Effect of Body Mass Index BMI on Technical Parameters (kVp and mAs) Selection in Chest X- Ray (18–45 Years) An Observational Study

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Abstract—Background: **The tube potential (kVp) and tube current–time product (mAs) chosen for a chest radiograph determine both image quality and patient dose. Body habitus is the main patient factor that changes the exposure needed, yet in many Indian departments technique is chosen empirically and the influence of body mass index (BMI) on that choice is rarely documented.** ***Objective:*** **To assess how BMI influences the selection of kVp and mAs for postero-anterior (PA) chest radiography in adults aged 18–45 years.** ***Methods:*** **An observational cross-sectional study was conducted on 90 adults referred for PA chest radiography at a tertiary teaching hospital in Bareilly, Uttar Pradesh, India, after institutional ethics approval. Age, sex, referring department, height and weight were recorded, and BMI was classified using WHO cut-offs. The kVp and mAs used for each examination were recorded from the console. Proportions are reported with Wilson 95% confidence intervals (CIs); associations between BMI category and exposure level were tested using Fisher's exact test, the Cochran–Armitage trend test and Spearman's rank correlation at a significance level of 0.05.** ***Results:*** **Of 90 participants, 50 (55.6%) were women and 45 (50.0%) were aged 36–45 years; 84 (93.3%) were outpatients. Overall, 48 participants (53.3%; 95% CI 43.1–63.3) had a BMI of 25 kg/m2 or more, including 33 (36.7%; 95% CI 27.4–47.0) with obesity. All overweight and obese participants were exposed at 70–80 kVp and 16–18 mAs, whereas normal-weight participants were exposed at 60–65 kVp and 14–16 mAs (Fisher's exact p below 0.001; phi coefficient 1.00). The proportion receiving high exposure factors rose across ordered BMI categories (Cochran–Armitage z = 8.66, p below 0.001; Spearman rho = 0.92, p below 0.001). On range midpoints, this corresponded to a 20.0% higher kVp, a 13.3% higher mAs and an estimated 1.63-fold higher relative tube output (kVp squared multiplied by mAs).** ***Conclusion:*** **BMI was strongly associated with the exposure factors chosen for adult chest radiography, and patients with a BMI of 25 kg/m2 or more received a substantially higher estimated tube output. BMI-based exposure charts, preferably combined with chest-thickness measurement and dose monitoring, are recommended to standardise technique and keep doses as low as reasonably achievable.**

***Index Terms*—Body mass index, chest radiography, exposure factors, kilovoltage peak, milliampere-seconds, obesity, radiation dose optimisation.**

I. Introduction

Chest radiography remains the most frequently performed radiological examination worldwide because it is fast, inexpensive and widely available, and it is often the first test for respiratory, cardiac and screening indications. Every examination involves exposure to ionising radiation, so each one must be justified and its dose optimised under the as-low-as-reasonably-achievable (ALARA) principle [1]. In projection radiography, optimisation depends mainly on the exposure factors set by the radiographer: the

tube potential (kVp), which sets beam energy and penetration, and the tube current–time product (mAs), which sets the number of photons reaching the patient [2].

With digital detectors, the link between dose and image appearance has largely disappeared. Over-exposure no longer produces a visibly dark image, which makes gradual "dose creep" possible, while under-exposure shows up as quantum noise [3-6]. As a result, appropriate exposure-factor selection depends heavily on the radiographer's judgement of patient size, and this judgement is often based on visual estimation rather than measurement.

Body habitus is the main patient-related determinant of the exposure required. Greater soft-tissue and adipose thickness increases attenuation and scatter, so a higher kVp, a higher mAs or both are needed to keep the signal at the detector adequate [2,7-9]. The global prevalence of obesity has risen steadily over the last three decades [10], and India now has a growing double burden of under- and over-nutrition. According to the fifth National Family Health Survey (NFHS-5, 2019–21), close to one in four Indian adults has a BMI of 25 kg/m² or more, with a steep rise among urban women [11,12]. Imaging departments therefore see more patients with larger body habitus, who present technical challenges in positioning, penetration, image quality and dose [7,8].

