Reducing Radiation Exposure in Children

Brent Colby, Radiation Physicist

Waldemar Storm, MD PICU

Deb Hanson, RN, Peds CCRN

Objectives

- Compare various radiation exposures.
- Discuss the risks of radiation exposure.
- Discuss use of CT Protocols.
- Provide education and resources for providers, radiologists, radiology technicians, nursing and parents.

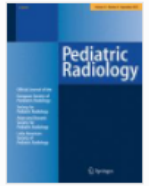
No Disclosures

- Brent Colby

Pediatric radiation safety

For starters…

- Radiation no doubt saves countless lives and reduces suffering
- The technology continues to evolve
  - Generally good
  - Buying new technology is occasionally helpful
  - Not training people on new (or existing) technology can be very harmful
- There is no free lunch
  - Risks and benefits
  - Physicists tend to dwell on risks



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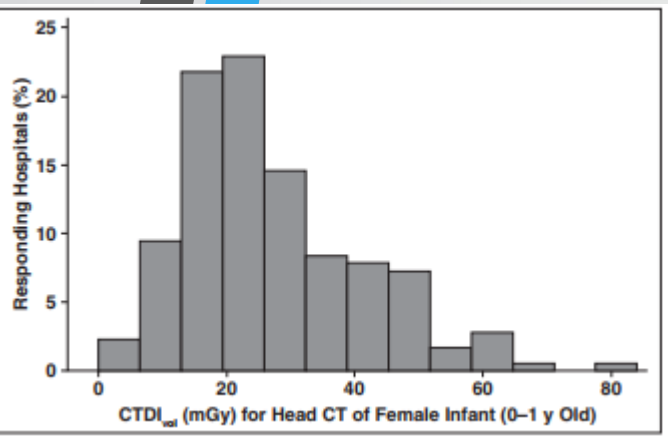
Radiation dose reduction in pediatric CT

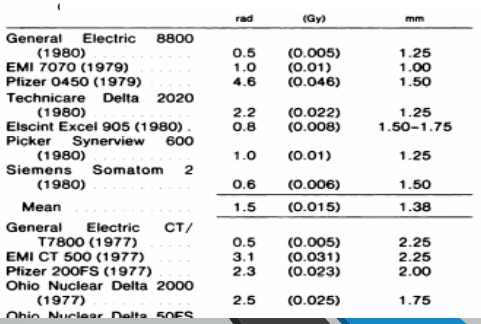
Authors | Authors and affiliations

A. E. Robinson, E. P. Hill, M. D. Harpen

Originals
Accepted: 11 June 1985



Kanal. National Survey on Ped Head. AJR 2015



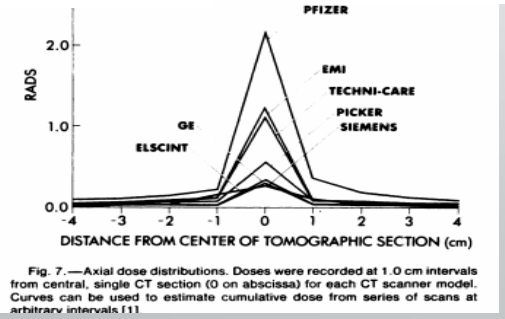


Fig. 7.—Axial dose distributions. Doses were recorded at 1.0 cm intervals from central, single CT section (0 on abscissa) for each CT scanner model. Curves can be used to estimate cumulative dose from series of scans at arbitrary intervals [1].

Brasch. CT scanning in children. AJR 1981

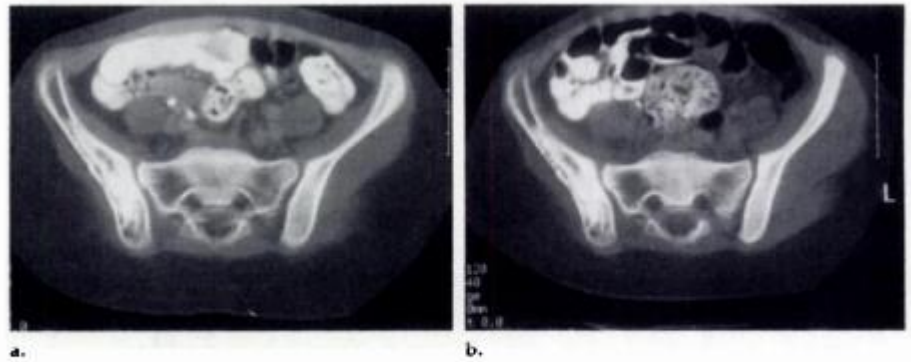
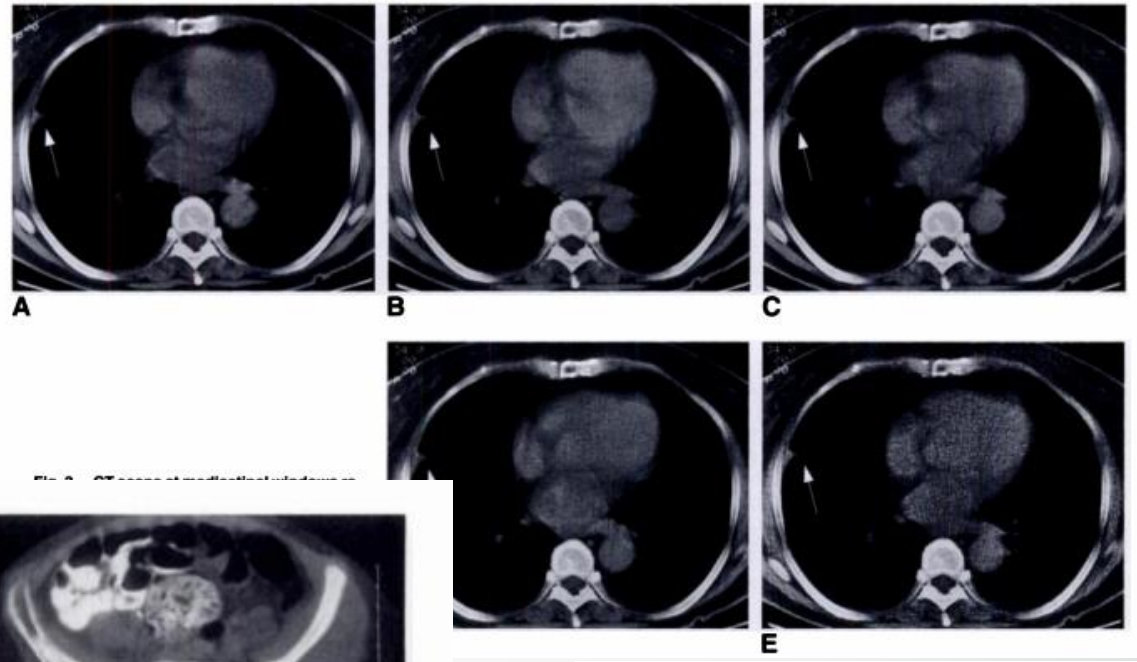


Figure 2. **(a)** Pelvic CT scan obtained at 240 mAs in a 9-year-old child. The scan received a grade of 4 in response to question 8 (assessing the final evaluation of the pelvis and the ability to reach a conclusion). **(b)** Scan obtained in the same child at 80 mAs. This scan also received a grade of 4 in response to question 8.

Kamel. Radiation dose reduction. Radiology 1994



Mayo. CT of the chest. AJR 1995

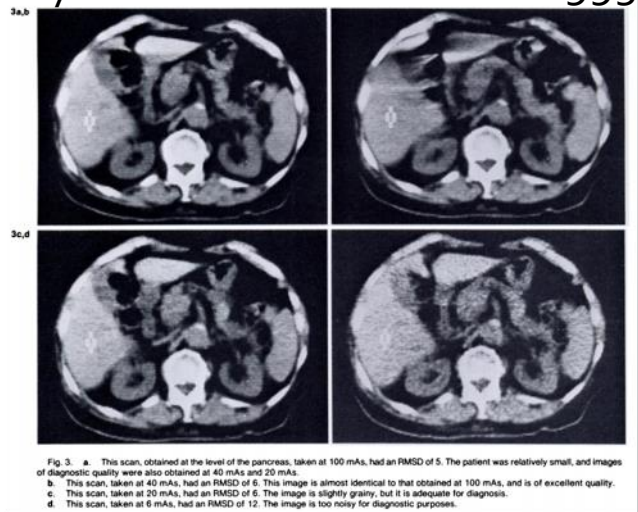


Fig. 3. a. This scan, obtained at the level of the pancreas, taken at 100 mAs, had an RMSD of 5. The patient was relatively small, and images of diagnostic quality were also obtained at 40 mAs and 20 mAs.
b. This scan, taken at 40 mAs, had an RMSD of 6. This image is almost identical to that obtained at 100 mAs, and is of excellent quality.
c. This scan, taken at 20 mAs, had an RMSD of 6. The image is slightly grainy, but it is adequate for diagnosis.
d. This scan, taken at 6 mAs, had an RMSD of 12. The image is too noisy for diagnostic purposes.

Haaga. The Effect of mAs. Radiology 1981

Google University: Pediatric CT radiation dose 3/22/2018

- 554,000 results
- Pediatric CT radiation dose reduction: 447,000 results
- Scholar.google.com, Pediatric CT radiation dose: 190,000 results
- Scholar.google.com Pediatric CT radiation dose reduction: 96,000 results

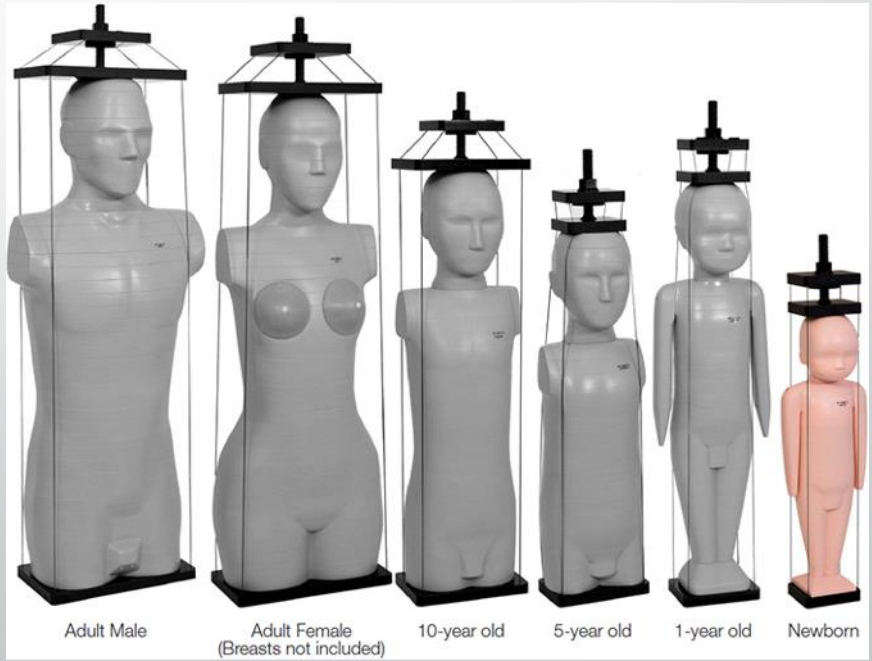
CT radiation dose reduction (more inclusive)

