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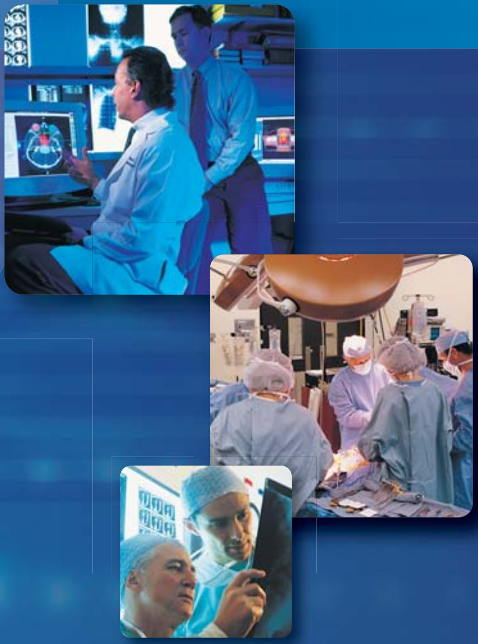
Computed Tomography for Pediatric Patients: Review of Clinical Effectiveness and Indications for Use



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Computed Tomography for Pediatric Patients: Review of Clinical Effectiveness and Indications for Use

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September 2009

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HEALTH TECHNOLOGY INQUIRY SERVICE (HTIS)

Health technology assessment (HTA) agencies face the challenge of providing quality assessments of medical technologies in a timely manner to support decision-making. Ideally, all important deliberations would be supported by comprehensive health technology assessment reports, but the urgency of some decisions often requires a more immediate response.

The Health Technology Inquiry Service (HTIS) provides Canadian health care decision-makers with health technology assessment information, based on the best available evidence, in a quick and efficient manner. Inquiries related to the assessment of health care technologies (drugs, devices, diagnostic tests, and surgical procedures) are accepted by the service. Information provided by the HTIS is tailored to meet the needs of decision-makers, taking into account the urgency, importance, and potential impact of the request.

Consultations with the requestor of this HTIS assessment indicated that a review of the literature would be beneficial. The research question and selection criteria were developed in consultation with the requestor. The literature search was carried out by an information specialist using a standardized search strategy. The review of evidence was conducted by one internal HTIS reviewer. The draft report was internally reviewed and externally peer-reviewed by two or more peer reviewers. All comments were reviewed internally to ensure that they were addressed appropriately.

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ACRONYMS AND ABBREVIATIONS

AATCM	automatic anatomic tube current modulation
ALARA	"as low as reasonably achievable" principle
BN	basal nuclei
cm	centimeter
CT	computed tomography
$\mathrm{CTDI}_{\mathrm{vol}}$	computed tomography dose index by volume
DWMRI	diffusion-weighted magnetic resonance imaging
E	effective radiation dose equivalent
H	Hounsfield units
κ	kappa coefficient
kVp	peak kilovoltage
mA	milliampere
mAs	milliampere second
MDCT	multidetector computed tomography
mGy	milligray
MRI	magnetic resonance imaging
mSv	millisievert
MSCT	multislice computed tomography
ROI	regions of interest

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TITLE: Computed Tomography for Pediatric Patients: Review of Clinical Effectiveness and Indications for Use

DATE: September 2009

EXECUTIVE SUMMARY

Context and Policy Issues

Computed tomography (CT) is one of the most commonly used diagnostic tools in medicine. Although it can improve certainty in diagnosis, research has shown that the low levels of ionizing radiation that are associated with CT scans can induce cancer. Because children are more susceptible to the risk of radiation-induced cancers, precautions (such as limiting access to CT based on clinical indication, limiting the scan range, decreasing the tube current, and using alternatives such as ultrasound and magnetic resonance imaging [MRI]) are generally taken in a pediatric population.

The introduction of multislice computed tomography (MSCT), which is also known as multidetector CT (MDCT), has resulted in the ability to simultaneously scan more than one cross-sectional image (slice) along a patient's longitudinal axis. Several whole organs can be scanned in one rotation when using an MSCT scanner, and the speed of the scan is improved. Although initial research showed increased radiation doses when the use of MSCT was compared with single-slice CT, recent studies show comparable or lower doses.

Because of the higher risk of radiation-induced cancers in children, clinicians are interested in selecting an appropriate MSCT scanner to balance the imaging quality and radiation doses among the available CT scanners with various numbers of slices. This review evaluates the clinical effectiveness of the different types of MSCT in disease diagnosis for common clinical indications of children and examines the radiation dose that is associated with various numbers of slices. The clinical effectiveness of MSCT was compared with that of two non-invasive diagnostic modalities: ultrasound scans and MRI.

Research Question

What is the clinical effectiveness of CT scanners with various numbers of slices for pediatric patients to obtain acceptable images for diagnosis and minimize radiation dose for common indications, including head CT for trauma, chest CT, cardiac CT, and abdominal CT?