A systematic review of patient-based exposure-factor selection concluded that radiographic technique should be individualised to patient size, but noted that evidence on which size metric to use, and how, remains limited [13]. Phantom work has shown that increasing body habitus in chest radiography raises the radiation dose and lowers image quality [14], and clinical studies of other projections and modalities have reported a consistent positive relationship between BMI and patient dose [15-17]. However, evidence from routine clinical chest radiography in young and middle-aged Indian adults is scarce, and published Indian dose surveys report exposure factors without stratifying by body habitus [18].

Given these gaps, the present study aimed to assess the effect of BMI on the selection of technical parameters (kVp and mAs) for PA chest radiography among adults aged 18–45 years in Bareilly district, Uttar Pradesh, India, and to estimate the relative increase in tube output associated with higher BMI.

II. Materials and Methods

Study design and setting

This hospital-based observational cross-sectional study was conducted in the Department of Radiodiagnosis of Shri Ram Murti Smarak Institute of Medical Sciences (SRMS IMS), a tertiary-care teaching hospital in Bareilly, Uttar Pradesh, India, over a period of six months following ethical approval (January–June 2024). The study is reported in accordance with the STROBE statement for cross-sectional studies [19].

Ethical approval

The study protocol (dated 14 December 2023) was reviewed and approved by the Institutional Ethics Committee of SRMS IMS, Bareilly, at its meeting on 21 December 2023 (Ref. No. SRMS IMS/IPS/ECC/2023/02; certificate dated 28 December 2023). Written informed consent was obtained from every participant before inclusion, and all data were anonymised before analysis. The study did not alter the clinical indication for the examination; only radiographs requested on clinical grounds were included.

Participants

Adults referred from the outpatient (OPD) and inpatient (IPD) departments for PA chest radiography were enrolled by convenience sampling. **Inclusion criteria** were age 18–45 years, a clinically indicated chest radiograph, ability to stand for an erect PA projection, and willingness to provide informed consent. **Exclusion criteria** were age outside 18–45 years, known or suspected pregnancy, contraindication to radiography, uncooperative or clinically unstable patients, and refusal of consent.

Sample size

A total of 90 consecutive eligible participants were enrolled during the study period. For the primary correlation objective, a sample of 85 is required to detect a correlation coefficient of 0.30 with 80% power at a two-sided α of 0.05 (Fisher z-transformation); the enrolled sample of 90 therefore provides 80% power to detect correlations of $|r| \geq 0.29$.

Data collection and variables

Data was captured on a structured proforma using Epicollect5 and exported to Microsoft Excel. Demographic variables were age (years, grouped as 18–26, 27–35 and 36–45 years), sex and referring department (OPD/IPD). Height and weight were measured with the participant in light clothing and without footwear, and BMI was calculated as weight (kg) divided by height squared (m^2). BMI was classified using the WHO international cut-offs [20]: underweight (<18.5 kg/m^2), normal (18.5–24.9 kg/m^2), overweight (25.0–29.9 kg/m^2) and obese (≥30.0 kg/m^2).

All examinations were erect PA chest radiographs acquired on Siemens X-ray machine and Allengers CR/DR system at a source-to-image distance of 180 cm with [grid / no grid], following the department's standard positioning protocol at full inspiration, consistent with the European quality criteria for PA chest radiographs [21]. Exposure factors were selected manually by the radiographer on duty according to routine practice, and the kVp and mAs used for each examination were recorded from the console. For analysis, the exposure technique was classified into two levels: **standard** (≤65 kVp and ≤16 mAs) and **high** (70–80 kVp and 16–18 mAs).

Statistical analysis

Categorical variables are presented as frequencies and percentages with Wilson score 95% confidence intervals (CIs) [22]. The sex distribution was compared with an equal (1:1) split using an exact binomial test, and the age-group distribution was compared with the distribution expected from the width of each age band using the chi-square goodness-of-fit test. The observed proportion of participants with BMI ≥25 kg/m^2 was compared with the sex-weighted national NFHS-5 prevalence (23.5%) using an exact binomial test [11].

