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ABSTRACT

BACKGROUND: Conventional imaging protocols used in pediatric head CT scanning without specific adaptations to lower radiation dose or "standard dose" pediatric head CTs increase unnecessary radiation exposure. Modifying CT parameters, utilizing iterative reconstruction, and adopting specialized protocols are ongoing strategies to lower radiation dose in pediatric head CTs.

PURPOSE: This article will review studies reducing radiation exposure in pediatric patients undergoing head CT and provide meta-analysis of percent radiation dose reduction of the studies.

DATA SOURCES: Following PRISMA guidelines, we utilized Embase.com, Ovid Medline, Scopus, the Cochrane Central Register of Controlled Trials (CENTRAL), the Cochrane Database of Systematic Reviews (CDSR), and Clinicaltrials.gov to identify all relevant articles pertaining to radiation dose reduction in pediatric head CT.

STUDY SELECTION: All human studies (excluding animal, phantom, and cadaveric) published after 2012, aiming to lower radiation dose of a "Routine" or "Standard" dose CT protocol in use, were selected for review and metanalyses.

DATA ANALYSIS: We extracted study characteristics such as location, sample size, scanner, clinical indication, CT protocol parameter modifications, iterative reconstruction method if applicable, dose reduction, image quality metrics, and overall findings. CT protocol parameter modifications and dose reduction were summarized using descriptive statistics. Metanalyses on percent dose reduction were performed. Metanalyses were subgrouped by clinical indication, use of iterative reconstruction, and age group to isolate sources of heterogeneity between studies.

DATA SYNTHESIS: This review identified 20 studies modifying their routine or standard dose pediatric head CT protocols on human patients. These studies modified CT parameters with or without the use of iterative reconstruction and/or used specialized protocols. Most common CT parameters modifications consisted of decreasing tube current time product (mAs) (N=13) and/or tube voltage (kV) (N=9). The most successful dose reduction studies had the clinical indication of craniosynostosis and utilized iterative reconstruction. Ernst et al. (2016) utilized Model Based Iterative Reconstruction (MBIR) for craniosynostosis and reduced effective dose by 97% and Lyoo et al. (2023) utilized Advanced Modeled Iterative Reconstruction (ADMIRE) with ClariCT for craniosynostosis and reduced CTDIvol by 95.9%. Metanalyses revealed significant differences in percent dose reduction based on clinical indication.

LIMITATIONS: Heterogeneity of study protocols, incomplete protocol/outcome reporting, and variability of institution, scanner, patient demographics, and clinical indication limit the generalizability of our findings.

CONCLUSIONS: This systematic review and metanalysis identifies tube current time product as the most commonly modified CT parameter and also highlights CT clinical indication as an important factor to isolate when comparing dose reduction studies. Further research should further investigate iterative reconstruction techniques as well as photon-counting CT to maximize radiation dose reduction of pediatric head CT.

ABBREVIATIONS: ADMIRE = advanced modeled iterative reconstruction, ASIR = adaptive statistical iterative reconstruction, CTDIvol = CT dose index volume, DLIR = deep learning iterative reconstruction, DLP = dose length product, FBP = filtered back-projection, IMR = iterative model reconstruction, MBIR = model-based iterative reconstruction

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INTRODUCTION

In the United States, approximately 5 to 9 million computed tomography (CT) scans are performed on children annually, with the head being the most scanned region[1]. Pediatric patients, due to their developmental stage and smaller body sizes, are particularly susceptible to the harmful effects of ionizing radiation from head CT[2]. Adopting strategies to reduce radiation dose in head CTs without compromising diagnostic quality is vital for the long-term health of pediatric patients.

Several strategies exist to reduce radiation dose in pediatric CT scans. Inherent to reducing radiation dose is tailoring CT scanning parameters. Several studies adjust CT parameters like tube voltage (kV)[3-7], tube current (mA)[3,5,6], tube current time product (mAs)[4,7-11],

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slice thickness (mm)[12], pitch[6,10,13,14], and rotation time (s)[10,14], trading off diagnostic accuracy to minimize radiation dose. CT protocols dedicated to craniofacial anomalies or hydrocephalus are especially able to reduce radiation dose[4,6,7,13], as they can tolerate lower image quality due to easy visualization of their structures. Craniofacial CT, specifically, benefits from high inherent contrast of bone, needing less tube voltage and tube current to maintain adequate diagnostic value[13].

Another strategy is utilizing kernels[4], which are mathematical filters, or iterative reconstruction, which are advanced image processing algorithms to repeatedly refine and enhance image quality and reduce image artifacts[15]. These methods can permit additional dose reduction by allowing lower threshold of image quality. However, advanced iterative reconstruction technologies require significantly more computational power, making them prone to slow processing times and limited to newer and more expensive CT scanner models[16]. Furthermore, iterative reconstruction algorithms can overcorrect and introduce artifacts to scans if radiation dose is reduced too drastically, making it even more imperative to strike a right balance between dose reduction and image quality[16].

This systematic review and meta-analysis will compare radiation dose reduction strategies, CT parameter modifications, and iterative reconstruction for head CT studies conducted on children. We aim to identify best practices to maximize radiation exposure reduction while maintaining image quality.

MATERIALS AND METHODS

This systematic review follows the PRISMA reporting guidelines[17]. The study was exempt from institutional review board approval after being determined as nonhuman subjects research and therefore was not registered.

Search Strategy

Biomedical literature databases were searched for records including the concepts of head, face, skull, low-dose CT, radiation exposure, and image quality. Search strategies were created using a combination of keywords and controlled vocabulary in Embase.com 1947- , Ovid Medline 1946- , Scopus 1823- , Cochrane Central Register of Controlled Trials (CENTRAL), The Cochrane Database of Systematic Reviews (CDSR), and Clinicaltrials.gov 1997- . All search strategies were completed December 11, 2023, with no added limits but animal studies were removed where possible and a total of 2,358 results were found. 989 duplicate records were deleted using Covidence.org resulting in a total of 1,369 unique citations included in the project library. Fully reproducible search strategies for each database can be found in *Online Supplemental Data*.

Screening Process and Eligibility Criteria

Four investigators collectively (KH, ASS, JBR, AB) performed the title, abstract, and full-text selection phases, with three votes necessary to reach a consensus.

Our exclusion criteria follow:

1. Exclude papers published before 2012 (include 2012)
2. Exclude all cone beam-based CT
3. Exclude all combined CT (PET/CT, SPECT/CT, MRI/CT, etc.) needs to explicitly be a low dose CT protocol
4. Exclude non-human studies, such as pig/animal models, synthetic skulls, phantom studies
5. Exclude all non-head studies: such as whole body, or lower body, or neck
6. Exclude all adult studies, must be <18 years old