Methods

Published literature was obtained by searching EMBASE and MEDLINE on the Ovid system between 2004 and April 2009. Regular alerts were established on EMBASE and MEDLINE, and information retrieved via alerts was current to June 8, 2009. Parallel searches were performed on PubMed and The Cochrane Library (Issue 2, 2009) databases. Initially, filters were applied to limit the retrieval to health technology assessments, systematic reviews, meta-analyses, randomized controlled trials, controlled clinical trials, and guidelines. The search was expanded to include observational studies that were published in the past five years when no relevant articles were identified during the first search. The Google search engine was used to search for information on the Internet. Two independent reviewers screened articles for selection.

Summary of Findings

There is little published evidence on the clinical effectiveness of CT scanners with various numbers of slices regarding head CT for trauma, chest CT, cardiac CT, and abdominal CT among pediatric patients. Although there have been studies performed with adult populations, there were only two MSCT studies that involved pediatric patients and that mentioned the number of slices.

Based on data from the included studies, the image quality of 64-MSCT and 16-MSCT was comparable, and the 64-slice scanner reduced radiation exposure by 26.3% compared with the 16-slice scanner. A lower tube voltage (80 kVp) resulted in reduced radiation dosage to patients without sacrificing image quality. The use of MSCT combined with automatic exposure control effectively reduced the radiation exposure. A comparison between a 16-slice MSCT scanner and MRI showed that CT was not as sensitive as diffusion-weighted MRI (DW MRI) in detecting brain injuries among children.

Conclusions and Implications for Decision-Making or Policy-Making

It is difficult to draw conclusions based on the limited data available. CT use, especially in children, has increased rapidly in recent years. It is challenging to find an appropriate balance between image quality and dosage of radiation exposure.

Well-designed clinical studies are needed to inform evidence-based decisions about the use of MSCT in a pediatric population. No recent relevant clinical practice guidelines were identified. As a result, there is a need to develop guidance for clinicians on the use of MSCT among children.

1 CONTEXT AND POLICY ISSUES

Computed tomography (CT) is one of the most commonly used diagnostic methods in medicine. Computed image analysis and X-rays are combined in CT to produce cross-sectional images (or slices) of the body. After a volume of the body is scanned, a technologist or radiologist can produce two-dimensional and three-dimensional images.[1] The use of CT can improve the certainty of disease diagnosis;[2] however, recent research has suggested that low levels of ionizing radiation, such as those associated with CT scans, can induce cancer.[3,4] Children are more susceptible to the risk of radiation-induced cancer compared with adults because a child's developing organs are more sensitive to radiation effects than adult organs. Also, the radiation exposure from a fixed set of CT parameters (for example, peak kilovoltage [kVp] and milliampere [mA]) results in a dose that is high for a child's smaller cross-sectional area. In addition, an infant or child has a longer life expectancy during which to develop radiation-induced cancers (the oncogenic effects of radiation may have a long latent period) compared with adults.[2,3] A guideline developed by the Canadian Association of Radiologists indicates that CT scanning protocols should be optimized to minimize radiation dose, particularly in children.[5] The "as low as reasonably achievable (ALARA) principle", which is used in practice, includes limiting access to CT based on clinical indication, limiting the scan range, decreasing the tube current, and using alternatives, such as ultrasound and magnetic resonance imaging (MRI).[4] An effective CT scanner offers the highest image quality and diagnostic effectiveness, and delivers the lowest possible radiation dose to the patient at the same time.[6]

Multislice computed tomography (MSCT), also known as multidetector CT (MDCT), has emerged in the past decade. The number of detector rows determines the number of slices that can be obtained.[7] The technology has been advancing so that the number of slices has increased from 4 to 8, 16, 32, 40, and 64, with 64-slice scanners being the most commonly used.[8] Systems with more detector rows (180, 256, and 320 slices) are commercially available.[7,9] Compared with the single-slice CT, multiple detector rows in MSCT permit simultaneous scanning of more than one slice along the patient's longitudinal axis.[8] There are potential benefits from using MSCT: it permits several whole organs to be scanned in one rotation and improves the speed needed to cover a given volume. The use of faster scanning is intended to reduce the need for sedation of children,[10,11] enable efficient blood-flow measurement through each phase of vasculature using contrast media, and facilitate multiplanar image reconstruction that can help the radiologist better visualize anatomic relationships.[7,9] In addition, MSCT can be used to cover the entire scan volume during one breath-hold. This allows for the reduction in motion artifacts during dynamic imaging applications, such as cardiac and perfusion studies and improved image quality.[7-9]