4,600,000 results

Radiation dose reduction: 4,930,000 results

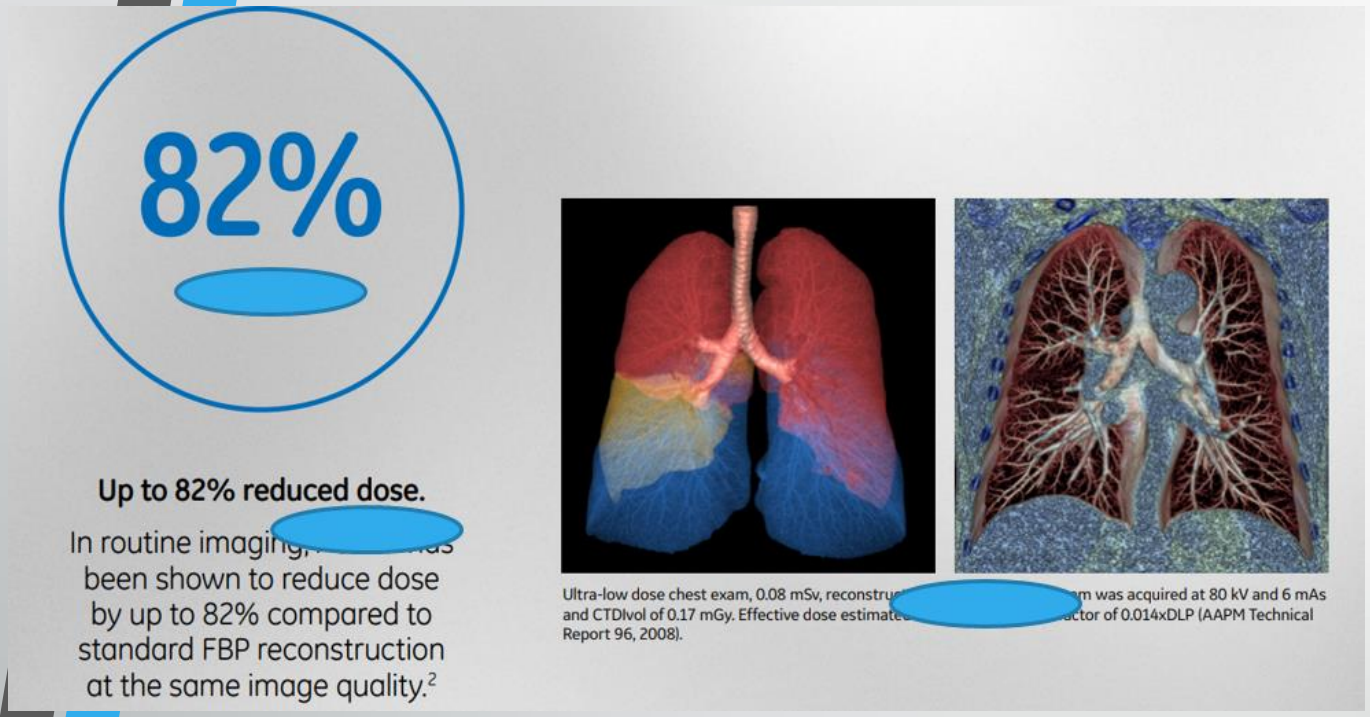
Pediatric radiation dose reduction: 1,260,000 results

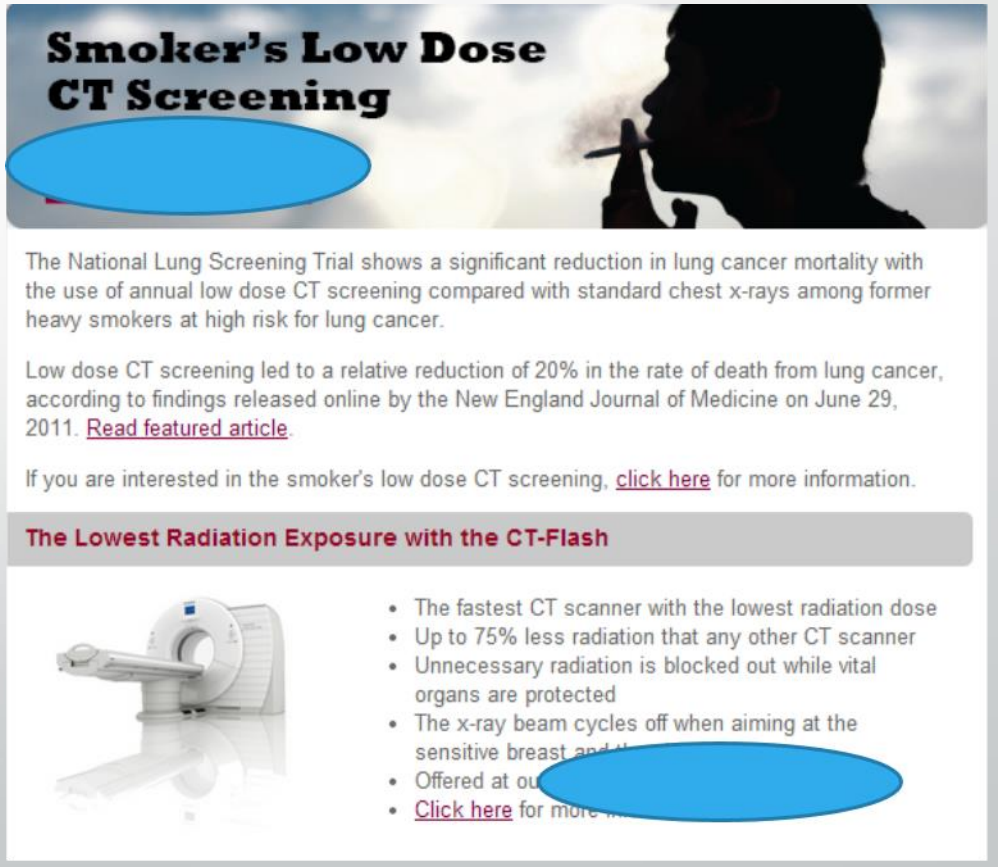
How a marketer thinks of this



How a Physicist thinks of this

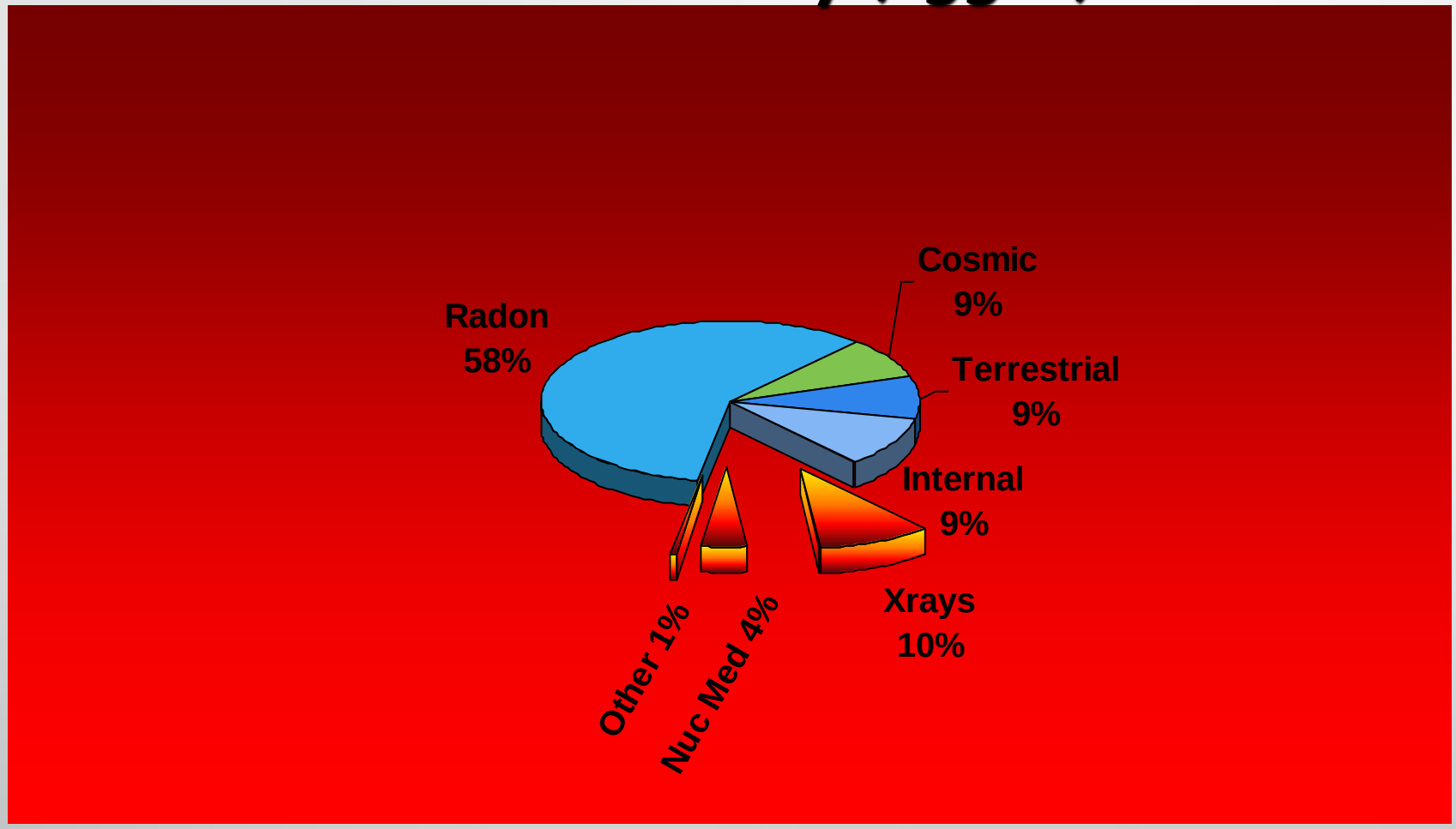
Not all information is good





We will start with some good information

Non-smoking midwestern US resident dose summary (1990s)



David J. Brenner[1]
Carl D. Elliston[1]
Eric J. Hall[1]
Walter E. Berdon[2]

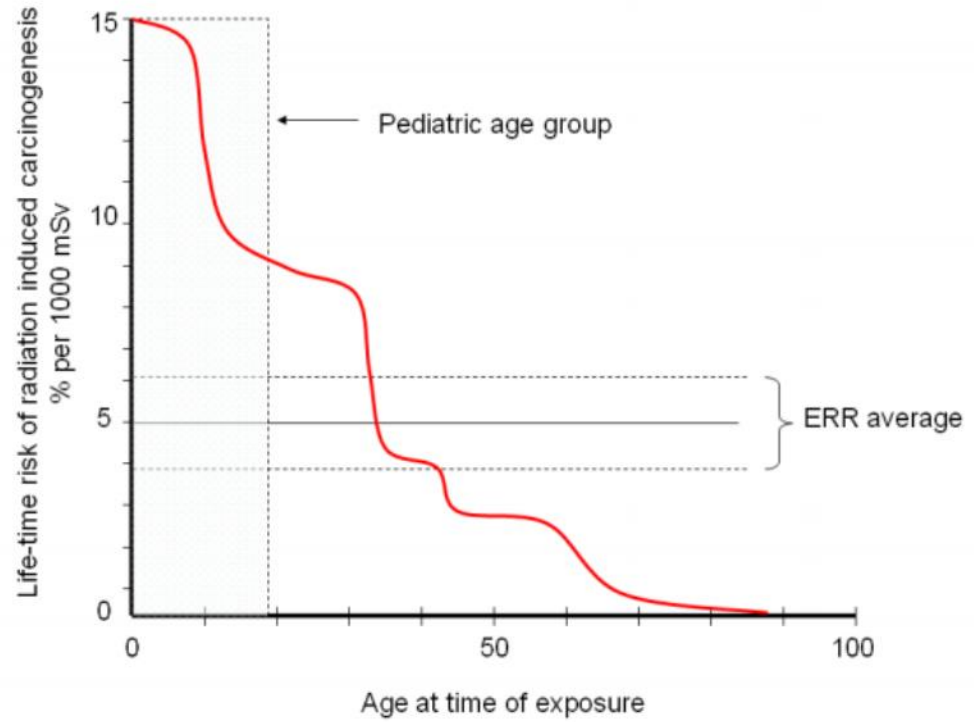


Figure 2 Adapted from ICRP Publication 60 (1990)

So how did we respond to the news?

