Minor Head Trauma in Kids: Controversies and Challenges  
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PART I: IMAGING AFTER HEAD TRAUMA IN INFANTS AND CHILDREN

Background: Pediatric Minor Head Trauma
- Pediatric minor head trauma accounts for ~600,000 ED visits annually
- About 50% of kids of head trauma get a CT, and the majority are those with “minor head trauma” (defined as a relatively minor mechanism, and GCS 14-15 at presentation)
- While children with minor head trauma account for 40-60% of traumatic brain injuries seen on CT, only 3-7% of these CT scans are positive (Palchak, Greenes)
  - Furthermore, a minority of these radiographic ICI’s are clinically significant (requiring intervention such as intubation, neurosurgery, hospital admission)
- With recent concern about increased lifetime risk of cancer from radiation exposure from CT scans (see below), interest has mounted in developing a clinical decision rule that can accurately identify children who can be safely observed with CT
- Therefore, the goals in selectively imaging infants and children with apparent minor head trauma are twofold:
  - To identify those with clinically significant ICI requiring early intervention and management
  - To minimize unnecessary radiographs, sedation and admissions

Previous Guidelines: Based on Loss of Consciousness (LOC):
- In 1999 the AAP released Guidelines for Management of Minor Closed Head Injury in Children 2-20 (for children with NO abnormalities of mental status or neurologic exam, or physical evidence of skull fracture). Their recommendations included:
  - Observation alone in those without LOC
  - CT vs observation in patients with brief LOC
    - Children with a negative CT could be safely discharge home
    - The role of additional risk factors (vomiting, seizures) was deemed “unclear”
- However, recently Palchak (2004) brought the role of LOC into question, finding that among >2000 children there were no cases of ICI among those with isolated LOC/amnesia (without any other signs or symptoms) = 100% negative predictive value

Recent Studies: Clinical Prediction Rules
- Several investigators have evaluated clinical decision rules designed to more selectively identify children at low risk of ICI who can be safely observed without imaging (Palchak, Sun, Atabaki, Omans)
- Recently, Kupperman (2009) derived and prospectively validated a decision rule in a large cohort of children <18
- While observation for 4-6 is often recommended as an alternative to CT scan, to date no study has specifically evaluated the role of observation for 4-6 hours in select children at risk for ICI.

Special Considerations in Children <2:
- Asymptomatic (occult) ICI is more prevalent in younger infants, particularly those <3 to 6 mo (up to 48% of infants with ICI may be asymptomatic)
  - Incidence of ICI in infants <2 with apparently minor HT is ~3%-6%, with highest incidence in the youngest infants (eg; < 3mo of age)
- A “lower threshold” for imaging is suggested in very young children because of occult ICI, as well as:
  - Difficult clinical assessment
  - Increased risk for skull fractures and ICI from minor trauma
  - Increased risk for non-accidental trauma (child abuse)
- However, selective imaging is even more important in young infants as the potential risks of CT scan are higher: they are more likely to require sedation, and more vulnerable to radiation effects
- This age group has been excluded from most guidelines (eg: AAP 1999 guidelines) and represents a small subgroup in most studies (with the exception of Kupperman, 2009)
Evidence: Imaging After Minor Head Trauma in Children <18

• Kupperman, 2009: this is the only decision rule validated in a prospective cohort (Figure 1a and 1b)

• Methods
  o Enrolled 42,412 kids 0-18 years with recent head trauma and GCS 14-15 at presentation
    ▪ Derivation set = 33,785 kids (8502 age < 2, 25,283 age 2-18)
    ▪ Validation set: 8,627 kids (2216 age <2, 6411 age 2-18)
  o Main outcome: “clinically-important traumatic brain injury” (ciTBI) = brain injury resulting in death, intubation, NS intervention or hosp admission ≥2 nights
    ▪ All pts contacted/med records reviewed 7-90 days after ED visit