Initial reports following the introduction of MSCT indicated increased patient radiation doses with the use of MSCT relative to single-slice CT. Recent studies have shown comparable or lower patient doses.[8] The reason for the conflicting results was that radiation doses were reduced in single-slice CT systems as the use of more inefficient gas ionization detectors was abandoned. The use of 4-MSCT systems temporarily reversed this downward trend, because early MSCT scanners had reduced dose efficiencies due to a large proportion of the

X-ray beam width not being used for imaging. Modern MSCT systems are more efficient in this regard.[8]

Clinicians are interested in selecting an appropriate MSCT scanner to balance imaging quality and radiation doses from available CT scanners with various numbers of slices. This review was undertaken to evaluate the image quality and examine the radiation dose of different CT scanners with various numbers of slices in disease diagnosis for common clinical indications among children. The clinical effectiveness of MSCT was compared with two other non-invasive diagnostic modalities: ultrasound scans and MRI. Both are practical alternatives for CT in some clinical situations (for example, brain imaging) without the risk of radiation exposure.[12,13]

2 RESEARCH QUESTION

What is the clinical effectiveness of computed tomography (CT) scanners with various numbers of slices for pediatric patients to obtain acceptable images for diagnosis and minimize radiation dose for common indications, including head CT for trauma, chest CT, cardiac CT, and abdominal CT?

3 METHODS

3.1 Literature Search

Peer-reviewed searches for published literature were conducted for this review. All search strategies were developed by an information specialist, with input from the project team.

The following bibliographic databases were searched through the Ovid interface: MEDLINE, MEDLINE In-Process & Other Non-Indexed Citations, and EMBASE. Parallel searches were run in PubMed and The Cochrane Library (Issue 2, 2009). The search strategy comprised controlled vocabulary, such as the National Library of Medicine's MeSH (Medical Subject Headings), and keywords. Methodological filters were applied to limit the retrieval to health technology assessments, systematic reviews, meta-analyses, randomized controlled trials, controlled clinical trials, and guidelines. When no relevant articles were identified during the first search, an observational filter was applied to a focused search (main concepts appeared in the title or main subject heading) for targeted observational studies. Appendix 1 shows the detailed search strategies.

The search was restricted to English-language clinical articles that were published between 2004 and April 2009. Regular alerts were established on EMBASE and MEDLINE, and information that was retrieved via alerts was current to June 8, 2009.

Grey literature (literature that is not commercially published) was identified by searching the websites of health technology assessment and related agencies, professional associations, and other specialized databases. Google and other Internet search engines were used to search for additional information. These searches were supplemented by hand-searching the bibliographies and abstracts of key papers, and through contacts with appropriate experts and agencies.

3.2 Article Selection

Two independent reviewers (SC and KM) reviewed the 992 titles and abstracts that were retrieved during the literature search using pre-determined selection criteria. After screening, 71 articles were retrieved for consideration. The two reviewers independently evaluated the full-text version of all 71 articles. Studies comparing CT scanners with different numbers of slices were included in this report. Also included were studies comparing MSCT with ultrasound or MRI. Studies were excluded because of inappropriate study design (they were not systematic reviews, or randomized controlled trials, or comparative studies, or clinical guidelines), inappropriate population (they were not pediatric patients), inappropriate intervention (not MSCT, or the number of slices was unspecified), or inappropriate comparator (not comparing with another MSCT, ultrasound, or MRI). Any differences in the selection of articles were resolved by discussion and consensus between reviewers. Appendix 2 presents the process of study selection.

4 SUMMARY OF FINDINGS

Two articles were included in this report. These were both observational studies that compared MSCT with MRI, or compared different MSCTs with different numbers of slices. Our search did not identify any health technology assessments, systematic reviews, randomized controlled trials, or clinical guidelines on the clinical effectiveness of MSCT in the pediatric population.

4.1 Observational Studies

Two observational studies were identified during the literature search.[14,15]