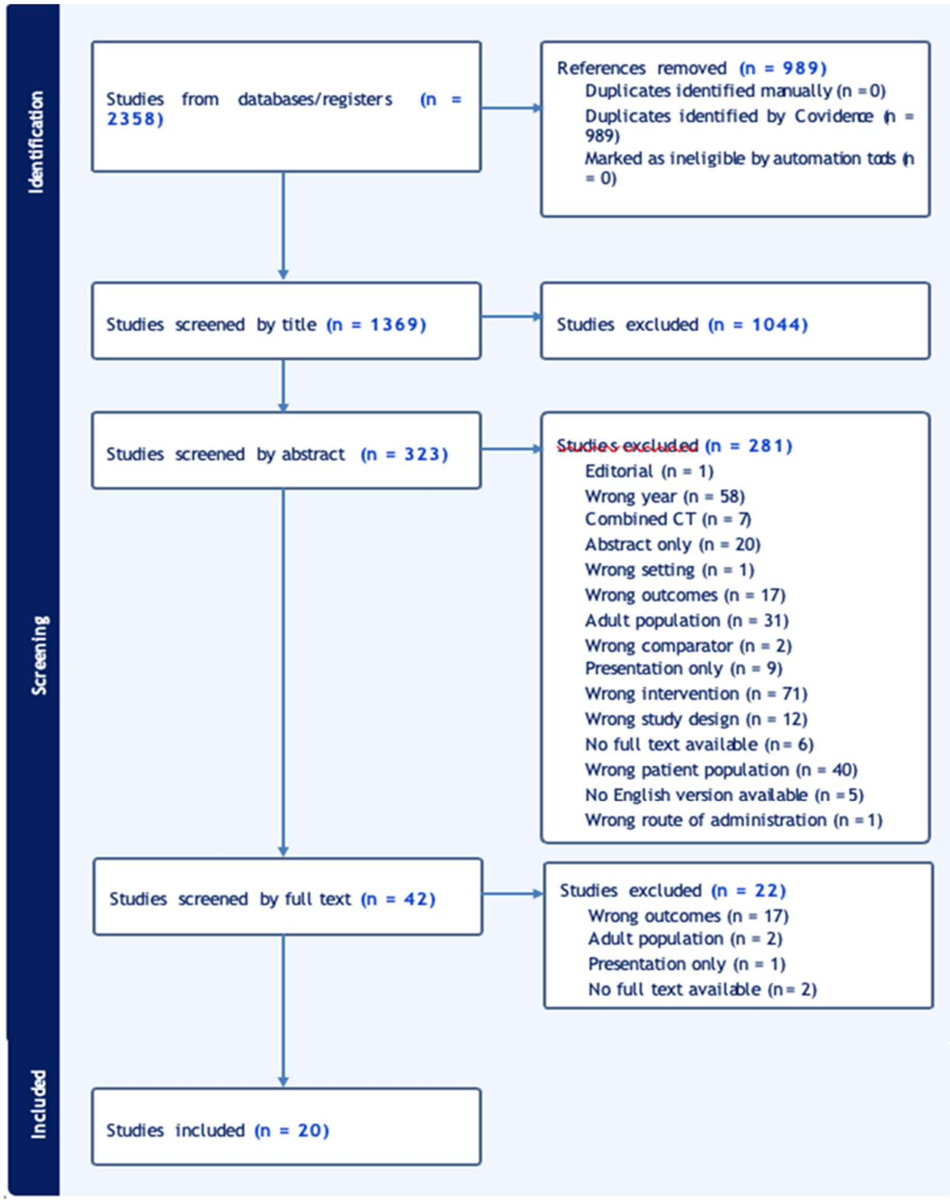

FIG 1. Prisma Screening Diagram

Data Extraction

Data such as CTDIvol, DLP, Effective Dose, Tube Voltage, Tube Effective Current, Tube Current, Slice Thickness, Pitch, Rotation Time, Scanner, CT Parameter modified, Iterative Reconstructive Method, Dose Reduction, Diagnostic Quality, and Effective Dose Conversion Factor were extracted from each article individually and crosschecked for accuracy. If CTDIvol, DLP, or Effective Dose were not reported in the study, missing values were computed using scan length (cm) or k coefficient if possible and applicable. 19. If CTDIvol, DLP, or Effective Dose were not reported or were unable to be computed, the study was excluded from dose reduction statistical analysis.

Several of the included studies stratified their data by age group, resulting in multiple reported values for CTDIvol, DLP, and Effective Dose. To summarize CT parameters and radiation doses across all studies, each study's multiple values were aggregated into a single value using weighted means. Additionally, for subgroup meta-analysis of percent dose reduction, each distinct age group within a study was treated as a separate study.

Statistical Analysis

Study characteristics such as CT protocol parameters, CTDIvol, DLP, and Effective Dose were compared between standard dose and low dose study protocols and were summarized with descriptive statistics and radar plot (Figure using Microsoft Excel). We conducted meta-analyses using the metagen function from the meta package in R (4.4.1)[18]. The meta-analysis followed a random effects model using the Hartung-Knapp adjustment to account for between-study variability and provide robust estimates. The primary effect size was the dose reduction ratio (%), with the associated standard errors used to compute weights for each study[19]. Studies that did not report variance metrics like standard error or standard deviation were not included in meta-analysis. Subgroup analyses were performed on predefined subgroups of Indication, With or Without Iterative Reconstruction, and Nearest Mean Age Group. Forest plots were generated for each subgroup analysis to visually represent individual study effect sizes, weights, subgroup summary, and overall pooled effect. A random effects model was applied to accommodate between study variability. Between-study heterogeneity was assessed using $\chi 2$ (Cochran's Q) and $p<0.0001$ indicated significant heterogeneity. Variance of the true effects across studies was represented by τ^2 and the percentage of total variation across studies due to heterogeneity rather than chance was quantified by I^2.[20]

Study Quality Assessment

The studies were assessed for quality by 2 independent blinded reviewers (KH and AB) using the National Institutes of Health Study Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies[21]. All studies were ranked as fair or better and the results are included in *Online Supplemental Data*.

RESULTS

Search and Data Extraction Results

Following the database search, 2358 articles were identified and screened for eligibility. Of these, 989 were excluded for being duplicates, 1044 were excluded by title screen, 281 were excluded by abstract screen, and 42 studies were selected for full text screening. In full text screening, 17 articles were excluded for wrong outcomes, 2 were excluded for the wrong population, 1 was excluded for being a presentation only, and 2 were excluded for having no full text. In total, 20 studies were included in this review. Two studies[8,11] did not report low or standard dose CTDIvol, DLP, or Effective Dose and two other studies[12,22] did not report standard dose CTDIvol, DLP, or Effective Dose and thus were excluded from radiation dose descriptive statistics. Therefore, descriptive statistics included 18 studies with 1620 low dose scans, and 1384 standard dose scans. Nine studies[5,8-12,22-24] did not report standard deviation or standard error and were ineligible for meta-analysis of percent dose reduction. In the eligible 11 studies[3,4,6,7,13,14,25-29] for meta-analysis, 878 low dose scans and 939 standard dose scans were included. Eligible studies for meta-analysis were further subgrouped by Clinical Indication, With or Without Iterative Reconstruction, and Nearest Mean Age Group. For Clinical Indication, 4 studies were identified as Emergency[14,26-28], 4 studies were identified as Craniofacial-Specific[4,6,7,13], 2 were identified as Ventricle-Specific[3,25], and 1 was identified as General[29]. For With or Without Iterative Reconstruction, 5 studies were identified as CT parameter modification only[3,4,6,7,25] and 6 studies were identified as CT parameter modification with iterative reconstruction[13,14,26-29].

Overview of Modified Protocols

The most commonly modified CT scanner parameters were tube current time product (mAs) (N=13)[4,7-12,14,22-25,27], followed by tube voltage (kV) (N=9)[3-7,13,23,27,28], current (mA) (N=6)[3,5,6,13,26,29], pitch (N=4)[6,10,13,14], rotation time (N=2)[10,14]. slice thickness (N=1)[12], and protocol time (N=1)[28]. Ten studies did not use iterative reconstruction[3-11,25], and 10 studies used iterative reconstruction[13,14,22-24,26-29]. Iterative reconstructive methods included Adaptive Statistical Iterative Reconstruction (ASIR) (N=3)[12,28,29], Advanced Modeled Iterative Reconstruction (ADMIRE) (N=2)[23,26], iDose4 (N=2)[24,27], Iterative Model Reconstruction (IMR) (N=2)[14,22], Model Based Iterative Reconstruction (MBIR) (N=1)[13], Deep learning ClariCT (N=1)[23], and Deep Learning Iterative Reconstruction (DLIR) (N=1)[12]. CT parameter values and radiation doses for the standard dose and low dose arms of each study are summarized in *TABLE 1. Summary of Low Dose and Standard Dose CT Protocol Parameter Values* and visualized in *FIG 2. Comparison of CT Parameter Values Radar Plot.*

	Standard Dose CT Protocol Mean	**Low Dose CT Protocol Mean**	**Standard Dose CT Protocol Range**	**Low Dose CT Protocol Range**
CTDIvol (mGy)	20.3 +/- 0.8	10.7 +/- 0.6	7.38 - 33.41	0.31 - 24.4
DLP (mGy.cm)	408 +/- 16.0	213 +/- 11	183.8 - 933	7.51 - 563
Effective Dose (mSv)	2.01 +/- 0.06	0.94 +/- 0.03	0.80 - 3.31	0.05 - 1.81
Tube Voltage (kV)	113.7 +/- 0.5	101.8 +/- 0.9	80 - 120	70 - 120
Tube Effective Current (mAs)	197.5 +/- 7.1	118.7 +/- 4.4	52 - 350	10 - 250