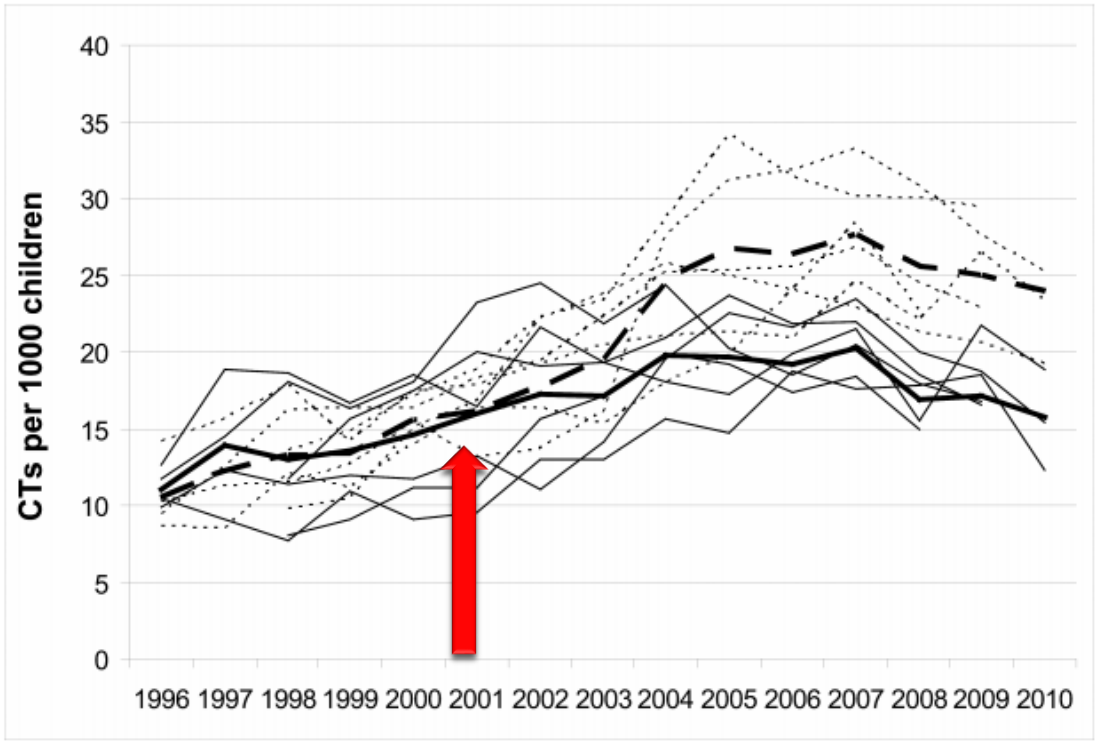
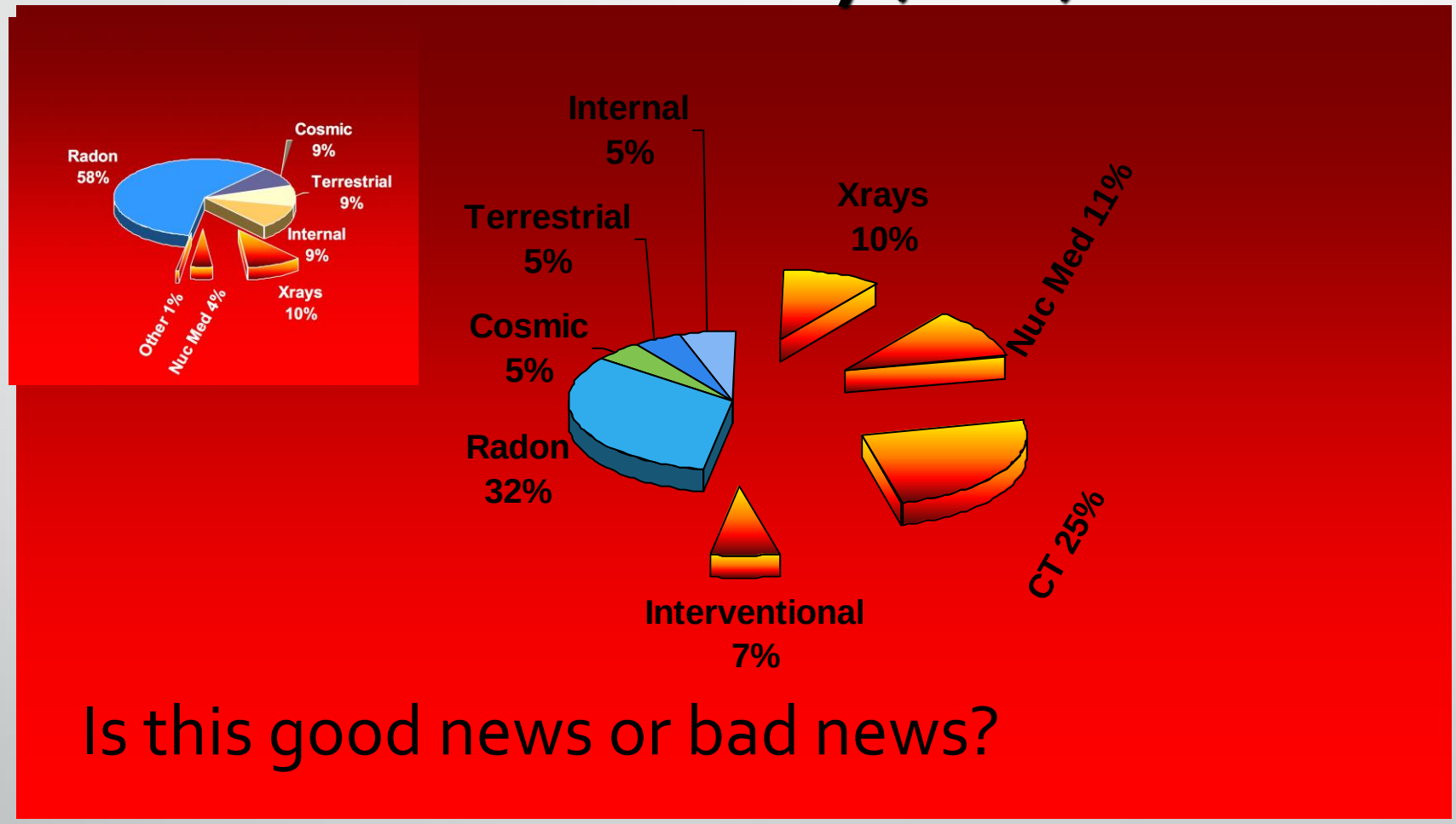


Figure 1. Trends in computed tomography (CT) use over time, by age group and health care system
Solid lines show rates for children <5 years; dashed lines show rates for children aged 5-14 years. Thin lines show rates at each health system and thick lines show the average rates across health systems.

Miglioretti, et al. Pediatric CT and associated radiation exposure and cancer risk. JAMA Pediatr 2013

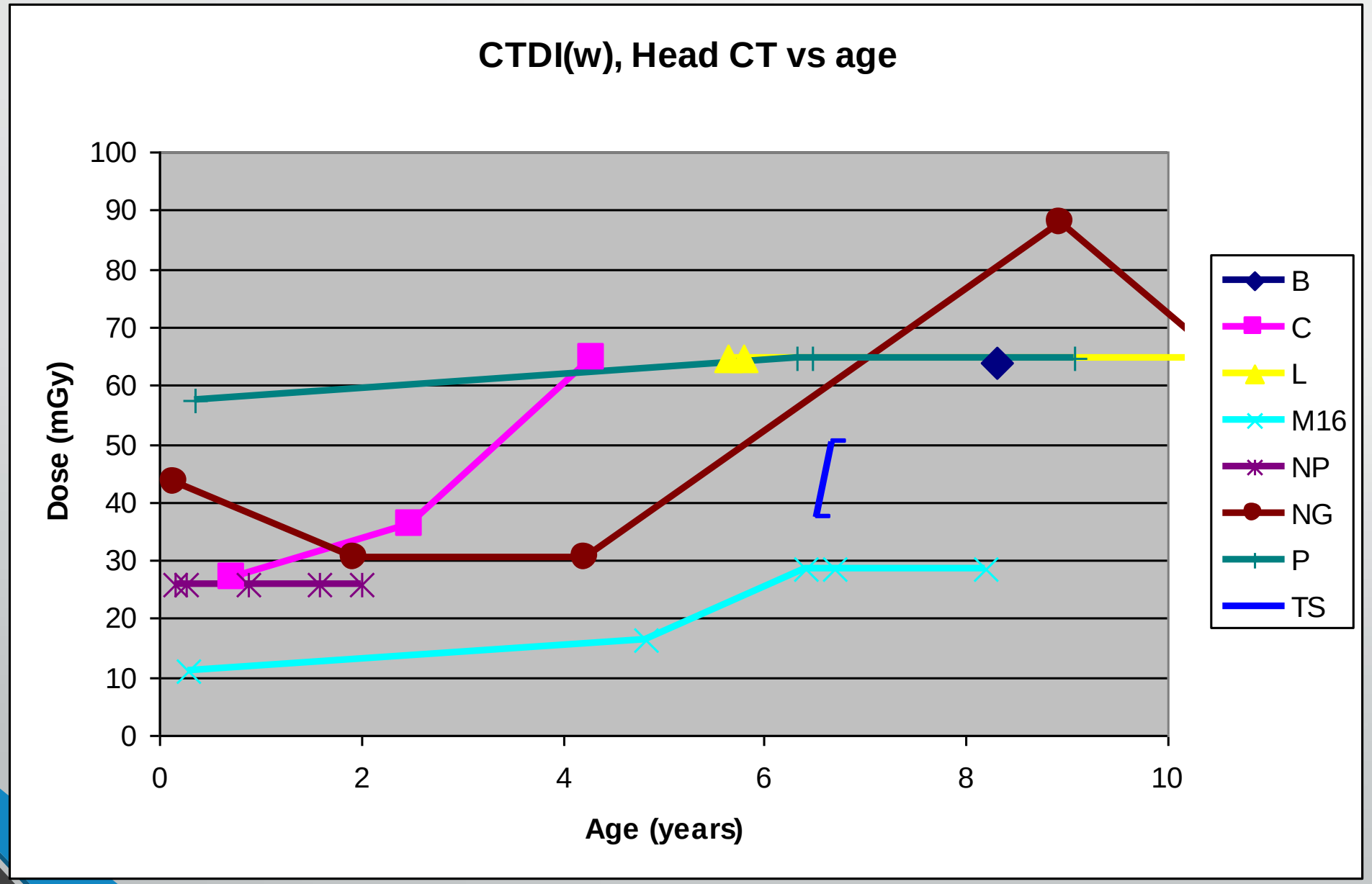
Non-smoking midwestern US resident dose summary (2006)

