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Vertical miscentering and effect on radiation dose to the lens in computed tomography head examination: A systematic review

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ABSTRACT

Computed tomography (CT) scanners are the foremost instruments for detecting pathology in the human body. The rising used of CT scanner to assess pathological and injuries to the area of brain has prompted concerns about the radiation dose absorbed by radiosensitive organs, particularly the eye lens. The purpose of this systematic review was to investigate the impact of vertical miscentering on the radiation dose to the lens during plain head CT examination. A systematic evaluation of the existing literature was performed utilizing the MyEBSCO platform, which encompasses 11 electronic databases, including MEDLINE and CINAHL. The research conducted from 2014 to 2025 was examined to ascertain the correlation among vertical miscentering, absorbed lens dose, and image quality. The exhaustive search found 59 relevant publications, all of which were rigorously reviewed. Of these, 9 papers advanced to full-text screening, and 5 were eventually included in the review. The findings consistently demonstrate that vertical miscentering significantly increases the absorbed dose to the lens. However, image quality remains largely unaffected when the miscentering is less than 5 cm inferiorly and image noise appears minimally impacted by minor miscentering. All reviewed studies reported an inverse-proportional relationship between vertical miscentering and lens dose. The literature collectively underscores that precise patient centering is critical for minimizing radiation exposure to the lens without compromising diagnostic image quality. Ensuring accurate positioning of the patient's head at the gantry isocenter remains essential.

1. Introduction

Computed tomography (CT) is one of the most used and successful diagnostic radiography methods in modern medical practice. Technological developments in CT, including high-speed scanning and its use as a screening tool for asymptomatic persons, have led to a substantial increase in the number of CT scans conducted worldwide (Al-Hayek et al., 2024). The utilization of Computed Tomography (CT) scans in assessing head injuries and pathology has become more prominent and significant due to its ability to produce detailed images of the skull, brain, and other surrounding structures such as the sinuses and petrous bone (I. Isa et al., 2019). The Head CT examination is also a favored imaging modality for quickly evaluating structural brain damage (Toyama et al., 2005). Despite all its advantages, CT scans also have limitations regarding radiation dose delivered to patients.

The impact of radiation dose and image noise has been a major concern for doctors, physicists, and many researchers since the early use of CT scans in the medical field (Karim et al., 2016; Toth et al., 2007). The eyes are among the most sensitive organs directly exposed to ionizing radiation during head CT examinations. The dose to the eyes in routine head CT has been reported to be around 50 mGy (Gaudreau et al., 2020). Even though these doses are far below the estimated threshold for lens opacities (500–2000 mGy), a previous study suggested a high probability of developing posterior subscapular cataracts from such radiation exposure (C. Anam et al., 2019a,b). The National Health Research Institutes database in 2013 suggests that the threshold for

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Table 1
PICO design framework adopted in the systematic review.

Component	Description
Population	CT scan of the head/brain on anthropomorphic phantoms or adult and paediatric patients.
Intervention	Miscentering, vertical off-centre positioning, table height, or dose optimization
Comparison	Isocentre
Outcome	Radiation dose to the lens, image quality

cataractogenic effect due to irradiation during head and neck CT scans may be as low as 250 mGy (Yuan et al., 2013).

In recent years, most vendors produce a CT scan with the latest technology, which has substantially contributed to dose optimization, raising the concern of this study in detecting radiation dose and image quality in patients. Automatic tube current modulation (ATCM) is a technological advancement that effectively diminishes radiation exposure by modulating the tube current output according to anticipated patient dimensions and regional attenuation to attain specified goal image quality (Ishita et al., 2022). The most modern technology, Organ Dose Modulation (ODM), reduces the x-ray tube current (mA) over the anterior half of the patient's body circumference in order to minimize radiation exposure to superficial radiosensitive organs such as the eyes, thyroid, and breast (Inoue et al., 2024). Previous study observes that ODM, ATCM, and bowtie filters are approaches used to limit radiation exposure while creating high-quality images (Dalah et al., 2024; Ishita et al., 2022). The scout image, however, determines how well tube current modulation works. Therefore, it is necessary to consider how vertical miscentering or an erroneous table height in relation to the isocenter affects the scout image, which might result in a higher or lower radiation dose for the patient.

The aspect of the problem that is of particular interest to this study focuses on the effect of miscentering and dose optimization methods on radiation dose and image quality. While previous research has addressed broader studies involving multiple CT scan examinations or invasive brain CT procedures such as contrast CT and CT perfusion, this study aims to investigate a less explored area vertical miscentering, especially in relation to the radiographer's techniques in positioning patients. This

