Review Article

# National Diagnostic Reference Levels in General Radiography: A Scoping Review

**Daniel Abbeyquaye[1,2], Stephen Inkoom[1,3], Theresa Bebaaku Dery[1,4], Shiraz Issahaku[1,4], Benard Ohene-Botwe[5]**

[1]Department of Medical Physics, Accra, University of Ghana, School of Nuclear and Allied Sciences, [2]Department of Biomedical Engineering, Faculty of Health and Allied Sciences, Koforidua Technical University, Koforidua, [3]Radiation Protection and Consultancy Centre, Radiation Protection Institute, Ghana Atomic Energy Commission, Accra, [4]Medical Radiation Physics Centre, Radiological and Medical Sciences Research Institute, Ghana Atomic Energy Commission, Accra, Ghana, [5]Department of Midwifery and Radiography, School of Health Sciences and Psychological Sciences, City, University of London, London, UK

## Abstract

The aim of this scoping review was to explore the state of proposed and established national diagnostic reference levels (NDRLs) in general radiography. It examined survey harmonization, radiological examinations, doses, and 20-year international trends in NDRLs. It also highlights NDRL survey strategies for dose optimization. A scoping review of the literature was carried out in accordance with the guidelines of the Preferred Reporting Items for Systematic and Meta-Analyses extension for Scoping Reviews. Searches were conducted in gray literature and electronic databases such as ScienceDirect, PubMed, CINAHL via EBSCOhost, and MEDLINE for NDRLs in general radiography for papers published from January 01, 1990, to April 20, 2024. A total of 4932 studies were identified with 22 articles selected for review. These articles were those based on an adult-human dosimetry survey. The NDRLs were set at the 75th percentile of 7 radiographic examinations and 13 projections. These have been presented with thematic analysis, narrative synthesis, and descriptive statistics. A consistent adherence to guidelines for NDRL surveys was observed despite methodological variations. NDRLs were less prevalent in low- and lower-middle-income countries. Chest PA and lumbar spine examinations were commonly reported, with lumbar spine LAT yielding the highest and chest PA the lowest doses. Proposed NDRLs from 2004 to 2013 indicated higher doses than those from 2014 to 2024, aligning with established NDRLs in the last decade. The introduction of quality control tests and radiographic image quality assessments is recommended to enhance result reliability and support dose optimization strategies, addressing gaps in current practices.

**Keywords:** Diagnostic reference levels, optimization, radiation dose, radiography, scoping review

**Received on: 18-12-2024** **Review completed on: 05-04-2025** **Accepted on: 09-04-2025** **Published on: 03-07-2025**

## Introduction

Despite the upsurge of advanced imaging modalities such as computed tomography (CT) and magnetic resonance imaging (MRI), general radiography remains the most widely used method for medical imaging.[1] However, X-rays could inflict stochastic effects.[2] X-ray doses in diagnostic radiography, therefore, need to be optimized to ensure patient safety while acquiring radiographs of optimum diagnostic quality. An effective optimization approach involves comparing recorded patient doses with dose data from regulatory agencies.[3]

Consequently, the term "investigation levels" of radiation doses was introduced in publication 60 by the International Commission on Radiological Protection (ICRP)[3] to be chosen by a regulatory agency. To buttress this concept, ICRP introduced the term "diagnostic reference level" (DRL) to ensure that radiation dose to patients is kept as low as reasonably achievable (ALARA)[4] or in the United Kingdom (UK) setting, as low as reasonably practicable (ALARP).[5] DRLs are used in radiological imaging to indicate whether the radiation dose is unusually high or low for that procedure.[6] This concept was enhanced by ICRP's practical recommendations.[7] ICRP, in Publication 103, recommended DRLs as an advisory measure to improve optimization, by identifying unusually high or unusually low patient dose levels, which might not be justified based on image quality requirements.[8] DRLs have also been adopted

Access this article online

Quick Response Code:

Website: www.jmp.org.in

DOI: 10.4103/jmp.jmp_213_24

**Address for correspondence:** Mr. Daniel Abbeyquaye, Department of Medical Physics, School of Nuclear and Allied Sciences, University of Ghana, P.O. Box AE 1, Accra, Ghana. E-mail: danny.abbeyquaye@gmail.com



**How to cite this article:** Abbeyquaye D, Inkoom S, Dery TB, Issahaku S, Botwe BO. National diagnostic reference levels in general radiography: A scoping review. J Med Phys 2025;50:207-16.

by the International Atomic Energy Agency (IAEA)[9] and the European Directive 2013/59/Euratom[10] as a tool for radiation dose optimization in diagnostic radiological examinations. Several attempts have been made to establish DRLs using guidelines set by either the European Commission (EC)[11] or those outlined by ICRP.[6]

Surveys or registry data of patients are used to set national DRLs (NDRLs) for radiological procedures in a country. The NDRL is defined as the 75th percentile value of the distribution of median values of a measured radiation dose at healthcare institutions across a nation relative to a particular examination.[6] To establish NDRLs, it is vital to survey diagnostic facilities that represent the surveyed country's geographical area and population.[12] Medium-to-large hospitals with substantial workloads offer current practice data within a reasonable timeframe. In smaller countries with under 50 facilities, ICRP recommends an initial study of 30%–50% of the facilities.[6] In countries with hundreds of healthcare facilities, ICRP suggests surveying about 30 randomly chosen hospitals with a large patient sample size as a reasonable starting point.[6] NDRL dosimetric quantities should be simple to measure and be based on doses that are measured in routine clinical practice. The EC[11] and ICRP[6] recommend the use of incident air kerma ($K_{a,i}$), entrance surface air kerma ($K_{a,e}$), and dose area product (or air kerma area product) ($P_{KA}$), as dose metrics in general radiography. $K_{a,e}$ can be measured directly using thermoluminescent dosimeters (TLDs) affixed to patient skin or indirectly by estimating $K_{a,i}$ from measured X-ray output and exposure factors, then applying a backscatter factor.[13] $P_{KA}$ can be measured using an ionization chamber that integrates the air kerma over the X-ray beam's cross-sectional area.

Regional DRLs (RDRLs) could be determined by using the median of NDRLs from several countries within that region.[14-16] These can serve as a prompt for neighboring nations to review their imaging techniques/protocols when their NDRLs exceed the RDRLs.[6] ICRP suggests updating NDRLs and RDRLs every 3–5 years or more frequently with advancements in imaging and technology.[6] Local DRLs (LDRLs) are based on surveys in a facility.[17] They are beneficial in optimization at a radiology unit or where there are no NDRLs.[6] Radiologic staff should integrate LDRLs into regular quality assurance programs, comparing local doses with NDRLs for continuous improvement of patients' radiation safety. NDRLs are not applied to individual patients, as radiation needs vary with patient demographics and imaging task requirements.[6] Furthermore, NDRLs should neither be applied as dose limits[11,18] nor dose constraints[7] to avert compromising patient safety and/or diagnostic outcomes. NDRLs should be applied flexibly, considering radiographic quality and sound clinical judgment.

