed clearly on CBCT
Two paramolars on the left side revealed clearly on CBCT

Unilateral radiolucency

Cyst or tumor......or something else?
3. Third Molar and Canal Position

In these views the relationship of the mandibular canal and impacted third molar is revealed.
Endodontic and periodontal applications

Root Fracture
Case: Why did the root canal treatment fail?
Root fracture case

The radiolucency extends to the level of the root fracture. This was not seen in the pa view.

Apical periodontitis and cardiovascular disease

Recent research has demonstrated a connection between apical periodontitis and a greater risk for cardiovascular disease

“Apical periodontitis and incident cardiovascular events in the Baltimore Longitudinal Study of Ageing”

Gomes MS, Hugo FN, Hilgert JB, Sant’Ana Filho M, Padilha DMP, Simonsick ED, Ferrucci L, Reynolds MA
International Journal of Endodontics: 2016 49 (4) 334-342

Size of apical lesion at the time of RCT and success rate

Recent research has also shown that the larger the lesion at the time of RCT the greater the risk for failure of the treatment.
Endodontic applications:
Persistent sensitivity on #3

First impression was nasopalatine duct cyst.......CBCT revealed something else
It may be a possible fracture or an odontogenic cyst or tumor.

Periapical lesion? Note that the periodontal ligament space is intact.
Corticated lesion centered over #8 revealed to be a Keratocystic Odontogenic Tumor (aka “OKC”)

First impression was periapical lesion.......CBCT revealed something else But not a nasopalatine duct cyst...no connection to the canal

Patient with mild discomfort

The periapical radiograph revealed very little bone loss
The 3D scan revealed extensive bone loss on the facial and through the furcation to the lingual aspect. An interesting perio/endo case...

A CBCT scan is obtained......and
Widespread bone loss around #2

Routine impacted canine case?
The XG 3D revealed extensive bone loss around the upper right first molar.

Drainage noted on lower right second molar but no radiolucency.
CBCT revealed a large interradicular radiolucency

Periapical lesion “discovered” on #15 with CBCT but not noticed on the panoramic image
Pa lesion “discovered” on #15 with CBCT **not noticed on panoramic image**

CBCT Evaluation of teeth not responding to endodontic therapy (missing MB 2 canal)
CBCT and the TMJ

Osteoarthritic changes in the Temporomandibular Joints

- Normal
- Flattening
- Erosions
- Osteophyte, sclerosis Pseudocyst

- Normal
- Flattening
- Osteophyte
Fracture through the glenoid fossa:
Not seen on the conventional panoramic images

4D Imaging

Pre and post treatment CBCT images can be superimposed and assessed with “mesh” visualization
Extraction site (with pain) seen on a panoramic radiograph
3D Cone beam CT Views

Mandibular fracture with osteomyelitis
Pathological Findings

Sinus Disease
• 50-year old female
• Pain in lower right thought to be associated with lower second molar
• Q: Where is the lesion?
Recurrent Keratocystic Odontogenic Tumor in Left Maxilla...difficult to tell on panoramic radiograph

Confirmed Recurrent Keratocystic Odontogenic Tumor: CBCT MPR views
- 12-year old female
- Slight swelling in the upper left: maxillary right premolars are displaced

Calcified Lymph Node: Deep cervical chain
Calcified Carotid Atheroma: Common Location
C-3 or C-4

Bilateral calcified carotid atheromas
BRONJ (bisphosphonate-related osteonecrosis of the jaws)

CBCT and panoramic radiography

These data demonstrate a significant advantage of CBCT over panoramic radiography for surgeons with regard to therapeutic planning for BRONJ.

Surgical evaluation of panoramic radiography and cone beam computed tomography for therapy planning of bisphosphonate-related osteonecrosis of the jaws

Recurrent Keratocystic Odontogenic Tumor in Left Maxilla...difficult to tell on panoramic radiograph
Confirmed Recurrent Keratocystic Odontogenic Tumor: CBCT MPR views

Unusual finding at an implant site
It turned out to be an oro-antral fistula from a previous extraction.

Calcified Carotid Atheroma: Common Location C-3 or C-4
Bilateral calcified carotid atheromas

Airway Assessment, Obstructive Sleep Apnea
Sleep Apnea: Airway analysis using CBCT

Using SiCAT Air

TMJ Function can be taken into account when designing the sleep apnea appliance

Two piece adjustable therapeutic appliance can be fabricated
Sleep appliance workflow

CBCT Scan → Airway and TMJ function analysis → Functional sleep appliance

Orthodontic applications

Creation of lateral and PA cephalometric radiographs from Galileos cone beam data
Impactions

- Location and orientation
- Morphology
- Relationships
  - Other teeth
  - Nasal fossa, maxillary sinus
- Path of alignment

Facially placed canine
Estimation of time to orthodontically correct was nine months
The panoramic image suggests that it may be possible to do so.

