Rethinking Risk and Benefit in Dental and Maxillofacial Imaging – Dose matters

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Background

- Radiation risk is frequently front page news recent example - Japan's Fukushima Nuclear Plant – following an Earthquake & Tsunami - 3/11/2011

- Our patients are concerned and often confused about risk associated with different exposures
- We can help by being well informed

Learning objectives:

- Identify the risks from ionizing radiation
- Describe options in CBCT units which affect dose
- Discuss importance of matching options to objectives of imaging
- Explore ways to reduce patient risk
- Explain how to talk about risks with patients

What are the risks?

Gamma bomb exposure

Radioactive spider bite

Stochastic vs Deterministic Effects

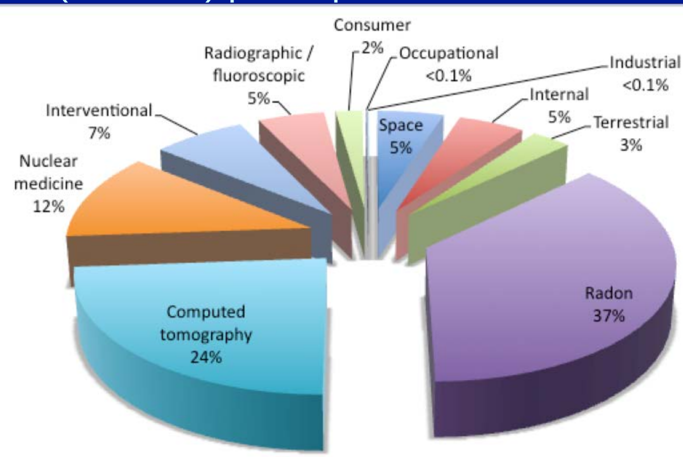
Stochastic effects

- A linear-no-threshold hypothesis of x ray risk fits most data for cancer development but is extrapolated to doses below
  - 100 mGy (adult exposure)
  - 10-20 mG (fetal exposure)
- No expressions of germ cell mutations have been observed in human populations

Deterministic effects (Non stochastic effects)

- Threshold for
  - in-utero birth defects
    100-250 mSv
  - Cataracts
    2-5 Gy
  - radiation burns
    3 Gy (reddening)
  - radiation mucositis
    30+ Gy
    (therapy typically 60-80 Gy)

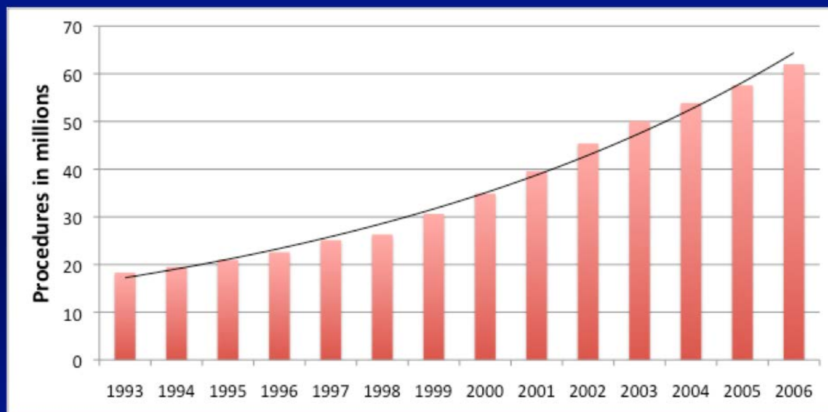
Source contribution to total effective dose (6.2 mSv) per capita in the US - 2006



Source	%	µSv
Ubiquitous background	50	3100
Medical	48	2976
Consumer	2	124

From NCRP REPORT No. 160, 2009

CT procedures per year - US

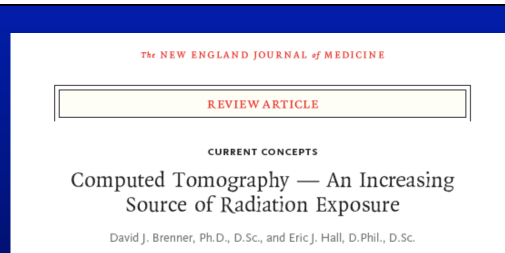


Annual growth of >10% per year

From NCRP REPORT No. 160, 2009

Background

NEJM 11-29-2007
Computed Tomography – An Increasing Source of Radiation Exposure
David Brenner, et al.