• Results
  o CT scans performed at physician’s discretion in 35% of kids overall (31% of kids <2)
  o Overall rate of TBI by CT of 5.2%, and ciTBI of 0.9% (same among 96 kids not initially CT’d)
    ▪ ciTBI in kids <2: 0.9% in derivation set/1.1% in validation set
    ▪ ciTBI in kids >2, 0.9% in derivation set/1% in validation set
  o In validation population, prediction rule performed very well in each age group
    ▪ Kids < 2: NPV of 100% (1176/1176), sens of 100% (25/25)
    ▪ Kids 2-18: NPV of 99.95% (3798/3800), sens of 96.8% (61/63)
  • Neither of the 2 kids missed by the rule required neurosurgery
    o Overall among kids < 2, the 53% with none of the predictors accounted for 20% of the CT scans
    o Overall among kids 2-18, the 59% with none of the predictors accounted for 25% of the CT scans
    o Of note, children 2-18 with certain isolated findings (LOC, vomiting or small scalp hematoma in infants >3mo) had <1% chance of ciTBI.

***These recommendations are summarized in Figures 1a and 1b in the appendix***

Recommendations: Selective Head Imaging of Infants and Children with Minor Head Trauma

1. Whenever possible, try to identify low-risk children who can be observed or followed without a scan
   • When a CT scan is indicated, use reduced milliampere-seconds dose when possible
   • Reduction in dose by 30-50% has not been shown to decrease study quality
   • Risk/benefit ratio of using diagnostic CT scans in children depends on risk of disease
     • In high-risk children, benefits of CT scans far exceed risk, scan should be performed
     • As risk of disease decreases, the relative concern for lifetime cancer risk increases
   • While young infants are at higher risk of ICI from apparently minor head trauma, these infants are especially vulnerable to effects of radiation

2. Kupperman Decision Rule (2009): the largest, and only prospectively validated rule (Figure 1a, 1b)
   • Potential reduction in CT scans of 20-25%
   • Kids < 2: NPV 100% if non-severe mechanism, normal MS, no palpable skull fracture and
     o LOC ≤ 5 sec
     o no non-frontal scalp hematoma
     o normal activity per parents
   • Kids 2-18: NPV 99.5% if non-severe mechanism, normal MS, no palpable skull fracture and
     o no LOC
     o no signs of basilar skull fracture
     o no vomiting
     o no severe headache
   • The authors recommend that “CT should be more strongly considered for children with multiple findings, worsening symptoms or signs, and for infants younger than 3 months. Clinician experience and parental preference should also be taken into account”

3. Other considerations:
   • If suspicion for child abuse is present, or no mechanism is proposed for the child’s findings, the clinician should have a lower threshold for performing a head CT
   • Observation vs Imaging
Specific data is lacking on the efficacy/safety of observing vs imaging in select patients

Consider in select children who DO NOT meet criteria for DC without CT
- Strong parental preference to avoid CT
- Certain isolated risk factors/mild symptoms

In children who meet criteria for DC without CT scan
- Consider observation in very young infants (<6 mo of age) or if mechanism unclear

PART II: QUANTIFYING DIAGNOSTIC RADIATION RISKS TO INFANTS AND CHILDREN

Background: Radiation from CT Scans in Children

- In 2007, Brody found that only 9-12% of physicians believe that radiation from CT scans could increase cancer risk, and 75% underestimate the equivalent # of CXR’s to one CT scan
- Children are at higher risk of cancer and CNS damage from radiation from CT scans for 3 reasons:
  - Growing tissues and organs are more sensitive to radiation effects
  - Oncogenic effects may have a longer latent period, giving children a higher lifetime cancer risk
  - A fixed dose of radiation delivered in most CT scans results in a dose that is relatively higher for the child (per surface area) than for the adult
- Frequency of CT scans is increasing, and accounts for the majority of total radiation delivered to children
  - Mettler (2000) reported that CT scans went from 6% to 11% of total radiographic procedures from 1990-1999, with studies of children <15 accounting for 11.2% of scans.
  - Wiest (2002) reported that CT scans represent 75% of diagnostic radiation delivered
- Quantifying radiation exposure:
  - Units:
    - Gray = unit of absorbed radiation dose
    - Sievert = unit of biological effect of radiation (adjusted for different types of radiation/tissue)
  - Estimated background radiation received by average person per year = 3 mSv (range = 1-10mSv)
  - Typical CT scan: 10-14 mSv depending on exam (and age)
  - Absorbed radiation exponentially higher the younger the child, esp < 1 year (Figure 2)
  - Estimated equivalent radiation for a standard dose CT scan of a 5 year old child (Brody, 2007)
    - Head CT is equivalent to 200 CXR’s
    - Abd CT equal to 250 CXR’s
- While reducing the milliamperes-seconds (mAs) radiation dose by 30-50% has not been shown to decrease CT scan quality (Abdelhalim, McCollough), many centers still use the full radiation dose for imaging children
  - For head CT’s, radiologists recommend a dose reduction by 2.5-fold for a neonate (McCollough, 2009)