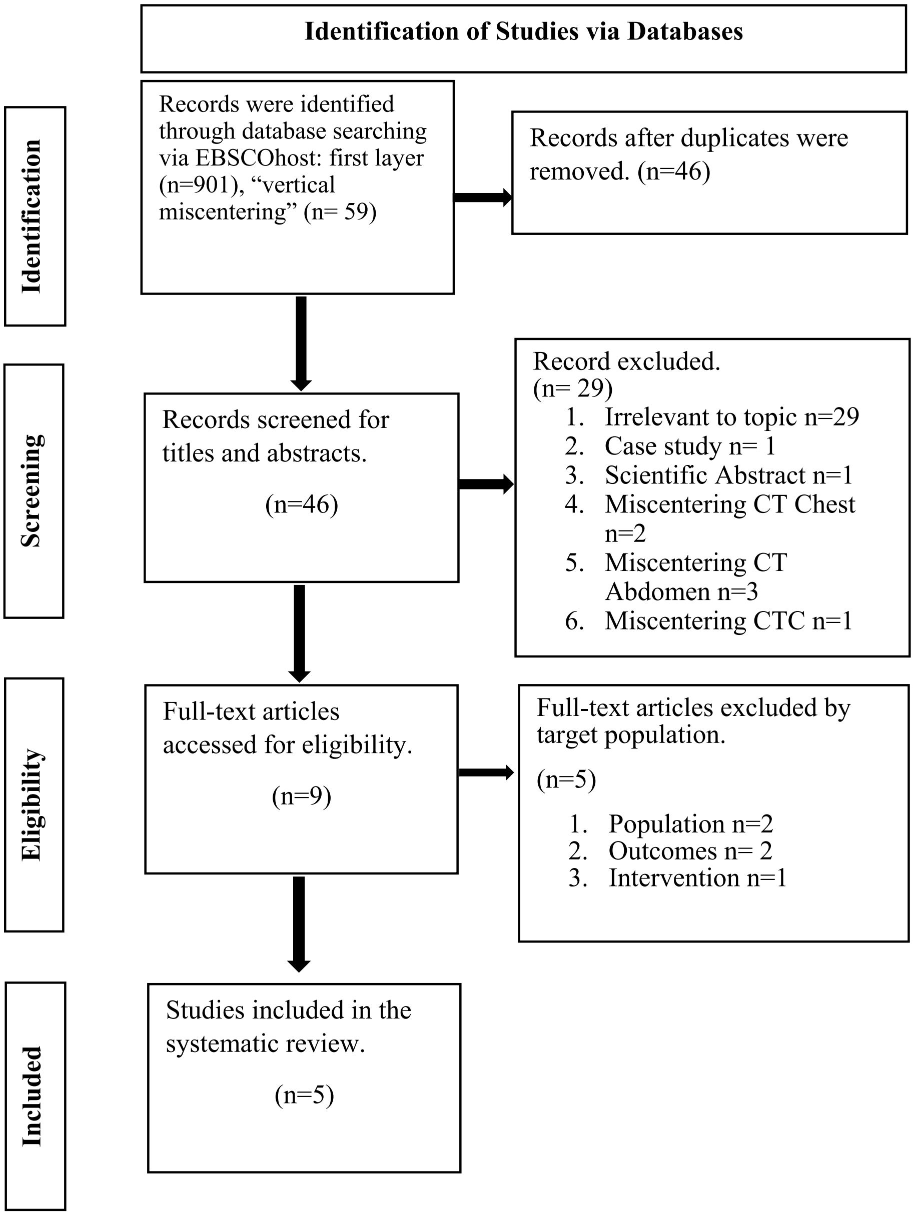

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart.

refined focus is critical, as it highlights the impact of proper positioning in conjunction with dose optimization protocols and emphasizes the importance of training radiologic technologists to improve their competency.

Thus, this systematic review intends to consolidate and evaluate existing evidence from various studies investigating the absorbed dose to the eye lens caused by vertical miscentering, either superior or inferior to the isocenter, during head CT examinations. This study seeks to analyze all available literature evaluating the effect of miscentering on radiation dose to the lens and image quality in head CT examinations. Additionally, consolidating evidence on dose optimization techniques such as ATCM, ODM and bowtie filters, provides insights into technological advancements and their limitations in reducing lens dose.

2. Methodology

This study is a systematic review study that used the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) (Page et al., 2021). The systematic review was conducted based on the steps described by Petticrew and Roberts (2006) The first step was formulating a clear research question or hypothesis. The second was determining the types of studies required to carry out the review. A comprehensive literature search was then performed to locate the relevant studies before they were screened and assessed to ensure they met the inclusion criteria. The studies were then critically appraised, and the findings from the included studies were synthesized and assessed for homogeneity. The final step was disseminating the outcome of the review.

The framework of this systematic review was modified from a previous study by Dunne et al. (2022), which used population-intervention-control-outcome (PICO) model as illustrated in Table 1.

2.1. Literature search strategy

A systematic literature search was conducted using the MyEBSCO platform https://search.ebscohost.com, covering 11 electronic databases including MEDLINE, CINAHL Plus with Full Text, Cochrane Central Register of Controlled Trials, Cochrane Clinical Answers, Cochrane Database of Systematic Review, Cochrane Methodology Register, eBook Collection (EBSCOhost), eBook Open Access (OA) Collection (EBSCOhost), Health Business Elite, MEDLINE Complete, Psychology and Behavioral Sciences Collection and SPORTDiscus with Full Text, to identify all relevant studies published over the past 10 years, up to May 2025. This search strategy was conducted to find all the relevant literatures regarding the effect of miscentering on radiation dose to the lens in head CT examination. All databases were reputable, interdisciplinary research platforms containing a diverse range of peer-reviewed articles and were regularly updated.

The electronic search strategy was generated using the following keywords: (radiation dose) AND lens AND (CT scan OR computed tomography OR cat scan) AND brain AND (effects OR impact OR consequences) AND (patient centering OR miscentering OR patient positioning OR table height or off-centering). Selected keywords combined with Medical Subject Headings (MeSH) for MEDLINE and CINAHL, were grouped according to key concepts and combined with the SmartText Searching operators to enable a more sensitive and focused search. The search primarily utilized the title and abstract of all articles published over the past 10 years, up to May 2025.

2.2. Data collection and analysis

The selection of the articles in this systematic review was made based on a few inclusion criteria: studies published in the English language, studies published within the last 10 years to May 2025, and studies with a specific research focus on the effect of miscentering on radiation dose to the lens in head CT. The exclusion criteria included: (i) studies not available in full text or not accessible through appropriate databases or sources, case reports, case series, and other systematic reviews; (ii) studies with incomplete or insufficient data or not relevant to the subject discussed. These criteria collectively aimed to ensure that the selected articles were comprehensive, accessible, relevant, and provided sufficient data for a meaningful review focused on CT scans and related subjects. The combination search strategy through EBSCOhost identified 901 articles, screening was based on vertical miscentering and dose optimization, which resulted in 59 articles identified (44 from the MEDLINE and 15 from CINAHL). After removing duplicates, 13 articles were excluded, and the titles and abstracts of the remaining 46 articles were screened. All 46 articles met the criteria for full-text review. Through further screening, 37 articles were excluded for meeting one or more of the above-mentioned exclusion criteria. Eventually, 5 articles were included in this systematic review. The study selection process followed the PRISMA 2020 guideline, which involved four main steps: identification, screening, eligibility, and inclusion, as illustrated in Fig. 1.

The data extracted from the studies included the main author, title of the article, year of publication, journal name, study design, population, research methodology applied, scanning parameters including the type of measurement apparatus and applications used to conduct the studies and lastly the findings. Three authors independently selected the studies to review, extracted and analyzed the data, and evaluated the quality of each investigation. Overall, all studies provided adequate findings to answer the research question regarding the effect of miscentering on the lens in head CT examinations. The extracted data elements were compiled into Excel spreadsheet generated from Scholarly Article Summarizer, which included general information and studies related data items. The details were listed in Table 2.