The NEW ENGLAND JOURNAL of MEDICINE

REVIEW ARTICLE

CURRENT CONCEPTS

Computed Tomography — An Increasing Source of Radiation Exposure

David J. Brenner, Ph.D., D.Sc., and Eric J. Hall, D.Phil., D.Sc.

- From 1.5% to 2% of all cancers in the United States may be attributable to the radiation from CT studies

Background: CT & CBCT Effective Doses (2007 ICRP)

- Large FOV CBCT scans
  68 – 1073 μSv
- Medium FOV CBCT scans
  69 – 560 μSv
- Small FOV CBCT scans
  189 – 652 μSv
- Medium FOV MDCT scans
  534 – 860 μSv

Ludlow JB, Ivanovic M. Comparative Dosimetry of Dental CBCT Devices and 64 row CT for Oral and Maxillofacial Radiology Oral Surg Oral Med Oral Pathol Oral Radiol Endodont 2008;106:930-938

Dose and Risk Estimation

- 1990 Recommendations of the International Commission on Radiological Protection
  - Effective dose calculation (Sv)
  - Summed doses to weighted organs & tissues known to be most susceptible to radiation damage
  - Mathematical expression: $E = \sum w_T \times H_T$

ICRP 2007 Recommendations

- 2007 Recommendations of the ICRP
  - Reassessment of Risk based on cancer incidence data from the Life Span Study of Japanese atomic bomb survivors
  - Revision of list of tissues
  - Adjustment of weights

Effective dose: $E = \sum w_T \times H_T$

Tissue weighting factors for calculation of Effective Dose – Comparison of 1990 and 2007 ICRP Recommendations

Tissue	*1990*[1] w_T	*2007*[2] w_T
Bone marrow	0.12	0.12
Breast	0.05	0.12
Colon	0.12	0.12
Lung	0.12	0.12
Stomach	0.12	0.12
Bladder	0.05	0.04
Esophagus	0.05	0.04
Gonads	0.20	0.08
Liver	0.05	0.04
Thyroid	0.05	0.04
Bone surface	0.01	0.01
Brain	remainder	0.01
Salivary glands	-	0.01
Skin	0.01	0.01
Remainder Tissues	0.05*	0.12†

* Adrenals, brain, upper large intestine, small intestine, kidney, muscle, pancreas, spleen, thymus, uterus

† Adrenals, Extrathoracic region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral Mucosa, Pancreas, Prostate, Small Intestine, Spleen, Thymus, and Uterus/cervix.

1. 1990 Recommendations of the ICRP. Publication 60. Ann ICRP 1991; 21: 1-201
2. 2007 Recommendations of the ICRP. Publication 103. Ann ICRP 2007; 37: 1-332

Summary of changes ICRP 1990 – 2007

- 4 additional weighted tissues
- 10% increase in weight of tissues located in maxillofacial area
- 28% increase in weight adjusted for distribution of tissues in maxillofacial area
  - 3 of the newly weighted tissues are entirely within the maxillofacial area: oral mucosa, extrathoracic region, and salivary glands

Effective Dose and Detriment (Risk) Calculation

- Detriment includes the weighted probabilities
  - fatal and non-fatal cancer
  - relative length of life lost
  - hereditary effects
- Cancer risk alone may be used for the 2007 ICRP risk estimates for dental radiography