The association between BMI category (<25 vs ≥25 kg/m^2) and exposure level (standard vs high) was tested with Fisher's exact test, and its strength was expressed as the phi (φ) coefficient. A linear trend in the proportion receiving high exposure across the four ordered BMI categories was assessed with the Cochran–Armitage test, and the monotonic association between ordinal BMI category and exposure level was quantified with Spearman's rank correlation (ρ) and Kendall's τ-b. To express the dosimetric meaning of the observed technique differences, a relative tube-output index proportional to $kVp^2 \times mAs$ was calculated at the midpoint and the limits of each exposure range and normalised to the normal-BMI midpoint (62.5 kVp, 15 mAs) [2]. A two-sided $p < 0.05$ was considered statistically significant. Analyses were performed in Python 3 (SciPy and statsmodels libraries).

III. Results

Participant characteristics

Ninety participants were analysed. Women made up 55.6% of the sample (n = 50; 95% CI 45.3–65.4) and men 44.4% (n = 40; 95% CI 34.6–54.7); this did not differ significantly from an equal split (exact binomial p = 0.343). Half the participants (n = 45; 50.0%) were aged 36–45 years, and the age distribution differed significantly from that expected from age-band width ($\chi^2 = 8.43$, df = 2, p = 0.015), reflecting more referrals in the oldest band. Almost all participants were outpatients (n = 84; 93.3%; 95% CI 86.2–96.9) (Table 1).

Table 1 Demographic characteristics of the study participants (n = 90)

Characteristic	n	%	95% CI*	Test statistic, p-value
Sex				
Male	40	44.4	34.6–54.7	Exact binomial vs 1:1, p = 0.343
Female	50	55.6	45.3–65.4	
Age group (years)				
18–26	25	27.8	19.6–37.8	χ^2 GOF = 8.43, df = 2, p = 0.015†
27–35	20	22.2	14.9–31.8	
36–45	45	50.0	39.9–60.1	
Referring department				
Outpatient (OPD)	84	93.3	86.2–96.9	Exact binomial, p < 0.001
Inpatient (IPD)	6	6.7	3.1–13.8	

*Wilson score interval. †Expected counts proportional to age-band width (9, 9 and 10 years: 28.9, 28.9 and 32.1). CI, confidence interval; GOF, goodness of fit.

Distribution of BMI

Normal BMI was the largest single category (n = 37; 41.1%), followed by obesity (n = 33; 36.7%), overweight (n = 15; 16.7%) and underweight (n = 5; 5.6%) (Table 2; Fig. 1). Overall, 48 participants (53.3%; 95% CI 43.1–63.3) had a BMI ≥25 kg/m². This proportion was more than twice the sex-weighted national NFHS-5 estimate of 23.5% (exact binomial p < 0.001), consistent with a hospital-referred population.

Table 2 Distribution of participants by WHO BMI category (n = 90)

BMI category	BMI (kg/m²)	n	%	95% CI*
Underweight	<18.5	5	5.6	2.4–12.4
Normal	18.5–24.9	37	41.1	31.5–51.4
Overweight	25.0–29.9	15	16.7	10.4–25.7
Obese	≥30.0	33	36.7	27.4–47.0
Overweight + obese	**≥25.0**	**48**	**53.3**	**43.1–63.3**

*Wilson score interval. Comparison of the BMI ≥25 kg/m² proportion with the sex-weighted NFHS-5 national prevalence (23.5%): exact binomial p < 0.001. Distribution across the four categories vs a uniform distribution: χ^2 = 30.36, df = 3, p < 0.001.