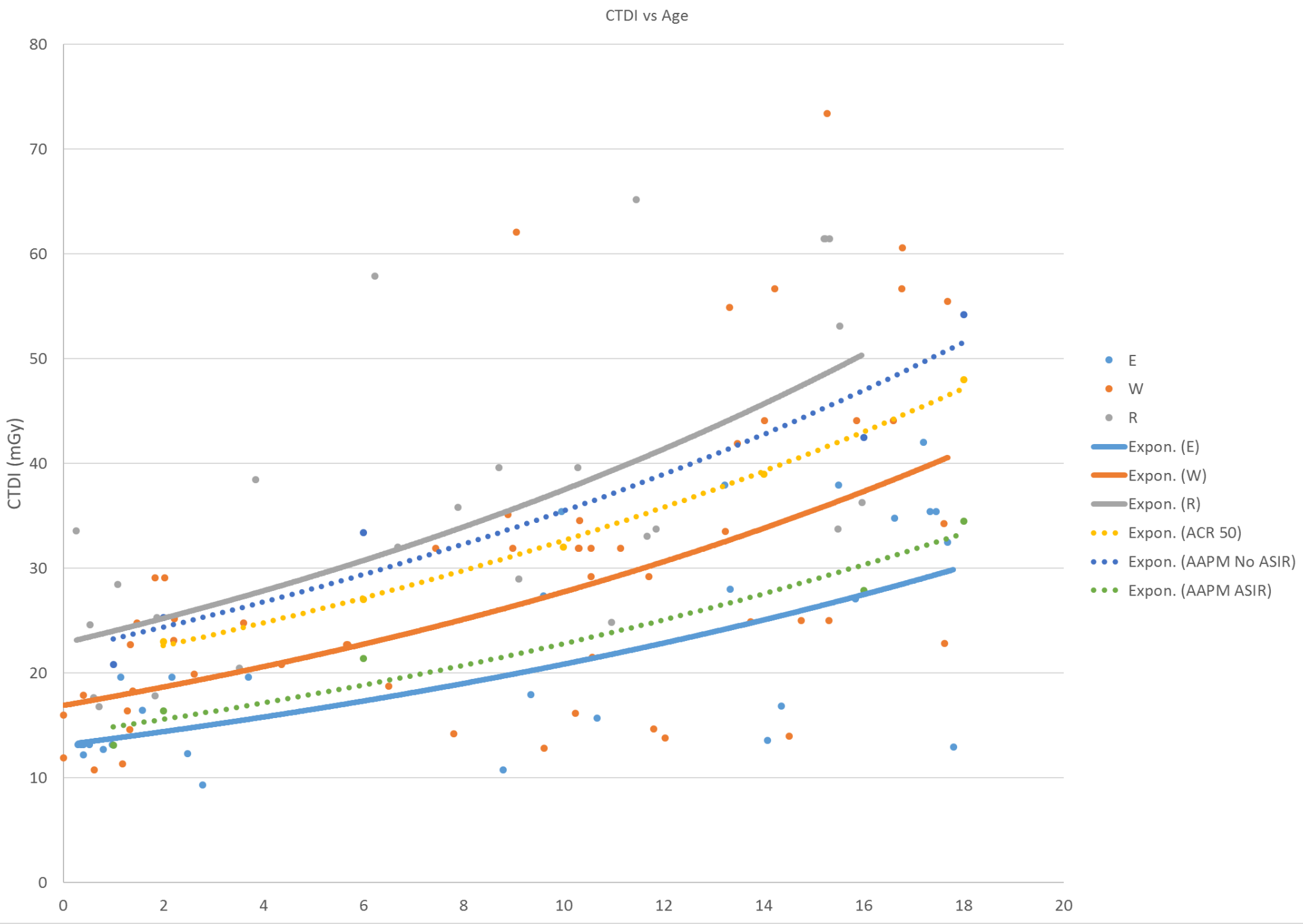


Is this good news or bad news?

Medical radiation: 0.5 mSv increased to 3.2 mSv

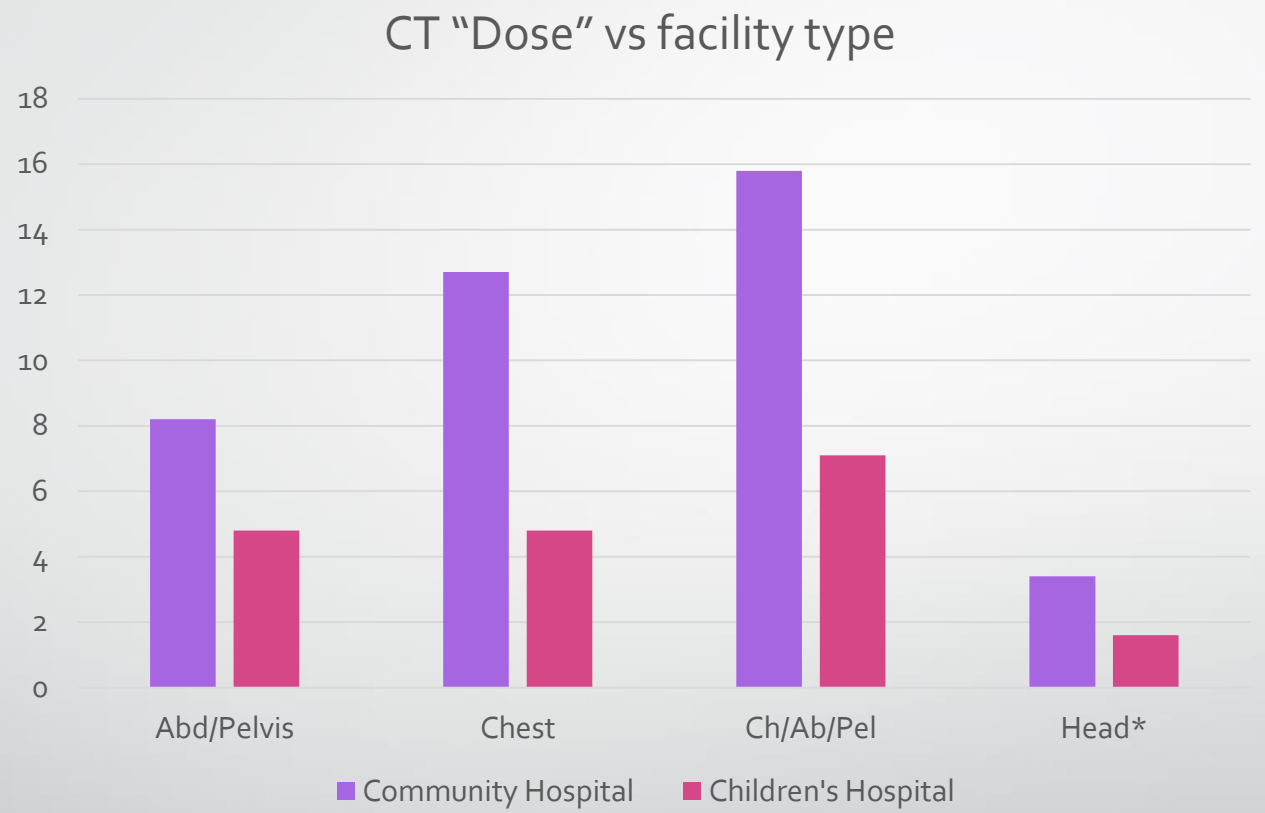
In 2009 (AJR + 8 years, peak CT?), still too little progress





Still too much variation in 2018

Peds vs General Hospitals National Scene



Agarwal. Pediatric Emergency CT Scans at a Children's Hospital and at Community Hospitals. AJR 2015

*Nabaweesi, et al. Injured Children Receive Twice the Radiation Dose at Nonpediatric Trauma Centers Compared with Pediatric Trauma Centers. JACR 2017.

My experience ~ 25 years, 100 facilities

- We have very fussy* Radiologists**
  - Some variation of this every time
- Not well correlated to results
- Too much emphasis on new machines
- Too little emphasis on "people"
- Radiation safety is no one's "job," but outsourced (at best) to a disinterested Physicist or Biomedical Engineer

Effectiveness of radiation reduction programs

Table 2. Quality Assessment of Studies Included in Systematic Review (n = 16)

	Selection	Study			Data Collection	Withdrawals &	Global
A							ng
L							
A							
Fetterly 2012	Weak	Moderate	Weak	Moderate	Weak	Moderate	Weak
Rehani 2012	Moderate	Moderate	Weak	Weak	Strong	Weak	Weak
Zhang 2012	Weak	Moderate	Weak	Moderate	Strong	Moderate	Weak
Birnbaum 2008	Weak	Weak	Weak	Moderate	Weak	Moderate	Weak
Duke 2012						eak	Weak
Duncan 2013						oderate	Weak
Miglioretti 2014	Moderate	Moderate	Moderate	Weak	Weak	Weak	Weak
Wilson 2014	Moderate	Moderate	Weak	Weak	Weak	Weak	Weak
Bussieres 2013	Moderate	Moderate	Moderate	Moderate	Weak	Moderate	Moderate
Frederick-Dyer 2013	Weak	Moderate	Weak	Moderate	Weak	Moderate	Weak
Stein 2010	Weak	Moderate	Weak	Weak	Weak	Moderate	Weak
Strother 2013	Weak	Moderate	Weak	Weak	Weak	Moderate	Weak
Hirvonen-Kari 2009	Weak	Moderate	Weak	Weak	Weak	Moderate	Weak

Note: For Global Rating: strong (no weak ratings); moderate (one weak rating); weak (two or more weak ratings). Ranking direction: weak: corresponds to shortcomings in study design and higher risk of bias.

Existing evidence on the effectiveness of policies aimed at reducing patient radiation dose is disperse and low in quality. Compared with other approaches, multipronged efforts may offer more patient protection.

Rephrased: Radiation safety is not one person's job.

Thaker et al. Effectiveness of policies on reducing exposure to ionizing radiation from medical imaging: a systematic review. JACR 2015

Here's what we *could* do

From: **The Use of Computed Tomography in Pediatrics and the Associated Radiation Exposure and Estimated Cancer Risk**

JAMA Pediatr. 2013;167(8):700-707. doi:10.1001/jamapediatrics.2013.311

Table 3. Projected Number of Future Radiation-Induced Cancers That Could Be Related to the Most Commonly Performed Pediatric CT Scans in the United States Under 3 Scenarios

Current

1/3 fewer

75%→median

CT Scan	Estimated No. of Pediatric Scans[a]	Projected No. of Future Radiation-Induced Cancers Related to Pediatric CT Use[b]								
		Scenario 1[c]			Scenario 2[d]			Scenario 3[e]		
		Solid Cancer	Leukemia	Total (95% UL)	Solid Cancer	Leukemia	Total (95% UL)	Solid Cancer	Leukemia	Total (95% UL)
Head	2.2	1000	210	1210 (630-2370)	670	140	810 (420-1580)	470	160	630 (320-1280)
Abdomen/pelvis	1.4	2810	110	2930 (1600-5360)	1880	80	1950 (1070-3600)	1660	70	1730 (950-3180)
Chest	0.2	340	10	350 (190-640)	230	10	230 (130-440)	200	10	210 (110-390)
Spine	0.2	370	10	390 (210-690)	250	10	260 (140-480)	210	10	210 (120-410)
Total	4.0	4530	340	4870 (2640-9080)	3020	230	3250 (1760-6060)	2540	240	2780 (1500-5220)

Abbreviations: CT, computed tomography; UL, uncertainty limit.

[a] In the millions.

[b] The numbers of cancers are rounded to the nearest 10.

[c] Doses reflect those observed in clinical practice.

[d] Number of CT scans reduced by one-third.

[e] Doses above the 75th percentile are lowered to median observed dose.