Tube Current (mA)	201.6 +/- 10.9	112.8 +/- 9.5	50 - 420	50 - 290
Slice Thickness (mm)	3.3 +/- 0.2	3.1 +/- 0.2	1.0 – 5.0	0.625 - 5.000
Pitch	0.88 +/- 0.03	0.84 +/- 0.03	0.60 - 1.50	0.39 - 1.50
Rotation Time (s)	0.60 +/- 0.03	0.55 +/- 0.01	0.25 - 1.50	0.25 - 1.00

TABLE 1. Summary of Low Dose and Standard Dose CT Protocol Parameter Values

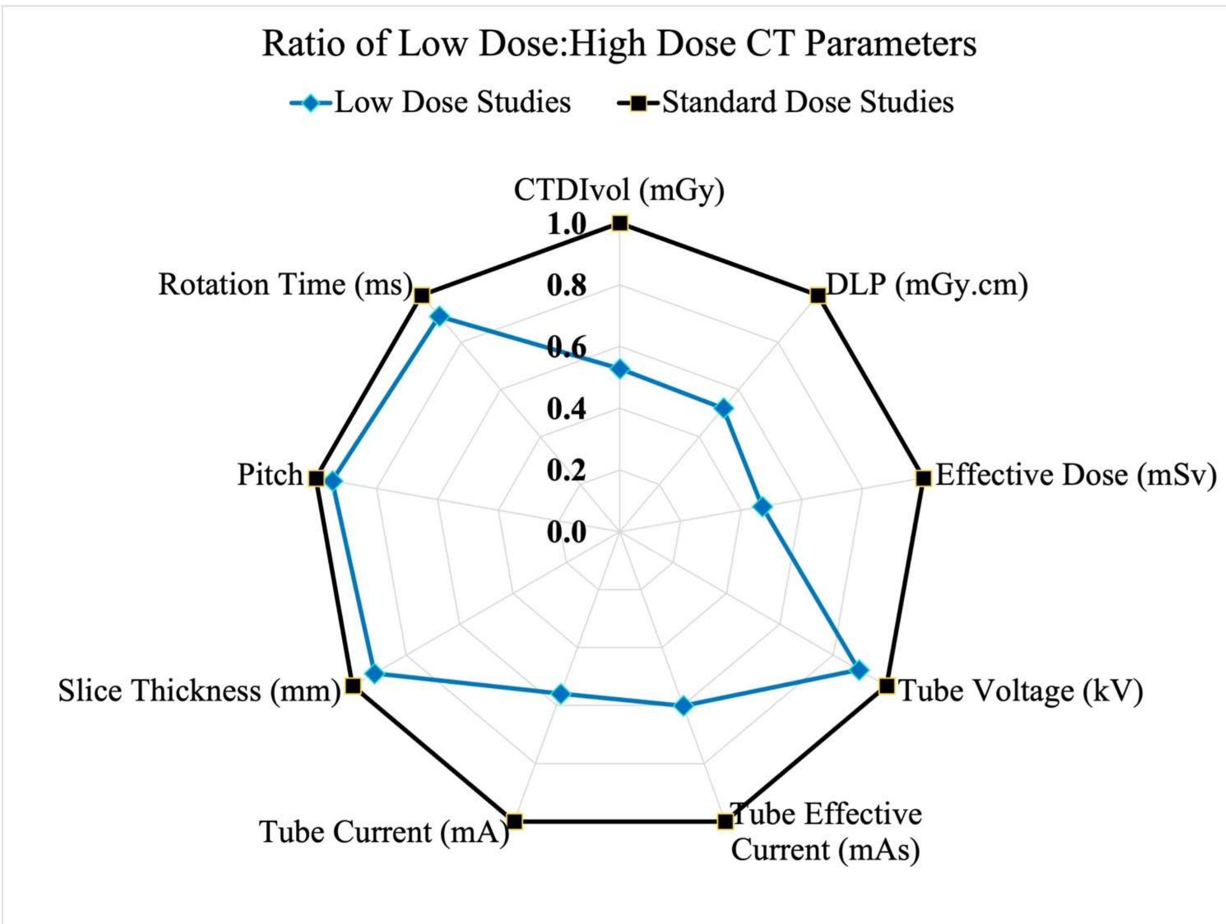

FIG 2. Comparison of CT Parameter Values Radar Plot

Iterative reconstruction methods had varying success in pediatric head CT dose reduction across multiple clinical indications.

For pediatric head CT for craniofacial specific indications, Ernst et al. (2016) utilized Model Based Iterative Reconstruction (MBIR) and reduced effective dose by 97%[13], and Lyoo et al. (2023) utilized Advanced Modeled Iterative Reconstruction (ADMIRE) with ClariCT and reduced CTDIvol by 95.9%[23]. However, these protocols were specific to craniosynostosis evaluation which have much lower thresholds for image quality. Still, other craniofacial/craniosynostosis protocols that did not use iterative reconstruction had lower percent dose reduction: Vazquez et al. (2013) reduced effective dose by 88%[6], Hye et al. (2022) reduced CTDIvol by 76.9%[4]. Zarei et al. (2022) reduced effective dose by 60%[7], and Komarraju et al. (2021) reduced effective dose by 51%.

For pediatric head CT for emergency indications, Sun et al. (2021) predicted that utilizing DLIR with High Setting (DL-H) for emergency indications could reduce radiation dose up to 85% and that DL-H was superior to ASIR-V in terms of image noise[12]. However, this predicted dose reduction of 85% with DL-H assumed the use of 5mm images which have less spatial resolution and clinical information than thinner images. Other iterative reconstructive methods for emergency use saw less success: Kadavigere et al. (2024) had 44.9-60.4% CTDIvol across different age groups using iDose4[27], Zhu et al. (2021) had 36.4% CTDIvol reduction using ASIR[28], Cho et al. (2020) had 30.6% CTDIvol reduction using ADMIRE[26], Southard et. al (2019) had 21.5% CTDIvol reduction using low dose IMR[14].

For pediatric head CT for ventricle specific indications, no studies were identified that used iterative reconstruction. Without iterative reconstruction, Morton et al. (2013) estimated 50-75% dose reduction but also evaluated craniofacial specific indications in addition to ventricle specific indications[11], Albert et al. (2015) reduced effective dose by 50.3%[3], Jończyk-Potoczna et al. (2012) reduced DLP by 40%[9], and Wallace et al. (2015) reduced CTDIvol by 39% but used automatic exposure control and automatic tube potential selection[25].

More characteristics of each study, including setting, sample size, scanner, clinical indication, study group stratification, CT parameter modifications, dose reductions, image quality metrics, and findings can be found in summary tables located in *Online Supplemental Data.*

Subgroup Meta-Analysis

We then performed subgroup meta-analyses on dose reduction percentages for each study (percent difference of radiation dose between the routine dose arm and low dose arm of each study) to identify effect modifiers and isolate heterogeneity between studies. Subgroups consisted of CT indication, with or without iterative reconstruction, and nearest mean age group. We included 11 studies[3,4,6,7,13,14,25-29] and excluded 9 studies[5,8-12,22-24] because they did not report the standard deviation or standard error necessary for meta-analysis.

CT indication subgrouping revealed nonsignificant heterogeneity in Ventricle Specific ($I^2 = 0\%$, $\tau^2 = 0$, $p = 0.6236$) and General ($I^2 = 0\%$, $\tau^2 = 0$, $p = 0.9989$) and significant heterogeneity in the Craniofacial Specific ($I^2 = 99.1\%$, $\tau^2 = 233.1796$, p = <0.0001) and Emergency ($I^2 =95.3\%$, $\tau^2 = 268.9531$, p = <0.0001) groups. Test for Indication subgroup differences was significant: $\chi^2_3 = 74.76$, df = 3 ($p < 0.0001$). In the meta-analysis, dose reduction percentages for Ventricle Specific indications were -49.23 [-59.93, -38.53], Emergency indications were -37.34 [-50.20, -24.47], Craniofacial Specific were -79.80 [-104.24, -55.36], and General were -32.86 [-34.96, -30.75]. See *FIG 3. Forest Plot Subgrouped by Indication.*