Cancer Risk = E(Sv) x 0.055

Cancer risks for children are 2 or more times greater than for adults

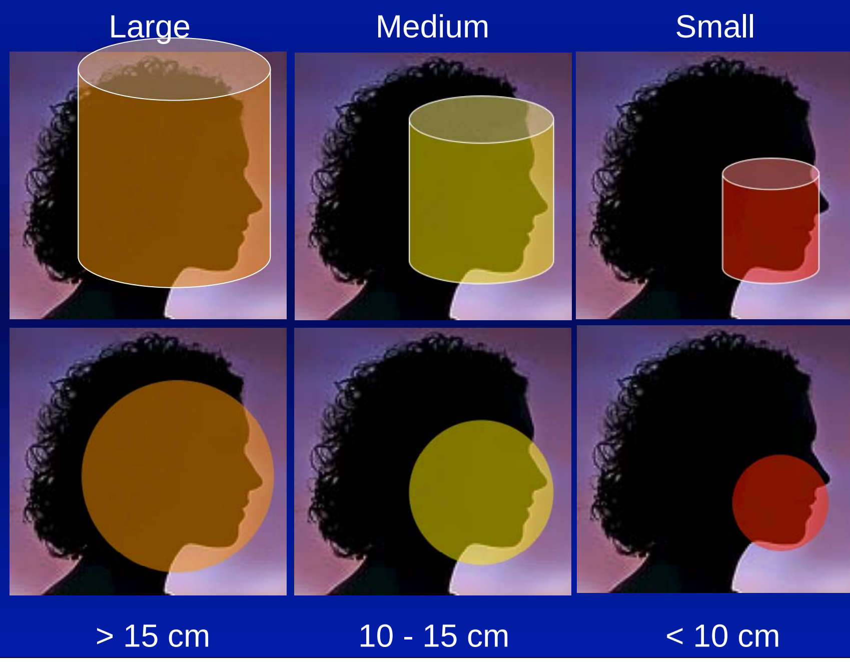
How do we measure dose?

- Effective Dose calculation preferred
- Human phantom studies
  - Expensive
- Simple acrylic phantoms – $CTDI_{VOL}$
  - Easy but inaccurate
- Monte Carlo modeling
  - Promising but model and software dependent
- Dose area Product x coefficient for head/neck exposure
  - Easy but inaccurate

RANDO

Level 6

Fields of view



Dental CBCT units available in the US

Small FOV

Unit Name	Company
Picasso Trio	VaTech
Accuitomo 80	J. Morita
Veraview-epocs 3D	J. Morita
9000 3D•	Kodak
Skyview 6" FOV	My-Ray
Promax CBCT	Planmeca
Orion	Ritter Imaging
Suni 3D	Suni
Prexion	TeraRecon
Auge Zio	Asahi Roentgen
OP 300 3D	Intrumentarium
Orthophos XG 3D	Sirona
9300	Kodak

Medium FOV

Unit Name	Company
NewTom Vgi	AFP Imaging
Reve 3D	VaTech
CB-500	Gendex
9500 3D med FOV	Kodak
Accuitomo 170	J. Morita
Skyview 9" FOV	My-Ray
Scanora 3D med FOV	Soredex
Galileos Comfort	Sirona
Galileos Compact	Sirona

Large FOV

Unit Name	Company
NewTom 3G	AFP Imaging
Alphard 3030	Belmont / Asahi
Master 3DS	VaTech
i-CAT Next Gen	Imaging Sciences Int
Ilumina	Imtech / 3M
9500 3D large FOV	Kodak
Promax 3D Max	Planmeca
NewTom 9000*	QR Verona
i-CAT Classic*	Imaging Sciences Int
CB Mercuray*	Hitachi Medical

* No longer manufactured

15 manufacturers – 32 units since 2000
(as many as 40 unit variations world-wide)

Field of view

- Note that detector sizes need to be larger than the FOV due to image magnification
- Image Intensifiers produce spherical FOVs
- Flat panels produce cylendrical FOVs
- Cylinders typically provide larger useful FOVs than spheres. Cylinder height ≠ Sphere diameter