Table Title:

Projected Number of Future Radiation-Induced Cancers That Could Be Related to the Most Commonly Performed Pediatric CT Scans in the United States Under 3 Scenarios

Home run case

[redacted]

2011

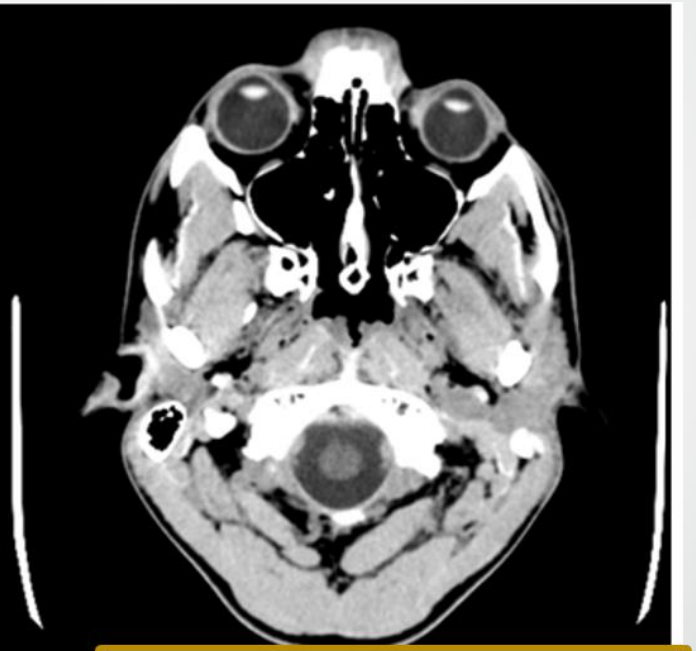
LightSpeed Ultra

Exam Description: CT HEAD WITHOUT CONTRA

Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	-	-	-	-
2	Scout	-	-	-	-
3	Axial	I61.000-I7.240	241.21	1358.52	Head 16
3	Axial	I4.750-S102.823	58.58	660.17	Head 16
			Total Exam DLP:	2018.69	

14 YO patient 2011 1/1



[redacted]

Exam Description: CT HEAD WITHOUT CONTRA

Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	-	-	-	-
2	Axial	S23.750-S178.830	22.76	364.30	Head 16
			Total Exam DLP:	364.30	

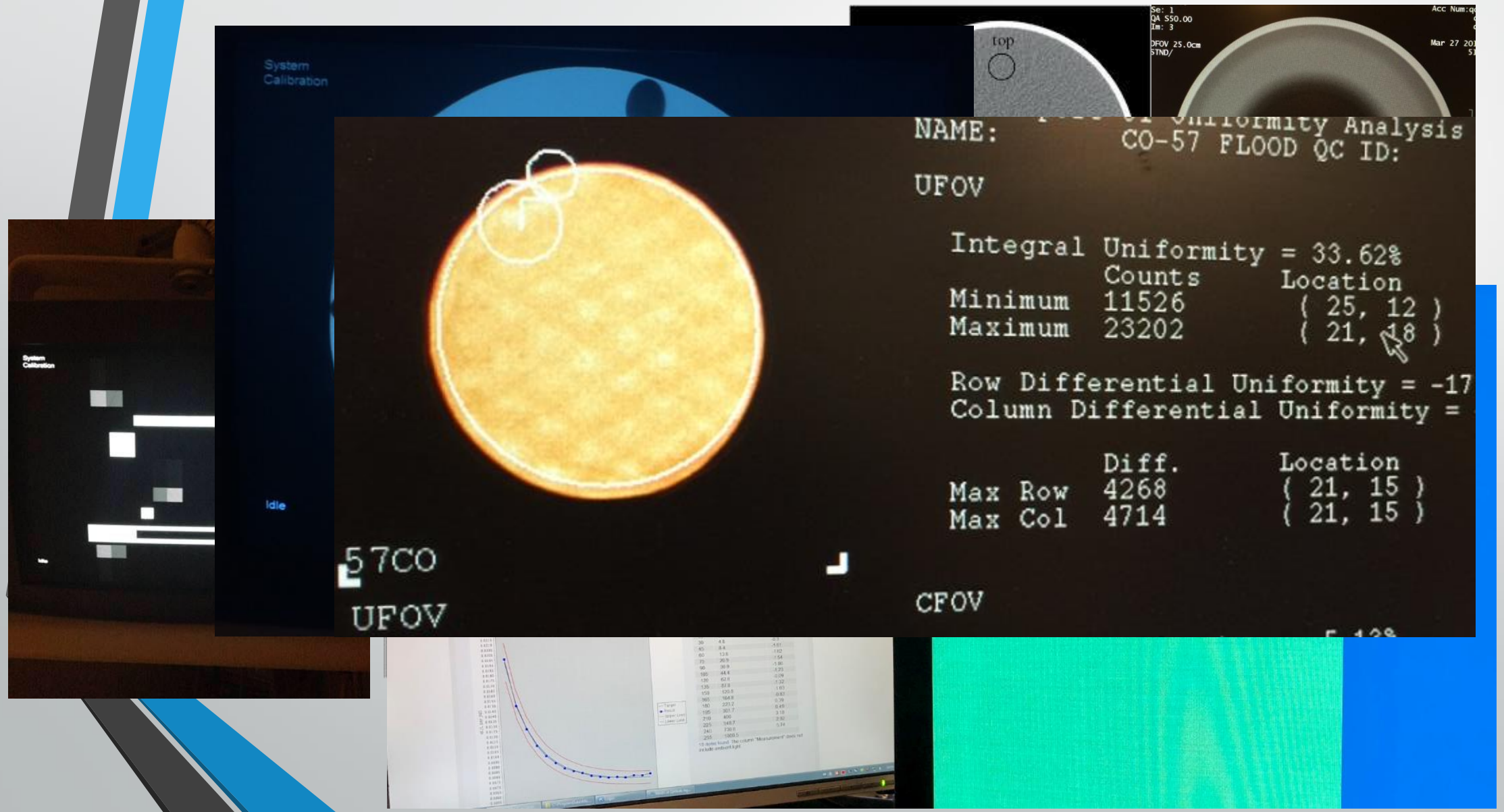
14 YO patient 2012 1/1

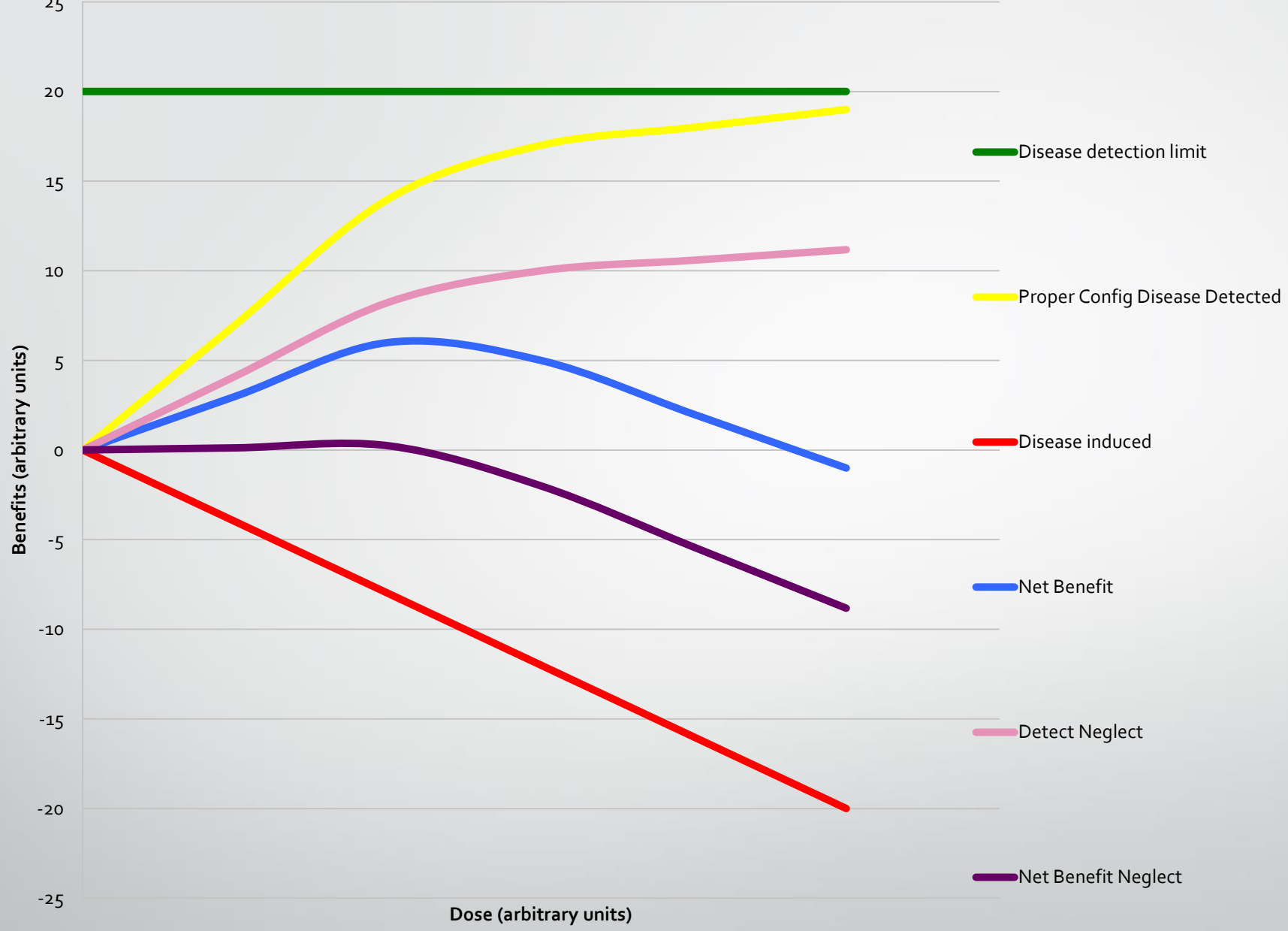
[redacted]

How (CT)?

- Entire team must be engaged
  - Radiologist—owns the quality
  - Technologist—can make a program sink or swim
  - Physicist—must be engaged, current, present
  - *These three must meet routinely*
  - Vendors—must be engaged, they do not lead
  - Administration—must clear the way for each of these
  - Referring Physicians—must hold everyone listed accountable
  - Profession—must be more transparent. Sometimes bad is just bad.

Safety is not a one time thing and it is not automatic





Having this very conversation is the most important part. Initiate it, participate, learn.

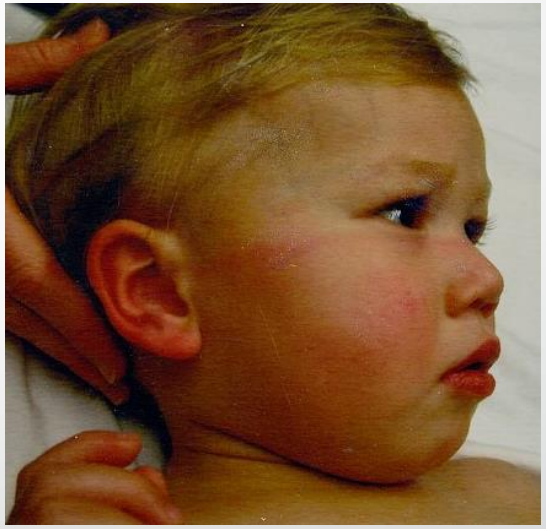
opment of Radiation Protection Standards. Radiographics 11(4) 699-712. (1991) with my own twist

How about other modalities?

- Broad strokes: Doses vary by at least a factor of two in CT
- My sense is that they vary much more in R/F
  - FDA NEXT found factors of 100
  - Some variation is professional judgment
  - Too much variation is negligence
- Nuclear Medicine doses vary less

How about other biological effects?

- Radiation burns (interventional radiology, CT)



- Tissue reactions (cataracts)

What assurance do I have that my patients (family) are being well cared for?