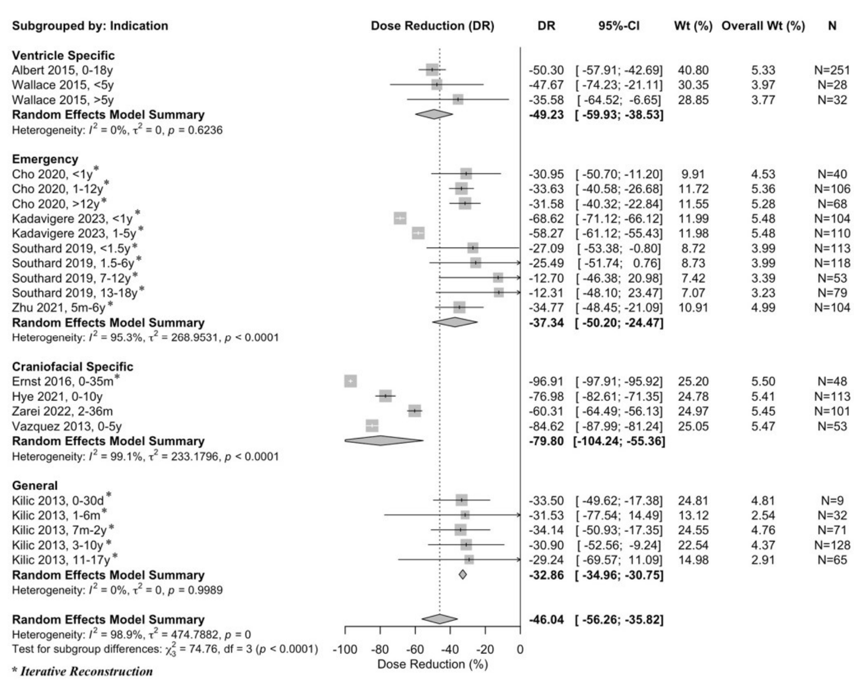

FIG 3. Forest Plot Subgrouped by Indication

With or Without Iterative Reconstruction subgrouping revealed significant heterogeneity in the Modify CT Parameters Only ($I^2 = 96.1\%$, $\tau^2 = 269.1748$, $p = <0.0001$) and Modify CT Parameters and Iterative Reconstruction ($I^2 = 99.1\%$, $\tau^2 = 457.1935$, $p = 0$). Test for Indication subgroup differences was significant as $p>0.01$ ($\chi^2_1 = 74.76$, df = 1, $p = 0.0153$). In the meta-analysis, dose reduction percentages for Modify CT parameters only were -62.21 [-81.12, -43.29], Modify CT parameters and Iterative Reconstruction were -39.81 [-51.72, -27.90]. See *FIG 4. Forest Plot Subgrouped by With or Without Iterative Reconstruction.*

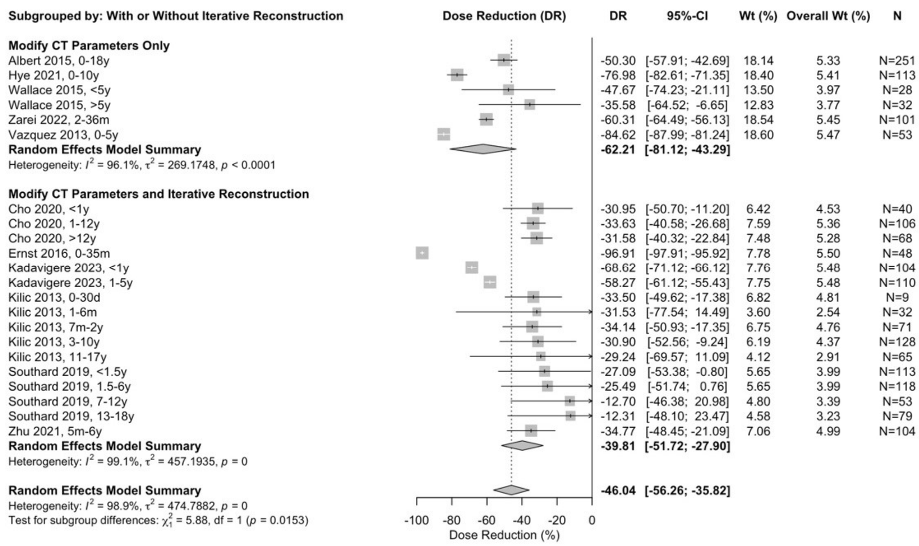

FIG 4. Forest Plot Subgrouped by With or Without Iterative Reconstruction

Nearest Age Group by Mean subgrouping revealed nonsignificant heterogeneity in the 10-18y ($I^2 = 0\%$, $\tau^2 = 0$, $p = 0.5903$), and significant heterogeneity in the 0-1y ($I^2 = 91.4\%$, $\tau^2 = 256.0053$, $p = <0.0001$), 1-5y ($I^2 = 99.3\%$, $\tau^2 = 598.7849$, $p = <0.0001$), 5-10y ($I^2 = 96.2\%$, $\tau^2 = 526.8881$, $p = <0.0001$). Test for Nearest Age Group by Mean subgroup differences was significant ($p>0.01$): ($\chi^2_3 = 10.02$, df = 3, $p = 0.0184$). In the meta-analysis, dose reduction percentages for 0-1y were -43.74 [-61.74, -25.75], 1-5y were -56.95[-78.12, -35.77], 5-10y were -40.53 [-70.67, -10.38], and 10-18y were -30.44 [-43.69, -17.20]. See *FIG 5. Forest Plot Subgrouped by Nearest Age Group by Mean.*

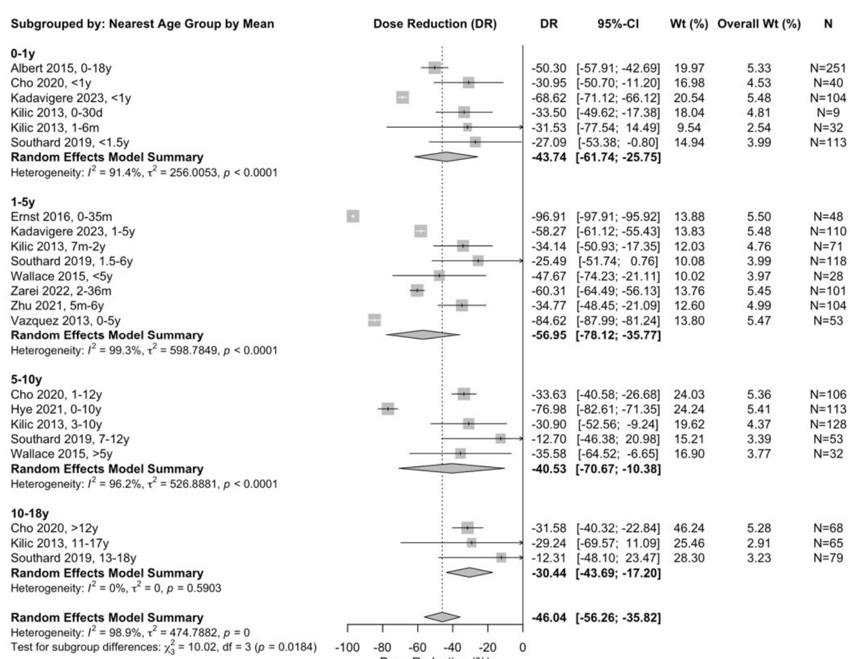

FIG 5. Forest Plot Subgrouped by Nearest Age Group by Mean

DISCUSSION

Background and Prior Literature

It is crucial to protect children from the long-term risks of radiation dose from CT. Adjusting CT acquisition parameters such as tube current and tube potential, and more recently, utilizing iterative reconstruction are techniques being implemented to decrease radiation dose from pediatric head CT[30]. However, adjusting CT parameters and utilizing iterative reconstruction requires a careful balance between dose reduction and image quality. This is difficult, as there is no clear consensus on best dose reduction practices, specifically for pediatric head CT.

Over the last two decades, pediatric CT dose reduction strategies with and without iterative reconstruction have been studied and implemented in human patients. This systematic review and meta-analysis focused on pediatric head CT, compiling CT protocol parameters modifications, iterative reconstruction used, and dose reduction values. We decided to analyze studies conducted in humans only, to identify dose reduction strategies pertinent to clinical practice. These stringent criteria allowed us to identify 20 dose reduction studies, 10 without the use of iterative reconstruction and 10 with the use of iterative reconstruction.

