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ARTICLE

# Impact of implementing national diagnostic reference levels on radiation dose optimization in adult chest CT scans: a comparative analysis

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**Abstract –** The management and optimization of radiation dose in computed tomography (CT) examinations is of paramount importance, especially when the safety of patients is concerned. This study evaluated the effect of implementing national diagnostic reference levels (NDRLs) for radiation dose optimization in 1991 adult chest CT scans at a major Saudi hospital. Data was analyzed before and after NDRL implementation, with 21.5% of scans using contrast and 78.5% without. Before implementation, 11.1% used contrast and 36.7% did not; after implementation, 10.4% used contrast and 41.7% did not. The majority (83.5%) of scans passed NDRL criteria [CTDIvol and DLP are set at 12 (mGy) and 430 (mGy · cm)], with higher pass rates for contrast (91.8%) versus non-contrast (81.5%) scans. Effective dose (ED) was compared before and after NDRL implementation. For non-contrast scans, ED declined 2.43% from $12.37 \pm 5.25$ mSv to $12.07 \pm 4.99$ mSv after implementation (non-significant, $p > 0.05$). For contrast scans, ED declined more substantially, 6.77% from $9.6 \pm 4.61$ mSv to $8.95 \pm 4.44$ mSv (non-significant, $p > 0.05$). The findings highlight higher NDRL compliance in procedures with contrast and show areas for dose optimization improvement in procedures without contrast. Results suggest NDRLs provide guidance for optimizing radiation dose, but other factors like patient characteristics, protocol settings, and quality assurance programs should also be considered to ensure doses are as low as reasonably achievable (ALARA) without compromising diagnostic quality. Regular monitoring and review of CT protocols is recommended to avoid unintended consequences of dose reduction. Continued optimization is encouraged to reduce dose while ensuring quality.

**Keywords:** radiation dose / computed tomography / national diagnostic reference levels / dose length product / effective dose

## 1 Introduction

Radiation dose optimization in medical imaging has long been a focal point in radiological practices, given the inherent trade-off between diagnostic accuracy and patient safety (Tsapaki, 2020). Computed tomography (CT) is a widely used diagnostic tool in radiology, providing high-resolution images of various anatomical structures and pathological conditions. However, CT exposes patients to relatively high doses of ionizing radiation compared to other radiological procedures. The rapid growth in CT utilization over the past few decades has raised concerns regarding the potential cancer risks associated with the cumulative radiation exposure in the population (Shubayr *et al.,* 2023). Several studies have demonstrated a clear association between exposure to ionizing radiation from CT scans and increased lifetime attributable risk of cancer (Alashban and Shubayr, 2023). Therefore, radiation protection in CT is essential to ensure that the benefits of the examination outweigh the potential harms, and that the radiation dose is kept as low as reasonably achievable (ALARA) without compromising the diagnostic quality.

One of the practical tools for radiation protection in CT is the use of diagnostic reference levels (DRLs), which provide guidance on radiation dose optimization in medical imaging procedures (Rao *et al.*, 2023; Jasieniak *et al.,* 2023). DRLs are

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indicative values of radiation dose for a given procedure based on audit data from a large number of patients at a local, regional or national level (Alashban and Shubayr, 2022). DRLs represent the third quartile of the observed dose distribution for a given procedure based on audit data from numerous patients at a local, regional, or national level. DRLs are not dose limits, but rather benchmarks for comparison and optimization of patient exposure (Damilakis *et al*., 2023). The DRLs can be expressed in terms of dose indices such as CT dose index (CTDI) and dose length product (DLP), which reflect the output of the CT scanner (Kanal *et al*., 2017). DRLs can help to identify unusually high or low doses for a particular procedure, and to initiate actions to optimize the exposure parameters and the quality assurance program.