However, national surveys to propose general radiography NDRLs have not received the needed attention,[19] especially in some low-income (LI) and lower-middle-income countries (LMICs)[20] due to data scarcity, budget constraints, ineffective collaboration between key stakeholders, and regulatory gaps.[20] To assess the extent, scope, and characteristics of NDRL research and identify gaps in the literature, a scoping review approach is preferred.[21,22] This scoping review thus explored the state of NDRLs based on the following questions: To what extent have LI and LMICs focused on the development of NDRLs? Are harmonized methods used in surveys to establish NDRLs in general radiography? What are the commonly reported radiological examinations and their typical doses in NDRL surveys? How have proposed NDRLs evolved over 20 years across countries – increased, decreased, or remained consistent? How can NDRL surveys be improved to influence dose optimization strategies?

# Methods

## Strategy for literature search

To guide this review, the five stages of Arksey and Malley's framework were used which involves identification of the research questions, selection of relevant studies, making study selections, charting, collating and summarizing the data, and finally, reporting the findings.[23] A scoping review of medical imaging and medical physics journals in gray literature, ScienceDirect, PubMed, CINAHL via EBSCOhost, and MEDLINE databases, was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis extension for Scoping Reviews (PRISMA-ScR)[24] guidelines. No published copy of the review protocol was available. Additional supplementary searches were done in Google Scholar, reference lists, and radiography-oriented journals for articles not indexed in the selected databases for literature published from January 01, 1990, to April 20, 2024. The resulting flowchart of the search is presented in Figure 1.

## Selection of relevant studies

This review utilized the Population, Intervention, and Comparative Observation (PICO) technique to choose the best keywords and search phrases.[25] *Cohort* and *Intervention* were substituted for the PICO parts.[26] In this review, "Cohort" refers to *radiography* procedures, and "Intervention" refers to *diagnostic reference levels*. This led to the creation of the search phrases "radiography" and "diagnostic reference levels," and other search phrases synonymous with these two main search phrases, presented in Table 1. Among the authors, three senior medical physicists, also research scientists, and one experienced radiographer validated search terms to ensure appropriateness in identifying pertinent studies on DRLs in general radiography.

The search terms on *general radiography* and *diagnostic reference levels* were developed using Medical Subject Headings[27] indicated in Table 2 as [mh]. Both indexed terms and free text words [tw] are presented in Table 2 and were used to capture the following concepts: diagnostic reference levels, general radiography, diagnostic, X-ray, and radiographic imaging. A step-wise search was conducted for each term or

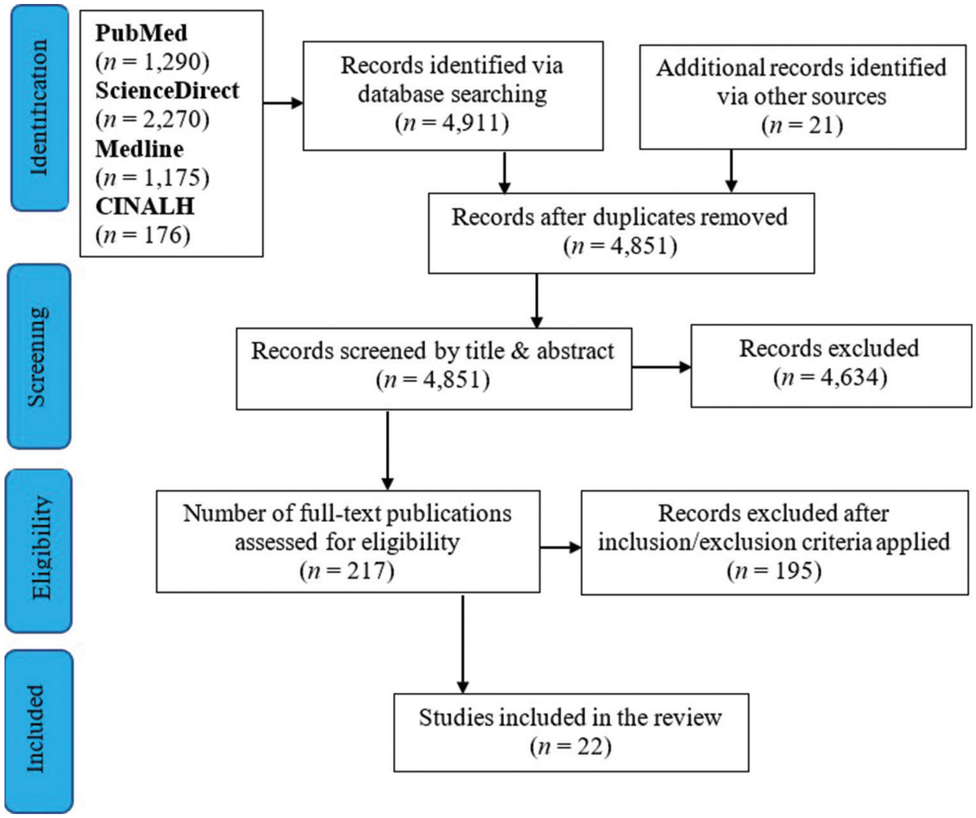


**Figure 1:** Preferred Reporting Items for Systematic Reviews and Meta-Analysis flowchart for literature search

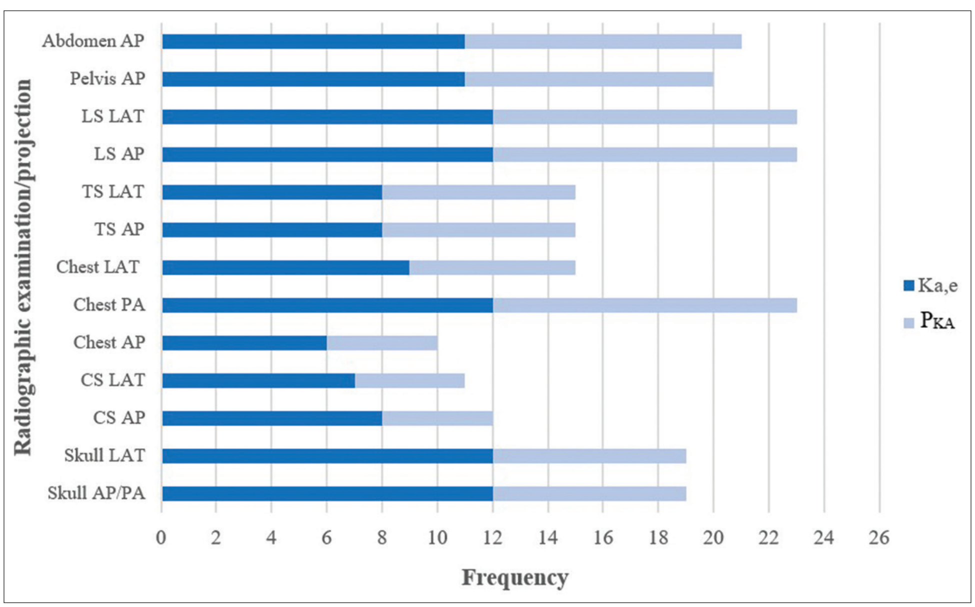


**Figure 2:** Frequency of performed radiographic examinations/projections

phrase from the selected databases in line with PRISMA-ScR's recommendations.[27] The search results from the PubMed database are presented in Table 2.