Through sensitivity analyses, we found significant heterogeneity between all studies eligible for metanalysis of dose reduction percentages. We then performed subgroup metanalyses using a random effects model and created forest plots in *Figures 3-5*. Even after subgrouping by CT Indication, With or Without Iterative Reconstruction, and Nearest Age Group by Mean, significant heterogeneity was still seen between studies ($p<0.001$). Still, subgrouping by indication revealed subgroup differences ($p<0.001$) between Ventricle Specific protocols (-49.23% Dose Reduction), Emergency protocols (-37.24%), Craniofacial Specific (-79.80%), and General (-32.86%), implying significant differences in levels of dose reduction based on CT indication.

Limitations

The low number of pediatric head CT dose reduction studies (N=20) further complicated by incomplete data and protocol detail reporting limited our descriptive statistics (N=18) and subgroup meta-analyses (N=11). Subgroup differences were detected in CT Indication, With or Without Iterative Reconstruction, and Nearest Age Group by Mean. However, heterogeneity was still significant after subgrouping and could not be teased out further due to limited sample size. As such, we were unable to properly isolate/compare dose reduction percentages of due to specific iterative reconstruction techniques. Instead, such studies must be carefully reviewed on a case-by-case basis in *Online Supplemental Data*, keeping in mind the impact that different age group, scanner, and clinical indication may have when comparing iterative reconstructive techniques. Further possible sources of heterogeneity, such as patient demographics, operative burden, radiology expertise, were not reported by selected studies, and thus could not be evaluated.

These limitations highlight the need for standardized reporting of protocol parameters in publications, and further research evaluating specific iterative reconstructive methods. Differences in reported metrics (e.g. CTDIvol, DLP, and effective dose) further complicate direct comparisons between studies. We specifically discourage using effective dose (mSv) to report radiation dose due to difference in conversion coefficients reported in the literature (Thomas et al. 2008[31], ICRP 2007[32], Radimetrics[8], Deak et al. (2010)[33], and Shrimpton et al. (2005)[34].

This review would not be complete without discussing the looming impact of photon counting CT, which was not found in the initial literature search for dose reduction strategies in pediatric head CT. Photon-counting detectors (PCDs) differ from energy-integrating detectors (EIDs) by counting each individual photon that passes through the patient, providing higher resolution and improved contrast at lower radiation doses, whereas EIDs aggregate the total energy of incoming photons, leading to less dose efficiency and lower image quality[35]. Since becoming clinically approved in 2021, photon-counting CTs have been used in both adults and children[36,37]. In adults, PCD-CT has successfully imaged temporal bone anatomy with more satisfactory visualization and dose than EIC-CT[38]. PCD-CT has also been used in children to image the temporal bone in children, abdomen, chest, and heart[39]. Most recently, in Sept 2024, a study by Srinivasan et Al, compared image quality and radiation dose between photon counting detector CT and energy integrating detector CT and found PCD CT reduced radiation dose by 43% overall, and over 70% in subgroups of children younger than 5 years[40]. However, we found no studies specifically dedicated to the utility of PCD-CT to replace the pediatric head CT. Another setback of photon counting CT is the high cost and overall low availability, as this technology is not yet mass-produced[41]. However, establishing it as a new standard of care for pediatric populations may hasten its arrival to the national scene, including even smaller community hospitals. At our institution, we are fortunate to have access to a Siemens NAEOTOM alpha photon-counting CT scanner and aim to study the efficacy, feasibility, and benefits of its use to improve the safety of pediatric head imaging for all patients.

Implications

Radiologists and technicians can optimize CT protocols by adjusting modifiable parameters like tube current and voltage. In this review, dose reduction studies consistently maintained diagnostic quality, indicating that these adjustments can be safely implemented. Most effective iterative reconstruction methods used were MBIR (97 ED% reduced)[13] and ADMIRE combined with ClariCT (95.9% CTDIvol reduced)[23] in craniosynostosis evaluation. However, the generalizability of this statement is limited due to decreased image quality thresholds for diagnosing craniosynostosis. With the limited number of pediatric head CT dose reduction studies conducted on humans, and the variances observed in clinical indication, scanner, operative burden, patient demographics, and other institution specific factors, it is too soon to say what dose reduction techniques are most effective for pediatric head CT. Moreover, limited sample size prevents us from teasing out additional sources of heterogeneity through statistical analysis. Looking ahead, photon-counting CT represents the future of medical imaging with its potential to be combined with existing iterative reconstruction and optimized protocols. Still, further research is needed on photon counting due to the cost, inaccessibility, and limited available literature, especially on pediatric head scans.

CONCLUSIONS

This systematic review affirms that significant radiation dose reductions in pediatric head CT scans can be achieved through both CT parameter adjustments and iterative reconstruction and highlights greatest dose reduction achieved with MBIR or ADMIRE combined with ClariCT for craniosynostosis evaluation. Meta-analysis of dose reduction percentages revealed CT clinical indication as an important factor to isolate with comparing dose reduction protocols or iterative reconstructive strategies for pediatric head CT. Finally, our review revealed a gap in literature in iterative reconstruction and photon counting CT studies for pediatric head CT scans. Future directions will involve studying the efficacy and feasibility of our NAEOTOM alpha photon-counting CT scanner at Washington University for pediatric head imaging.

ACKNOWLEDGMENTS

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SUPPLEMENTAL FILES

Supplemental Table 1. Quality Assessment based on the National Institutes of Health Study Quality Assessment Tool.

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Overall Quality
Albert 2015	Y	Y	N	N	Y	Y	N	N	NA	Y	N	Y	Fair
Bingyang 2021	Y	Y	N	Y	Y	Y	Y	Y	NA	Y	Y	Y	Good
Cho 2020	Y	Y	N	Y	Y	Y	N	Y	NA	Y	Y	Y	Good
Ernst 2016	Y	Y	N	Y	Y	Y	Y	Y	NA	Y	Y	Y	Good
Hye 2021	Y	Y	N	Y	Y	Y	N	Y	NA	Y	Y	Y	Good
Jończyk-Potoczna 2012	Y	Y	N	Y	Y	Y	N	Y	NA	Y	N	Y	Good
Kadavigere 2024	Y	Y	N	Y	Y	Y	N	Y	NA	Y	Y	Y	Good
Karappara 2020	Y	Y	N	Y	Y	Y	N	Y	NA	Y	Y	Y	Good
Kilic 2013	Y	Y	N	Y	Y	Y	N	Y	NA	Y	Y	Y	Good
Komarraju 2021	Y	Y	N	Y	Y	Y	N	Y	NA	Y	Y	Y	Good
Lyoo 2023	Y	Y	N	Y	Y	Y	N	Y	NA	Y	Y	Y	Good
Morton 2013	Y	Y	N	Y	Y	Y	N	Y	NA	Y	Y	Y	Good
Rabinowich 2023	Y	Y	N	Y	Y	Y	N	Y	NA	Y	Y	Y	Good
Southard 2019	Y	Y	N	Y	Y	Y	N	Y	NA	Y	Y	Y	Good
Sun 2021	Y	Y	N	Y	Y	Y	N	Y	NA	Y	Y	Y	Good
Thomas 2018	Y	Y	N	Y	Y	Y	N	Y	NA	Y	Y	Y	Good

Vazquez 2013	Y	Y	N	Y	Y	Y	N	Y	NA	Y	Y	Y	Good
Wallace 2015	Y	Y	N	Y	Y	Y	N	Y	NA	Y	Y	Y	Good
Zarei 2022	Y	Y	N	Y	Y	Y	N	Y	NA	Y	Y	Y	Good
Zhu 2021	Y	Y	N	Y	Y	Y	N	Y	NA	Y	Y	Y	Good

Y, yes; N, no; NA, not applicable.