Table 2
List of the relevant information and element for the systematic review and meta-analysis.

Item (s)	Extraction Data	
	Contents	Element
1	General information	Title of the article Main authors Publication year Study design Methodology used Type of scan (axial vs helical) Manufacturer of the CT (brand)
2	Studies related data	The technical parameters (kVp, mAs) Dose Length Product (DLP), CTDI_{vol} and effective dose. organ tube-current modulation

2.3. Quality Assessment

The quality of the studies was assessed using the Quality Assessment of Diagnostic Accuracy 2 (QUADAS-2) tool, which evaluates the risk of bias and applicability of the included studies (Yang et al., 2024). Risk of bias refers to flaws in study design or methodology that could lead to inaccurate or biased results and was tabulated in Table 3. Applicability concerns arise when study findings differ from the intended review question (Whiting et al., 2011). The QUADAS-2 was developed by the University of Amsterdam Academic Medical Centre and the University of York are widely recognized and recommended for evaluating diagnostic test accuracy in systematic reviews by organizations such as Cochrane, the Agency for Healthcare Research and Quality, and the UK National Institute for Health and Clinical Excellence (Whiting et al., 2011).

This systematic review study provided comprehensive insights into the effects of miscentering on radiation dose to the lens during head CT

Table 3
QUADAS-2 risk and applicability assessment.

Study	Risk of Bias				Applicability Concerns		
	Patient Selection	Index Test	Reference Standard	Flow and Timing	Patient Selection	Index Test	Reference Standard
Kataria et al. (2016)	L	H	L	U	L	H	L
Anam et al. (2019)	L	H	L	L	L	H	L
Euler et al. (2019)	L	L	L	L	U	L	L
Sookpeng et al. (2019)	L	L	L	L	L	L	L
Ishita et al. (2022)	L	L	L	L	L	L	L

L = Low risk; H= High risk; U= Unclear risk.

Table 4
Characteristics of included studies.

Author	Country	Journal	Publisher	SJR 2024	H-Index	Citation
Kataria et al. (2016)	Sweden	Radiation Protection Dosimetry	Oxford University Press	0.255 (Q3)	82	32
Anam et al. (2019)	Japan	Journal of Physics	IOP Publisher	0.18 (−)	99	17
Euler et al. (2019)	Switzerland	European Journal of Radiology	Springer-Verlag	4.7	139	20
Sookpeng et al. (2019)	Thailand	Journal of Radiology Nursing	Elsevier	1.4 (Q4)	139	8
Ishita et al. (2022)	Japan	European Journal of Radiology	Elsevier	0.94 (Q1)	127	6

Table 5
Summary of articles included in Review according to PICO.

Author	Objectives	Study Design	Population	Methodology (Intervention)	Outcomes
Kataria et al. (2016)	To measure the variation in organ dose during CT head examinations.	Experimental study	The anthropomorphic male phantom.	An anthropomorphic phantom was scanned using a 128-slices CT scanner. Two TLD tablets were placed at both eyes and scan made at +3 cm and -5cm off-centre.	The relative absorbed organ dose deviations of ventrally located eyes received less dose (5.6 %–39 %) at +3 cm off centre compared to isocenter and higher doses (5.2 %–12 %) at -5cm off center.
Anam et al. (2019)	To evaluate the eye lens dose due to miscentering, and to assess the possibility of eye lens dose reduction through miscentering phenomenon.	Experimental Study	The head CTDI phantom and the anthropomorphic phantom.	The head CTDI phantom and anthropomorphic phantoms were scanned at, +2 cm, +4 cm +6 cm and -2cm, -4 cm, -6 cm to simulate off centre. Dose recorded using the RPL detector placed on the surface of both eyes and pencil ion chamber in the head CTDI phantom.	Eye dose was reduced to about 10 % at +2 cm, 20 % at +4 cm, and more than 30 % at +6 cm above the isocenter. Eye dose increased about 20 % at -2cm, 30 % at -4cm and more than 40 % at -6cm below the isocenter.
Euler et al. (2019)	To assess the impact of patient off-cantering on organ dose and image noise for head CT.	Experimental study	The paediatric anthropomorphic phantom.	The paediatric phantom was scanned using a 128-slice CT Scanner at +2 cm, +4 cm +6 cm and -2cm, -4 cm, -6 cm relative to the isocenter. A MOSFET dosimeter was placed on the surface of both eyes.	The radiation doses to the eyes decreased linearly with table height, from 37.35 mGy at −6 cm to 27.1 mGy at +6 cm. Organ dose differences compared to isocenter were −16 % to 19 % for the eyes.
Sookpeng et al. (2019)	To evaluate the effect of vertical miscentering on eye lens radiation doses in patient underwent CT head examination.	Experimental Study	The anthropomorphic head phantom	The anthropomorphic head phantom was scanned using a 16-slice CT scanner at varying vertical positions of +1 cm, +3 cm, −2 cm, −3 cm, and −5 cm relative to the isocenter. A NanoDot dosimeter was positioned on the surface of both eyes to measure the absorbed dose and the equivalent dose to the lens.	The doses were lower by 9.5 %–34 % when table heights were above isocenter and 9.5 %–44 % higher when table heights were below the isocenter. The average dose difference compared to isocenter was −9.46 % at +1 cm, −33.6 % at +3 cm, 9.46 % at -2cm, 23.5 % at -3cm and 43.7 % at -5cm.
Ishita et al. (2022)	To prove that the locally absorbed doses in tissues and organs are affected by inaccurate table height in computed tomography.	Experimental study	The anthropomorphic phantom.	The anthropomorphic phantom was scanned using a 320-row multidetector CT scanner to measure the absorbed dose at ten different table heights: T-40 mm, T-20 mm, Tgt, T+20 mm, and T+40 mm. The average dose of the left and right lens was recorded using a glass dosimeter placed on both eyes' surfaces.	The absorbed dose in the lens was decreased when table height increased. The absorbed dose at T+40 mm decreased by 27.27 % compared to the isocenter. When table height was lowered, the absorbed doses in the lens increased. The absorbed dose at T-40mm increased by 17.77 % compared to the isocenter.

examinations, emphasizing the importance of accurate patient positioning to reduce radiation risks.