Evidence: How High is the Lifetime Risk of Cancer from Pediatric CT?

- Prospective studies are needed to truly quantify lifetime cancer risk from childhood CT scans
  - For sufficient power to detect an increase in lifetime cancer risk of .02% (over baseline estimate of 20%) such a study would require close to a million subjects (Brody, 2007)
- Most studies estimate lifetime risk using models based on risk per dose delivered
  - These estimates come from long-term cohort studies of populations exposed to radiation (eg: Chernobyl, tinea capitis treatment in the 1950’s)
- The National Research Council’s 2006 report on the Biological Effects of Ionizing Radiation reported an estimated 800 additional cases of cancer for each 100,000 people exposed to 100mSv of ionizing radiation
  - This risk is linear, giving an additional 100 cases/100,000 people (0.1%) for each 10mSv, etc
- The increased lifetime risk of cancer from a CT scan is greater the younger the child (Figure 2)
- Estimated proportion of cancers attributable to CT radiation ranges from 0.4% to 2% (Brenner, 2007)
  - Although childhood CT scans represent 4% of total scans by number, individuals scanned as children may represent 16-20% of total attributable cancer deaths
  o For a 1 year old: 0.18% from abdominal CT, and 0.07% head CT
    ▪ This is a lifetime additional risk of 1/ 550 from abd CT, and 1/1500 from head CT
  o At the current rate of 600,000 abd or head CT’s done yearly on kids <15 years of age
    ▪ ~500 kids (170 from head CT, 310 abdominal CT) per year would be expected to ultimately die from cancer attributable to the CT radiation
    ▪ This represents a 0.35% increase over the baseline lifetime cancer rate (20%)
• Stein et al (2008) used published organ-specific radiation doses from a single head CT to estimate the increased lifetime risk of associated cancers.
  o For a 1-year old child, a single head CT could cause an associated tumor in 0.22%, 30% of which will die.
  o This is a shortened life expectancy of 0.04 among all exposed 1-year-olds.

Conclusions: CT scans and Cancer
• While difficult to quantify, radiation from CT scans causes a small but appreciable increase in lifetime cancer risk
• The effective organ dose of radiation, as well as the increase in lifetime attributable cancer risk from CT scans, are greater the younger the child (Figure 2)
  o Up to 20% of cancers attributable to CT scans occur in individuals exposed in childhood
  o Estimated excess lifetime risk of cancer in a 1-yr-old attributable to a single head CT is 1/1500
  o 170 kids <15 per year could be expected to eventually die from head CT’s at the current rate we are performing them
• There is a dose-response curve to the increased lifetime risk of cancer (Figure 3)
• To reduce unnecessary cancer deaths, providers should employ a selective approach to CT scanning, as well as use decreased radiation doses when CT scans are indicated

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Evidence: Can Radiation From Head CT Cause Cognitive Impairment?
• Impaired cognitive function has been demonstrated in children exposed to high-doses of ionizing radiation in utero
• Studies of children receiving radiation for leukemia and brain tumors are difficult to interpret due to confounding
• A 2004 study (Hall) looked at cognitive function in Swedish adult men who received low-dose radiation before 18 mo for cutaneous hemangioma between 1930 and 1959
  o Average estimated absorbed dose was 52 mGy
  o Decrease in high school attendance seen for all groups with radiation doses > 100mGy, compared with lowest doses (1-20 mGy)
  o Dose-response: Decreased odds of high school attendance with increasing doses
• This study’s conclusions are controversial, but suggests the possibility that doses within the range possible for head CT scans of infants may affect cognitive function, with a dose-response relationship