Supplemental Table 2: Summary Table of Dose Reduction Studies without Iterative Reconstruction

Albert 2015: Strategies for Computed Tomography Radiation Dose Reduction in Pediatric Neuroimaging
Setting: Arkansas Children's Hospital, 96 Low Dose CT Scans
Scanner: Not Specified
Indication: Hydrocephalus, Ventriculomegaly, CSF Shunt (Ventricle-Specific)
CT Protocol Strata: By Age and By Indication
CT Protocol Modifications: Tube Voltage (kV), Tube Current (mA)
Dose Reduction: 50.3% Effective Dose (mSv)
Effective Dose Conversion Factor: Thomas 2008, *Pediatr Radiol*
Image Quality Metrics: Diagnosis of Hydrocephalus, Ventriculomegaly, CSF Shunt
Findings: Low dose shunt protocol maintains diagnostic quality for hydrocephalus, ventriculomegaly, CSF shunts.
Bingyang 2021: A Preliminary Study of Personalized Head CT Scan in Pediatric Patients
Setting: Jilin University First Hospital, 68 Low Dose CT Scans
Scanner: GE VCT 64
Indication: Varied from Neurosurgery, Neurology, Emergency Departments (Emergency)
CT Protocol Strata: By Head Circumference (54.1-57.0 cm, 51.1-54.0 cm, 48.1-51.0 cm)
CT Protocol Modifications: Tube Current Time Product (mAs)
Dose Reduction Brain: 25% at 200mAs, 33% at 150mAs, 49% at 100mAs, CTDIvol
Dose Reduction Eye Lenses: 20% at 200mAs, 37% at 150mAs, 50% at 100mAs, CTDIvol
Dose Reduction Salivary Glands: 6% at 200mAs, 34% at 150mAs, 57% at 100mAs, CTDIvol
Effective Dose Calculation: Radimetrics Organ Specific Data, CTDIvol summation
Image Quality Metrics: Subjective (Noise, Artifacts, Anatomical Details and Lesion), Objective (Mean CT Density, CNR, SNR)
Findings: Lower tube current time product (mAs) protocols have decreased but acceptable subjective image quality and no significant differences in objective image quality.
Hye 2022: Feasibility of Pediatric Low-Dose Facial CT Reconstructed with Filtered Back Projection Using Adequate Kernels
Setting: Chungnam National University Hospital, 73 Low Dose CT Scans
Scanner: Siemens Somatom Sensation 64
Indication: Facial CT of Children <10y at Emergency Department (Craniofacial Specific)

CT Protocol Strata: N/A
CT Protocol Modifications: Decreased Tube Voltage (kV), Tube Current Time Product (mAs)
Dose Reduction: 76.9% CTDIvol
Image Quality Metrics: Qualitative (Bony Structures: Nasal Bone, Bony Orbit; Soft Tissue Structures: Medial Rectus Muscle, Optic Nerve), Quantitative: (Noise: SD of Air, Mean CT Attenuation: Medial Rectus Muscle, Optic Nerve, Orbital Fat), CNR, SNR
Findings: Addition of soft tissue kernel image to low-dose facial CT protocol maintains image quality comparable to standard dose protocol.
Jończyk-Potoczna 2012: Low-Dose Protocol for Head CT in Evaluation of Hydrocephalus in Children
Setting: Poznań University of Medical Sciences, 128 Low Dose CT Scans
Scanner: Siemens Somatom Definition AS
Indication: Hydrocephalus or Suspected Ventriculo-peritoneal Shunt Failure (Ventricle Specific)
CT Protocol Strata: By Body Mass
CT Protocol Modifications: Decreased Tube Current Time Product (mAs)
Dose Reduction: 40% DLP
Effective Dose Conversion Factor: Thomas 2008, *Pediatr Radiol*
Image Quality Metrics: Qualitative: (Evaluation of ventricle widths, supracerebral fluid spaces, cortico-subcortical junction, ventriculo-peritoneal shunt catheter)
Findings: Low dose protocol maintains full diagnostic value for hydrocephalus.
Karappara 2020: Optimization of Pediatric CT Brain Protocol to Achieve Reduced Patient Dose
Setting: Manipal College of Health Professions, 69 Low Dose CT Scans
Scanner: Philips Brilliance 64
Indication: General
CT Protocol Strata: By Age (1-4y, 5-9y, 10-16y)
CT Protocol Modifications: Decreased Tube Current Time Product (mAs)
Dose Reduction: 71% (1-4y), 59% (5-9y), 37% (10-16y), Effective Dose
Effective Dose Conversion Factor: Lewis 2005, *Natl Radiol Prot Board*
Image Quality Metrics: Qualitative: (Noise and Image Acceptability, Gray-White Matter Differentiation, Sharpness of Subarachnoid Space, Visualization of Posterior Fossa Structures, Streak Artifacts)
Findings: Low dose protocol maintains acceptable image quality for brain CT.
Komarraju 2021: Ultra-Low-Dose Computed Tomography Protocol for Preoperative Evaluation in Children With Craniofacial Anomalies
Setting: Tertiary Children's Hospital, 90 Low Dose, 110 Ultra Low Dose CT Scans
Scanner: Not Specified
Indication: Preoperative Evaluation of Craniofacial Anomalies (Craniofacial Specific)

CT Protocol Strata: N/A
CT Protocol Modifications: Decreased Tube Voltage (kV), Tube Current (mA)
Dose Reduction: 51% Effective Dose Reduction
Effective Dose Conversion Factor: ICRP 2007
Image Quality Metrics: Qualitative: (Visualization, Critical Reproduction) Quantitative: (Objective Image Noise)
Findings: Low dose optimized protocol maintained good image quality for craniofacial anomalies.
Morton 2013: Low-Dose Head Computed Tomography in Children: A Single Institutional Experience in Pediatric Radiation Risk Reduction
Setting: Seattle Children's Hospital, 624 Low Dose CT Scans
Scanner: Not Specified
Indication: Varied, Mostly Hydrocephalic Patients with Shunts (70%), Postop Craniosynostosis Imaging (12%) (Ventricle and Craniofacial Specific)
CT Protocol Strata: Full, Half, Quarter Dose
CT Protocol Modifications: Decreased Tube Current Time Product (mAs)
Dose Reduction: Not Specified (Estimated 50-75%)
Image Quality Metrics: Qualitative: (Subjective Quality, Satisfaction)
Findings: Quarter dose protocol can evaluate hydrocephalus, skull and face bones, and intracerebral hemorrhage adequately.
Vazquez 2013: Optimised Low-Dose Multidetector CT Protocol for Children with Cranial Deformity
Setting: University Hospital Complex of Vigo, 71 Low Dose CT Scans
Scanner: GE VCT 64
Indication: Cranial Deformity (Craniofacial Specific)
CT Protocol Strata: N/A
CT Protocol Modifications: Decreased Tube Voltage (kV), Decreased Tube Current (mA)
Dose Reduction: 88% Effective Dose Reduction
Effective Dose Conversion Factor: ICRP 2007
Image Quality Metrics: Qualitative: (Visualization, Critical Reproduction) Quantitative: (Objective Image Noise)
Findings: Low dose adaptive MDCT protocol for pediatric skull evaluation provides good quality studies.
Wallace 2015: Evaluation of the Use of Automatic Exposure Control and Automatic Tube Potential Selection in Low-Dose Cerebrospinal Fluid Shunt Head CT
Setting: Washington University School of Medicine, 30 Low Dose CT Scans
Scanner: SOMATOM Definition Flash (Low Dose Protocol), SOMATOM Definition AS (Fixed Protocol)
Indication: CSF Shunt Complication Evaluation (Ventricle Specific)
CT Protocol Strata: Fixed vs Automatic Exposure Control (CareDose4D) and Tube Potential Selection (CARE kV)
CT Protocol Modifications: Automatic Exposure Control (AEC) and Automated Tube Potential Selection (Tube Potential Unchanged, Tube Current

Time Product Decreased)
Dose Reduction: 39% CTDIvol Reduction
Image Quality Metrics: Qualitative: (Diagnostic Evaluation, Visualization, Noise, Resolution)
Findings: Shunt protocol using AEC and ATPS reduces radiation dose and produces diagnostic images of comparable quality to fixed parameter protocols.
Zarei 2022: Evaluation of Low-Dose 3D Skull CT Images in Craniosynostosis
Setting: Shiraz University of Medical Sciences, 57 Low Dose CT Scans
Scanner: GE BrightSpeed Edge 8 Slice MDCT
Indication: Evaluation of Craniosynostosis (Craniofacial Specific)
CT Protocol Strata: N/A
CT Protocol Modifications: Decreased Tube Voltage (kV), Decreased Tube Current Time Product (mAs)
Dose Reduction: 60% Effective Dose Reduction
Effective Dose Conversion Factor: Deak 2010, *Radiology*
Image Quality Metrics: Qualitative: (Diagnostic Quality), Quantitative: (SNR)
Findings: Low dose protocol can scan skull bone with adequate diagnostic quality.