Herzog et al. conducted a retrospective evaluation among children with congenital thoracic cardiovascular abnormalities to assess the effect of weight-based scanning protocols and automatic anatomic tube current modulation (AATCM) on a 64-MSCT scanner. This study also compared the angiography results with those of cardiac sonography, angiography, or findings from surgery.[14] Among the 68 patients who were evaluated, 38 underwent a procedure using 64-MSCT (SOMATOM Sensation Cardiac 64, Siemens Medical Solutions) with AATCM, and 30 underwent a procedure using 16-MSCT (LightSpeed VCT Series, GE Healthcare). The mean age in the 64-MSCT group was 5.8 years (range 1 day to 15 years). The mean age was 6.0 years (range 1 day to 15 years) in the 16-MSCT group. The scans using 64-MSCT were performed with commercially available tube current modulation software (CAREDose4D, Siemens Medical Solutions) with online monitoring of tissue attenuation and real-time adjustment of the base tube current as a function of the projection angle. Three levels of tube voltages were used in the 64-MSCT group: 80 kVp, 100 kVp, and 120 kVp. Scans were compared with those done using 16-MSCT, a tube voltage of 120 kVp, and a tube current ranging between 32 mA and 110 mA. Each participant was analyzed independently by an experienced cardiovascular radiologist and an experienced pediatric radiologist. Both professionals were aware of the clinical data, but they were blinded to the scanning parameters and patient characteristics such as weight, age, and sex. Each data set was assessed for image noise and graded for image quality. Image noise was determined by measuring the standard deviation, using Hounsfield units, in four regions of interest (ROI) consistently placed in the descending aorta, the trachea, the pulmonary artery, and the right greater pectoralis muscle. An average noise value of the four ROI measurements was calculated for each participant in the study. The criteria for image quality grading were the subjective perception of image noise, soft-tissue contrast, sharpness of tissue interfaces, conspicuity of anatomic detail, and degree of image degradation by streak or beam-hardening artifacts. All relevant vascular structures (heart, thoracic aorta, supra-aortic branches, pulmonary arteries and veins) were assessed by both professionals, who used a five-point scale to assess the image quality (1 for unacceptable and 5 for excellent diagnostic quality). On the basis of the individual scores for relevant vascular structures and anatomic anomalies, an average quality score was calculated for each participant. The quality was considered to be sufficient when the score was 3 or higher.

Patient characteristics in the 64-MSCT group and the 16-MSCT group were similar for age, height, and weight. The mean scanning time in the 64-MSCT group was 4.3 seconds. The mean scanning time in the 16-MSCT group was 10.4 seconds.

The main findings were:

- 64-MSCT and AATCM compared with the reference (64-MSCT without AATCM) at the three-voltage levels:
  - The use of 64-MSCT resulted in a statistically significant reduction in average tube current-time product (−57.8%) compared with the reference ($P < 0.05$)
  - The use of 64-MSCT resulted in a reduction in mean volume CT dose index ($CTDI_{vol}$) (−56.3%) compared with the reference (P value and 95% confidence interval were not reported)
  - The use of 64-MSCT resulted in a reduction in mean dose-length product (−54.9%) compared with the reference (P value and 95% confidence interval were not reported)
  - The use of 64-MSCT resulted in a reduction in estimated mean effective radiation dose equivalent (E) (−60.3%) compared with the reference (P value and 95% confidence interval were not reported).
- 64-MSCT and AATCM compared with 16-MSCT at the 120 kVp level:
  - The use of 64-MSCT resulted in a statistically significant reduction in average tube current-time product (−26.3%) compared with 16-MSCT ($P < 0.05$)
  - The use of 64-MSCT resulted in a reduction in mean $CTDI_{vol}$ (−61.5%) compared with 16-MSCT (P value and 95% confidence interval were not reported)
  - The use of 64-MSCT resulted in a reduction in mean dose-length product (−40.3%) compared with 16-MSCT (P value and 95% confidence interval were not reported)
  - The use of 64-MSCT resulted in a reduction in the estimated mean radiation dose equivalent (−39.7%) compared with 16-MSCT (P value and 95% confidence interval were not reported)
  - There was no statistically significant difference between the two groups in image quality score (3.8 ± 0.3 compared with 3.6 ± 0.4, $P = 0.97$) and image noise (9.1 ± 2.8H compared with 8.9 ± 4.5H, $P = 0.31$).
- When scans using 64-MSCT and AATCM were done at different levels of tube voltages, the tube current-time product was statistically significantly lower for 80 kVp scans than for 100 kVp and 120 kVp scans. The image quality was similar across the three levels.
- All cardiovascular defects that had been detected by MSCT scans were correlated with findings from cardiac sonography. No details were reported.

Table 1 presents the comparisons between 64-MSCT and the reference, and between 64-MSCT and 16-MSCT.

The authors concluded that when using 64-MSCT among pediatric patients, AATCM, combined with low tube voltage settings, significantly reduced radiation exposure.

Table 1: Radiation Exposure: 64-MSCT With AATCM Versus 64-MSCT Without AATCM (Overall Results for Three Voltage Levels); 64-MSCT With AATCM Versus 16-MSCT for 120 kPv Scans[13]

Outcomes	64-MSCT With AATCM	64-MSCT Without AATCM (Reference)	64-MSCT With AATCM	16-MSCT
tube current-time product (mAs, mean ± SD)	54.1 ± 44.0	128 ± 77.5	76.6 ± 48.0	104 ± 37.8
$CTDI_{vol}$ (mGy, mean ± SD)	2.8 ± 3.1	6.4 ± 6.0	5.3 ± 3.2	13.8 ± 5.0
DLP (mGy × cm, mean ± SD)	77.1 ± 103.7	171 ± 200.2	156.8 ± 123.5	262.8 ± 125.7
E (mSv, mean ± SD)	2.5 ± 2.1	6.3 ± 4.4	4.4 ± 2.1	7.3 ± 2.8

AATCM = automatic anatomic tube current modulation; cm = centimeter; CT = computed tomography; $CTDI_{vol}$ = CT dose index by volume; DLP = dose-length product; E = effective radiation dose equivalent; mAs = milliampere second; mGy = milligray; MSCT = multislice CT; mSv = millisievert; SD = standard deviation.