Conclusion:
• While cognitive effects of low-dose diagnostic radiation may be difficult to quantify, the Hall study provides additional evidence for the importance of selective imaging, and low-dose protocols

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PART III: RETURN TO PLAY AFTER HEAD TRAUMA/CONCUSSION
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Background:
• 26% of closed head injuries in children occur during sports (Meehan, 2009)
• Concussions represent 8.9% of all high school athletic injuries
• Definitions of concussion:
  o The American Academy of Neurology definition: “a trauma-induced alteration in mental status that may or may not involve loss of consciousness”
  o Zurich statement (2009): “a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces”
5 major features:
- Direct blow or impulsive force to head
- Short-lived impairment, spontaneous resolution
- Symptoms result from functional disturbance
- Graded clinical symptoms that resolve in a sequential course
- No abnormality on imaging

Pathophysiology and Symptoms
- From animal models:
  - Disruption of neuronal membrane leads to $K^+$ efflux to extracellular space
  - Release of glutamate causes further $K^+$ efflux, and suppression of neuronal activity
  - Na""/K" pumps increase activity, resulting in ATP and glucose consumption
  - Lactate and CBF increase
  - Ca"" accumulates in cells, impairing oxidative metabolism, resulting in cell death
  - Hypermetabolic state is followed by hypometabolic state, lasting up to 4 weeks
- Early symptoms include headache, confusion and amnesia, dizziness, vertigo or imbalance, lack of awareness of surroundings, and nausea and vomiting (LOC in only 10%)
- Later symptoms (developing over hours/days) include mood and cognitive disturbances, sensitivity to light and noise, and sleep disturbances

Epidemiology
- Up to 3.8 million sport-related concussions yearly in the US
- Football is the most likely sport to cause head injury overall, and most concussions occur in boys
  - Most injuries to girls occur during soccer or basketball
  - In same sports, girls more likely to get concussions (may represent underreporting in boys)
- Young athletes are at highest risk
  - >90% of sports head-injury fatalities occurred in high school or younger (Halstead, 2011)
  - Catastrophic football head injuries are 3x more likely to occur in high school than college athletes

Recurrent sports-related traumatic brain injury (TBI) in children/adolescents
- "Second-impact syndrome" refers to rapid clinical deterioration after a relatively minor head trauma (or even a nonspecific fall or blow to the body) in an athlete who is still symptomatic after a concussion.
  - Proposed mechanism: cerebral vascular dysregulation leads to rapid onset cerebral edema
  - The term is controversial: little evidence that this syndrome is distinct from the diffuse cerebral edema which may occur in young people after sports-related head trauma (McCrory, 1998)
- Risk of recurrent TBI seems to be higher after an initial concussion/TBI
  - Those who experience LOC are 6 times more likely than those without to sustain another concussion
  - The risk of recurrent concussion is highest 7 to 10 days after the first concussion, and with each concussion, the risk of future concussions increases. (Meehan, 2009)
  - Individuals with three concussions have a three times greater risk of future concussion compared with those without concussion. (Guskiewicz, 1993)
- Reasons for increased risk of repeated TBI as well as ICI after initial concussion include:
  - Certain athletes’ styles of play may predispose them to concussion
  - Certain athletes are more susceptible to concussion
  - Players who sustain multiple concussions may receive more play time
  - Subtle decreased in function (eg: processing time) may make athletes with recent concussion more vulnerable to repeat injury
- Recurrent concussion may cause long-term sequelae, such as neuropsychological impairments, headaches, vertigo and epilepsy
  - Good data on reduced cognitive function after concussion are lacking

Management:
- Classification of severity
  - Multiple grading scales have been proposed, few validated as predictive of recovery
A recent review by Meehan (2009) recommends that grading scales based on LOC and amnesia not be used, as these factors have not been shown to predict the severity or duration of concussion.

- Current recommendation is to use symptom-based approach to return-to-play

### Concussion Assessment Tools

#### 1. Sideline assessments

- **Maddock’s Questions:**
  - Which ground (field) are we at?
  - Which team are we playing today?
  - Who is your opponent at present?
  - Which quarter (period) is it?
  - How far into the quarter (period) is it?
  - Which side scored the last goal (points)?
  - Which team did we play last week?
  - Did we win last week?