3. Results

The classification of the articles based on journal quality was made in accordance with the Scimago Journal and Country Rank. The metric was based on the latest Scopus data as of published over the past 10 years, up to May 2025. The majority of the five evaluated papers were published in respectable Scopus-indexed journals, as evidenced by the fact that two of them were indexed in the Q1 quartiles, two in the Q3 quartiles, and one was not assigned a quartile. The majority of the research was carried

Table 6
Type of anthropomorphic, dosimeter and dose reader used in the studies.

Study	Anthropomorphic phantom	Dosimeter	Dose reader	Uncertainty
Kataria et al. (2016)	Model 701-D (CIRS, Norfolk, USA)	TLD	RE-2000 TLD reader (RADOS Technology Oy, Turku, Finland) CT Expo software tool (version 2.3.1)	≤20 % (Sadek et al., 2022)
Anam et al. (2019)	16 cm CTDI Head Phantom	10 cm Pencil Ionization Chamber	Electrometer	≤10 % (de Castro et al., 2016)
	Antropomorphic Head (Model Not Stated)	1.5 mm × 12 mm RPL detectors (type GD352 M, Chiyoda Technol Corporation, Japan)	RPL Dose Ace reader (type FGD-1000)	
Euler et al. (2019)	ATOM Model 705-C (CIRS, Norfolk, USA)	MOSFET, TN-502RD-H (Best Medical Canada)	–	≤5 % (Kohno et al., 2011)
Sookpeng et al. (2019)	RSD Model RS-108 (Radiology Support Devices, NC, USA)	NanoDot™ (Al2O3:C) dosimeter (Landauer, Inc., IL, USA) 100-mm-long ionization chamber (Model 10X5-3CT; Radcal Corporation, CA, USA)	MicroStar reader (Landauer, Inc., IL, USA) Electrometer (Model 9100)	≤2 % (Akyol et al., 2019)
Ishita et al. (2022)	Anthropomorphic Phantom (THRA1 type; KYOTO KAGAKU, Tokyo, Japan)	Glass dosimeters (AGC Techno Glass, Shizuoka, Japan)	FDG-1000 dose reader (AGC Techno Glass)	3.45 % (Oonsiri et al., 2019)

out in 2019, while the most current study was released in 2022. The characteristics of the articles are shown in Table 4.

All the reviewed articles provided results that addressed the focus question regarding the effect of miscentering on lens dose. The evidence indicated that miscentering significantly impacts the radiation dose to the lens. All five studies concluded that vertical miscentering below the isocenter leads to a significant increase in lens dose. On the other hand, the vertical miscentering superior to the isocenter resulted in decreased dose to the lens. Previous study observed a standard deviation percentage difference of −39 %–43.7 % for miscentering from lowest to highest (Kataria et al., 2016; Sookpeng et al., 2019). Table 5 shows the studies were summarized using the Population-Intervention-Comparator-Outcomes (PICO) framework.

All the reviewed articles were conducted using anthropomorphic head phantoms, anthropomorphic adult, pediatric phantoms, 16 cm CTDI head phantoms and human subjects. Various types of dosimeters, as listed in Table 6, were used to measure the absorbed dose in addition to the dose descriptors CTDI_{vol} and DLP derived from the CT scanner. The dosimeters that were used in the studies included the MOSFET (TN-502RD-H, Best Medical Canada), NanoDot™ (Al_2O_3:C) dosimeter (Landauer, Inc., IL, USA), glass dosimeter (AGC Techno Glass, Shizuoka, Japan), thermoluminescence dosimeter (TLD), radio-photoluminescence detectors (type GD352 M, Chiyoda Technol Corporation, Japan), and 10 cm pencil ionization chamber.

The highest percentage of dose differences relative to the isocenter was reported by Sookpeng et al. (2019), with a recorded value of 43.7 % (69.97 mGy) compared to 48.71 mGy for a miscentering of 5 cm (Sookpeng et al., 2019). Similarly, Anam et al. (2019a,b) observed that the dose differences exceeding 40 % when the table height was 6 cm below the isocenter as demonstrated in Fig. 2 (Anam et al., 2019a,b). The highest dose reduction was recorded when the table height was increased, ranging from 38.5 % to 39 % at 3 cm superior to the isocenter, as reported by Kataria et al. (2016). In contrast, the lowest dose reduction in pediatric phantoms simulating 5-year-old children was 17.5 % at a table height of 6 cm above the isocenter, while a dose increment of 10 % was reported at 6 cm below the isocenter.

The types of scanners, bowtie filters, and dose optimization techniques used in the studies are shown in Table 7, along with their relationship to organ dose and image quality. The effect of miscentering to the image quality was observed in three studies out of five articles reviewed. The image quality was measured as the standard deviation of CT attenuation expressed in HU unit. The relationship between image noise and patient position was almost linear but inverse to the relationship observed for organ dosage. Generally, the effect of miscentering on image quality was not significant, except when the table was lowered more than 5 cm relative to the isocenter, where the posterior part of the phantoms showed significant image noise ($p < 0.05$) due to the bowtie filter effect as reported by Sookpeng et al. (2019).

Table 8 shows the variations of the scanner's technical parameters, which vary from vendor to vendor. The dose optimization technique is used by using ATCM to optimize radiation dose in the CT scan of the head, which is either axial or helical. All the studies utilized the ATCM except for study by Anam et al. (2019a,b) where axial scanning was made in fixed mA acquisition mode. The investigated studies provided data for each degree of miscentering based on the CT dose metrics in term of CTDI_{vol} and DLP values, which were derived from the scanner's dose descriptors and expressed in mGy and mGy·cm, respectively.

The absorbed lens dose for each miscentering level was expressed in mGy and the dose difference between miscentering and isocenter value was expressed in percentage. There were variations in the data presentation based on the method used to measure the dose as tabulated in Table 9 and Fig. 3. The studies by Sookpeng et al. (2019) and Ishita et al. (2022) presented the data of the absorbed dose as mean and standard deviation denoted in mGy. Whilst study by Anam et al. (2019a,b) however presented the value of the mean of CTDI_{vol} and absorbed dose to the lens normalized by 100 mAs.