Chau et al. compared the predominant pattern of brain injury detected using CT, conventional MRI, and diffusion-weighted MRI (DWMRI) among term newborns with neonatal encephalopathy on the third day of life.[15] All patients were evaluated using a Philips Brilliance 16-slice multidetector CT scanner. Conventional MRI and DWMRI examinations were performed immediately after the CT scan using a Siemens 1.5 Tesla Avanto system. DWMRI was the gold standard. The CT images were reviewed by an experienced neuroradiologist who was blinded to the newborns' medical history. The MRI images were reviewed by two study investigators and classified by consensus. The predominant pattern of brain injury was classified as normal, watershed, basal nuclei (BN), total injury, or focal-multifocal injury. A follow-up conventional MRI examination was performed on days 8 to 10, based on clinical need. Agreement between CT and MRI findings was described using the kappa coefficient (κ). The strength of agreement was interpreted using the scale that was proposed by Landis and Koch (poor or fair when κ = 0 to 0.40; good when κ = 0.41 to 0.60; excellent when κ = 0.61 to 0.80; almost perfect when κ = 0.81 to 1).[15]

Forty-eight newborns were included in the study. There was good agreement on the predominant pattern of brain injury using CT and DWMRI (κ = 0.56, 67% agreement). Comparing CT with DWMRI, agreement was noted in 13 of 16 infants with the normal pattern, 3 of 4 with the watershed pattern, 6 of 8 with the BN pattern, 6 of 7 with the total pattern, and 4 of 13 with the focal-multifocal injury pattern. Thus, the sensitivities of CT examinations were 81.25% for normal, 75% for watershed, 75% for BN, 85.71% for total, and 30.77% for focal-multifocal. The specificity of CT examinations was 68.75% for normal, 88.64% for watershed, 97.5% for BN, 100% for total, and 100% for focal-multifocal. Most of the disagreement occurred in focal-multifocal injuries when fewer lesions were detected using CT examinations compared with DWMRI.

Nineteen newborns underwent follow-up MRI examinations in the second week of life, and the predominant pattern that was seen on day three using DWMRI was confirmed. This indicated that 16-MSCT was less sensitive compared with DWMRI in diagnosing brain injuries among children.

4.2 Limitations

Insufficient data are available to evaluate the relationship between levels of MSCT and radiation exposure in children. Even though the literature search was expanded to include observational trials with a comparator group in the past five years, only two studies were selected. Both studies involved small samples (68 and 48), and one[14] examined the radiation doses between groups. There was no compelling evidence provided by the studies to answer the research questions because of the study design that was used. The results should be interpreted with caution because 64-MSCT and 16-MSCT were used in different patient groups. In addition, one study[14] compared MSCT with ultrasound examinations, but the details of the results were not reported. Clinical trials of head CT for trauma, chest CT other than cardiac CT, or abdominal CT in children were not identified.

5 CONCLUSIONS AND IMPLICATIONS FOR DECISION-MAKING OR POLICY-MAKING

There is limited published evidence that can be used to answer the research question. Most of the studies on the use of MSCT that were identified during the literature search were performed in adult populations, or the authors did not specify the number of slices for the scanner. As a result, the information was not relevant to our assessment.

Evidence-based guidelines[5,16] on CT scanning in disease diagnosis did not provide guidance on the use of MSCT in children. Two comparative studies met our selection criteria. One study[14] compared 64-MSCT with 16-MSCT in children with congenital cardiovascular abnormalities and reported a shorter scanning time when the scanner with the most slices was used. The image quality of 64-MSCT and 16-MSCT was comparable and considered to be sufficient. The 64-MSCT scanner produced statistically significantly reduced radiation exposure compared with the 16-MSCT scanner. The adoption of an appropriate protocol (80 kVp) was related to lower radiation doses without compromising the image quality. Another study[15] that compared 16-MSCT with MRI indicated that CT was not as sensitive as DWMRI in detecting certain lesions among children with brain injuries. It is difficult to draw conclusions based on these limited data.