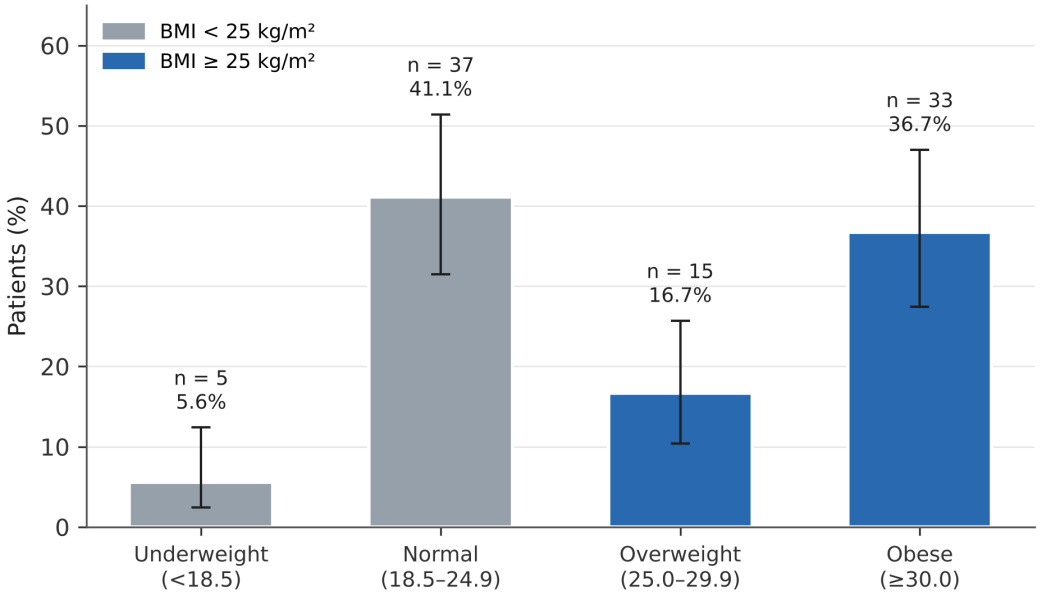

Fig. 1. Distribution of participants by WHO body mass index category. Bars show percentages and error bars show Wilson 95% confidence intervals; grey bars are BMI <25 kg/m² and blue bars are BMI ≥25 kg/m² (n = 90).

Association between BMI and exposure factors

Exposure factors differed systematically by BMI category (Table 3; Fig. 2). Participants with normal BMI were exposed at 60–65 kVp and 14–16 mAs. Every overweight and obese participant (48/48) was exposed at the high level of 70–80 kVp and 16–18 mAs, while no participant with BMI <25 kg/m² (0/42) received high exposure factors (Fisher's exact $p < 0.001$; $\varphi = 1.00$). The exposure factors recorded for underweight participants (>60 kVp, >14 mAs) fell within or just above the standard range and could not be distinguished from those of normal-weight participants, so the group was classified as standard. The proportion receiving high exposure rose monotonically across ordered BMI categories (0%, 0%, 100% and 100%; Cochran–Armitage $z = 8.66$, $p < 0.001$), and ordinal BMI category correlated strongly with exposure level (Spearman $\rho = 0.923$, $p < 0.001$; Kendall τ-b = 0.865, $p < 0.001$).

Table 3 Exposure factors used for PA chest radiography by BMI category

BMI category (n)	kVp used	mAs used	Exposure level	High exposure, n (%)
Underweight (5)	>60	>14	Standard	0 (0.0)
Normal (37)	60–65	14–16	Standard	0 (0.0)
Overweight (15)	70–80	16–18	High	15 (100.0)
Obese (33)	70–80	16–18	High	33 (100.0)

BMI <25 vs ≥25 kg/m² × standard vs high exposure: Fisher's exact $p < 0.001$; $\chi^2 = 90.0$, df = 1, $p < 0.001$; $\varphi = 1.00$. Trend across four ordered BMI categories: Cochran–Armitage $z = 8.66$, $p < 0.001$. Ordinal BMI category vs exposure level: Spearman $\rho = 0.923$, $p < 0.001$; Kendall τ-b = 0.865, $p < 0.001$.