- Professional certifications
  - Physicists, Radiologists: ABR
  - Technologists: ARRT in each modality, CNMT
- Professional accreditations
  - ACR in each modality
  - ACR DICOE!
- State health departments do not regulate clinical medicine

Summary

- The biological consequences of radiation exposure are non trivial
- The profession should do more to protect patients
- Everyone has a role

Radiation Exposure Magnitude

Radiation Exposure in X-rays

Study Ordered	Equivalent Dose
CT Head	20 CXR
CT C-Spine	60 CXR
CT Chest	70 CXR
CT Abdomen/Pelvis	100 CXR
C-Spine Series	16 CXR

Radiologyinfo.org

Radiation Risks

Radiation Risks

- Lifetime cancer risk of a 1 year old from **ONE** CT scan of the abdomen and pelvis is **1 in 550**
- Lifetime cancer risk of a 1 year old from **ONE** CT scan of the head is **1 in 1500**
- If you take 600,000 as a average number of CT scans done in children under 15:
  - **500 children will die from the CT scan they received**

AJR:176, February 2001

- In the US, ~ 4 million pediatric CT scans each year, estimated to cause 4870 future cancers
  - ~1/3 scans may have been unnecessary
- Tissues are more radiosensitive in children (2-10x more)
- Longer lifetime to manifest radiation-induced injury
- Cumulative effect of repeated exams

Quick Pediatric CT Scan Facts

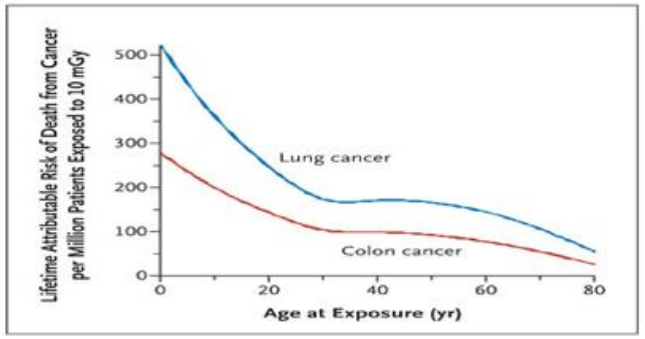
Radiation Exposure in X-rays

Study Ordered	Equivalent Dose
CT Head	20 CXR
CT C-Spine	60 CXR
CT Chest	70 CXR
CT Abdomen/Pelvis	100 CXR
C-Spine Series	16 CXR

Radiologyinfo.org

Pediatric Radiation Exposure

- Pediatrics represents a small fraction of tests, BUT the fraction is increasing
- Higher radiation doses and larger lifetime risk results in a higher lifetime cancer mortality risk
- Lifetime risk of cancer in a single dose of radiation is higher in children



NEJM:357:2277-2284, November 2007

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- If you take 600,000 as a average number of CT scans done in children under 15:
  - **500 children will die from the CT scan they received**

AJR:176, February 2001

Alternatives

- Evaluate and determine if there is a need for radiologic studies
- Get baseline studies **FIRST**
- Never delay transfer to definitive care to get scans
- If it is felt that a CT scan is needed, USE contrast to decrease the need for repeated CT scans at the definitive care facility.

Dr. Storm

Dr. Storm

- Established habits of over- ordering CTs
- Change in practice → new practice patterns utilizing evidence-based guidelines
- Transfer considerations: perform only the MINIMUM of radiological exams
- Many specific studies may be deferred until arrival at a trauma center

Considerations

- Sedation risks

- ED physician medical and legal considerations

  - **Documentation:**

  1- " Head CT not performed. Not indicated under the PECARN guidelines"

  or 2- "Patient will be observed for x # hours as recommended in PECARN guidelines…."

  3- Parental instructions

- **BPAs:** evidenced-based guidelines intended to encourage best practices

Things to Consider

- Not every patient requires every radiologic study
- Is the x-ray or CT indicated by the patient's injury or symptoms?
- Will the x-ray or CT contribute to a clinical decision at this point in time?
- Will the x-ray or CT need to be repeated, if the patient is being transferred?

- **Diagnostic Accuracy and Patient Safety are both priorities.**

Questions

- Right test?
- Right time?
- Clinician and radiologist discussion?
- Skill level of technologist?
- Sedation required?
- Pressure from parents/legal system?

Who's Responsibility is it to Limit Exposure?

- Emergency/Trauma providers and staff
- Radiology Technicians
- Radiologists
- Nursing
- Radiation safety experts (Physicists)
- Equipment manufacturers (vendors)
- Regulatory agencies
- BPAs

In Summary

- Acknowledge medical-legal and missed diagnoses concerns
- Evidence – based guidelines and tools are readily available
- Next section includes PECARN, NEXUS and other useful tools

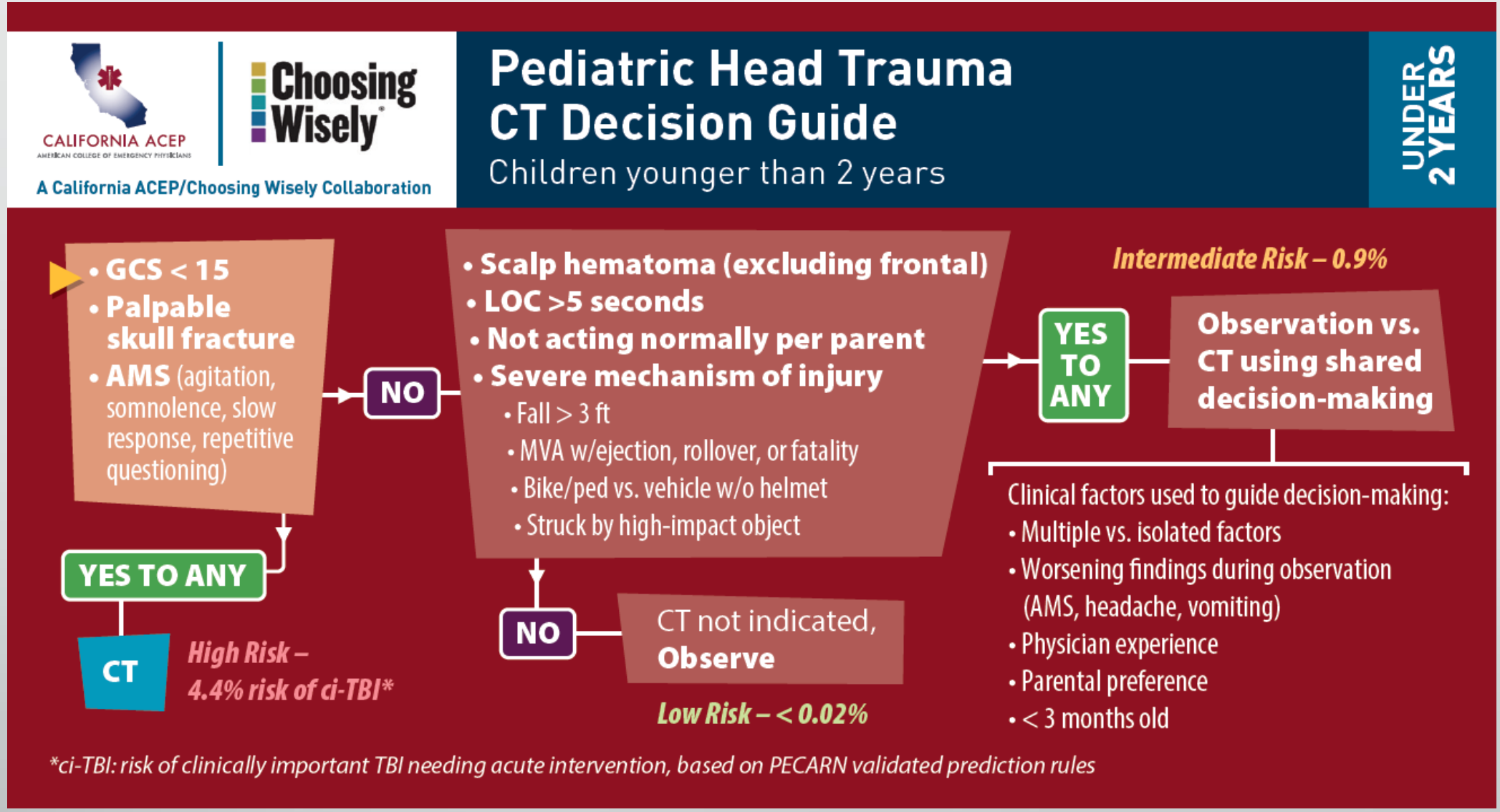
Deb H

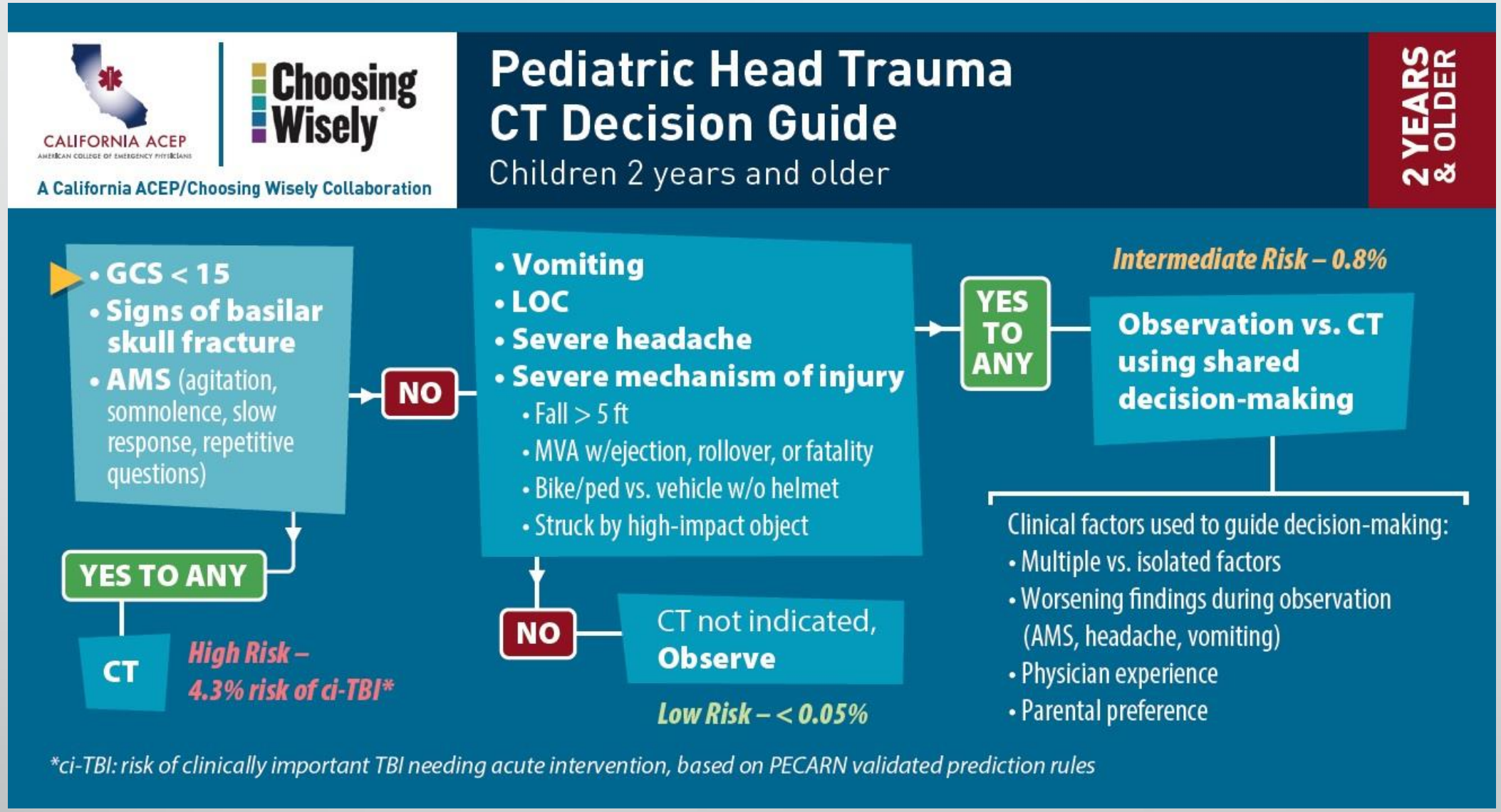
Image Gently: National Campaign to Reduce Radiation Exposure

www.imagegently.org

Pediatric Emergency Care Applied Research Network

- First federally-funded pediatric emergency medicine research network in the United States
- Conducts high-priority, multi-institutional research on prevention & management of acute illnesses & injuries in children & youth of all ages