Large FOV Units ex: Kodak 9500

- 60 - 90 kV
- 2 - 15 mA
- Pulsed
- Flat Panel
  large FOV version
  (18 cm x 20 cm)

Large FOV CBCT Dose Calculations (Based on ICRP 2007 Recommendations)

Large FOV Techniques	Effective Dose in µSv	Dose as multiple of average† Panoramic Dose	Days of per capita back-ground*	Probability of x in a million fatal cancer‡
NewTom3G – Large FOV	68	4	8	4
CB Mercuray – “Facial” FOV (maximum quality)	1073	67	131	59
CB Mercuray – “Facial” FOV (standard quality)	569	35	69	31
i-CAT Classic Extended Field	70	4	8	4
Next Generation i-CAT Portrait mode	74	5	9	4
Kodak 9500 21 cm x 18 cm (medium adult)	163	10	20	9
Iluma – (standard)	98	6	12	5
Iluma – (ultra)	498	31	61	27
SCANORA 3D dual scan	125	8	15	7

*3,000 µSv, NCRP Report No. 145, 2003 †Average of 5 units ‡dose in µSv x 5.5×10^{-2}

7.7X

Medium FOV units ex: Kodak 9500

- 60 - 90 kV
- 2 - 15 mA
- Pulsed
- Flat Panel medium FOV version (9 cm x 15 cm)

Medium FOV CBCT Dose Calculations (Based on ICRP 2007 Recommendations)

Medium FOV Techniques	Effective Dose in µSv	Dose as multiple of average† Panoramic Dose	Days of per capita back-ground*	Probability of x in a million fatal cancer‡
CB Mercuray – “Panoramic” FOV	560	35	68	30.8
Classic i-CAT – Standard scan	69	4	8	3.8
Next Generation i-CAT Landscape mode	87	5	11	4.8
Galileos – (default exposure)	70	4	9	3.9
SCANORA 3D – large FOV	76	5	9	4.2
Newtom VG	109	7	13	6.0
CB-500 – extended diameter scan	89	6	11	4.9
Kodak 9500 9 cm x 15 cm (medium adult)	98	6	12	5
Somaton 64 MDCT	860	53	105	47.3
Somaton 64 MDCT w/ CARE Dose 4D	534	33	65	29.4

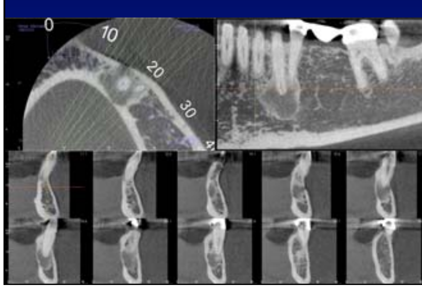
≈

12X

*3,000 µSv, NCRP Report No. 145, 2003 †Average of 5 units ‡dose in µSv x $5.5x10^{-2}$

Small FOV Units ex: Kodak 9000 3D

- Panoramic unit
- Sensor switches from pan to 3D electronically
- Volume size: 3.7 cm x 5 cm
- Voxel size 67 µm
- CMOS w/ optical fiber
- 60 - 90 kV
- 2 - 15 mA
- Pulsed
- 16 bit



Small FOV CBCT Dose Calculations
(Based on ICRP 2007 Recommendations)

Small FOV Techniques	Effective Dose in µSv	Dose as multiple of average† Panoramic Dose	Days of per capita back-ground*	Probability of x in a million fatal cancer‡
CB Mercuray – "I" FOV (maxillary)	407	25	50	22
CB-500 8 cm x 8 cm Standard 0.3 or 0.4 mm	115	7	14	6
Orthophos XG 3D – 8 cm x 8 cm (medium adult)	64	4	7	4
Promax 3D – 8 cm x 8 cm (medium adult)	216	30	59	27
PreXion 3D – 8 cm x 8 cm (standard exposure)	189	12	23	10
OP300 – 8 cm x 6 cm FOV Standard dose & res	66	4	8	4
SCANORA 3D – 6 cm x 6 cm (avg sextant)	38	3	6	3
Kodak 9000 – 4 cm x 5 cm (avg sextant)	21	1	2	1