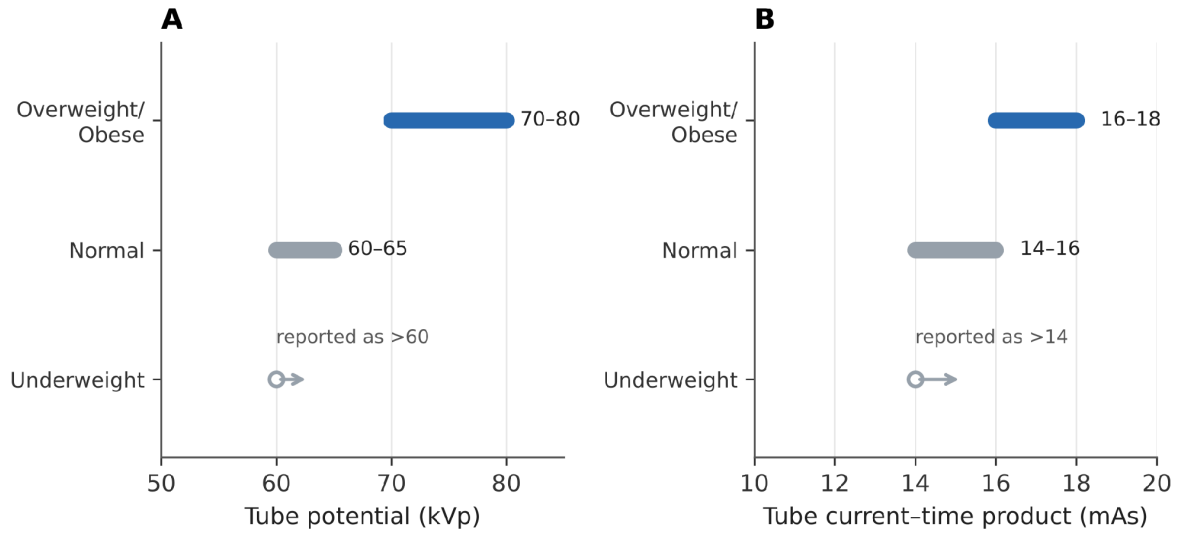

Fig. 2. Ranges of (A) tube potential (kVp) and (B) tube current–time product (mAs) used for PA chest radiography by BMI group. For underweight participants only the lower bound was recorded (open circle with arrow).

Estimated effect on tube output

On range midpoints, participants with BMI ≥25 kg/m² were exposed at a 20.0% higher kVp (75 vs 62.5 kVp) and a 13.3% higher mAs (17 vs 15 mAs). Because tube output rises roughly with the square of kVp and in direct proportion to mAs, this corresponds to an estimated relative tube-output index of 1.63 (range 1.34–1.97) compared with the normal-BMI midpoint (range 0.86–1.15) (Table 4; Fig. 3). The output ranges of the two groups did not overlap.

Table 4 Relative tube-output index ($\propto$ kVp² × mAs) by exposure level

Exposure level	kVp (range; midpoint)	mAs (range; midpoint)	Relative output, midpoint	Relative output, range
Standard (BMI <25 kg/m^2)	60–65; 62.5	14–16; 15	1.00 (reference)	0.86–1.15
High (BMI ≥25 kg/m^2)	70–80; 75	16–18; 17	1.63	1.34–1.97
Change at midpoint	+20.0%	+13.3%	+63%	—

The index is a physics-based approximation of relative X-ray tube output at the beam entrance (output $\propto$ kVp² × mAs) and does not replace measured entrance surface dose, dose–area product or exposure index.