Previous research indicated that the amount of radiation dose that a patient receives from a CT scan depends on the design of the scanner and the way that the scanner is used (different settings of scanning parameters such as kVp, mAs, and scan length). A variation in these parameters results in greater dose differences than those due to scanner design.[17] One study[14] showed that an automatic exposure control system, AATCM, reduced the radiation dose in pediatric patients when AATCM was combined with 64-MSCT. Some manufacturers have developed protocols that are specific to the pediatric population to help physicians use the lowest radiation dose possible, while maintaining diagnostic image quality.[18,19] Compliance with size- or age-adapted pediatric CT scanning protocols is recommended, because this is related to dose reduction, and the clinically relevant image quality is not compromised.[8,20]

CT use has increased rapidly.[21] In the past two decades, the use of CT scanning has increased by more than 800% worldwide.[8] One study published in 2008 reported that in 1993, 6% of CT examinations were performed in children. The percentage has increased to 10%, delivering approximately 67% of the collective radiation dose to children.[14] It is a challenge to find an appropriate balance between image quality and radiation dose.

Well-designed clinical studies are needed to provide more rigorous evidence on the clinical effectiveness of using MSCT in the pediatric population. In addition, there is a need to develop clinical practice guidelines on the use of MSCT in children.

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APPENDIX 1: LITERATURE SEARCH STRATEGIES

Overview	
Interface:	Ovid
Databases:	EMBASE <1996 to 2009 Week 19> Ovid MEDLINE(R) In-Process & Other Non-Indexed Citations and Ovid MEDLINE(R) 1950 - Present **Note:** Subject headings have been customized for each database. Duplicates between databases were removed in Ovid.
Date of Search:	May 11, 2009
Alerts:	Weekly search updates began May 15, 2009 until June 8, 2009.
Study Types:	Systematic reviews; meta-analyses; health technology assessments; randomized controlled trials; controlled clinical trials; observational trials.
Limits:	Publication years 2004 – June 2009 English language
Syntax Guide	
/	At the end of a phrase, searches the phrase as a subject heading
exp	Explode a subject heading
*	Before a word, indicates that the marked subject heading is a primary topic; or, after a word, a truncation symbol (wildcard) to retrieve plurals or varying endings
* or $	At the end of a word indicates truncation
?	Truncation symbol for one or no characters only
ADJ	Requires words are adjacent to each other (in any order)
ADJ#	Adjacency within # number of words (in any order)
.ti.	Title
.ab.	Abstract
.hw.	Heading Word; usually includes subject headings and controlled vocabulary
.pt.	Publication type
.jw.	Journal word
.md.	Methodology
.mp.	Mapping alias (searches title, abstract, heading words, table of contents and key phrase identifiers)

Ovid Multi-database Strategy	
Computed Tomography MEDLINE	
1	exp Tomography, X-Ray Computed/ or Tomography Scanners, X-Ray Computed/
2	((CT or CTs or CAT) adj3 (scan* or x-ray* or cine or helical or spiral or colonograph* or virtual colonoscopy* or volume* or cone beam*)).ti,ab.
3	(compute* adj3 tomograph*).ti,ab.
4	(tomodensitometr* or electron beam tomograph* or tomograph* scan* or EBCT or MDCT).ti,ab.
5	(x ray* adj3 (microtomograph* or microcomput*)).ti,ab.
6	or/1-5
Paediatrics MEDLINE	
7	exp Pediatrics/ or Hospitals, Pediatric/ or exp Intensive Care Units, Pediatric/ or exp Adolescent/ or exp Child/ or exp Infant/
8	(paediatric* or pediatric* or child* or infant* or baby or babies or newborn* or neonat* or preemie* or infancy or girl* or boy* or kid or kids or teen* or youngster* or youth* or adolescen* or preschooler* or pre schooler*).ti,ab.
9	7 or 8
10	6 and 9
11	10
12	limit 11 to (english language and yr="2004 -Current")
SR/HTA/MA	
13	meta-analysis.pt.
14	meta-analysis/ or systematic review/ or meta-analysis as topic/ or exp technology assessment, biomedical/
15	((systematic* adj3 (review* or overview*)) or (methodologic* adj3 (review* or overview*))).ti,ab.
16	((quantitative adj3 (review* or overview* or synthes*)) or (research adj3 (integrati* or overview*))).ti,ab.
17	((integrative adj3 (review* or overview*)) or (collaborative adj3 (review* or overview*)) or (pool* adj3 analy*)).ti,ab.
18	(data synthes* or data extraction* or data abstraction*).ti,ab.
19	(handsearch* or hand search*).ti,ab.
20	(mantel haenszel or peto or der simonian or dersimonian or fixed effect* or latin square*).ti,ab.
21	(met analy* or metanaly* or health technology assessment* or HTA or HTAs).ti,ab.
22	(meta regression* or metaregression* or mega regression*).ti,ab.
23	(meta-analy* or metaanaly* or systematic review* or biomedical technology assessment* or bio-medical technology assessment*).mp,hw.
24	(medline or Cochrane or pubmed or medlars).ti,ab,hw.
25	(cochrane or health technology assessment or evidence report).jw.
26	(meta-analysis or systematic review).md.
27	or/13-26
28	27 and 12
RCTs	
29	Randomized Controlled Trial.pt.
30	Randomized Controlled Trials as Topic/