## Inclusion and exclusion criteria

Articles were included if NDRLs were set for adult patients in general radiography for examinations that contribute to higher effective doses (EDs) and increased risk to radiosensitive tissues/organs. Selected articles were those dating back to the 1990s since the concept of DRLs was first introduced in 1990 by ICRP.[3] Only English language publications with reporting NDRLs with the requisite study design were included. Articles excluded were those that disqualify a study upon further study such as reviews, case studies, insufficient review parameters,

**Table 1: Search terms and phrases with Boolean operators for the cohort and intervention**

| Cohort | Intervention |
|---|---|
| Radiography | DRLs |
| OR | OR |
| General radiography | Dose reference levels |
| OR | OR |
| Radiographic examinations | Reference dose levels |
| OR | OR |
| Radiographic procedures | Reference levels |
| OR | OR |
| Radiographic imaging | DRLs |
| OR | OR |
| Diagnostic examinations | DRL |
| OR | OR |
| Diagnostic procedures | Dose audit |
| OR | |
| Diagnostic imaging | |
| OR | |
| Diagnostic radiography | |
| OR | |
| Projection radiography | |
| OR | |
| X-ray | |
| OR | |
| X-ray examinations | |
| OR | |
| X-ray procedures | |
| OR | |
| X-ray imaging | |

DRLs: Diagnostic reference level

**Table 2: Grouped terms and key search phrases with Boolean operators**

| Number GI | Search phrases or terms | Number of publications |
|---|---|---|
| GI-1 | "dose reference level*" [tw] OR | 108 |
| | "diagnostic reference level*" [tw] OR | 897 |
| | "reference dose level*" [tw] OR | 72 |
| | "reference level*" [tw] OR | 3030 |
| | DRL [tw] OR | 1331 |
| | DRLs [tw] OR | 573 |
| | "dose audit*" [tw] | 74 |
| GI-2 | "diagnostic reference level*" [mh] OR | 143 |
| GI-3 | radiograph* [tw] OR | 401,201 |
| | "general radiograph*" [tw] OR | 201 |
| | (radiograph* AND examination*) OR | 52,858 |
| | (radiograph* AND procedure*) OR | 59,659 |
| | (radiograph* AND imaging) OR | 301,841 |
| | "diagnostic examination*" [tw] OR | 1650 |
| | "diagnostic procedure*" [tw] OR | 19,725 |
| | "diagnostic imaging" [tw] OR | 1,254,077 |
| | "diagnostic radiograph*" [tw] OR | 560 |
| | "projection radiograph*" [tw] OR | 1496 |
| | "X-ray*" [tw] OR | 841,670 |
| | "X-ray examination*" [tw] OR | 3,707 |
| | "X-ray procedure*" [tw] OR | 184 |
| | "X-ray imaging" [tw] | 4763 |
| GI-4 | radiograph* [mh] OR | 849,039 |
| | "diagnostic imaging" [mh] | 2,280,845 |
| **Number GI** | **Combinations made** | **Number of publications** |
| GI-5 | #GI-1 OR #GI-2 | 4175 |
| GI-6 | #GI-3 OR #GI-4 | 2,931,493 |
| GI-7 | #GI-5 AND #GI-6 | 1290 |

*Truncation symbol that searches for a root word and retrieve word variations of the root word. [tw]: Text word search for terminologies in titles, abstracts, and other text fields, [mh]: Medical subject heading terminologies used to search controlled vocabularies for indexing articles, GI: Grouped item, DRL: Diagnostic reference level

inaccessibility of full-text, LDRL and RDRL publications, and nongeneral radiographic NDRL publications.

## Making study selection

All the authors evaluated search results, determined relevance by skimming titles and abstracts, and removed duplicates. Three authors independently reviewed full copies of potential papers, consulting the wider team to resolve inclusion discrepancies for the final review. All authors were involved in the final review of the selected publications. As a scoping review explores the extent and nature of the literature, formal quality appraisal of included and excluded studies was not required,[22,28] thus a dedicated quality appraisal was not conducted.

## Charting and data collation

Charting was conducted using a structured form designed in Microsoft Excel to capture detailed information from the studies included in the review. Extracted data included study subjects, sample sizes (patients and hospitals), the country and year of NDRL proposal, methods of NDRL estimation, radiographic examinations reported, dosimetric quantities assessed and their results, radiographic image quality ($R_{IQ}$) considerations, and whether quality control (QC) tests were conducted before data collection. The initial charting of data for each publication was performed by the first author and subsequently reviewed and validated by all authors. Findings were synthesized through thematic analysis to identify key patterns and gaps in qualitative data while quantitative data (NDRL values) were summarized numerically. These were supplemented by narrative synthesis to provide a comprehensive summary of the reviewed content. In addition, a numerical summary was presented to describe key characteristics of the included studies, as proposed by Arksey and Malley.[23]

## Summarizing and reporting of the findings

This was conducted by integrating both quantitative and qualitative data to answer the review questions. Quantitative findings were summarized using descriptive statistics such as frequency, standard deviation, mean, and median. These these have been presented in tables and figures. Thematic and narrative analyses of qualitative data were used to provide a cohesive summary and interpretation of the findings across the included publications.

## Results

Figure 1 presents a total of 4932 records which were identified through database searching and supplementary sources. After screening and full-text evaluation, 22 publications, including 12 proposed NDRLs ($NDRLs_p$) [Table 3] and 10 established NDRLs ($NDRLs_E$) [Table 4], were selected for the review. Table 3 presents primary review parameters, including methodologies for estimating patient $K_{a,e}$. Table 3 also presents the World Bank's income classification of countries.[29] Table 4 provides a reduced subset due to limitations arising from parameter unavailability and the varied presentation formats of $NDRLs_E$ publications. NDRL values for the frequently performed X-ray examinations/projections featured across the publications are presented in Table 5 (NDRLs in $K_{a,e}$) and Table 6 (NDRLs in $P_{KA}$). To set NDRLs, priority should be given to radiographic procedures contributing significantly to collective ED[52] and performed frequently. It is essential to specify the projections and the clinical imaging task related to the procedure.[6] Key examinations include chest, cervical spine (CS), pelvis, thoracic spine, abdomen, skull, and lumbar spine (LS).[45] Despite the low dose, chest X-rays are significant due to their high frequency,[53] with an estimated 8.3 million requests in England between 2019 and 2020.[54]

Tables 7 and 8 present the mean value ($\bar{d}$) ± standard deviation (σ) and median of the examination-specific NDRLs for $K_{a,e}$ and $P_{KA}$, respectively, for $NDRLs_p$ from 2004–2013 to 2014–2024. These were compared with $NDRLs_E$ between 2014 and 2024 to illustrate how NDRLsp have changed over the last 20 years.