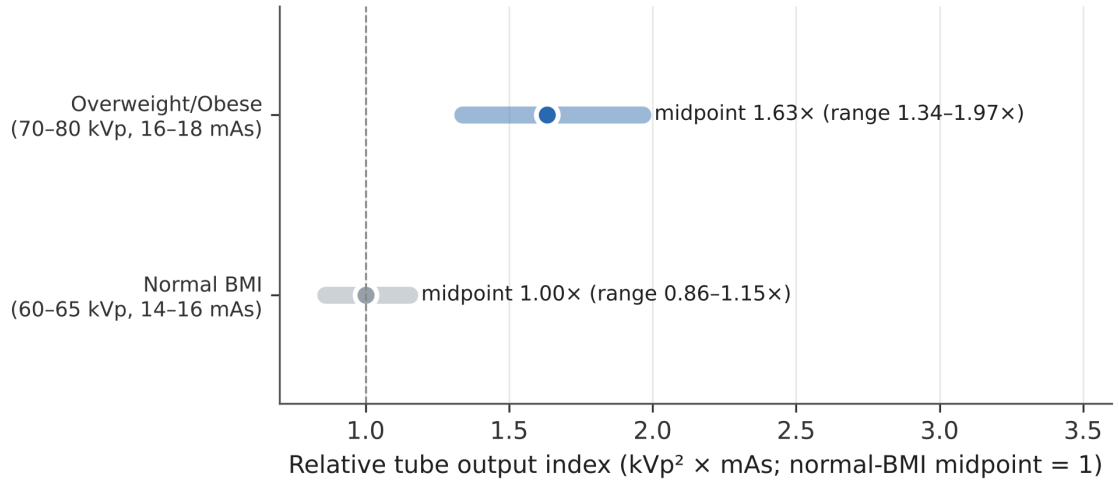

Fig. 3. Estimated relative tube-output index (kVp² × mAs) for standard and high exposure techniques, normalised to the normal-BMI midpoint (dashed line = 1.0). Dots show range midpoints; bars show the range between the lowest and highest settings.

IV. Discussion

This study found that BMI was strongly associated with the exposure factors used for routine adult PA chest radiography. Every overweight and obese participant was imaged at a higher kVp and mAs than normal-weight participants, which on range midpoints corresponds to about 63% more estimated tube output. More than half the participants had a BMI ≥25 kg/m², so this BMI-driven increase in technique affected the majority of chest examinations in this young-to-middle-aged adult population.

The direction of the association agrees with the physics of attenuation and with earlier work. In an anthropomorphic phantom study of chest radiography, Al-Murshedi et al. showed that increasing body habitus raised the radiation dose and degraded image quality, and that exposure factors must be adapted to habitus to keep images diagnostic [14]. Clinical dose surveys have likewise shown that patient dose rises with body size across common radiographic examinations [15], and Zalokar et al. reported that dose in pelvic radiography increased significantly with BMI [16]. Modelling by Yanch et al. showed that added adipose tissue can multiply the effective dose of a chest radiograph several-fold, depending on fat distribution and projection [9]. In a large cardiac imaging cohort, Sperry et al. found that higher BMI was associated with greater radiation exposure in every modality used to evaluate chest pain [17]. Similar relationships have been described for CT, where technique factors and dose increase with patient weight or BMI [23,24]. Our results extend these observations to routine clinical chest radiography in an Indian setting.

The exposure factors observed for normal-BMI participants (60–65 kVp, 14–16 mAs) are close to the third-quartile chest PA values of 62 kVp and 20 mAs reported in a computed radiography dose survey from Mumbai [18]. That survey, like most Indian dose audits, did not stratify technique by body habitus. The present data show that a single “typical” chest technique hides a clear BMI-related step change and argue for BMI-stratified local diagnostic reference levels, in line with ICRP guidance that reference levels should be set for defined patient-size groups [25].

How kVp and mAs are increased also matters. In the present study, both kVp and mAs were increased for heavier patients. Phantom evidence on the “10 kVp rule” shows that raising tube potential by 10 kVp while halving mAs reduced effective dose by about 36% in chest computed radiography without a significant loss of perceived image quality [26]. Similarly, Alzyoud et al. showed that combining automatic exposure control with higher tube potentials substantially reduced effective dose in larger patients while keeping image quality acceptable [27]. In digital chest radiography, Sun et al. also showed that optimising kVp could save a large share of the entrance skin dose without compromising image quality [28]. Increasing mAs alongside kVp, as observed here, therefore probably leaves room for dose reduction in patients with higher

BMI, and these findings should prompt a local optimisation exercise rather than be taken as a recommended technique.

The perfect separation of exposure levels between BMI groups suggests that radiographers in this department used a practical, category-based approach: a visual estimate of size triggered a step to a "large patient" technique. This is consistent with the systematic review by Ching et al., which found that exposure-factor selection in practice is largely experience-based and that no single size descriptor is universally adopted [13]. Other surveys show that exposure factors do not always follow patient size consistently. Moey et al. found a significant kVp–weight correlation at one hospital but none at another [29], which suggests that size-based adjustment depends on local practice. A structured BMI- or thickness-based exposure chart would make the current informal practice explicit, reproducible and auditable.