6.4X

*3,000 µSv, NCRP Report No. 145, 2003; †Average of 5 units; ‡dose in µSv x 5.5×10^{-2}

Kodak 9000 effective dose*

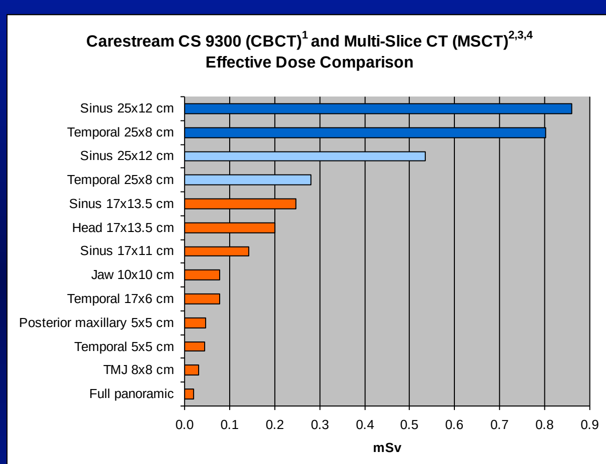
Technique	Effective Dose in µSv	Dose as multiple of average Panoramic Dose†	Days of per capita background	Probability of x in a million fatal cancer
Max Right Posterior	10	0.6	1	0.5
Max Anterior	5	0.3	1	0.3
Maxillary stitched arch	25	1.6	3	1.4
Mand Left Posterior	38	2.4	5	2.1
Mand Anterior	22	1.3	3	1.2
Mandibular stitched arch	98	6.1	12	5.4

* ICRP 2007 calculation
† Average of 5 units: Sirona - Orthophos XG, Planmeca - ProMax, Kodak - 9000, SCANORA 3D, Instrumentarium - OP 200 VT

Variable FOV units ex: Kodak 9300

- 7 FOVs + pan
- Voxel size 90-500 µ
- Scan time 12-28 sec

Effective Dose Comparison of Carestream CS 9300[1] Cone Beam CT (CBCT) and Multi-Slice CT (MSCT)[2,3,4] Systems



[1] Ludlow JB. Effective doses of CS 9300 cone beam CT system conducted in June 2011. ICRP 2007 tissue weights used. Absorbed dose calculated for bone marrow, thyroid, esophagus, skin, bone surface, salivary glands, brain, lymphatic nodes, extrathoracic airway, muscle, oral mucosa.

[2] Faccioli et al. Radiation dose saving through the use of cone beam CT in hearing impaired patients. Radiol Med. 114: 1308-1319, 2009.

[3] Niu et al. Radiation dose to the lens using different temporal bone CT scanning protocols. AJNR 31: 226-229, 2010.

[4] Ludlow JB, Ivanovic M. Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 106: 106-114, 2008.

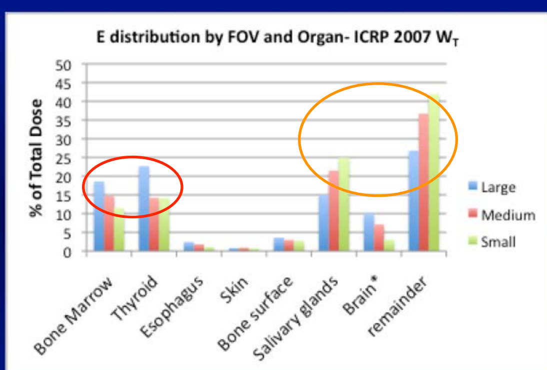
Panoramic Replacement?