4. Discussion

Vertical miscentering affects the lens's radiation dose, as demonstrated in the studies. The radiation dose delivered to the phantom by CT increases and decreases as the phantom is altered from the isocenter depending the table height. The effect of miscentering and the dose received by the anterior organ such as the lens is inversely proportional with respect to isocenter (Anam et al., 2019a,b; Euler et al., 2019; Kataria et al., 2016; Sookpeng et al., 2019; Ishita et al., 2022). Superior miscentering, by increasing the table height above the isocenter decreases the dose to the lens and lowers the table height inferiorly increases the radiation dose to the lens. Doses reported when table height 2 cm–6 cm above the isocenter are 10 %–30 % lower but 10 %–40 % higher when table height is 2 cm–6 cm below. The study by Kaasalainen (2014) also reported 23 % dose decreases in adult chest phantoms for a table position of 6 cm above the isocenter.

The relationship between dose and vertical miscentering is strongly influenced by bowtie filter performance (B. Kataria et al., 2016; Toth et al., 2007). At the isocenter, the bowtie filter's attenuation pattern corresponds to the patient's cross-sectional form, effectively filtering out low-energy photons that would otherwise increase surface dose while contributing little to image quality (Zhang et al., 2016). This promotes homogeneous radiation dose distribution throughout the imaging field.

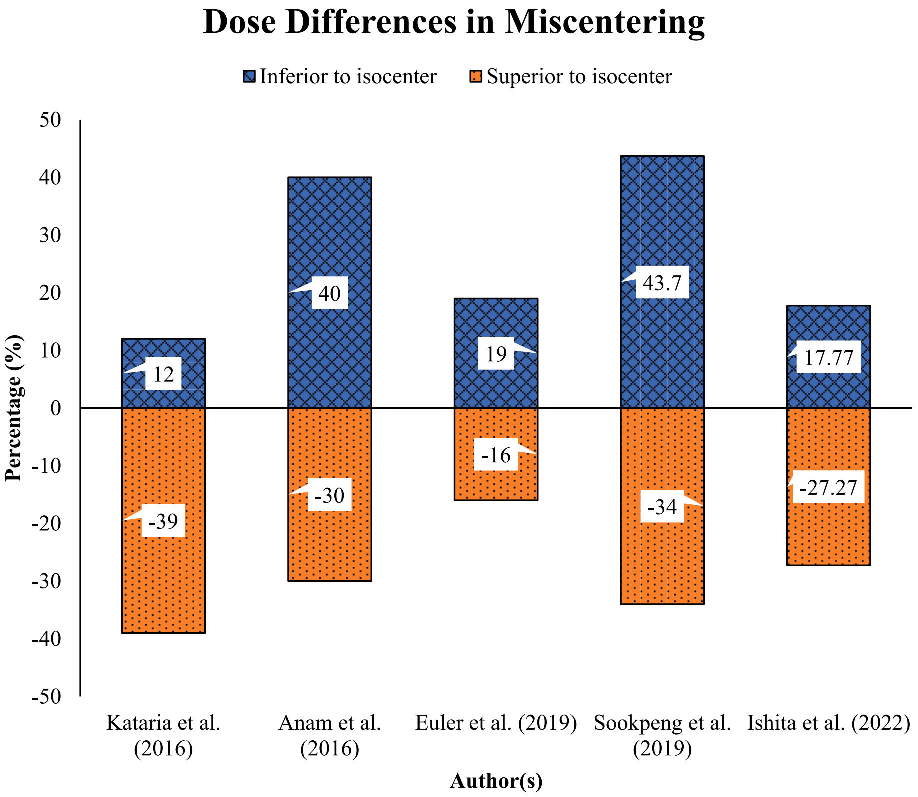

Fig. 2. Vertical miscentering distance with reference to the scanner isocenter for all authors included in the review. The measurements reflect the deviation (in percentage) of patient positioning from the ideal isocenter alignment during CT acquisition.

Significantly higher doses occur with inferior miscentering due to the eye's ventral location (~10 cm anterior to center), which places it at the filter's center where less attenuation occurs leading to dose increases up to 40 % (Sookpeng et al., 2019). In contrast, superior miscentering moves the eye toward the edge of the beam and filter, reducing dose via greater attenuation and less direct irradiation.

The result is consistent with a study conducted by Habibzadeh et al. (2012) using three different types of scanners, the 64-slice GE Lightspeed VCT, 8-slice GE Brightspeed Edge, and 4-slice GE lightspeed QX/I (Habibzadeh et al., 2012). The increase in surface dose due to miscentering measured using CTDI-32 phantom at 2 cm, 4 cm and 6 cm below isocenter are noticed in 64-slices scanner, 8-slices scanner, and 4-slices scanner. The dose increment recorded are 13.5 %, 33.3 % and 51.1 % in 64-slices scanner, 14.4 %, 33.6 % and 53 % in 8-slices scanner and 14.9 %, 32.9 % and 51.4 % in 4-slices scanner. However, a study by Isa et al. (2019) using a CTDI head phantom reported significant increases in mean $\mathrm{CTDI_{vol}}$ value during miscentering: 105.06 mGy at +10 cm above and 105.51 mGy at −10 cm below, compared to 99.7 mGy at the isocenter. This finding is not identical to the values reported in this systematic review using the same CTDI phantom. According to the study by Anam et al. (2019a,b) recorded a 15 % decrease in $\mathrm{CTDI_{vol}}$ at both superior and inferior miscentering. Although using the same central hole to measure $\mathrm{CTDI_{vol}}$, the differences are likely due to variations in technical parameters such as the scanning mode.

The differences in detector rows, parameter settings, and scanning mode affect radiation dose to the lens in head CT. The Multi Detector CT (MDCT) systems have multiple rows of detectors allowing faster image acquisition, but a higher number of detectors may increase the patient dose. Smaller detectors use a smaller X-ray beam, resulting in longer scan times and potentially higher doses. Manufacturers produce CT scanners with different detector configurations. Although most MDCT scanners use both helical and axial modes with the scanning parameters vary. Previous studies show that the helical technique records significantly higher doses compared to conventional axial mode due to smaller slice thickness, narrow collimation, and a higher number of slices (Dousi et al., 2021). Since this study used ATCM, the results for axial and helical scans differ significantly based on beam geometry, table movement, and exposure settings.