Supplemental Table 3: Summary Table of Dose Reduction Studies with Iterative Reconstruction

Cho 2020: Pediatric Head Computed Tomography with Advanced Modeled Iterative Reconstruction: Focus on Image Quality and Reduction of Radiation Dose
Setting: Ewha Womans University Mokdong Hospital, 109 Low Dose CT Scans
Indication: Emergency (Head Trauma, Seizure, Severe Syncope, Headache, Vomiting or Fever)
Scanner: SOMATOM Definition Flash 128
CT Protocol Strata: Age (<1y, 1-12y, >12y)
CT Protocol Modifications: ADMIRE, Decrease in Tube Current (mA)
Dose Reduction: 30.6% CTDIvol Reduction
Image Quality Metrics: Quantitative: (Noise, SNR, CNR of Air, CSF, White Matter), Qualitative (Subjective Noise, Gray-White Matter Differentiation of the Supra- and Infratentorial levels, Sharpness, Artifact, Overall Diagnostic Image Quality)
Findings: ADMIRE enables significant dose reduction while maintaining quantitative and qualitative image quality in emergent pediatric head CT.
Ernst 2016: Dedicated Sub 0.1 mSv 3DCT using MBIR in Children with Suspected Craniosynostosis: Quality Assessment
Setting: University Hospital Brussels, 24 Low Dose CT Scans
Scanner: Philips Brilliance CT 64 vs GE Discovery 750HD
Indication: Isolated Non-Syndromic Cranial Deformity, 0-35 months age, and Referral for Cranial 3DCT. (Craniofacial Specific)
CT Protocol Strata: N/A

CT Protocol Modifications: MBIR, Decrease in Tube Voltage (kV) and Tube Current Time Product (mAs)
Dose Reduction: 97% Effective Dose Reduction
Effective Dose Conversion Factor: ICRP 2007
Image Quality Metrics: Qualitative: (Image noise, Overall Diagnostic Acceptability, Artifacts). Quantitative: (SNR at Clivus, Sharpness of Cranial Bone-Brain Interface)
Findings: Dedicated 0.1 mSv cranial 3DCT protocol can be used for craniosynostosis diagnosis without loss in image quality.
Kadavigere 2024: Low Dose Pediatric CT Head Protocol using Iterative Reconstruction Techniques: A Comparison with Standard Dose Protocol
Setting: Kasturba Medical College, 71 Low Dose CT Scans
Scanner: Philips Incisive CT 128
Indication: Emergency (Seizures, Traumatic Brain Injury, Hydrocephalus, VPS, Malfunctioning Meningitis)
CT Protocol Strata: Age (<1y, 1-5y)
CT Protocol Modifications: iDose4, Decrease in Tube Voltage (kV) and Tube Effective Current (mAs)
Dose Reduction: 60.4% CTDIvol Reduction in age <1y, 44.9% CTDIvol Reduction in age 1-5y
Image Quality Metrics: Quantitative: (Image Noise, SNR, CNR). Qualitative: (Subjective Image Noise, Gray-White Matter Differentiation, Streak Artifacts, Overall Image Quality)
Findings: iDose4 enables significant dose reduction while maintaining image quality for emergent pediatric head CT
Kilic 2013: Quantitative and Qualitative Comparison of Standard-Dose and Low-Dose Pediatric Head Computed Tomography: A Retrospective Study Assessing the Effect of Adaptive Statistical Iterative Reconstruction
Setting: Gazi University School of Medicine, 153 Low Dose CT Scans
Scanner: GE BrightSpeed 16 MDCT
Indication: General (Referral for Non-Contrast Head CT)
CT Protocol Strata: N/A
CT Protocol Modifications: 30% ASIR, Decrease in Tube Current (mA)
Dose Reduction: 29% CTDIvol Reduction
Image Quality Metrics: Quantitative: (Noise, CNR, SNR of Air, CSF, White Matter), Qualitative: (Subjective Image Noise, Diagnostic Acceptability, Sharpness, Artifact)
Findings: 30% ASIR enables significant dose reduction while producing diagnostically acceptable pediatric head CT examinations.
Lyoo 2023: Ultra-low-dose Computed Tomography with Deep Learning Reconstruction for Craniosynostosis at Radiation Doses Comparable to Skull Radiographs: A Pilot Study
Setting: Seoul National University Hospital, 14 Ultra-Low-Dose CT Scans
Scanner: SOMATOM Force 192
Indication: Suspected Craniosynostosis (Craniofacial Specific)

CT Protocol Strata: With and without deep learning reconstruction
CT Protocol Modifications: ADMIRE, Deep learning ClariCT, ClariPi, Decrease in Tube Voltage (kV) and Tube Effective Current (mAs)
Dose Reduction: 95.9% CTDIvol reduction
Image Quality Metrics: Quantitative: (SNR), Qualitative (Overall Image Quality, Surface Coarseness, Sutural Patency)
Findings: Deep learning reconstruction maintains image quality, SNR, and diagnostic accuracy in ultra-low-dose craniofacial CT images for craniosynostosis.
Rabinowich 2023: Pediatric Low-dose Head CT: Image Quality Improvement using Iterative Model Reconstruction
Setting: Tel Aviv Sourasky Medical Center, 233 Low Dose CT Scans
Scanner: Philips Brilliance iCT 256
Indication: Emergency (Seizure, Headache, Fever, Hydrocephalus, or Head Trauma)
CT Protocol Strata: Age: (<1y, 1–5y, 5–10y, >10y)
CT Protocol Modifications: IMR, Tube Current Time Product Based on Age (mAs)
Dose Reduction: No Dose Reduction, Image Quality Improvement Study
Image Quality Metrics: Quantitative: (SNR and CNR Between Gray, White Matter in Supratentorial Region, Posterior Fossa), Subjective: (Supra- and Infratentorial Gray-White Matter Differentiation, Overall Image Quality, Posterior Fossa Image Distortion Due to Beam Hardening, Visibility of Anatomic Structures)
Findings: IMR improves image quality, reduces noise, and improves contrast in supra- and infratentorial brain regions compared to FBP in emergent pediatric head CT.
Southard 2019: Comparison of Iterative Model Reconstruction versus Filtered Back-Projection in Pediatric Emergency Head CT: Dose, Image Quality, and Image-Reconstruction Times
Setting: Phoenix Children's Hospital, 190 Low Dose CT Scans
Scanner: Philips Brilliance iCT 256 vs Philips Brilliance 64
Indication: Emergency (Head CT Without Contrast + 3D Reconstruction)
CT Protocol Strata: Age (<1.5y, 1.5–6y, 7–12y, >13y)
CT Protocol Modifications: Low Dose IMR, Tube Current Time Product Based on Age (mAs), Decrease Pitch, Rotation Speed (s)
Dose Reduction: 21.5% CTDIvol reduction
Image Quality Metrics: Quantitative: (Mean CT Density, Standard Deviation, SNR, CNR of White Matter, Thalamus), Qualitative: (Gray-White Matter Differentiation, Anatomic Detail)
Findings: IMR significantly reduces radiation dose, improving SNR, CNR, and subjective image quality compared with FBP.
Sun 2021: Application of a Deep Learning Image Reconstruction (DLIR) Algorithm in Head CT imaging for Children to Improve Image Quality and Lesion Detection
Setting: Beijing Children’s Hospital, 50 Low Dose CT Scans
Scanner: GE Revolution 256