The DRL concept allows comparison of an individual facility's typical radiation dose to the national benchmark for that examination. Regular nationwide surveys are required to update DRLs periodically to reflect evolving CT technology and practice (Nam *et al*., 2022; Abuzaid *et al*., 2020b). Many countries have implemented national DRLs (NDRLs) as a radiation protection tool to guide CT practice towards optimization (Kumsa *et al*., 2023; Rao *et al*., 2023). Several studies have evaluated the implementation of NDRLs in different countries and regions and reported significant dose reduction and optimization for various CT examinations (Korir *et al*., 2016; Skovorodko *et al*., 2022; Demb *et al*., 2017; Wachabauer *et al*. 2020).

The Saudi Food and Drug Authority (SFDA) recently established national DRLs (NDRLs) for CT examinations commonly performed in Saudi Arabia. However, the impact of implementing DRLs on patient radiation exposure has not been extensively evaluated in Saudi Arabia. Therefore, the aim of this study is to investigate the impact of the implementation of NDRLs on patient radiation dose in terms of effective dose (ED)&9472; during chest CT examinations for adult patients in Saudi Arabia. Chest CT is one of the most frequently performed CT examinations, and it involves relatively high radiation doses, which make it a suitable candidate for dose optimization and audit.

## 2 Materials and methods

### 2.1 Study setting and data collection

Retrospectively, data were collected from four CT scanners (SOMATOM Definition AS 64-slice, SOMATOM Definition flash dual-source 128-slice, Siemens, Munich, Germany) at the Radiology Department in a major hospital in Jeddah, Saudi Arabia. The dataset comprises two-time frames: from March 2021 to February 2022 when NDRLs was not implemented yet; and from March 2022 to February 2023 when NDRLs has been incorporated into clinical settings. Prior to commencing of the study, medical ethics approval was obtained from the Research Ethics Committee (REC) of King Fahd Armed Forces Hospital (KFAFH) (REC 621). The collected data were anonymized, analyzed, and reported solely in an aggregate form.

### 2.2 Data extraction and parameters

The data was extracted from the Picture Archiving Communication System (PACS). The imaging parameters and dose metrics of CT chest imaging from adult patients were collected. The CT examinations included both contrasted and non-contrasted studies. Data comprised dose reports pertinent to the respective chest CT scan, including the scan protocol (*i.e.*, kVp, mAs, scan length, DLP and $CTDI_{vol}$).

### 2.3 Calculation method for effective dose

To estimate the ED from Chest CT scans, we utilized the DLP, and a region-specific conversion factor known as the k-factor. The ED calculation is based on the formula:

$$ED(mSv) = DLP(\mathrm{mGy{\cdot}cm}) \times k - factor\left(\frac{\mathrm{mSv}}{\mathrm{mGy{\cdot}cm}}\right)$$

For our study, the k-factor for chest CT was sourced from the recently published data from a large registry/phantom library, taking into account scanner manufacturers (Chu *et al*, 2023), which is different from previous k-factors that were derived from theoretical models rather than real patient data. As stated by Chu *et al*., "the new coefficients offer reasonably reliable values for estimating effective dose." The k-factor for chest CT for Siemens scanner is 0.040 mSv/(mGy · cm) (Chu *et al*., 2023). It should be noted that value of 0.040 is about 1.8 and 2.6 times the previous values of 0.020, 0.014, and 0.0146 from previous published k-factors (Huda *et al*., 2008; Deak *et al*., 2010; Shrimpton *et al*., 2006). In addition, the ED is not intended for dose to an individual; intended for populations.

### 2.4 Reference levels

Based on the NDRLs for chest CT, the reference levels for CTDIvol and DLP are set at 12 (mGy) and 430 (mGy · cm), respectively. These levels act as benchmarks to assess pass/fail outcomes in imaging procedures. For this study, a procedure recording a CTDIvol over 12 or a DLP over 430 would be classified as a failure. Conversely, if both CTDIvol and DLP values are at or below these thresholds, the procedure is deemed a pass. Applying these standards to the provided data, any case with a CTDIvol exceeding 12 is labeled as "Fail CTDIvol," while those surpassing a DLP of 430 are marked as "Fail DLP." Cases exceeding both limits are categorized as "Fail CTDIvol and DLP," and those within the thresholds for both measures are classified as "Pass."