CALIFORNIA ACEP
AMERICAN COLLEGE OF EMERGENCY PHYSICIANS
Choosing Wisely
A California ACEP/Choosing Wisely Collaboration
Pediatric Head Trauma
CT Decision Guide
Children younger than 2 years
UNDER 2 YEARS
• GCS < 15
• Palpable skull fracture
• AMS (agitation, somnolence, slow response, repetitive questioning)
NO
YES TO ANY
CT
High Risk – 4.4% risk of ci-TBI*
• Scalp hematoma (excluding frontal)
• LOC >5 seconds
• Not acting normally per parent
• Severe mechanism of injury
• Fall > 3 ft
• MVA w/ejection, rollover, or fatality
• Bike/ped vs. vehicle w/o helmet
• Struck by high-impact object
NO
CT not indicated, Observe
Low Risk – < 0.02%
Intermediate Risk – 0.9%
YES TO ANY
Observation vs. CT using shared decision-making
Clinical factors used to guide decision-making:
• Multiple vs. isolated factors
• Worsening findings during observation (AMS, headache, vomiting)
• Physician experience
• Parental preference
• < 3 months old
*ci-TBI: risk of clinically important TBI needing acute intervention, based on PECARN validated prediction rules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Choosing Wisely
A California ACEP/Choosing Wisely Collaboration
Pediatric Head Trauma
CT Decision Guide
Children 2 years and older
2 YEARS & OLDER
• GCS < 15
• Signs of basilar skull fracture
• AMS (agitation, somnolence, slow response, repetitive questions)
YES TO ANY
CT
High Risk – 4.3% risk of ci-TBI*
NO
• Vomiting
• LOC
• Severe headache
• Severe mechanism of injury
• Fall > 5 ft
• MVA w/ejection, rollover, or fatality
• Bike/ped vs. vehicle w/o helmet
• Struck by high-impact object
NO
CT not indicated, Observe
Low Risk – < 0.05%
YES TO ANY
Intermediate Risk – 0.8%
Observation vs. CT using shared decision-making
Clinical factors used to guide decision-making:
• Multiple vs. isolated factors
• Worsening findings during observation (AMS, headache, vomiting)
• Physician experience
• Parental preference
*ci-TBI: risk of clinically important TBI needing acute intervention, based on PECARN validated prediction rules

Cervical Spine Injury Decision- Making

PECARN DECISION RULE

PARAMETER	Adjusted OR (95% CI)
Altered mental status	3.0 (2.1-4.3)
Focal neurologic deficits	8.3 (5.6-12.2)
Complaint of neck pain	3.2 (2.3-4.4)
High risk MVC	2.5 (1.8-3.6)
Diving	73 (9.6-555)
Substantial torso injuries	1.9 (1.1-3.4)
Torticollis	1.8 (1.1-3.4)
Predisposing conditions	15.6 (2.9-78)
ANY Parameter Present = Positive Rule - XRAY ALL Parameters Absent = Negative Rule – No XRAY	

NEXUS

- National Emergency X-Radiography Utilization Study
- Located in Trauma Treatment Guidelines Manual

C- Spine Clearance

If patient already meets criteria for transfer - defer CT of the c-spine, and maintain C-Spine immobilization. CT of the c-spine with coronal and sagittal reconstructions has become the standard of care **if** the NEXUS criteria are not met.

NEXUS CRITERIA

Bedside clearance of C-Spine is appropriate when:

- **Patient is NOT intoxicated.**
- **Patient has normal mentation (GCS = 15).**
- **Patient has NO neurologic deficits.**
- **Patient has NO midline neck pain.**
- **Patient has NO distracting injuries.**

CT can still miss injuries that are ligamentous in nature.

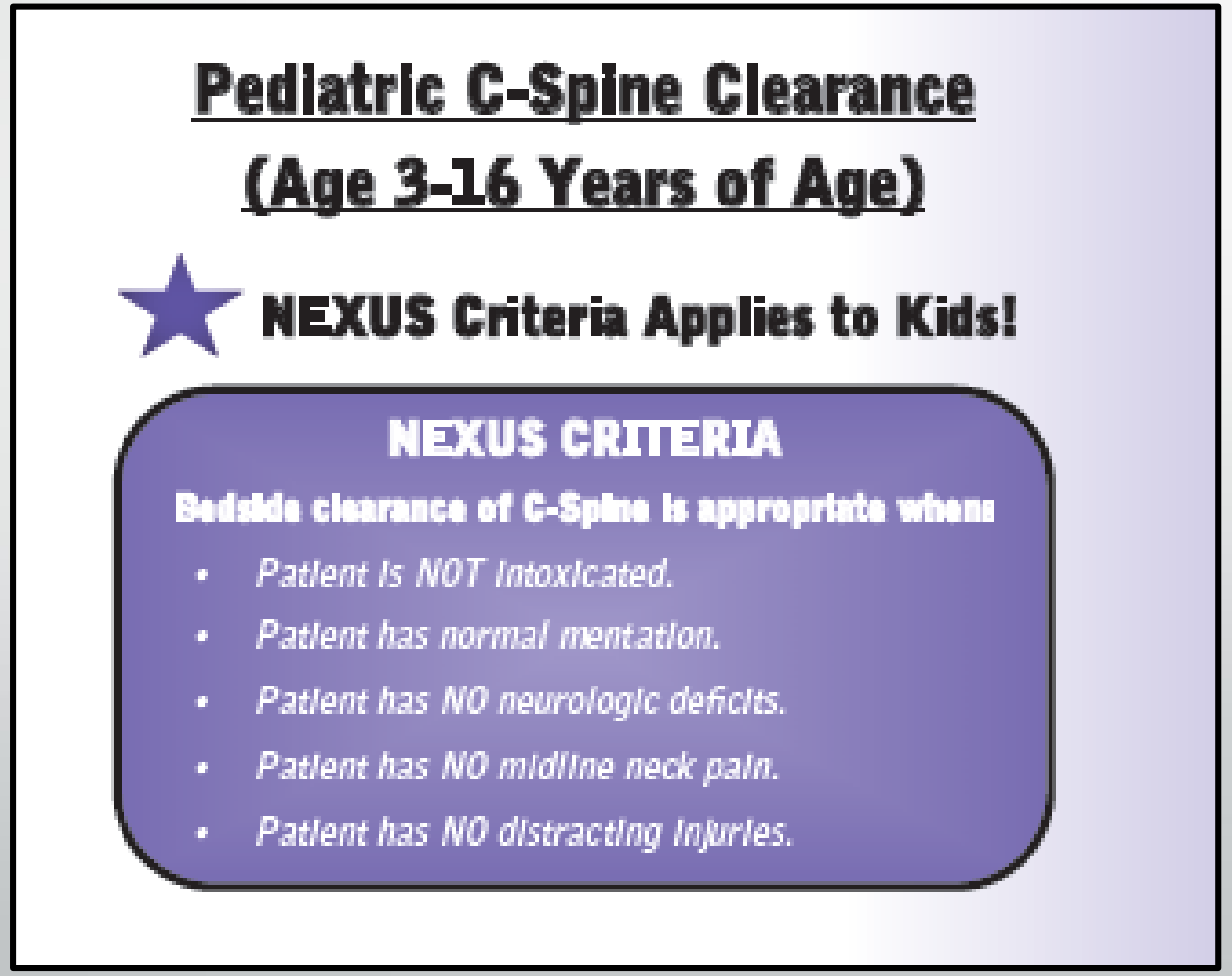
If midline neck pain and/or a neurologic deficit is present with a normal appearing CT scan, further imaging with MRI and evaluation by a neurosurgeon may be indicated. The cervical collar should be left in place, c-spine precautions maintained, and consultation with a higher level trauma center obtained.

Helpful Hint: *If your CT scanner is < 16 slice, obtain a lateral c-spine x-ray in addition to the CT to assist the radiologist in obtaining an accurate read.*

Consider removing patient from back board after initial EMS transport.

NEXUS Criteria

(located in Trauma Treatment Guidelines manual)



Pediatric C-Spine Clearance

Age < 3:

- C-Spine injury in children < 3 years is extremely rare, occurring in < 1% of injuries in this age group.
- Nearly all injuries in this age group occur above C3
- Factors associated with C-Spine injury in children < 3 are:
  - GCS <14
  - GCS eye score = 1
  - MVC mechanism
  - Maybe higher incidents of injury between 2 and 3 years of age.

Reference: Pieretti-Vanmarcke, et al. J Trauma. 2009;67: 543-550.

NEXUS Criteria

Clinically Clearing the Pediatric C-Spine:

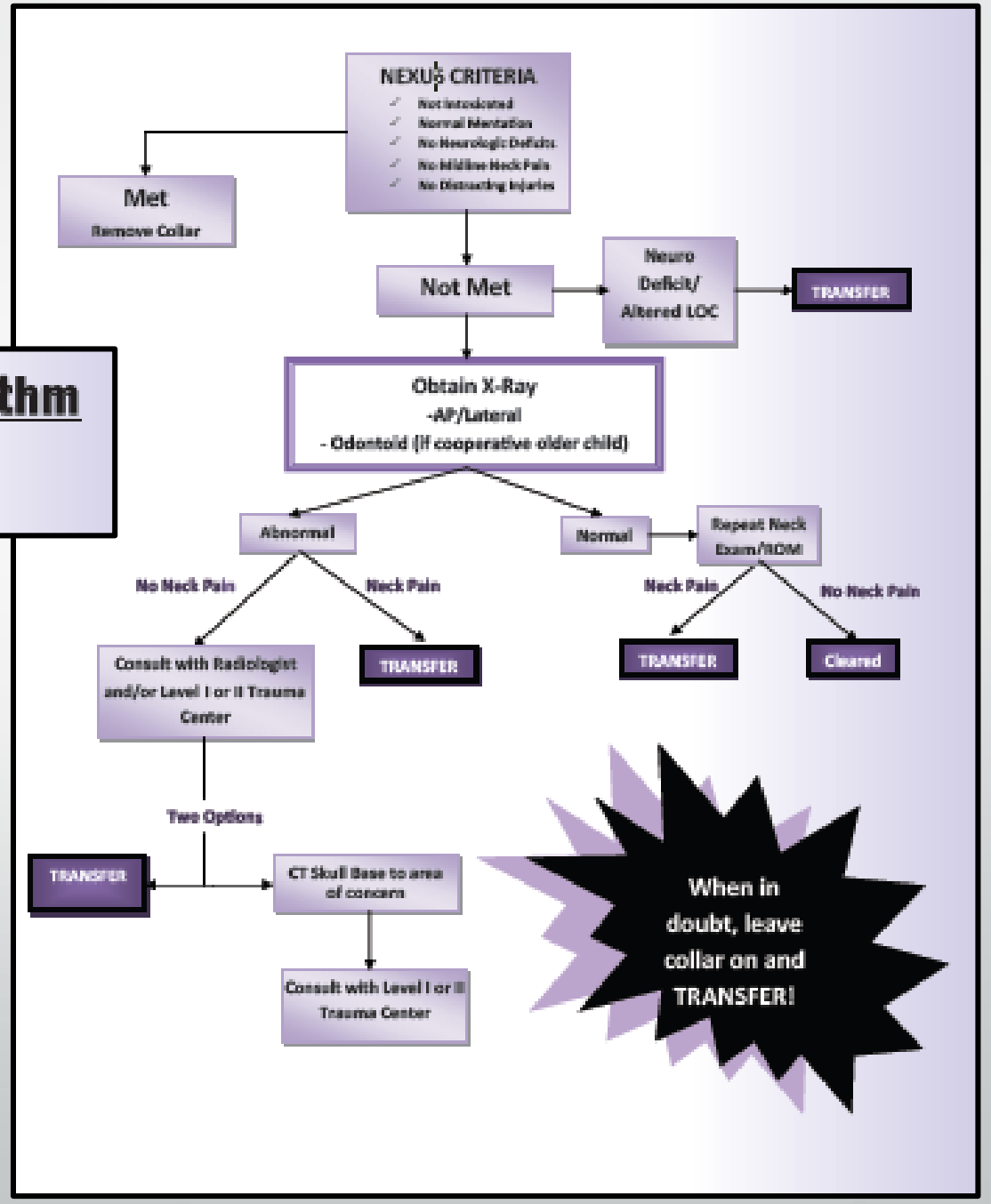
Mental status should be AGE APPROPRIATE

- Ask the parents to help you assess this!
- If mental status is altered, **DO NOT CLINICALLY CLEAR**
  - Obtain Imaging (**SEE ALGORITHM NEXT PAGE**)