Indication: Emergency (Head Trauma, Convulsion, Mental Symptoms, Exclude Intracranial Abnormalities)
CT Protocol Strata: N/A
CT Protocol Modifications: 50% ASIR-V, 100% ASIR-V, or Deep Learning Image Reconstruction (DLIR) with High Setting (DL-H), Slice Thickness (5 vs 0.625 mm), Tube Current Time Product Based on Age (mAs), Detector Coverage (cm) Based on Head Size
Dose Reduction: 85% Dose Reduction Estimated with DL-H and 5mm Slice Thickness
Image Quality Metrics: Quantitative: (CT Attenuation, Standard Deviation of Gray, White Matter in Basal Ganglia). Qualitative: (Clarity of Sulci/Cisterns, White and Gray Matter Boundary, Overall Image Quality)
Findings: DLIR at the high setting (DL-H) improves CT image quality, lesion detection at significant reduced doses compared to FBP.
Thomas 2018: Comparing Fourth Generation Statistical Iterative Reconstruction Technique to Standard Filtered Back Projection in Pediatric Head Computed Tomography Examinations
Setting: Phoenix Children's Hospital, 157 Low Dose CT Scans
Scanner: Philips Brilliance iCT 256
Indication: Pediatric Head CT
CT Protocol Strata: Age (0-1.5y, 1.5-7y, 7-13y, >13y)
CT Protocol Modifications: iDose4, Tube Current Time Product Based on Age (mAs)
Dose Reduction: 37.2% CTDIvol Reduction for Age 0-1.5y, 23.4% CTDIvol Reduction for Age 1.5-7y, 26.92% CTDIvol Reduction for Age 7-13y, 25.6% CTDIvol Reduction of Age >13y
Image Quality Metrics: Quantitative: (SNR, CNR for Gray Matter, White Matter), Qualitative: (Gray-White Differentiation, Image Noise/Graininess, Scatter-Related Artifacts, Image Sharpness, Visibility of Small Structures)
Findings: iDose4 significantly reduces radiation dose while maintaining or improving image quality compared to FBP in younger patients.
Zhu 2021: Imaging Pediatric Acute Head Trauma Using 100-kVp Low Dose CT with Adaptive Statistical Iterative Reconstruction (ASIR-V) in Single Rotation on a 16 cm Wide-detector CT
Setting: Affiliated Hospital of Ankang University, 50 Low Dose CT Scans
Scanner: GE Revolution 256 vs GE VCT 64
Indication: Emergency (Ruling Out Intracranial Lesions After Acute Head Trauma, 0-6 Years Age)
CT Protocol Strata: N/A
CT Protocol Modifications: 70% ASIR, Decrease in Tube Voltage (kV) and Protocol Time (s)
Dose Reduction: 36.4% CTDIvol Reduction
Image Quality Metrics: Quantitative: (CT Attenuation Value, CNR, and Standard Deviation of Gray Matter, White Matter at Cerebellum and Thalamus), Qualitative: (Motion Artifacts, Overall Image Quality)
Findings: 70% ASIR-V significantly reduces dose and provides high-quality images with less motion for children with acute head trauma.

Supplement 4: Search Strategies

Embase
Date Searched: 12/11/2023
Applied Database Supplied Limits: none
Number of Results: 894

Full Search Strategy:

(('craniofacial synostosis'/exp OR 'craniofacial malformation'/exp OR 'face'/de OR 'head'/de OR 'craniofacial morphology'/exp OR 'skull'/de OR (craniofacial OR craniostenosis OR ‘cranial suture synostosis’ OR ‘cranial synostosis’ OR ‘cranio-stenosis’ OR ‘cranio-synostosis’ OR craniosynostoses OR craniosynostosis OR ‘face cranium synostosis’ OR stenocephaly OR ‘synostosis craniofacialis’ OR ‘craniofacial synostosis’ OR face OR midface OR midfacies OR head OR skull OR 'cranial bone' OR 'cranial volume' OR cranium):ti,ab,kw) AND ('computer assisted tomography'/exp OR 'low-dose computed tomography'/exp OR 'ultra low dose computed tomography'/exp OR 'x-ray computed tomography'/exp OR (compute* NEAR/4 tomograph*):ti,ab,kw OR ((CAT OR CT) NEAR/3 scan*):ti,ab,kw) AND ('low drug dose'/exp OR (‘low dose’ OR ‘low dosage’ OR ‘low-dose’ OR ‘low-dosage’ OR ‘Ultra-low-dose’ OR ‘low radiation’ OR 'low-radiation’):ti,ab,kw) AND ('diagnostic imaging'/exp OR 'image analysis'/exp OR 'image artifact'/exp OR 'image quality'/exp OR 'radiation'/de OR 'radiation attenuation'/exp OR 'radiation dose'/de OR 'radiation exposure'/de OR 'radiation hazard'/exp OR radiation:ti,ab,kw OR ((diagnostic OR medical OR artefact OR artifact OR analysis OR quality) NEAR/3 (imaging OR image)):ti,ab,kw)) NOT ('animal'/de NOT ('animal'/de AND ‘human’/de))

Ovid Medline
Date Searched: 12/11/2023
Applied Database Supplied Limits: none
Number of Results: 539

Full Search Strategy:

((Craniofacial Abnormalities/ OR Face/ OR Head/ OR Skull/ OR (craniofacial OR craniostenosis OR cranial suture synostosis OR cranial synostosis OR cranio-stenosis OR cranio-synostosis OR craniosynostoses OR craniosynostosis OR face cranium synostosis OR stenocephaly OR synostosis craniofacialis OR craniofacial synostosis OR face OR midface OR midfacies OR head OR skull OR cranial bone OR cranial volume OR cranium).ti,ab,kf.) AND (exp Tomography, X-Ray Computed/ OR (compute* ADJ4 tomograph*).ti,ab,kf. OR ((CAT OR CT) ADJ3 scan*).ti,ab,kf.) AND ((low dose OR low dosage OR low-dose OR low-dosage OR Ultra-low-dose OR low radiation OR low-radiation).ti,ab,kf.) AND (exp Diagnostic Imaging/ OR exp Image Interpretation, Computer-Assisted/ OR Radiation/ OR Radiation Dosage/ OR Radiation Exposure/ OR radiation.ti,ab,kf. OR ((diagnostic OR medical OR artefact OR artifact OR analysis OR quality) ADJ3 (imaging OR image)).ti,ab,kf.)) NOT (Animals/ NOT (Animals/ AND Humans/))

Scopus
Date Searched: 12/11/2023
Applied Database Supplied Limits: none
Number of Results: 871

Full Search Strategy:

(((TITLE-ABS-KEY(craniofacial OR craniostenosis OR “cranial suture synostosis” OR “cranial synostosis” OR “cranio-stenosis” OR “cranio-synostosis” OR craniosynostoses OR craniosynostosis OR “face cranium synostosis” OR stenocephaly OR “synostosis craniofacialis” OR “craniofacial synostosis” OR face OR midface OR midfacies OR head OR skull OR “cranial bone” OR “cranial volume” OR cranium))) AND ((TITLE-ABS-KEY(compute* W/4 tomograph*)) OR (TITLE-ABS-KEY((CAT OR CT) W/3 scan*))) AND ((TITLE-ABS-

KEY("low dose" OR "low dosage" OR "low-dose" OR "low-dosage" OR "Ultra-low-dose" OR "low radiation" OR "low-radiation"))) AND ((TITLE-ABS-KEY(radiation)) OR (TITLE-ABS-KEY((diagnostic OR medical OR artefact OR artifact OR analysis OR quality) W/3 (imaging OR image))))) AND NOT ((TITLE(Animals)) AND NOT ((TITLE(Animal AND Humans))))

The Cochrane Library
Date Searched: 12/11/2023
Applied Database Supplied Limits: none
Number of Results
CENTRAL: 53
CDSR: 1

Full Search Strategy:

([mh "Craniofacial Abnormalities"] OR [mh "Face"] OR [mh "Head"] OR [mh "Skull"] OR (craniofacial OR craniostenosis OR "cranial suture synostosis" OR "cranial synostosis" OR "cranio stenosis" OR "cranio synostosis" OR craniosynostoses OR craniosynostosis OR "face cranium synostosis" OR stenocephaly OR "synostosis craniofacialis" OR "craniofacial synostosis" OR face OR midface OR midfacies OR head OR skull OR "cranial bone" OR "cranial volume" OR cranium):ti,ab,kw) AND ([mh "Tomography, X-Ray Computed"] OR (compute* NEAR/4 tomograph*):ti,ab,kw OR ((CAT OR CT) NEAR/3 scan*):ti,ab,kw) AND (("low dose" OR "low dosage" OR "low radiation"):ti,ab,kw) AND ([mh "Diagnostic Imaging"] OR [mh "Image Interpretation, Computer-Assisted"] OR [mh "Radiation"] OR [mh "Radiation Dosage"] OR [mh "Radiation Exposure"] OR radiation:ti,ab,kw OR ((diagnostic OR medical OR artefact OR artifact OR analysis OR quality) NEAR/3 (imaging OR image)):ti,ab,kw)

ClinicalTrials.gov
Date Searched: 12/11/2023
Number of Results: 33

Full Search Strategy:

("craniofacial synostosis" OR face OR head OR skull) AND ("diagnostic imaging" OR "image analysis" OR "radiation dosage" OR "radiation exposure")- *other terms*
AND
("computer assisted tomography" OR "x-ray computed tomography" OR "CAT scan")
AND ("low-dose" OR "Ultra-low-dose" OR "low-radiation") -*intervention/treatment*