## Discussion

### Efforts and initiatives in low-income and lower-middle-income countries

All identified $NDRLs_E$ were from high-income countries, indicating less attention to NDRL establishment in LI and LMICs. In Table 3, 40% of $NDRLs_P$ were in LI and LMICs, compared to 60% in upper-middle and high-income countries. The variation in NDRL values across countries highlights the need for each country to establish its own NDRLs. In LI and LMICs, factors such as older equipment and fewer qualified radiography personnel[20] necessitate NDRL establishment. LI and LMICs could enhance capacities for national dosimetry by incorporating $NDRLs_p$ and

**Table 3: Summary of key parameter-data extracted from the national diagnostic reference levelsP publications**

| Study | Year | Country | Sample size | | NDRL dose metric | | Procedure frequency | | QC | IQ | Income classification[29] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Patients | Facilities | Quantity | Method | Examinations | Projections | | | |
| Welarathna *et al*.[30] | 2024 | Sri Lanka | 894 | 6 | $P_{KA}$ | Direct (DAP meter) | 3 | 4 | N/A | Yes | LMI |
| Ahmed *et al*.[31] | 2020 | Sudan | 1629 | 29 | $K_{a,e}$ | Indirect | 5 | 7 | N/A | N/A | LI |
| Dimov *et al*.[32] | 2018 | Bulgaria | 5731 | >20[a] | $P_{KA}$ | Direct (DAP meter) | 6 | 9 | Yes | N/A | HI |
| Wachabauer *et al*.[33] | 2019 | Austria | 15,305 | 312 | $P_{KA}$ | Direct (DAP meter) | 5 | 9 | N/A | N/A | HI |
| Deevband *et al*.[34] | 2018 | Iran | 10,080 | 75 | $K_{a,e}$ | Indirect | 7 | 11 | N/A | N/A | UMI |
| Korir *et al*.[35] | 2018 | Kenya | 1206 | 10 | $K_{a,e}$ | Indirect | 15 | 24 | Yes | Yes | LMI |
| Hiswara *et al*.[36] | 2016 | Indonesia | 1208 | 44 | $K_{a,e}$ | Direct (TLD) | 8 | 13 | Yes | N/A | UMI |
| KhiarA *et al*.[37] | 2016 | Sudan | 1490 | 15 | $K_{a,e}$ | Indirect | 8 | 11 | N/A | N/A | LI |
| Kharita *et al*.[38] | 2010 | Syria | 1308 | 26 | $P_{KA}$ | Direct (DAP meter) | 8 | 9 | N/A | N/A | LI |
| Asadinezhad and Bahreyni Toossi[39] | 2008 | Iran | 1601 | 31 | $K_{a,e}$ | Direct (TLD) | 7 | 14 | Yes | Yes | UMI |
| Škrk *et al*.[40] | 2006 | Slovenia | >2000 | 33 | $K_{a,e}$ | Indirect and direct (TLD) | 9 | 15 | N/A | N/A | HI |
| Aroua *et al*.[41] | 2004 | Switzerland | N/A | N/A | $K_{a,e}$ | Indirect | 8 | 12 | N/A | N/A | HI |

[a]Authors reported this as the number of X-ray systems. N/A: Unable to explicitly infer from publication, LI: Low-income, LMI: Lower middle-income, UMI: Upper middle-income, HI: High-income, TLD: Thermoluminescent dosimeters, NDRL: National diagnostic reference level, DAP: Dose area product

**Table 4: Summary of the key data extracted from the national diagnostic reference levels$_E$ publications**

| | Ireland[42] | Poland[43] | UK[44] | Malta[45] | Saudi Arabia[46] | France[47] | Italy[48] | Japan[49] | Germany[50] | Korea[51] |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2023 | 2023 | 2022 | 2022 | 2022 | 2019–2021 | 2020 | 2020 | 2019 | 2016 |
| DRL metric | $P_{KA}$ | $P_{KA}$ | $K_{a,e}$, $P_{KA}$ | $P_{KA}$ | $P_{KA}$ | $P_{KA}$ | $K_{a,e}$, $P_{KA}$ | $K_{a,e}$ | $P_{KA}$ | $K_{a,e}$ |
| Procedure frequency | | | | | | | | | | |
| Examinations | 7 | 6 | 9 | 8 | 2 | 7 | 3 | 7 | 8 | 15 |
| Projections | 12 | 10 | 16 | 15 | 3 | 12 | 7 | 9 | 12 | 22 |

DRL: Diagnostic reference level

**Table 5: $K_{a,e}$ (mGy) national diagnostic reference levels for frequently performed radiographic examinations (with three projections; anterior-posterior, posterior-anterior, and lateral) from 12 of the selected publications**

| Study | Skull | | Cervical spine | | Chest | | | Thoracic spine | | Lumbar spine | | Pelvis | Abdomen |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AP/PA | LAT | AP | LAT | AP | PA | LAT | AP | LAT | AP | LAT | AP | AP |
| **$NDRLs_P$** | | | | | | | | | | | | | |
| Ahmed *et al*.[31] | 3.50 | 1.70 | -- | -- | -- | 0.60 | -- | -- | -- | 3.70 | 8.00 | 2.60 | 2.70 |
| Deevband *et al*.[34] | 1.30 | 1.17 | 0.77 | 0.85 | -- | 0.63 | 1.11 | 1.73 | 2.35 | 2.69 | 4.22 | 1.62 | 2.00 |
| Korir *et al*.[35] | 7.00[a] | 0.30 | 2.00 | 3.00 | 1.00 | 0.50 | 5.00 | 7.00 | 9.00 | 5.00 | 11.00 | 5.00 | 4.00 |
| Hiswara *et al*.[36] | 1.58 | 1.38 | 0.89 | 0.92 | 0.33 | | 1.18 | -- | -- | 3.14[b] | 5.84 | 1.98 | 2.60 |
| Khiar *et al*.[37] | 1.90[c] | 1.20 | 1.35 | 1.67 | -- | 0.54 | -- | -- | -- | 6.43 | 18.50 | 3.00 | 3.00 |
| Asadinezhad and Bahreyni Toossi[39] | 2.85/2.83 | 1.93 | 1.83 | 0.93 | 0.97 | 0.41 | 2.03 | 2.72 | 5.29 | 3.43 | 8.41 | 3.18 | 4.06 |
| Škrk *et al*.[40] | 2.54 | 2.02 | 1.73 | 1.83 | 0.35 | 0.35 | 1.20 | 7.69 | 10.13 | 7.98 | 19.67 | 5.83 | 6.18 |
| Aroua *et al*.[41] | 5.40 | 3.50 | 3.10 | -- | -- | 0.20 | 0.40 | 7.00 | 21.00 | 8.70 | 26.00 | 7.80 | 7.00 |
| **$NDRLs_E$** | | | | | | | | | | | | | |
| UK[44] | 1.80 | 1.10 | -- | -- | 0.20 | 0.15 | 0.50 | 3.50 | 7.00 | 5.70 | 10.00 | 4.00 | 4.00 |
| Compagnone[48] | 2.50 | 2.00 | -- | -- | -- | 0.30 | 1.00 | -- | -- | 6.00 | 15.00 | -- | -- |
| Japan[49] | 2.50 | | 0.80 | | -- | 0.40[d], 0.30[e], 0.20[f] | -- | 3.00 | 5.00 | 3.50 | 9.00 | 2.50 | 2.50 |
| Do[51] | 2.70 | 3.11 | -- | -- | 1.75 | 0.58 | 3.08 | 4.09 | 9.22 | 4.74 | 12.7 | 3.94 | 3.90 |