- CBCT is inferior to conventional panoramic imaging for
  - Caries interpretation
    - False positive diagnoses
    - Radiation dose
  - Periodontal assessment
    - Metal artifact effects
- Some CBCT units have a conventional panoramic option

Kodak 9000 3D

Affect of layer thickness on CT panoramic image

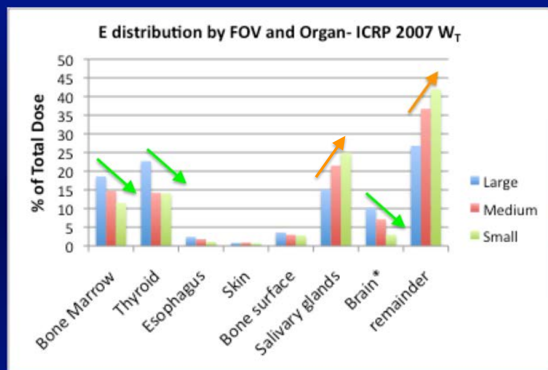
Effective dose distribution in maxillofacial imaging



40% of total E dose is from bone marrow & thyroid exposure

55% of total E dose is from salivary gland and remainder exposure

Effect of Field of View on dose distribution



Dose proportion <u>decreases</u> with decreasing FOV

Dose proportion <u>increases</u> with decreasing FOV

Example of use of field restriction to reduce dose

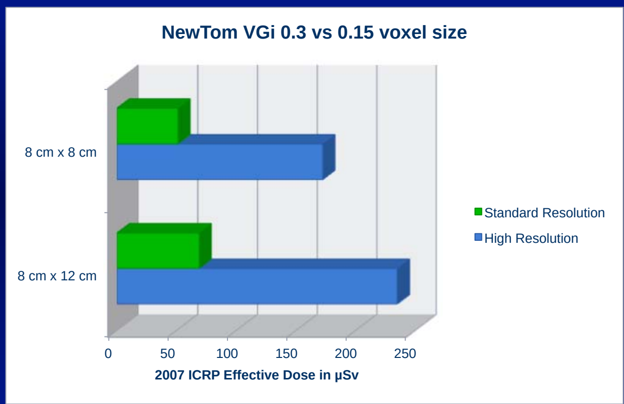
Orthophos XG 3D

Region	setting	Small Adult Dose in μSv	% change from standard centered view
Central	Full 8 cm x 8 cm	64	0%
TMJ	Full 8 cm x 8 cm	56	13%
	Collimated 8 cm x 6 cm	20	69%

Other dose associated technical factors

- Pulsed x-ray source
- Scintillator coating
  - Cesium Iodide
  - Gadolinium Oxy-bromide
- Detector design
  - Image intensifier / Sphere
  - Flat panel / Cylinder
- Resolution?

Spatial Resolution and Dose



Average of 70% reduction in dose from use of the standard resolution option

Additional dose associated technical factors

- kVp
- Added filtration

Kodak 9500 3D
Effect of added filtration and increased kV

Effective dose ICRP 2007 µSv	pre-production configuration	added filtration configuration	% reduction in dose
Large FOV (18 x 21 cm)			
Small adult		93	
Medium adult	282	163	42%
Large adult	339	260	23%
Medium FOV (9 x 15 cm)			
Small adult	171	76	56%
Medium adult	200	98	51%
Large adult		166	
avg reduction			43%

The most significant dose associated factor

patient selection criteria

ADA/FDA Selection Criteria

- THE SELECTION OF PATIENTS FOR DENTAL RADIOGRAPHIC EXAMINATIONS
  - Originally developed 1987
  - Most recently revised 2004

http://www.ada.org/prof/resources/topics/topics_radiography_examinations.pdf

USE OF CONE-BEAM COMPUTED TOMOGRAPHY IN ENDODONTICS
Joint Position Statement of the American Association of Endodontists and the American Academy of Oral and Maxillofacial Radiology

- What patients are most likely to benefit?
  - Difficult diagnosis
    - Equivocal signs / symptoms
    - Superimposed structure
    - Internal / external resorbtion
  - Unusual morphology
    - Root or canal numbers
    - Root curvature
  - Intraoperative complication
  - Refractory to conventional treatment
  - Pre-surgical
    - Proximity and relationship to nerve canal or sinus
  - Pathology of non-endodontic origin suspected