Understanding dosimetry uncertainties is crucial for accurate dose-response analysis. Ionization chambers like the 10 cm pencil chamber and 100-mm-long Radcal 10X5-3CT are reference standards due to high accuracy and stability, with uncertainties of ±4 % to ±7 %. The Radiophotoluminescence (RPL) glass dosimeters (e.g., GD352 M by Chiyoda Technol and AGC Techno Glass) offer good reproducibility but exhibit ±5 % to ±10 % uncertainty due to energy dependence and readout variability (Huang and Hsu, 2011). Metal Oxide Semiconductor Field Effect Transistor (MOSFET) dosimeters (e.g., TN-502RD-H) are sensitive and suitable for in vivo use but are prone to ±6 % to ±10 % uncertainty from angular and temperature dependencies (Ehringfeld et al., 2005). Optically Stimulated Luminescence (OSL) dosimeters like NanoDot™ (Al_2O_3:C) also show ±5 % to ±10 % uncertainty, requiring careful handling due to light fading and directional sensitivity (Akyol et al., 2019). Computational tools such as CT-EXPO v2.5 and VirtualDose™ CT, based on Monte Carlo simulations, have higher uncertainties (±10 % to ±20 %) due to reliance on scanner-specific input and anatomical realism (Ding et al., 2015; Stamm and Nagel, 2002).

There are two main types of dose estimation errors in radiation studies. Classical error, unrelated to true dose, weakens observed risk and leads to underestimation. Berkson error, unrelated to estimated dose, arises from assigning average group doses to individuals, causing mismatches in actual exposure (Gilbert, 2009). Shared errors affect groups due to common misassumptions and can introduce systematic biases. These errors distort dose-response curves and reduce study power, especially in low-dose research. While statistical correction is possible, it cannot fully restore precision. Reducing these errors requires collaboration between dosimetrists and statisticians. In general, dose

Table 7
Comparison of scanner, size of bowtie filter applied, dose optimization techniques and effect on radiation to the lens and image noise.

Author	CT Scanner	Bowtie Filter	Dose Optimization	Image Quality	Effect on radiation dose	Image qualiy
Kataria et al. (2016)	128-slices Somatom Definition AS, Siemens Healthcare.	Medium	Caredose 4D Gantry Tilt	Not observed	A lower dose to the lens was observed when positioned above the isocenter, while a higher dose was recorded when positioned below the isocenter.	No noticeable effect on image quality was documented.
Anam et al. (2019)	16-slices MDCT Toshiba Alexion™ 4	Wide	Not stated	Observed	The eye dose decreased when the position was off-center above the isocenter and increased when off-center below the isocenter. Image noise was slightly higher with superior off-centering, though the difference was insignificant.	Positioning the phantom higher than the isocenter led to a marked increase in image noise. At 2 cm above the isocenter, noise rose by about 10 % in the CTDI phantom and 20 % in the anthropomorphic one. At 4 cm, the increase reached approximately 20 % and 40 %, respectively. Such increases in noise can compromise image clarity and diagnostic reliability.
Euler et al. (2019)	128-slice Somatom Edge Plus, Siemens Healthineers.	Wide	Caredose 4D	Observed	Superior off-centering reduces the dose to the eyes, whereas inferior off-centering increases it. The differences in organ dose and image quality were influenced by the use of a bowtie filter in pediatric head CT scans	An inverse relationship was observed between image noise and radiation dose with changes in patient positioning. As off-centering varied, noise per mGy ranged from 0.12 to 0.23 HU/mGy for the supratentorial brain, 0.14 to 0.3 HU/mGy for the infratentorial brain, and 0.07 to 0.15 HU/mGy for the eyes.
Sookpeng et al. (2019)	16-slice GE Brivo	Medium	Smart mA	Observed	The phantom eye lens doses and image noise significantly increased when the table was positioned 5 cm below the isocenter due to the effect of the bowtie filter	The study found that image noise remained consistent across most table positions, except when the table was 5 cm below the isocenter. In that case, increased noise was noted at the phantom's posterior section, likely due to altered interaction with the bow tie filter, which caused greater attenuation at the edges.
Ishita et al. (2022)	320-row multidetector CT Aquilion One Vision, Canon Medical Systems.	Medium	Volume EC Automatic exposure control	Not Observed	The lens had highest absorbed doses at a table height of −40 mm. The table height influenced the absorbed dose. However, the $CTDI_{vol}$ was sustained by automatic height control (AHC). The proper centering was crucial, even while employing AHC.	No meaningful differences in image noise were found across varying table heights. The findings suggest that minor vertical shifts did not significantly affect image quality, indicating that the images remained consistently clear regardless of the table setting.

Table 8
The technical parameter of CT scanner used for each of the studies.

Author	Scanner	Acquisition Type	ATCM	Voltage (kVp)	Tube Current (mAs)	Rotation Time/cycle (s)	Pitch	Slice Thickness (mm)	Collimation (mm)
Kataria et al. (2016)	Siemens	Helical	On	120	350	0.5	0.55	1	0.6
Anam et al. (2019)	Toshiba	Axial	Off	120	120	1.0	–	8	–
		Axial	Off	100	100	–	–	4	–
Euler et al. (2019)	Siemens	Helical	On	100	595	1.0	1	5	128 x 0.6
Sookpeng et al. (2019)	GE	Helical	On	120	100–180	1.0	0.562	1.25	20
Ishita et al. (2022)	Canon	Helical	On	120	10–500	0.5	0.81	–	0.5 x 80

uncertainties are more likely to obscure real effects than create false ones. Ongoing efforts to measure and minimize these uncertainties are key to improving risk assessment (Daniels et al., 2020).

A study by (Nuntue et al., 2021) demonstrated the effect of detector rows and scanning parameters on Entrance Surface Air Kerma (ESAK) to the lens in 64-slice versus 32-slice MDCT. The difference in mean ESAK ranged from 21.57 % to 37.50 %. The study also found that using ATCM in helical mode reduced lens dose, highlighting how technical discrepancies affect $CTDI_{vol}$, DLP, and absorbed dose in head CT. Additionally, the type of bowtie filter used affects lens dose. Narrower filters (small/medium) provide lower peak eye lens dose compared to standard filters, especially in CT head perfusion (Al-Hayek et al., 2022). Dose reductions of 24 %–35 % were observed, with potential reduction up to 50 % when combined with a table height 4 cm above isocenter.