[a]Value in the publication was for only AP, [b]Value in the publication was for both AP and PA, [c]Value in the publication was for only PA, [d]At <100 kV, [e]At ≥100 kV, [f]Medical checkup ≥100 kV. -- Data unavailable from the publication. AP: Anterior–posterior, PA: Posterior–anterior, LAT: Lateral, NDRLs: National diagnostic reference levels

**Table 6: PKA (Gy cm²) diagnostic reference levels for frequently performed radiographic indications from 12 of the selected publications**

| Study | Skull | | Cervical spine | | Chest | | | Thoracic spine | | Lumbar spine | | Pelvis | Abdomen |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AP/PA | LAT | AP | LAT | AP | PA | LAT | AP | LAT | AP | LAT | AP | AP |
| **$NDRLs_P$** | | | | | | | | | | | | | |
| Welarathna *et al*.[30] | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1.43 | 2.38 | -- | 2.24 |
| Dimov *et al*.[32][a] | 0.80 | 0.75 | -- | -- | -- | 0.45 | -- | 1.10 | 2.20 | 2.40 | 3.60 | 2.30 | 3.00 |
| Wachabauer *et al*.[33] | 0.49 | 0.49 | -- | -- | 0.20[b] | 0.13 | 0.42 | -- | -- | 1.76 | 3.10 | 1.94 | 1.84 |
| Kharita *et al*.[38] | 2.13 | | -- | -- | -- | 1.68 | -- | -- | -- | 8.62[c] | 18.47 | 5.76[d] | 6.57 |
| **$NDRLs_E$** | | | | | | | | | | | | | |
| Ireland[42] | -- | -- | 0.16 | 0.19 | 0.13 | 0.12 | -- | 0.76 | 1.80 | 1.60 | 2.24 | 1.91 | 1.70 |
| Jasieniak *et al*.[43] | 1.10 | 1.00 | -- | -- | -- | 0.20 | 1.00 | 2.20 | 3.20 | 3.20 | 8.00 | 5.00 | 5.00 |
| UK[44] | -- | -- | 0.15 | 0.15 | 0.15 | 0.10 | -- | 1.00 | 1.50 | 1.50 | 2.50 | 2.20 | 2.50 |
| Malta[45] | 0.62/0.67 | 0.47 | 0.18 | 0.13 | -- | 0.15 | 0.80 | 0.99 | 1.61 | 3.75 | 2.92 | 2.35 | 1.76 |
| Saudi Arabia[46] | -- | -- | -- | -- | 0.49 | -- | | -- | -- | -- | -- | -- | -- |
| France[47] | -- | -- | 0.27 | | -- | 0.16 | 0.41 | 0.76 | 0.90 | 2.04 | 3.09 | 2.71 | 2.59 |
| Italy[48][e] | 1.00 | 1.00 | -- | -- | -- | 0.25 | 1.00 | -- | -- | 1.50 | 4.00 | -- | -- |
| Germany[50] | 0.60 | 0.50 | -- | -- | -- | 0.15 | 0.40 | 1.10[c] | 1.40 | 2.00[c] | 3.50 | 2.50 | 2.30 |

[a]Dose data from the third national survey, [b]Authors reported this figure for bedside chest, [c]Value in the article was for both AP and PA, [d]Value in the publication was for both pelvis AP and hip AP, [e]Some values have been rounded off to two decimal places, --:Data unavailable from the publication. AP: Anterior–posterior, PA: Posterior–anterior, LAT: Lateral, NDRLs: National diagnostic reference levels

institutional dose data. Legislative and regulatory measures should be established to ensure regular updates, compliance, and policymaker involvement for effective NDRL implementation.

## Facilities and subjects

All the reviewed studies adhered to the ICRP recommendations[6] on the selection of facilities for the NDRL survey. Welarathna *et al*.[30] selected six facilities from five of Sri Lanka's nine provinces, choosing locations based on annual workload and population density, making it suitable for inclusion in this review. $NDRLs_E$ are typically from an extensive facility sample size using a standardized repository of dose information,[44] including dose data from professional institutions.[50] For instance, 320 hospitals covering at least

**Table 7: Mean and median $K_{a,e}$ (mGy) values of national diagnostic reference levels from the reviewed articles**

| | Skull | | Cervical spine | | Chest | | | Thoracic spine | | Lumbar spine | | Pelvis | Abdomen |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AP/PA | LAT | AP | LAT | AP | PA | LAT | AP | LAT | AP | LAT | AP | AP |
| $NDRLs_P$ (2004–2013) | | | | | | | | | | | | | |
| $\bar{d}\pm\sigma$ | 3.6±1.6 | 2.5±0.9 | 2.2±0.8 | 1.4±0.6 | 0.7±0.3 | 0.3±0.1 | 1.2±0.8 | 5.8±2.7 | 12.1±8.0 | 6.7±2.9 | 18.0±8.9 | 5.6±2.3 | 5.7±1.5 |
| Median | 2.8 | 2.0 | 1.8 | 1.4 | 0.7 | 0.4 | 1.2 | 7.0 | 10.1 | 8.0 | 19.7 | 5.8 | 6.2 |
| $NDRLs_P$ (2014–2024) | | | | | | | | | | | | | |
| $\bar{d}\pm\sigma$ | 3.1±2.4 | 1.2±0.5 | 1.3±0.6 | 1.6±1.0 | 0.7±0.5 | 0.7±0.3 | 3.1±2.8 | 4.4±3.7 | 4.8±3.6 | 4.7±1.5 | 8.7±6.5 | 3.0±1.2 | 2.9±0.8 |
| Median | 1.9 | 1.2 | 1.1 | 1.3 | 0.7 | 0.6 | 3.1 | 4.4 | 3.1 | 5.0 | 8.0 | 2.6 | 2.9 |
| $NDRLs_E$ (2014–2024) | | | | | | | | | | | | | |
| $\bar{d}\pm\sigma$ | 2.4±0.4 | 2.2±0.9 | 0.8 | | 1.0±1.1 | 0.3±0.2 | 1.5±1.4 | 3.5±0.6 | 7.1±2.1 | 5.0±1.1 | 11.7±2.7 | 3.5±0.9 | 3.5±0.8 |
| Median | 2.5 | 2.3 | | | 1.0 | 0.3 | 1.0 | 3.5 | 7.0 | 5.2 | 11.4 | 3.9 | 3.9 |