Joint Position Statement of the
American Association of Orthodontists and the
American Academy of Oral and Maxillofacial Radiology

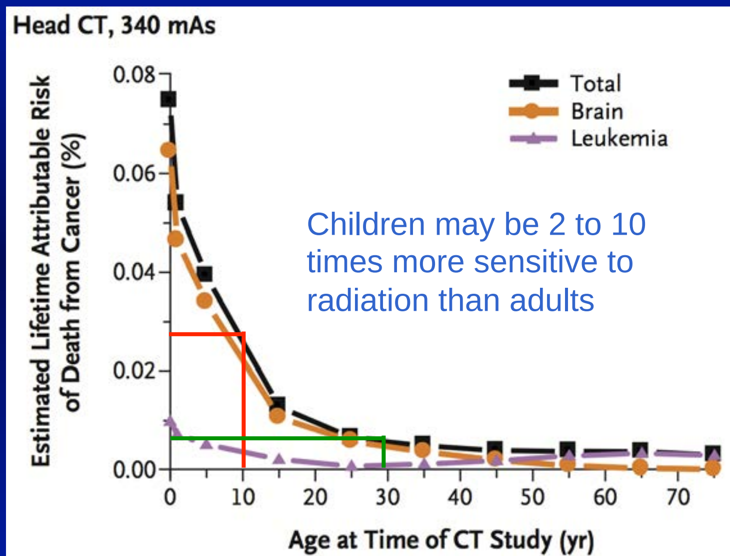
THE USE OF RADIOLOGY RADIOGRAPHIC EXAMINATIONS IN ORTHODONTICS

currently under development

children may be two to ten times or more sensitive to radiation carcinogenesis than mature adults*

*Smith-Bindman R, et al. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. Arch Intern Med. 2009

Risk differences due to age



Brenner D. 2007 NEJM

Risk vs Benefit

Risks

- Dollars
- Dose
- ALARA

Benefits?

Explaining Risk to patients

Do

- Provide an estimate of cancer risk (this should be adjusted for children)
- Compare with Ubiquitous Background Dose
- Compare with alternative exam equivalence (pan or FMX)
- Compare with Commonly encountered risks of life

Don't

- Say it's nothing, it's unimportant, or similar dismissive statements.
- Use analogy of a day at the beach

Comparable Risk Table

Situation of a one in million risk of dying

Risk	Quantity	Nature
Life		
Living in stone building	2 Months	Natural Radioactivity
Living in Denver, CO	2 weeks	Cosmic Radiation
Travel		
Canoe	6 minutes	Accident
Bicycle	10 miles	Accident
Car	300 miles	Accident
Airplane	1000 miles	Accident
Airplane	6000 miles	Cosmic Radiation
Work		
Typical Factory	10 days	Accident
Miscellaneous		
Smoking	1.4 cigarettes	Cardiovascular Disease, Cancer
Wine	500 cc	Cirrhosis

Explaining Benefit to the patients and parents

- Accurate diagnosis =
  - Reduced cost
  - reduced time
  - reduced discomfort
  - Better outcomes
  - Fewer complications

Risk Example

- The effective dose from a Kodak 9000 medium adult panoramic scan is about 15 µSv
- The effective dose from average Kodak 9000 4 x 5 cm jaw sextant is about 21 µSv
- This dose from these combined examinations is equivalent to about 4 days of average naturally occurring background dose
- The added risk of cancer from this dose is about 2 in 1,000,000 exposures. Keep in mind the population risk of lifetime fatal cancer is 1 in 5.

In accordance with the AGD, I declare that I have received expense reimbursement and honoraria from Carestream Dental for dosimetry studies performed on Carestream CBCT units discussed in this presentation and have received expense reimbursement and an honorarium for this talk.

Course Code

4440-031115-58

1 - CE unit

Presentation slides available at:
http://www.unc.edu/~jbl

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