Image quality is also affected. Although the relationship between image noise and positioning is inverse to absorbed dose, the increase in noise is relatively small. The previous study by Anam et al. (2019a,b) found a 10 %–20 % noise increase in anterior parts when the phantom was 2 cm above the isocenter. The average noise for standard head CT protocols was 8.07 % (above) vs. 6.82 % (below) (I. N. C. Isa et al., 2019). Noise decreases with greater slice thickness and is measured using standard deviation in the ROI (Alshipli and Kabir, 2017). The image noise and radiation exposure in CT imaging is substantially influenced by scanner type, slice thickness, and helical pitch. Deviations from a pitch value of 1.0 during helical scanning cause equivalent dose variations, with lower pitches increasing and higher pitches decreasing radiation exposure (Goldman, 2007). At the bowtie filter's edge, photon attenuation reduces fluence and increases noise. According to the study by Sookpeng et al. (2019) reported significantly higher posterior noise ($p < 0.05$) at 5 cm inferior miscentering due to this phenomenon.

ATCM in a modern scanners helps optimize dose while preserving image quality. The value of $CTDI_{vol}$ is generally lower with ATCM than fixed mA (Dabli et al., 2023). The latest ATCM system by GE Healthcare, named GE's organ-based Smart mA, lowered eye dose by 25.88 % and CTDIvol by 9.39 % in head CT (Kim et al., 2017). However, ATCM requires precise phantom positioning at the gantry isocenter. The study by

Table 9
Level of vertical miscentering, the dose descriptor and absorbed eye lens dose recorded for each of the studies.

Author	Misentering (cm)	Dose Descriptor		Absorbed Organ dose (mGy)				Organ Dose (mSv)	Relative Organ Dose Deviation (%)
		$CTDI_{vol}$ (mGy)	DLP (mGy. cm)	Right eyes	Left eyes	Average	Difference (%)		
Kataria et al. (2016)	+3	57.57	939.3-	–	–	–	–	–	−39 to −38.5
	0	61.19	928	–	–	–	–	54.4	0
	−5	65.84	1031	–	–	–	–	–	5.2 to 12[b]
Anam et al. (2019) [a]	+6	0.60	–	0.7	0.5	–	–	–	−30
	+4	0.75	–	0.7	0.7	–	–	–	−20
	+2	1.00	–	0.9	0.9	–	–	–	−10
	0	1.00	–	1.0	1.0	–	–	–	0
	−2	1.18[b]	–	1.1[b]	1.3[b]	–	–	–	20[b]
	−4	1.25[b]	–	1.5[b]	1.5[b]	–	–	–	30[b]
	−6	1.26[b]	–	1.7[b]	1.7[b]	–	–	–	40[b]
Euler et al. (2019)	+6	–	–	27.3 ± 3.4	26.9 ± 1.8	–	–	–	−17.5
	+4	–	–	29.3 ± 4.5	29.7 ± 4.9	–	–	–	–
	+2	–	–	31.8 ± 3.2	32.0 ± 2.1	–	–	–	–
	0	–	–	32.6 ± 4.1	31.3 ± 3.2	–	–	–	–
	−2	–	–	32.0 ± 3.3[b]	32.8 ± 4.3[b]	–	–	–	–
	−4	–	–	33.3 ± 2.4[b]	34.7 ± 4.0[b]	–	–	–	–
	−6	–	–	37.5 ± 3.3[b]	37.2 ± 4.6[b]	–	–	–	10
Sookpeng et al. (2019)	+3	47.38	1059	29.60	35.06	32.34	–	–	−33.6
	+1	47.08	1052	43.51	44.69	44.10	–	–	−9.46
	0	47.38	1059	47.82	49.59	48.71	–	–	–
	−2	47.08	1052	52.53[b]	54.10[b]	53.31[b]	–	–	9.46[b]
	−3	47.08	1052	58.21[b]	62.13[b]	60.17[b]	–	–	23.5[b]
	−5	46.77	1034	68.21[b]	71.74[b]	69.97[b]	–	–	43.7[b]
Ishita et al. (2022)	+4	12.78 ± 0.15	–	9.52 ± 0.25	9.50 ± 0.31	9.51 ± 0.28	−27.27 ± 3.02	–	–
	+2	13.32 ± 0.22	–	11.19 ± 0.15	11.17 ± 0.20	11.18 ± 0.18	−14.51 ± 2.82	–	–
	0	13.42 ± 0.22	–	13.18 ± 0.30	12.98 ± 0.41	13.08 ± 0.38	–	–	–
	−2	13.40 ± 0.24	–	13.70 ± 0.39[b]	14.25 ± 0.78[b]	13.97 ± 0.67[b]	+6.87 ± 5.99[b]	–	–
	−4	13.30 ± 0.15	–	15.08 ± 0.96[b]	15.72 ± 1.40[b]	15.40 ± 1.24[b]	+17.77 ± 10.07[b]	–	–

[a] Normalized $CTDI_{vol}$ and absorbed dose (mGy/100 mAs).
[b] Higher doses relative to isocenter.

Söderberg (2016) showed $CTDI_{vol}$ increased by 18 % at 5 cm above and decreased by 15 % at 5 cm below the isocenter, even with ATCM (Söderberg, 2016). Similar findings were reported by Zhang et al. (2016).

The scout image is a key to ATCM's modulation decisions. Miscentering distorts the scout image magnifying it when above the isocenter—causing overestimation of phantom size and increased tube current (Sookpeng et al., 2019). Organ-based ATCM reduces anterior tube current by 30 % across a 90° arc but may still increase lens dose if miscentering brings the eyes into the beam path (Kim et al., 2017).

Interestingly, $CTDI_{vol}$ and DLP remain nearly constant across different miscentering levels in head CT due to lateral scout use, which avoids magnification. According to the study by Sookpeng et al. (2019) reported that 5.75 % increase in $CTDI_{vol}$ with AP scout compared to lateral. However, study by Söderberg (2016) found that using both AP and lateral scouts in CT thorax led to dose variations depending on table height (Söderberg, 2016; Sookpeng et al., 2019).