AP: Anterior–posterior, PA: Posterior–anterior, LAT: Lateral, NDRLs: National diagnostic reference levels

23% of health facilities with diagnostic X-ray systems were used for the UK $NDRLs_E$.[44,55]

NDRLs for adults are preferably established by standardizing patient sizes using a weight range of about 50 kg to 90 kg to achieve a mean weight of 70 ± 10 kg depending on the weight distribution of the country.[6] This practice was followed in all reviewed publications. While anthropomorphic phantoms aid dose-delivery experiments, using them for DRLs is not recommended as they may not align with typical clinical requirements for an imaging task.[6,52]

## Dosimetric quantities

This review notes a predominance of $NDRLs_p$ set for $K_{a,e}$, emphasizing its reliability,[56] reproducibility, and ease of estimation. $K_{a,e}$ was estimated in eight $NDRLs_p$, out of which five were through the indirect method and two through the direct method with TLDs. Škrk *et al*.[40] reported both direct and indirect methods for assessing $K_{a,e}$. $P_{KA}$ was assessed in four $NDRLs_p$. Conversely, $P_{KA}$ was predominantly estimated across eight $NDRLs_E$ as opposed to four for $K_{a,e}$. Among the reviewed $NDRLs_p$, reporting of $P_{KA}$ increased from one (2004–2013) to three in the last decade. The comprehensive inclusion of both $K_{a,e}$ and $P_{KA}$ metrics in literature could facilitate future NDRL comparisons irrespective of the chosen dose metric for a DRL study. This would also enhance analytical comparability and data synthesis.

Kharita *et al.*[38] and Korir *et al.*[35] reported ED (Sv), as a dose metric, while Vodovatov *et al*.[57] recommended ED for setting NDRLs in Russia using a pooled method. ED is useful in estimating radiation risk to patients; however, its use in setting NDRLs is discouraged[6,52] because it does not directly evaluate ionizing radiation for medical imaging tasks, it is relatively challenging to measure, and may not be readily available for frequent comparisons as required for NDRLs.[6]

## Setting of national diagnostic reference levels

All the NDRLs presented in the reviewed articles were set at the 75th percentile. Significant differences were seen in NDRL values among the reviewed publications for each examination. This is further highlighted with the large standard deviations observed across different studies, especially for spine examinations. Variations in NDRL values may be attributed to factors such as differences in body mass index density distribution of patients in different countries,[58] influencing exposure factor selection and patient dose.[59] In addition, variations in X-ray systems, imaging techniques, and the absence of QC tests before surveys[60] could contribute to country-to-country differences in NDRL values. Only Asadinezhad and Toosi,[39] Hiswara *et al.,*[36] and Korir *et al.*[35] among the reported that QC tests were done before the patient survey.

## Radiographic examinations and doses

Radiographic examinations of the extremities,[35,36,38] shoulders,[35,37,38] clavicle,[35] knee joint,[37] hip,[35,38,40,41,51] urinary system,[38] lumbosacral joint,[40] and mandible[35] were seen in the literature but were infrequently reported. Hence, these examinations were not included this review. Chest PA, LS AP, and LS LAT were the most reported for the combination of $K_{a,e}$ and $P_{KA}$. Chest AP was the least reported. Figure 2 further illustrates the frequency of radiographic examinations reported in the reviewed articles. The emergence of CT and MRI imaging has resulted in a gradual decrease in reliance on general radiography for spine[61] and skull[62] examinations. However, limited availability and nonaffordability of CT and MRI services in LI and LMICs make general radiography systems an often-utilized modality for skull and spine imaging. Consequently, there is a need for incorporating skull and spine examinations in NDRLs where necessary, especially in LI and LMICs.

The median LS LAT $K_{a,e}$ for the combined $NDRLs_p$ and $NDRLs_E$ ($NDRLs_c$) was 3.29 mGy lower than the EU RDRL[14] median for LS LAT (16 mGy). Similar trends were observed for $P_{KA}$ NDRLs. The higher LS LAT dose is because this exposure is to an anatomical region with high X-ray attenuation and longer transverse plane, requiring increased beam energy to penetrate the pelvic bones. Chest PA for $NDRLs_c$ exhibited the lowest radiation exposure with a $K_{a,e}$ of $\bar{d} = 0.41$ mGy, while chest AP had the lowest $P_{KA}$ for $NDRLs_C$ ($\bar{d}$ = 0.24 Gycm$^2$). However, $NDRLs_E$ for chest PA showed a lower $P_{KA}$ of $\bar{d} = 0.33$ Gycm$^2$ compared to the chest PA $K_{PA}$ mean for both $NDRLs_p$ and $NDRLs_c$. The low dose associated with chest PA and AP

**Table 8: Mean and median $P_{KA}$ (Gy cm²) values of national diagnostic reference levels from the reviewed articles**

| | Skull | | Cervical spine | | Chest | | | Thoracic spine | | Lumbar spine | | Pelvis | Abdomen |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AP/PA | LAT | AP | LAT | AP | PA | LAT | AP | LAT | AP | LAT | AP | AP |
| $NDRLs_P$[a] (2004–2013) | | | | | | | | | | | | | |
| $\bar{d}$ | 2.13 | 2.13 | -- | -- | -- | 1.68 | -- | -- | -- | 8.62 | 18.47 | 5.76 | 6.57 |
| $NDRLs_P$ (2014–2024) | | | | | | | | | | | | | |
| $\bar{d}\pm\sigma$ | 0.6±0.2 | 0.6±0.2 | -- | -- | 0.2 | 0.3±0.2 | 0.4 | 1.1 | 2.2 | 1.9±0.5 | 3.0±0.6 | 2.1±0.3 | 2.4±0.6 |
| Median | 0.6 | 0.6 | -- | -- | | 0.3 | | | | 1.8 | 3.1 | 2.1 | 2.2 |
| $NDRLs_E$ (2014–2024) | | | | | | | | | | | | | |
| $\bar{d}\pm\sigma$ | 0.80±0.23 | 0.74±0.30 | 0.19±0.05 | 0.19±0.06 | 0.26±0.20 | 0.20±0.13 | 0.72±0.30 | 1.14±0.54 | 1.74±0.78 | 2.23±0.89 | 3.75±1.96 | 2.78±1.12 | 2.64±1.21 |
| Median | 0.67 | 0.75 | 0.17 | 0.17 | 0.15 | 0.15 | 0.80 | 1.00 | 1.56 | 2.00 | 3.09 | 2.43 | 2.40 |

[a]$\sigma$ and medians are excluded because only one publication was in this year range. -- Not available, NDRLs: National diagnostic reference levels, AP: Anterior–posterior, PA: Posterior–anterior, LAT: Lateral

projection is due to the thinner chest tissue thickness and less dense anatomical structures within the thoracic cavity.