### 2.5 Statistical analysis

Statistical analyses were performed using SPSS Statistics software (SPSS version 26, IBM, USA). Descriptive and inferential statistics were conducted. Percentage change was conducted for prior to and after the implementation of NDRLs for radiation parameters. Mann–Whitney *U* test was used to compare the ED prior to and after the implementation of NDRLs. A *p* value of 0.05 was set for significance.

## 3 Results

In our study, we analyzed data from a total of 1,991 chest CT scans. 429 scans (21.5%) were performed with contrast, while 1,562 scans (78.5%) were conducted without contrast. For collected data before the implementation of NDRLs,

**Table 1.** Radiation dose parameters in adult patients undergoing CT chest scans prior to NDRLs implementation.

| Parameters | CT contrast | |
|---|---|---|
| | Without contrast | With contrast |
| kVp | 118.27 ± 5.26 | 101.35 ± 7.86 |
| mAs | 1469 ± 578.84 | 1604 ± 662.84 |
| $CTDI_{vol}$ (mGy) | 8.82 ± 3.38 | 6.33 ± 2.69 |
| DLP (mGy.cm) | 309.33 ± 131.18 | 239.98 ± 115.19 |

**Table 2.** Radiation dose parameters in adult patients undergoing CT chest scans post-NDRLs implementation.

| Parameters | CT contrast | |
|---|---|---|
| | Without contrast | With contrast |
| kVp | 118.33 ± 5.52 | 100.76 ± 6.47 |
| mAs | 433.46 ± 530 | 1614 ± 684 |
| CTDIvol (mGy) | 8.72 ± 2.33 | 6.20 ± 2.63 |
| DLP (mGy.cm) | 301.86 ± 124.32 | 233.8 ± 110.9 |

221 of these scans (11.1%) were with contrast and 731 scans (36.7%) were without contrast. After NDRLs implementation, the number of scans with contrast was 208 (10.4%), while those without contrast were 831 (41.7%).

### 3.1 Results prior to NDRLs implementation

Prior to the implementation of NDRLs, the study documented varied radiation dose metrics for adult patients undergoing CT chest scans, with and without contrast, as shown in Table 1. In adults undergoing non-contrast CT, kVp was 118.27 ± 5.26, mAs was 1469 ± 578.84, CTDIvol was 8.82 ± 3.38 mGy, DLP was 309.33 ± 131.18 mGy.cm. For contrast scans, kVp, mAs, CTDIvol and DLP were 101.35 ± 7.86, 1604 ± 662.84, 6.33 ± 2.69 mGy, and 239.98 ± 115.19, respectively.

### 3.2 Results post-NDRLs implementation

After the implementation of NDRLs, the dose metrics for CT chest examinations showed changes across adult patients, and for both without and with contrast-enhanced scans, as shown in Table 2. For patients undergoing CT chest examinations without contrast, the kVp was 118.33 ± 5.52, the mAs was 1433.46 ± 530, the CTDIvol was 8.72 ± 2.33 mGy, and the DLP was 301.86 ± 124.32 mGy cm. For patients undergoing CT chest examinations with contrast-enhanced scans, the kVp was 100.76 ± 6.47, the mAs was 1614 ± 684, the CTDIvol was 6.20 ± 2.63 mGy, and the DLP was 233.8 ± 110.9 mGy cm.

### 3.3 Comparison of radiation dose parameters

The implementation of NDRLs has resulted in various changes in radiation dose parameters across different patient categories, as illustrated in Table 3. In the cohort without contrast, the changes were slight, with a 0.05% increase in kVp, decreases in mAs by 2.42%, CTDIvol by 1.13%, DLP by 2.41%, and ED by 2.29%. Chest CT with contrast-enhanced scans resulted in a 0.58% decrease in kVp, a 0.62% increase in mAs, and decreases in CTDIvol by 2.05%, and DLP by 2.58%.