In addition, most of the manufacturer have introduced innovations like automated positioning systems. A 3D infrared camera reduced average vertical miscentering from 18 mm to 4 mm for CT abdomen and from 19 mm to 7 mm for CT thorax (Saltybaeva et al., 2018). AI-based methods improved positioning accuracy by 99 %, reduced noise, and increased dose uniformity (Gang et al., 2021; Manava et al., 2023). However, these systems are not yet optimized for pediatrics and require newer software versions. Dynamic beam filters have also shown promise in improving dose distribution in off-centered patients (İçöz and Gül, 2025).

CT scanners have recently added auto couch height positioning compensation known as an Automatic Height Correction (AHC), which adjusts output dosage variances based on table height. The role of AHC was to adjust tube current modulation based on scout photographs and preserve $CTDI_{vol}$ across various table heights (Ishita et al., 2022). However, absorbed dose to organs like the lens still varies with table height. The previous study by Barreto et al. (2019) found that AHC reduced organ dose variation from 35 % to 18 %, demonstrating its benefit in minimizing but not eliminating the impact of miscentering (Barreto et al., 2019).

This systematic review has a few limitations. First, the included investigations range from 2014 to 2025, and changes in CT scanner types, protocols, and dose optimization technologies throughout this period may generate variability that reduces comparability. Second, just five studies were included in the final review, which limited the findings' generalizability. Third, most research relied on retrospective data and phantom-based simulations, which may not adequately account for real-world clinical differences in patient posture and anatomy. Finally, while the review focuses on vertical miscentering, it does not consider other aspects such as lateral miscentering, head tilt, or gantry angle modifications, which may have an impact on lens dose and image quality.

5. Conclusion

The vertical miscentering in head CT examination has led a major impact on radiation exposure and image quality. Even little deviations from the gantry isocenter can result in increased radiation exposure

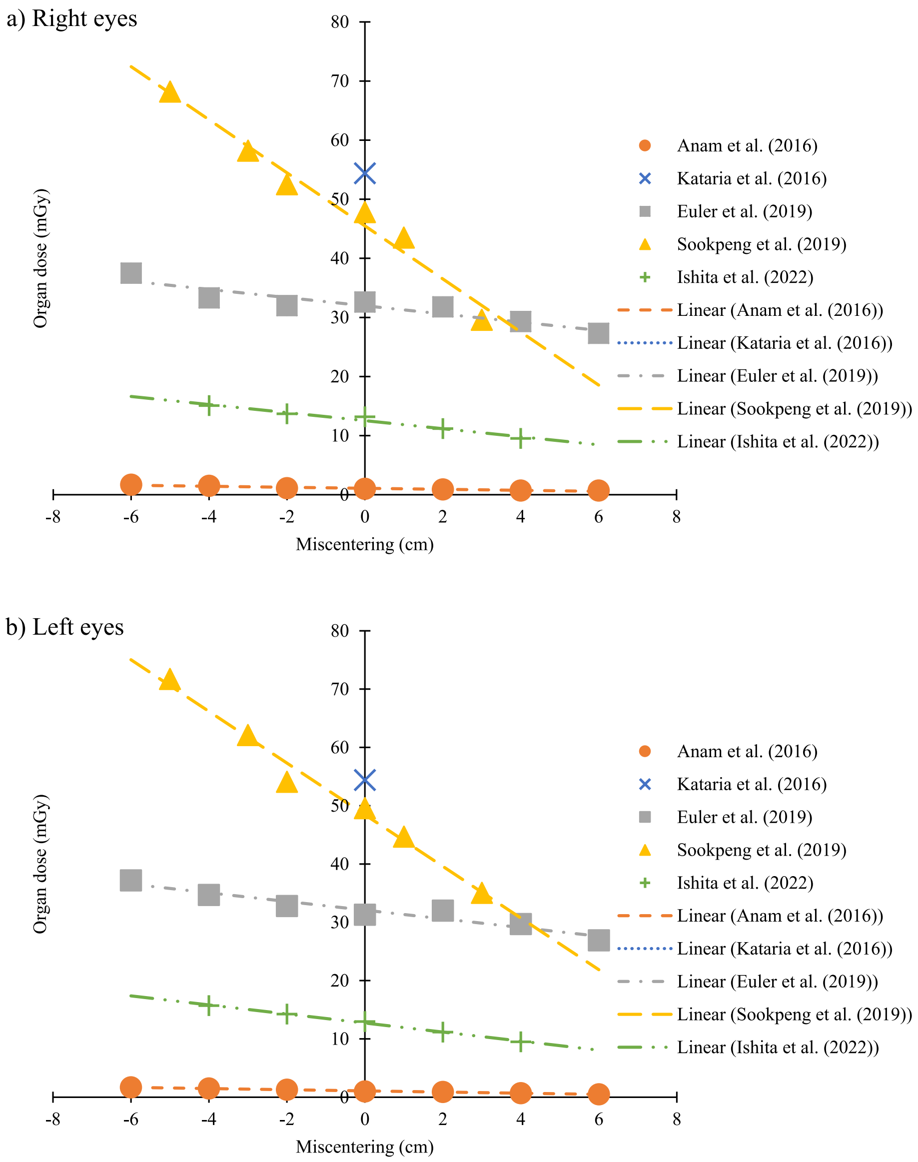

Fig. 3. Effect of patient miscentering on organ dose (mGy) to the (a) right (b) left eye lens.

especially to the eyes and mild image deterioration. This problem can be avoided by combining accurate patient location with sophisticated technology such as AI and infrared systems, as well as extensive radiographer training. Ensuring appropriate alignment is critical for improving patient safety and diagnostic accuracy.

CRediT authorship contribution statement

Izdihar Kamal: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization. **Mohd Khairul Fazwan Mohd Yusof:** Methodology, Formal analysis. **Muhammad Khalis Abdul Karim:** Project administration, Funding acquisition. **Nur Anis Izzati Che Mut:** Validation, Supervision. **Suffian Mohamad Tajudin:** Software, Project administration. **Aminatul Saadiah Abdul Jamil:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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