BMI is a convenient but imperfect surrogate for chest attenuation, because it does not capture fat distribution or chest anteroposterior thickness. Phantom work in digital chest radiography shows that entrance surface dose rises with body thickness even when the exposure index stays constant under automatic exposure control [30]. In a clinical study of 805 PA chest examinations, higher BMI was associated with a lower exposure index [31], which suggests that detector-based indicators should be interpreted together with patient size [32]. Measuring chest thickness with callipers alongside BMI would improve future technique charts. Positioning strategies that reduce the effective tissue path, such as displacing anterior abdominal fat during erect pelvic radiography, have also lowered dose in overweight patients [33], and increasing the source-to-image distance has reduced dose without loss of image quality [34]. Phantom work further suggests that digital systems tolerate substantial over-exposure without visible change, so technique increases for larger patients can go unnoticed unless they are audited [6].

Two further points help interpret these findings. First, larger body habitus does not seem to compromise the diagnostic value of chest radiography when technique is adapted: Heston and Jiang found that chest radiograph–CT concordance did not differ by BMI [35]. Increasing exposure for obese patients therefore has a clear diagnostic rationale, and the aim should be to optimise the increment rather than avoid it. Second, this study used WHO international BMI cut-offs. Using the lower Asian-specific action points (≥23 kg/m² for increased risk) would have moved some normal-weight participants into higher-risk categories [36,37], which may matter if BMI-based technique charts are adopted in South Asian populations.

Strengths and limitations

The study used directly measured height and weight, recorded exposure factors from the console during routine practice, had institutional ethics approval and is reported according to STROBE. Several limitations should be noted. First, exposure factors were analysed as category-level ranges rather than as continuous patient-level values. The association measures therefore describe how technique was allocated between BMI groups, and they cannot estimate a per-unit change in kVp or mAs per kg/m². Second, no direct dose metric (entrance surface dose, dose–area product or exposure index) was recorded, and the tube-output index is a physics-based approximation. Third, image quality was not graded quantitatively, so the planned secondary objective of linking BMI and technique to diagnostic quality could not be addressed. Fourth, chest thickness, use of automatic exposure control and inter-radiographer variation were not recorded. Finally, this was a single-centre convenience sample with only five underweight participants, which limits generalisability and precision for that subgroup.

Implications for practice

Departments should (i) develop BMI-stratified (preferably thickness-stratified) exposure charts for PA chest radiography; (ii) prefer higher kVp with proportionately lower mAs for larger patients where the detector system allows; (iii) monitor exposure index and dose–area product by BMI group to detect dose creep; and (iv) set BMI-stratified local diagnostic reference levels [1,3,25,32].

V. Conclusion

Among adults aged 18–45 years undergoing PA chest radiography, BMI was strongly associated with exposure-factor selection. Overweight and obese patients, who made up more than half the sample, were consistently imaged at 70–80 kVp and 16–18 mAs, compared with 60–65 kVp and 14–16 mAs for normal-weight patients, an estimated 1.6-fold higher tube output. Standardised BMI- and thickness-based exposure protocols, higher-kVp/lower-mAs strategies and routine dose monitoring are recommended so that image quality is maintained and doses are kept as low as reasonably achievable. Prospective studies with patient-level exposure data, measured dose and graded image quality are needed to define optimal technique for each BMI category.

VI. Declarations

Ethics approval and consent to participate: Approved by the Institutional Ethics Committee, SRMS IMS, Bareilly (Ref. No. SRMS IMS/IPS/ECC/2023/02; meeting of 21 December 2023). Written informed consent was obtained from all participants.

Consent for publication: Not applicable; no identifiable participant data or images are included.

Data availability: The anonymised dataset is available from the corresponding author on reasonable request.
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Conflicts of interest: The authors declare no conflicts of interest.

Author contributions (CRediT): Tanuja Chauhan – conceptualisation, data collection, formal analysis, writing – original draft. Priyanka Saxena – supervision, methodology, writing – review and editing. Both authors approved the final manuscript.

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