### 3.4 Pass/fail distribution post-NDRLs implementation

In Table 4, evaluating contrast-related procedures against NDRLs, 91.8% (191/208) passed with contrast and 81.5% (677/831) without contrast, yielding an overall pass rate of 83.5% (868/1039). CTDIvol failures were 2.9% (6/208) with contrast and 4.9% (41/831) without contrast; DLP failures were 1.9% (4/208) with contrast and 4.4% (20/831) without contrast. Also, 3.4% (7/208) of procedures with contrast and 11.2% (93/831) without contrast failed both CTDIvol and DLP, resulting in a combined failure rate of 9.6% (100/1039).

**Table 3.** Percentage change in radiation dose parameters for patients undergoing CT scans post-NDRLs implementation.

| Parameters | CT contrast | |
|---|---|---|
| Chest CT | Without contrast | With contrast |
| kVp | 0.05% | –0.58% |
| mAs | –2.42% | 0.62% |
| $CTDl_{vol}$ (mGy) | –1.13% | –2.05% |
| DLP (mGy. cm) | –2.41% | –2.58% |

**Table 4.** Pass/fail distribution of contrast-related procedures based on NDRLs.

| Pass/fail level | Without contrast $N = 831$ | With contrast $N = 208$ | Total |
|---|---|---|---|
| Pass | 677 (81.5 %) | 191 (91.8 %) | 868 (83.5%) |
| Fail CTDIvol | 41 (4.9 %) | 6 (2.9 %) | 47 (4.5%) |
| Fail DLP | 20 (4.4%) | 4 (1.9 %) | 24 (2.3%) |
| Fail CTDIvol and DLP | (11.2 %) | 7 (3.4 %) | (9.6) |

### 3.5 Changes in patient effective dose

Figure 1 represents the results of the ED before and after implementing NDRLs. Prior to introducing NDRLs, the ED for non-contrast CT scans was 12.37 ± 5.25 mSv, and for contrast scans was 9.6 ± 4.61 mSv. After the implementation of NDRLs, there were changes in the ED: Among adults, the ED for non-contrast CT scans showed a small decline of 2.43% to 12.07 ± 4.99 mSv, and for contrast scans, a more pronounced reduction of 6.77% to 8.95 ± 4.44 mSv. There were no statistically significant different ($p > 0.05$).