## Variation of proposed national diagnostic reference levels over time

The mean $K_{a,e}$ for LS LAT in $NDRLs_p$ (12.71 mGy) exceeded that of $NDRLs_E$ by 1.03 mGy, largely due to variations between older $NDRLs_p$ data (2004-2013, $\bar{d}$ = 18.0 mGy) and more recent data (2013-2024, $\bar{d}$ = 8.7 mGy). For chest PA examinations, a significant reduction in average $P_{KA}$ was observed in the last decade compared to 2004–2013, although an increased average $K_{a,e}$ was noted for publications from 2014–2024, influenced by the high $K_{a,e}$ of 1.18 mGy reported by Hiswara *et al*.[36] $NDRLs_E$ for chest PA $K_{a,e}$ examinations (0.3 mGy) was the same for $NDRLs_p$ chest PA $K_{a,e}$. for the 2004–2013 period. In CS LAT examinations, $NDRLs_p$ $K_{a,e}$ increased by 14.3% among the publications within the 2014–2024 period, which was largely influenced by the $K_{a,e}$ reported by Korir *et al*.[35] for CS LAT examination (3.0 mGy). Nevertheless, Japan's[49] $NDRLs_E$ $K_{a,e}$ for the CS LAT examination in 2020 was 42.9% lower than the 2004–2013 $NDRLs_p$ CS LAT examinations' $K_{a,e}$. Overall, $NDRLs_p$ for other examinations reported by the publications in 2014–2024 were lower than those reported in 2004–2013, likely due to advancements in X-ray technology, improved detector systems, and optimized imaging protocols. This highlights the necessity for regular updates of existing $NDRLs_E$ to avoid reliance on obsolete dose data.

## Quality control tests and radiographic quality considerations

Before dosimetric surveys, conducting QC tests is essential to ensure parameters influencing patient exposure and $R_{IQ}$ are within acceptable limits. Given the volume of facilities and time constraints in nationwide surveys, simple QC procedures targeting exposure factors and image quality could be considered. However, explicit reporting of QC test conduction was absent in most reviewed studies. A simple visual grading assessment of $R_{IQ}$ for survey radiographs is also suggested. Achieving optimal patient safety requires balancing dose reduction with adequate $R_{IQ}$,[6] as reliance on NDRL values alone, without $R_{IQ}$ considerations, is insufficient.[6] Kharita *et al*.[38] reported including only diagnostically acceptable radiographs, whereas Asadinezhad and Toosi[39] and Korir *et al.*[35] included $R_{IQ}$ evaluations in their studies. Incorporating QC tests and $R_{IQ}$ assessments enhances NDRL surveys by increasing result reliability and identifying optimization opportunities, such as addressing high patient doses due to exposure factors exceeding tolerance limits.

## Limitations

The review included only articles published in English Language, potentially excluding relevant publications in other languages, which may limit the comprehensiveness of the findings. The relatively small number of studies meeting the inclusion criteria reduces the generalizability of the results. Furthermore, the NDRLs reported in the included studies were derived from patient populations with varying demographics, which limits the applicability of the findings to specific national contexts or uniform implementation. In addition, variations in methodologies, imaging protocols, and equipment across studies could introduce potential inconsistencies in the reported NDRLs analysis.

## Conclusion

A scoping review of 22 publications that presented NDRLs for 7 examinations and 13 projections commonly performed in general radiography has been conducted using the PRISMA-ScR guidelines. NDRLs$_p$ and NDRLs$_E$ in LI and LMICs are scanty in literature. Despite the nonharmonization in survey methodologies, the methods used by the surveyed publications were consistent with established guidelines. NDRLs were proposed for $K_{PA}$ and $K_{a,e}$, with both being extensively used as dose metrics. Chest PA, LS AP, and LS LAT were the most frequently reported; LS LAT exhibited the highest patient dose, while chest PA showed the lowest dose. Overall, NDRLs$_p$ from 2004 to 2013 reported higher doses than both NDRLs$_p$ and NDRLs$_E$ published from 2014 to 2024. QC tests and $R_{IQ}$ assessments are needed to complement and enhance confidence in NDRL values while providing opportunities for dose optimization. Furthermore, researchers and countries are encouraged to increase dose surveys for NDRL establishment by fostering collaboration among key stakeholders for the establishment of NDRLs to assist in patient radiation dose optimization.

### Financial support and sponsorship

This work was partially funded under the University of Ghana BANGA-Africa Project Grant for thesis completion scheme.

### Conflicts of interest

There are no conflicts of interest.