Ovid Multi-database Strategy	
31	Randomized Controlled Trial/
32	Randomization/
33	Random Allocation/
34	Double-Blind Method/
35	Double Blind Procedure/
36	Double-Blind Studies/
37	Single-Blind Method/
38	Single Blind Procedure/
39	Single-Blind Studies/
40	Placebos/
41	Placebo/
42	(random* or sham or placebo*).ti,ab,hw.
43	((singl* or doubl*) adj (blind* or dumm* or mask*)).ti,ab,hw.
44	((tripl* or trebl*) adj (blind* or dumm* or mask*)).ti,ab,hw.
45	or/29-44
46	45 and 12
Guidelines	
47	Guidelines as topic/ or Health Planning Guidelines/ or Practice Guidelines as Topic/ or Consensus Development Conferences as Topic/ or Critical Pathways/
48	(Guideline or Practice Guideline or Consensus Development Conference or Consensus Development Conference, NIH).pt.
49	((critical adj (path? or pathway? or protocol?)) or (care adj (map? or path? or plan? or pathway? or consensus))).ti,ab.
50	(guideline* or standards).ti.
51	(expert consensus or consensus statement or consensus conference* or consensus development or clinical guideline* or practice guideline* or practice parameter* or position statement* or policy statement* or CPG or CPGs or treatment protocol* or best practice*).ti,ab.
52	or/47-51
53	12 and 52
54	28 or 46 or 53
55	*practice guideline/ or *clinical pathway/ or *clinical protocol/ or *consensus development/ or *good clinical practice/
56	(guideline* or standards).ti.
57	(critical adj (path? or pathway? or protocol?)).ti,ab.
58	(practice parameter$ or position statement$).ti,ab.
59	guideline?.ti.
60	(expert consensus or consensus statement or consensus conference* or consensus development or clinical guideline* or practice guideline* or policy statement* or CPG or CPGs or treatment protocol* or best practice*).ti,ab.
61	(care adj (map? or path? or plan? or pathway? or consensus)).ti,ab.
62	or/55-61
63	12 and (27 or 45 or 52)
64	63 use prmz

Ovid Multi-database Strategy	
Computed Tomography Embase	
65	*Computed Tomography Scanner/ or *Computer Assisted Tomography/
66	(compute* adj3 tomograph*).ti.
67	(CT or CTs or CAT).ti.
Paediatrics EMBASE	
68	infant/ or child/ or preschool child/ or school child/ or adolescent/ or Pediatrics/
69	infant/ or child/ or preschool child/ or school child/ or adolescent/ or *Pediatrics/
70	(paediatric* or pediatric* or child* or infant* or baby or babies or newborn* or neonat* or preemie* or infancy or girl* or boy* or kid or kids or teen* or youngster* or youth* or adolescen* or preschooler* or pre schooler*).ti.
71	(65 or 66 or 67) and (68 or 70)
72	(65 or 66 or 67) and (69 or 70)
73	71 and (27 or 45 or 62)
74	73
75	limit 74 to english language
76	limit 75 to yr="2004 -Current"
77	76 use emef
78	77 or 64
79	remove duplicates from 78
80	79 use emef
81	79 use prmz
CCTs	
82	(Randomized Controlled Trial or Controlled Clinical Trial).pt.
83	Randomized Controlled Trial/
84	Randomized Controlled Trials as Topic/
85	Controlled Clinical Trial/
86	Controlled Clinical Trials as Topic/
87	Randomization/
88	Random Allocation/
89	Double-Blind Method/
90	Double Blind Procedure/
91	Double-Blind Studies/
92	Single-Blind Method/
93	Single Blind Procedure/
94	Single-Blind Studies/
95	Placebos/
96	Placebo/
97	Control Groups/
98	Control Group/
99	(random* or sham or placebo*).ti,ab,hw.
100	((singl* or doubl*) adj (blind* or dumm* or mask*)).ti,ab,hw.
101	((tripl* or trebl*) adj (blind* or dumm* or mask*)).ti,ab,hw.
102	(control* adj3 (study or studies or trial*)).ti,ab,hw.