- **Standardized assessment of concussion (SAC)**
  - Decrease from baseline is 95% sensitive and 76% specific for concussion
  - Tests orientation, immediate memory, concentration and delayed recall

- **SCAT and SCAT-2**
  - Incorporates SAC, BESS (Balance Error Scoring System), Maddock’s and GCS
  - Not yet validated
  - Important to know athlete’s baseline (Valovich McLeod: Male athletes scored lower, younger athletes scored lower, and those with concussion history scored lower)

#### 2. Neuropsychological testing

- May be performed by neuropsychologists, or via computerized assessments
- Numerous computerized assessments are available for use by trainers or physicians (eg: ImPACT)
  - Meehan (2012): 40% of high schools surveyed used a computerized assessment tool
  - Those with computerized tool less likely to return to play, more likely to return to play after evaluation by a physician
  - While validity and reliability have been reported, most studies performed by test manufacturers
  - May be useful for providers who see a large number of concussed kids, and do not have access to formal neuropsychological testing

- No guidelines about when to re-administer tests
- **A symptomatic athlete should not return to play, even if neuropsychiatric testing is normal**

### Imaging for Sport-Related Concussion

- By definition, routine CT and MRI do not contribute to evaluation, management or prognosis
- Imaging should be selectively performed in kids with focal neurologic findings, persistently altered mental status or worsening symptoms
- Currently, there is insufficient evidence on utility of newer imaging modalities, such as diffusion tensor imaging, FMRI and PET scans, to recommend their use

### Physical and Cognitive Rest

- Removal from or reduced time in school, reduction of workload, and additional time to complete tasks
- Avoidance of other concentration tasks, including video-games, computer use, and TV viewing
- Avoid physical exertion until asymptomatic (see “Graded Return to Play”, below)

### Prevention:

- Helmet use:
  - Case-control studies show reduced concussions, but causality unclear (helmet, or safer play?)
- Education: Parent handouts from the AAP available at www.healthychildren.org
Handouts available on minor head trauma, sport-related head trauma, and sports safety.

- Advocacy
  - Increased awareness has led to better wider acceptance of the dangers, and wider use of standard assessment tools, and state legislation

Guidelines for Return to Play:
- While a number of guidelines (Cantu, Colorado, American Academy of Neurology) have been proposed, all are based on expert consensus rather than evidence.
- What these guidelines have in common
  - Athletes suspected of concussion should be removed immediately, and should not return to play until signs/symptoms of acute concussion have resolved ("when in doubt, sit them out")
  - Many guidelines grade severity of injury according to LOC and amnesia (controversial): any LOC or concussion symptoms > 15 min, or amnesia should not return until asymptomatic for 1 week
  - None have been prospectively validated
- A proposed reasonable approach, based on consensus, includes
  - No player should return until symptoms have completely resolved
  - Use a stepwise approach for return to play
  - Younger athletes should be managed more conservatively
  - For an athlete with recurrent or severe/prolonged concussion, both the injury and the athlete’s return to play should be managed by an expert with experience in sports-related concussion
- The Zurich Consensus Statement on Concussion in Sport (McCrory 2009) recommends
  - Six–day graduated return to play, progressing to next step if remains symptomatic X 24 hours (Table 1)

Table 1: Graduated Return to Play for Athletes with Concussion (Zurich Consensus Statement on Concussion in Sport)

<table>
<thead>
<tr>
<th>Rehabilitation stage</th>
<th>Exercise Allowed</th>
<th>Objective</th>
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<tbody>
<tr>
<td>1. No activity</td>
<td>Complete physical and cognitive rest</td>
<td>Recovery</td>
</tr>
<tr>
<td>2. Light aerobic exercise</td>
<td>Light walking, swimming, stationary cycling. No resistance training</td>
<td>Increase heart rate, up to 70% of max</td>
</tr>
<tr>
<td>3. Sport-specific exercise</td>
<td>Simple skating or running drills, no impact</td>
<td>Add movement</td>
</tr>
<tr>
<td>4. Non-contact training drills</td>
<td>Complex drills, such as passing, no impact. Resistance training OK</td>
<td>Introduce coordination and cognition, conditioning</td>
</tr>
<tr>
<td>5. Full contact practice</td>
<td>Normal training activities</td>
<td>Restore confidence, assessment of function by coaches</td>
</tr>
<tr>
<td>6. Return to play</td>
<td>Normal game play</td>
<td>Return to play</td>
</tr>
</tbody>
</table>
Imaging for Head Trauma:


Cancer and MR Risk from CT Scans


Sports Concussion:
**Figure 1a: Proposed Guidelines for Imaging after Minor Head Trauma in Children <2**


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Child <2 yrs with apparent minor head trauma

**Is the child at HIGH RISK for clinically-important traumatic brain injury (cITBI)?**

- GCS < 14 (on non-verbal child GCS)
- Other signs of altered mental status
- Signs of skull fracture

Yes

CT scan recommended

13.9% of population† 4.4% risk of cITBI

†includes pts from derivation and validation set (n=10,817)

No

Predictors of cITBI?

- Occipital/parietal/temporal scalp hematoma
- History of LOC ≥5 seconds
- Severe mechanism
- Not acting normally per parent

Yes

Observation desired

32.6% of population† 0.9% risk of cITBI

Reassess for predictors of cITBI after 4-6 hours

No

CT scan NOT recommended

53.5% of population† <0.02% risk of cITBI

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Discharge if Meets Criteria

- **Reliable caregiver**
- No significant extracranial injuries or other indications for admission
- No suspicion for abuse or neglect

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Definitions

1. **Altered mental status**
   - Agitation or somnolence
   - Repetitive questioning (for age)
   - Slow response to verbal communication

2. **Signs of skull fracture**
   - Palpable skull fracture
   - Periorbital or retro-auricular bruising (Battle’s sign)
   - CSF otorrhea or rhinorrhea
   - Hemotympanum

3. **Severe Mechanism**
   - MVC with patient ejection, death of another passenger or rollover
   - Ped or bicycle struck by MV without helmet
   - Fall of more than 3 ft
   - Head struck by high-impact object
   - Intentional injury (child abuse) suspected
Figure 1b: Proposed Guidelines for Imaging after Minor Head Trauma in Children 2-18

Child 2-18 yrs with apparent minor head trauma

Is the child at HIGH RISK for clinically-important traumatic brain injury (cTBI)?
- GCS < 14
- Other signs of altered mental status
- Signs of skull fracture

Predictors of cTBI?
- History of LOC
- History of vomiting
- Severe mechanism (see box)
- Severe headache

CT scan NOT recommended

Discharge if Meets Criteria
- Reliable caregiver
- No significant extracranial injuries or other indications for admission
- No suspicion for abuse or neglect

CT scan recommended

14% of population†
4.3% risk of cTBI

†includes pts from derivation and validation set (n=31,694)

Observation vs CT scan?
- Consider other clinical factors:
  - Worsening symptoms/signs after initial evaluation/observation
  - Multiple vs isolated findings
  - Parent preference

Observation desired

Reassess for predictors of cTBI after 4-6 hours

Definities

1. Altered mental status
   - Agitation or somnolence
   - Repetitive questioning
   - Slow response to verbal communication

2. Signs of skull fracture
   - Palpable skull fracture
   - Periorbital or retro-auricular bruising (Battle's sign)
   - CSF otorrhea or rhinorrhea
   - Hemotympanum

3. Severe Mechanism
   - MVC with patient ejection, death of another passenger or rollover
   - Ped or bicycle struck by MV without helmet
   - Fall of more than 5 ft
   - Head struck by high-impact object
   - Intentional injury (child abuse) suspected

* cTBI results in
  - Death
  - Neurosurgical intervention
  - Intubation > 24 h
  - Hospitalization > 2 nights

† 4.3% risk of cTBI
27.7% of population†
0.9% risk of cTBI
58.3% of population†<0.05% risk of cTBI
Figure 2: Estimated Organ-specific Brain Radiation Dose for Head CT by Age from Brenner, 2007

Figure 3: Estimated Lifetime Attributable Risk of Death from Cancer Due to Head CT by Age from Brenner, 2007