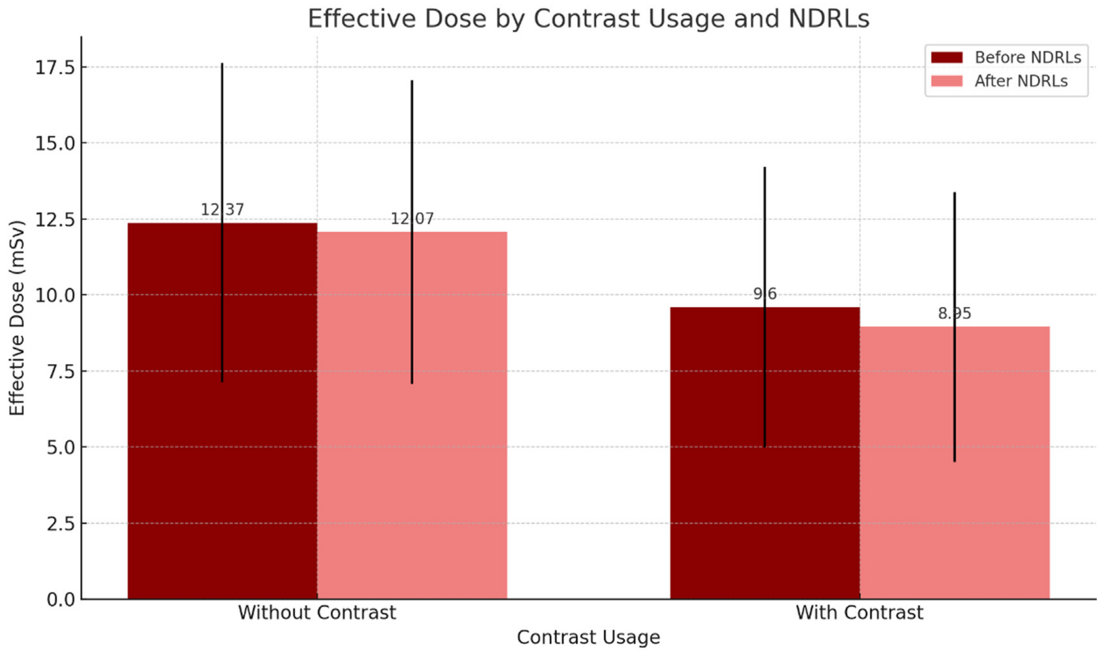


**Fig. 1.** Effective doses by contrast use prior to and post-NDRLs implementation.

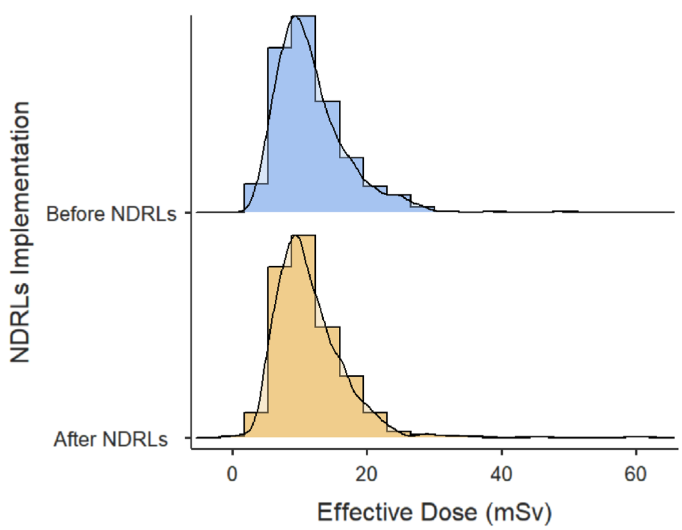


**Fig. 2.** Distribution of Effective doses prior to and post-NDRLs implementation.

Comparing the distribution of ED before and after the implementation of NDRLs is presented in Figure 2. The ED distribution before the implementation of NDRLs appears roughly normally distributed, with a clear peak and a tail extending to the right, indicating that there is a wide range of higher EDs. The ED distribution after NDRLs implementation also appears normally distributed but shows a notable shift towards the left compared to the 'before NDRLs' distribution, with the peak at a lower dose, and the distribution is tighter, with fewer instances of higher EDs.

## 4 Discussion

The implementation of NDRLs is pivotal in standardizing radiation doses across medical imaging procedures, thereby enhancing patient safety by minimizing unnecessary exposure. NDRLs serve as a benchmark for radiological practices, promoting the optimization of dose protocols to align with best practice standards and ultimately improve patient care outcomes. In this study, implementing NDRLs has led to changes in radiation dose metrics for adult patients undergoing CT chest scans, with and without contrast.

The observed changes in radiation dose parameters for CT chest scans following the implementation of NDRLs suggest a potential impact on patient radiation exposure. The general decrease in mAs, CTDIvol, and DLP for non-contrast scans, and in kVp, CTDIvol, and DLP for contrast-enhanced scans, indicates a reduction in radiation dose. This aligns with previous research that has highlighted the role of NDRLs in optimizing patient dose levels (Abuzaid *et al.*, 2020a).

However, the slight increase in mAs for contrast-enhanced scans and in kVp for non-contrast scans warrants further investigation. The negligible increase, although counterintuitive, may be indicative of adjustments made to maintain image quality. It is crucial to balance the need for diagnostic image quality with the goal of minimizing radiation exposure. Studies have reported a reduction in radiation exposure without compromising image quality (Kumamaru *et al.*, 2016; Aberle *et al.*, 2020; Sarma *et al.*, 2022). These findings highlight the importance of continuous monitoring and adjustment of CT scan parameters in line with NDRLs to ensure optimal patient safety.