Ovid Multi-database Strategy	
103	(Nonrandom* or non random* or non-random* or quasi-random*).ti,ab,hw.
104	(allocated adj1 to).ti,ab,hw.
105	((open label or open-label) adj5 (study or studies or trial*)).ti,ab,hw.
106	or/82-105
Ultrasound	
107	exp Endosonography/ or exp Ultrasonography/ or Ultrasound/ or Echography/ or (ultrasound* or ultrasonography or endosonograph* or ultrasonic or ultrasonic imag* or sonograph* or echograph* or echotomograph* or sonogram or sonograph*).ti,ab.
Magnetic Resonance Imaging	
108	exp Magnetic resonance imaging/ or Nuclear Magnetic Resonance Imaging/ or (magnetic resonance or MRI or fMRI).ti,ab.
109	107 or 108
110	12 use prmz
111	110 and 109 and 106
112	71 use emef
113	112
114	limit 113 to english language
115	limit 114 to yr="2004 -Current"
116	115 and 109 and 106
117	111 or 116
118	remove duplicates from 117
119	118 not 79
120	119 use prmz
121	119 use emef

Ovid Multi-database Focused Observational Study Strategy	
Focused Computed Tomography (MEDLINE)	
1	*Tomography, X-Ray Computed/ or *Tomography Scanners, X-Ray Computed/
2	((CT or CTs or CAT) adj3 (scan* or x-ray* or cine or helical or spiral or colonograph* or virtual colonoscopy* or volume* or cone beam*)).ti.
3	(compute* adj3 tomograph*).ti.
4	(tomodensitometr* or electron beam tomograph* or tomograph* scan* or EBCT or MDCT).ti.
5	(x ray* adj3 (microtomograph* or microcomput*)).ti.
6	4 or 1 or 3 or 2 or 5
Focused Paediatrics (MEDLINE)	
7	*Pediatrics/ or *Hospitals, Pediatric/ or *Intensive Care Units, Pediatric/ or *Adolescent/ or *Child/ or *Infant/
8	(paediatric* or pediatric* or child* or infant* or baby or babies or newborn* or neonat* or preemie* or infancy or girl* or boy* or kid or kids or teen* or youngster* or youth* or adolescen* or preschooler* or pre schooler*).ti.
9	8 or 7
10	6 and 9
11	10 use prmz
	Focused Computed Tomography (Embase)

Ovid Multi-database Focused Observational Study Strategy	
12	*Computed Tomography Scanner/ or *Computer Assisted Tomography/
13	(compute* adj3 tomograph*).ti.
14	(CT or CTs or CAT).ti.
15	13 or 12 or 14
Focused Paediatrics (EMBASE)	
16	*infant/ or *child/ or *preschool child/ or *school child/ or *adolescent/ or *Pediatrics/
17	(paediatric* or pediatric* or child* or infant* or baby or babies or newborn* or neonat* or preemie* or infancy or girl* or boy* or kid or kids or teen* or youngster* or youth* or adolescen* or preschooler* or pre schooler*).ti.
18	16 or 17
19	18 and 15
20	19 use emef
21	11 or 20
	Observational studies
22	epidemiologic methods/
23	epidemiologic studies/
24	Cohort studies/
25	longitudinal studies/
26	prospective studies/
27	follow-up studies/
28	retrospective studies/
29	case-control studies/
30	cross-sectional study/
31	(observational adj3 (study or studies or design or analysis ar analyses)).ti,ab.
32	(cohort adj3 (study or studies or design or analysis or analyses)).ti,ab.
33	(prospective adj3 (study or studies or design or analysis or analyses or cohort)).ti,ab.
34	((follow up or longitudinal or multidimensional or multi dimensional or case control or cross sectional or case comparison) adj3 (study or studies or design or analysis or analyses)).ti,ab.
35	(prevalence adj3 (study or studies or analysis or analyses)).ti,ab.
36	observational study/
37	Cohort analysis/
38	longitudinal study/
39	follow up/
40	retrospective study/
41	exp case control study/
42	or/22-41
43	42 and 21
44	limit 43 to english language
45	limit 44 to human
46	limit 45 to yr="2004 - 2009"
47	Remove duplicates

Other Databases	
PubMed	Search conducted for in process records using keywords and the same limits and study types as per the Medline search, with syntax adjusted for the PubMed database
Cochrane Library Issue 2, 2009;	Same MeSH, keywords, and date limits used as per Medline search, excluding study type restrictions. Syntax adjusted for Cochrane Library database.

Grey Literature

Dates for Search:	April 14, 2009 – April 17, 2009
Keywords:	Included terms for Computed Tomography scanners with a focus on radiation dose for paediatric patients
Limits:	Publication years 2004 - present

The following sections of the CADTH grey literature checklist, *Grey Matters: A Practical Search Tool for Evidence-Based Medicine* (http://www.cadth.ca/index.php/en/cadth/products) were searched:

- Health Technology Assessment (HTA) Agencies
- Clinical Practice Guidelines
- Advisories and Warnings (Health Canada Alerts only)
- Databases (free)
- INTERNET SEARCH (under Miscellaneous)
- OPEN ACCESS JOURNALS (also under Miscellaneous).

Organizations

National Cancer Institute (http://www.cancer.gov/)
American College of Radiology (http://www.acr.org/)

APPENDIX 2: STUDY SELECTION