The CBCT volume suggests differently.
Example case using 4D Imaging

Preoperative CBCT @ T1
Treatment time until T2: 9 months;
Mandibular condyles demonstrate osteoarthritic changes
The Future of Segmentation and 3D Printing

Segmentation from a patient’s CT scan could be used to print out a patient specific anatomical scaffold and then use stem cells to generate vasculature and bone (1,2).

Human TMJ engineered grown in vitro Gordana Vunjak-Novakovic, Ph.D


Andreas Herrmann of the University of Groningen in the Netherlands and his colleagues have developed an antimicrobial plastic, allowing them to 3D print teeth that also kill bacteria.” NewScientist.com
Segmentation and subtraction for early detection of periodontal bone loss

2D does not show bone loss between #19, 18  3D shows the loss in red

Cone-Beam Computed Tomography Volume Registration for the Analysis of Periodontal Bone Changes

Green PT\textsuperscript{1}, Mol A\textsuperscript{2}, Tyndall D\textsuperscript{3}, Moretti A\textsuperscript{2}, Kohltfarber H\textsuperscript{3}

\textsuperscript{1}Department of Diagnostic Sciences and \textsuperscript{2}Department of Periodontology, University of North Carolina at Chapel Hill School of Dentistry, Chapel Hill, NC
\textsuperscript{3}Department of Radiology and Imaging Sciences, Loma Linda University School of Dentistry, Loma Linda, CA

CBCT and caries detection

The XG3D showed significantly better cavitation detection sensitivity (0.62) than the other modalities (0.48–0.57).

…. The CBCT with artefact reduction demonstrated promising sensitivity/specificity for caries detection, somewhat improved depth accuracy and substantially improved cavitation detection.
What about dentoalveolar disease diagnosis?

- **Caries?**....conditional (still need intraoral)
  - Interproximal
  - Occlusal
  - Can detect cavitation better
- **Periodontal bone architecture?**...yes

CBCT was shown to provide financial cost benefits and time-savings for furcation-involved maxillary molars, especially for more complex treatments involving maxillary second molars. From Walter C, Schmidt JC, Dula K, Sculean A. Cone beam computed tomography (CBCT) for diagnosis and treatment planning in periodontology: A systematic review. Quintessence Int. 2016;47(1):25-37.

- **Endodontic applications?**...yes
  - Periapical lesions
  - Root fractures
  - Unfilled thin canals
  - Non-healing root canals treatment
- **Panoramic replacement?**..yes

Future Developments in 3D Imaging

Future developments in CBCT
- Reduced costs and dose
- Customized fields of view
- More efficient flat panel detectors
- Automatic Exposure Control
- Improved software and software interfaces

Methods other than CBCT
- **Tomosynthesis and carbon nanotube x-ray sources**
Digital Tomosynthesis

Current research at the University of North Carolina School of Dentistry Radiology Group and the Department of Physics and Astronomy

- A Collaborative Effort Involving Faculty and Graduate students
- Dr. Otto Zhou: Department of Physics
- Dr. Andre Mol: Department of Diagnostic Sciences
- Dr. Enrique Platin: Department of Diagnostic Sciences
- Dr. Lars Gaalaas: Radiology Resident


3D Intraoral Radiography: Tomosynthesis Theory


Aperture-Determined Continuum of Radiographic Options

Circular Distribution of Point Sources

Respective Projections (shown distributed on laterally shifted screens)

Shift and add screens so disks superimpose

Shift and add screens so squares superimpose

Increasing Equivalent Aperture

Increasing Projection Angle (degrees)
3D Intraoral Radiography

IMAGES – Tooth Anatomy

Standard 2D periapical

Tomosynthesis

3D Intraoral Radiography

IMAGES – OPENING CONTACTS

Standard 2D periapical

Tomosynthesis
3D Intraoral Radiography

Advanced reconstruction techniques maximize image quality with minimum dose

Storage Phosphor

Digital Tomosynthesis

Today’s Digital Dentistry is the ...
In the future 3D won’t be the diving board into dentistry

...it will be the pool

Remember: A sad tooth makes a sad patient and happy tooth makes a happy patient