The findings presented in Table 4 offer significant insights into the pass/fail distribution of contrast-related procedures against NDRLs. The pass/fail distribution based on NDRLs shows that most cases (83.5%) passed the criteria. This is consistent with a range of studies that have found that most cases pass the NDRLs, suggesting that radiation doses in medical imaging are generally below the recommended NDRLs (Wachabauer *et al,* 2020*;* Bijwaard *et al.,* 2017*).*

The higher pass rate in procedures with contrast (91.8%) compared to those without (81.5%) suggests that the use of contrast in diagnostic imaging might be associated with better adherence to NDRL standards. This could be due to more precise imaging achieved with contrast agents, leading to optimized radiation doses. Subsequently, the ED for non-contrast CT scans showed a small decline of 2.43%, and for contrast scans, a more pronounced reduction of 6.77% (non-significant, $p > 0.05$). However, even small reductions in radiation exposure can be beneficial, especially when considering the cumulative effects of radiation from multiple CT scans over time. The use of NDRLs has been particularly effective in reversing the upward trend in radiation dose for chest CT scans (Rawat *et al,* 2015*;* Yang, 2020).

Overall, prior to NDRLs, the ED distribution shows a wider range and a right-skewed tail of higher EDs, while post-NDRLs, the distribution shifts leftward with a lower peak dose and a tighter distribution, indicating lower average EDs with reduced variability and fewer high-dose instances. Moreover, the findings highlight higher NDRL compliance in procedures with contrast and indicates areas for dose optimization improvement in procedures without contrast. Ensuring adherence to NDRLs in these procedures is essential for patient safety, the overall effectiveness of diagnostic imaging and regulatory compliance. This might involve revisiting protocol standards, enhancing training, or incorporating advanced imaging technologies that optimize dose without compromising diagnostic quality (Greenwood *et al.,* 2015*;* Guerra *et al.* 2019; Tsapaki, 2020).

A critical aspect to consider when evaluating the impact of NDRLs on radiological practices is the temporal proximity between the NDRL implementation and the subsequent evaluation period. The interval observed in this study is notably brief, suggesting that the window for instituting substantial modifications in clinical practices was limited. This constraint highlights a potential impediment to realizing more significant reductions in patient exposure to radiation. Furthermore, the endeavor to decrease patient exposure through changes in radiological practices extends beyond mere procedural adjustments; it fundamentally necessitates awareness-raising actions and a commitment to continuous professional education (Bertho and Habib, 2023). The importance of ongoing education for healthcare professionals in facilitating the adoption of safer, more effective radiological techniques that align with NDRL guidelines, emphasizing that such educational initiatives are vital for sustaining long-term improvements in patient safety and care quality.

### 4.1 Limitations of the study

This study has some limitations that should be considered when interpreting the results. This study only focused on chest CT examinations, which may not reflect the radiation dose variation and optimization for other CT examinations in different body regions. Future studies should include more body organs and larger and more representative samples,

## 5 Conclusion

The adoption of the NDRLs has resulted in reduction in radiation doses during CT chest examinations. The ED declined by 2.29% for non-contrast and 6.63% for contrast CT scans A better adherence to NDRL standards with contrast use, as evidenced by a higher pass rate than non-contrast scans (91.8% vs. 81.5%). These findings suggest a regular monitoring and review for CT procedures to avoid unintended consequences. Therefore, this study recommends that CT users should follow the NDRLs as a guidance, but also consider other factors such as patient characteristics, protocol settings, and quality assurance program to ensure that the radiation dose is kept as low as reasonably achievable (ALARA) without compromising the diagnostic quality.

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### Conflicts of Interest

The author declares that he has no conflicts of interest in relation to this article.

### Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

### Author contribution statement

R. Sindi: Conceptualization, Methodology, Investigation, Writing – Original Draft, Project Administration. B. Al-Shamrani: Data curation, Investigation. A. Bana: Data curation, Investigation. F. Al-Qurashi: Data curation, Investigation. M. Al-Qarhi: Data curation, Investigation. B. Al-Shehri: Resources, Investigation. R. Al-Otaibi: Investigation, Formal Analysis. S. Aldawood: Validation, Visualization, Funding Acquisition. N. Shubayr: Conceptualization, Formal Analysis, Writing – Review & Editing, Writing – Original Draft, Supervision.

## Ethics approval

All ethical considerations were adhered to, including obtaining institutional review board approval. Confidentiality and anonymity were strictly maintained.

## Informed consent

This study did not require informed consent.

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