A child does NOT need imaging when:

- ✓ Normal Alertness/Mental Status
- ✓ No Midline Neck Pain
- ✓ No Neurologic Impairment
- ✓ No Distracting Injuries

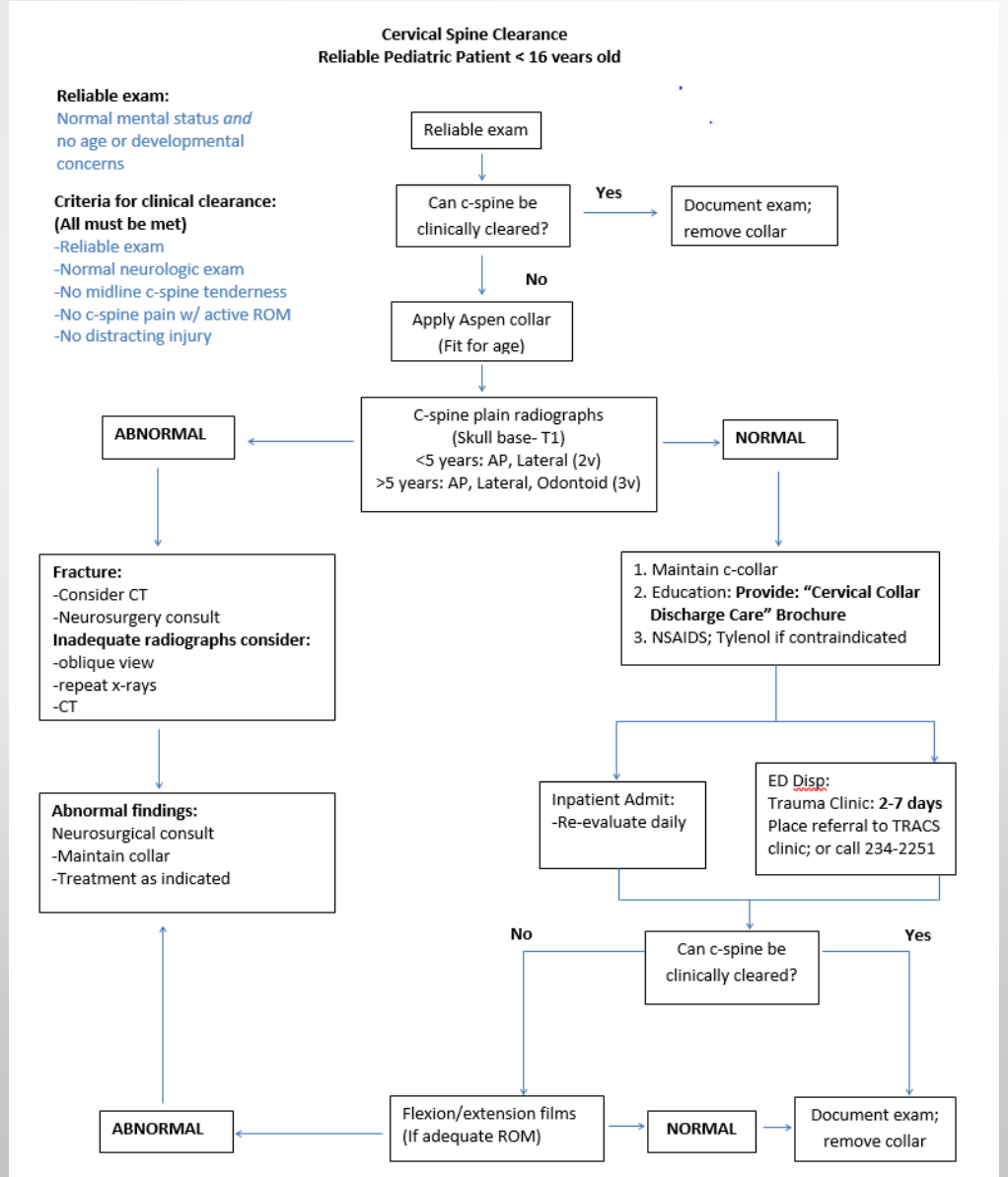
Pediatric C-Spine Clearance Algorithm (3-16 Years of Age)



NEXUS Criteria

Cervical Spine Clearance Algorithm

(Adapted from Cincinnati Children's Hospital)



Chest

- ATLS guidelines require only a chest x-ray as a screening tool and imply selective use of chest CT as an accurate screening method for aortic injury
- CT Chest: indicated only for patient with penetrating or crushing trauma
- SCRAP Rule: a guideline developed in Ontario with sensitivity of 100% & negative predictive value of 100%. See references. Results in 19 % reduction in CT scans and no missed major thoracic injuries.

Blunt Abdominal Trauma

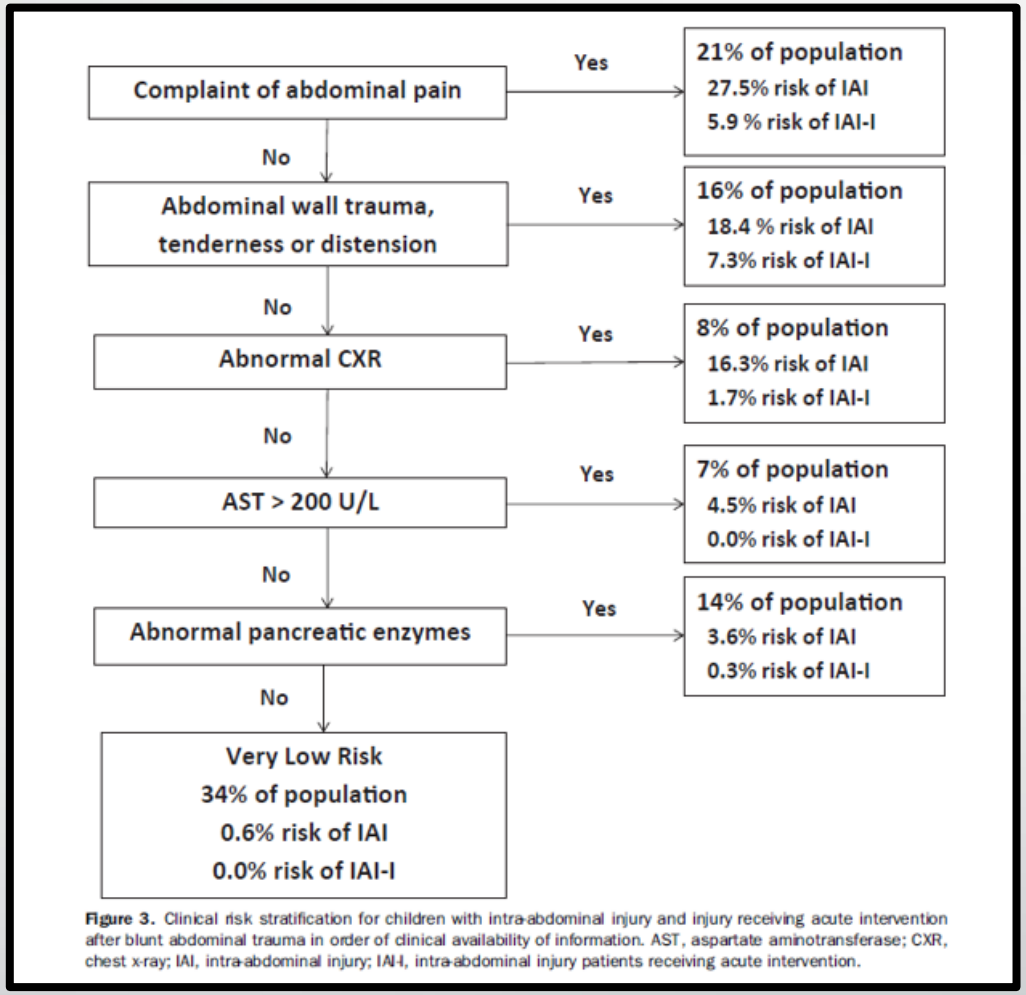


Figure 3. Clinical risk stratification for children with intra-abdominal injury and injury receiving acute intervention after blunt abdominal trauma in order of clinical availability of information. AST, aspartate aminotransferase; CXR, chest x-ray; IAI, intra-abdominal injury; IAI-I, intra-abdominal injury patients receiving acute intervention.

Reference: *Identifying Children at Very Low Risk for Blunt Intra-Abdominal Injury in Whom CT of the Abdomen Can Be Avoided Safely*. December 2016. Streck, C., Vogel, A., Zhang, J., et al, with the Pediatric Surgery Research Collaborative. Eberlein, Timothy J., Editor-in-Chief.

J Am Coll Surg, Vol. 224, No. 4, pg. 449 – 458, April 2017 10/26/2017

Abdominal CTs

- Often, the guideline will lead to NO abdominal/pelvis CT
- If the decision has been made by other criteria that the patient is to be transferred, then abdominal/pelvis CT might best be deferred to receiving facility -- unless there is need for immediate intervention.

Abdominal CTs

- Abdominal CT appears indicated per guidelines, multiple considerations:
- Risk vs. Urgency:

  1- Incorrect dose of IV contrast

  2- Incorrect timing of IV contrast

  3- Likelihood of repeat CT at receiving facility

  ** Many abdominal CTs must be repeated; who best to do it if necessary?

  ** Also will delay transfer

Pelvis X-rays

- First line trauma x-rays recommended: chest, pelvis, and possible lateral c-spine

Case Study

- 6 year old female
- MOI: Pedestrian vs. car: hit while crossing a street
  - pickup unable to stop on ice ~ 20 mph
  - child hit by front of pickup & thrown ~ 10 feet
- Awake and alert on scene
- EMS placed cervical collar & immobilized on backboard
- To critical access hospital

Emergency Room Workup

- GCS 15 PERL
- vital signs: 114/53 127 24 98.7 (T) 94% on RA
- Primary & secondary survey performed
- No life-threatening interventions necessary

stop

Emergency Room Workup

- Diagnostics
  - CT head
  - CT cervical spine
  - CT chest
  - CT abdomen
  - CT pelvis
  - x-rays facial bone, pelvis, right elbow, right knee

**Exposure: equivalent of > 250 CXR!!

We CAN do better:

- Image when there is a clear medical benefit
- Use radiation appropriate dosing based on child's size
- Image only area of concern
- Avoid multiple (repeated) scans if possible
- Use alternative diagnostic studies
- Increase awareness
- Utilize technology/EMR

In Summary

- Physics & Clinical reasons presented today demonstrate that we CAN do better.
- Current practices are largely due to established habits, which we are reluctant to let go.
- If evidence-based practice illustrates a better method, why are we so lazy?
- We owe it to our patients, adults & children, to minimize harmful exposure to radiation.
- A little effort to establish new practice patterns in your own environment will yield huge patient and practice rewards for the future generations.

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- Image Gently www.imagegently.org
- NEXUS https://www.mdcalc.com/nexus-criteria-c-spine-imaging
- PECARN https://www.mdcalc.com/pecarn-pediatric-head-injury-trauma-algorithm

Questions

Contact Information

- Brent.Colby@sanfordhealth.org
- Waldemar.Storm@sanfordhealth.org
- Debra.Hanson@sanfordhealth.org

Thank you for your attention!

Please share this presentation (perhaps require participation) with your respective ED physicians, Surgeons, NP & PA providers, Radiologists (& read services), Radiology technicians and nursing staff members.

We all have a professional obligation to do the right thing for our children & their future:

REDUCE RADIATION EXPOSURE!!