## References

1. UNSCEAR. UNSCEAR 2020/2021 Report to the General Assembly – Scientific Annex A: Evaluation of Medical Exposure to Ionizing Radiation. Volume I. New York: United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR); 2021. Available from: https://www.unscear.org/unscear/uploads/documents/unscear-reports/UNSCEAR_2020_21_Report_Vol.I.pdf. [Last accessed on 2024 Mar 04].
2. Hall EJ, Brenner DJ. Cancer risks from diagnostic radiology. Br J Radiol 2008;81:362-78.
3. ICRP. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Ann. ICRP 1991;21:1-3.
4. ICRP. Radiological Protection and Safety in Medicine. ICRP Publication 73. Ann. ICRP 1996;26.
5. Hurst J, McIntyre J, Tamauchi Y, Kinuhata H, Kodama T. A summary of the 'ALARP' principle and associated thinking. J Nucl Sci Technol 2019;56:241-53.
6. ICRP. Diagnostic Reference Levels in Medical Imaging. ICRP Publication 135. Ann. ICRP 2017;46. Available from https://journals.sagepub.com/doi/pdf/10.1177/ANIB_46_1 [Last accessed on 2023 Jan 08].
7. ICRP. Diagnostic reference levels in medical imaging: Review and additional advice. ICRP supporting guidance 2. Ann ICRP 2001;31:33-52.
8. ICRP. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 2007;37.
9. IAEA. Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. In International Atomic Energy Agency, IAEA (Issue General Safety Requirements (GSR) Part 3). Vienna, Austria. 2014.
10. The Council of the European Union. European Council Directive 2013/59/Euratom on basic safety standards for protection against the dangers arising from exposure to ionising radiation and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. OJ of the EU L13 2014;57:1-73.
11. European Commission. Guidance on Diagnostic Reference Levels for Medical Exposures. Radiation Protection 109. Luxemborg: European Commission (EC); 1999.
12. Seeram E, Brennan PC. Radiation Protection in Diagnostic X-Ray Imaging. United States of America: Jones and Bartlett Learning LLC; 2017.
13. IAEA. Dosimetry in Diagnostic Radiology: An International Code of Practice. TRS No. 457. International Atomic Energy Agency (IAEA). Vienna, Austria. 2007.
14. Damilakis J, Frija G, Jaschke W, Paulo G, Repussard A, Schegerer A, *et al*. European Study on Clinical Diagnostic Reference Levels for X-ray Medical Imaging. 195th ed. Luxemborg: European Commission; 2021.
15. Blanco S, Mora P, Almonte N, Benavente T, Benson N, Blanco D, *et al.* Determination of diagnostic reference levels in general radiography in Latin America. Radiat Prot Dosimetry 2013;156:303-9.
16. Krisanachinda A, Matsubara K, Haryanto F, Anam C, Krisanachinda A, Srimahachota S, et *al*. The Asean Diagnostic Reference Levels in Medical Imaging. Med Phys Int Jour 2022;10:46-51.
17. Sharma R, Sharma SD, Pawar S, Chaubey A, Kantharia S, Babu DA. Radiation dose to patients from X-ray radiographic examinations using computed radiography imaging system. J Med Phys 2015;40:29-37.
18. Matthews K, Brennan PC. The application of diagnostic reference levels: General principles and an Irish perspective. Radiography 2009;15:171-8.
19. Roch P, Célier D, Dessaud C, Etard C. Using diagnostic reference levels to evaluate the improvement of patient dose optimisation and the influence of recent technologies in radiography and computed tomography. Eur J Radiol 2018;98:68-74.
20. Meyer S, Groenewald WA, Pitcher RD. Diagnostic reference levels in low- and middle-income countries: Early "ALARAm" bells? Acta Radiol 2017;58:442-8.
21. Mays N, Roberts E, Popay J. Synthesising research evidence. In Fulop N, Allen P, Clarke A, Black N, Fulop N, Anderson S; editors. Methods for studying the delivery and organisation of health services. London: Routledge. 2001.
22. Munn Z, Peters MD, Stern C, Tufanaru C, McArthur A, Aromataris E. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. BMC Med Res Methodol 2018;18:143.
23. Arksey H, Malley LO. Scoping studies: Towards a methodological framework. Int J Soc Res Methodol Theory Pract 2005;8:19-32.
24. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, *et al.* PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. Ann Intern Med 2018;169:467-73.
25. Higgins JPT, Green S. Cochrane Handbook for Systematic reviews of Interventions. Chochrane Book Series. Wiley-Blackwell. The Cochrane Collaboration and John Wiley & Sons, Ltd., Publication. Chichester, England. 2008.
26. Centre for Reviews and Dissemination. Systematic Reviews: CRD's Guidance for Undertaking Reviews in Health Care. England: CRD, University of York; 2009.
27. Baumann N. How to use the medical subject headings (MeSH). Int J Clin Pract 2016;70:171-4.
28. Levac D, Colquhoun H, O'Brien KK. Scoping studies: Advancing the methodology. Implement Sci 2010;5:69.
29. The World Bank. World Bank Country and Lending Groups. Available from: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups. [Last

accessed on 2024 Dec 12].
30. Welarathna S, Velautham S, Sarasanandarajah S. Towards the establishment of national diagnostic reference levels for abdomen, KUB, and lumbar spine x-ray examinations in Sri Lanka: A multi-centric study. J Radiol Prot 2024;44:021506. [doi: 10.1088/1361-6498/ad3837].
31. Ahmed NA, Basheir EH, Farah AB, Mohammedzein TS, Suliman II. Proposed national diagnostic reference levels for standard radiographic x-ray procedures in Sudan. Radiat Prot Dosimetry 2020;190:419-26.
32. Dimov A, Tsanev I, Ivanova D, Simeonov F. Elaboration of New NDRLs as Part of Third National Patient Dose Survey in Diagnostic Radiology in Bulgaria. In: Lhotska L, Sukupova L, Lacković I, Ibbott G. (eds) World Congress on Medical Physics and Biomedical Engineering 2018. IFMBE Proceedings, vol 68/2. Springer; 2019.
33. Wachabauer D, Röthlin F, Moshammer HM, Homolka P. Diagnostic reference levels for conventional radiography and fluoroscopy in Austria: Results and updated National Diagnostic Reference Levels derived from a nationwide survey. Eur J Radiol 2019;113:135-9.
34. Deevband M, Mohsenzadeh B, Pouriran R. The National Diagnostic Reference Level in routine digital radiography examinations in Iran. Biomed J Sci Tech Res 2018;7:6183-92.
35. Korir G, Wambani J, Korir I, Tries M, Ali Z, Rugut J. Quantitative quality assurance and establishment of national diagnostic reference levels for adult general radiography in Kenya. J Radiol Diagn Methods 2018;1:1-7.
36. Hiswara E, Prasetio H, Kartikasari D, Nuraeni N, Sandy KY. Preliminary values of diagnostic reference level for selected x-ray examinations in Indonesia. Atom Indones 2016;42:99-104.
37. KhiarA AA, Hamza AO, Abbas NA. Dose reference levels in radiography for the most common examinations in Sudan. Sudan J Med Sci 2016;11:7-16.
38. Kharita MH, Khedr MS, Wannus KM. Survey of patient doses from conventional diagnostic radiographic examinations in Syria. Radiat Prot Dosimetry 2010;140:163-5.
39. Asadinezhad M, Bahreyni Toossi MT. Doses to patients in some routine diagnostic X-ray examinations in Iran: Proposed the first Iranian diagnostic reference levels. Radiat Prot Dosimetry 2008;132:409-14.
40. Škrk D, Zdešar U, Žontar D. Diagnostic reference levels for X-ray examinations in Slovenia. Radiol Oncol 2006;40:189-95.
41. Aroua A, Besançon A, Buchillier-Decka I, Trueb P, Valley JF, Verdun FR, *et al.* Adult reference levels in diagnostic and interventional radiology for temporary use in Switzerland. Radiat Prot Dosimetry 2004;111:289-95.
42. Health Information and Quality Authority. Diagnostic Reference Levels. Guidance on the Establishment, Use and Review of Diagnostic Reference Levels for Medical Exposure to Ionising Radiation; 2023. p. 1-49. Available from: https://www.hiqa.ie/sites/default/files/2023-11/Diagnostic-Reference-Levels-Undertaking-guidance-2023.pdf. [Last accessed 2024 May 03].
43. Jasieniak J, Kuchcińska A, Podgórska J, Cieszanowski A. Summary of radiation dose management and optimization: Comparison of radiation protection measures between Poland and other countries. Pol J Radiol 2023;88:e12-21.
44. UK Health Security Agency. National Diagnostic Reference Levels (NDRLs) from 2022. Gov.UK; 2022. p. 1-18. Available from: https://www.gov.uk/government/publications/diagnostic-radiology-national-diagnostic-reference-levels-ndrls/ndrl#national-drls-for-computed-tomography. [Last accessed 2024 Apr 28].
45. Commission for the Protection From Ionising and Non-Ionising Radiation. Guidance on the Use of Diagnostic Reference Levels for Medical Exposures. Malta: Commission for the Protection From Ionising and Non-Ionising Radiation; 2022. Available from: https://rpc.gov.mt/wp-content/uploads/2022/11/DRL-Guidance-Jan-2022-revised-26-Jan-22-.pdf. [Last accessed 2024 May 04].
46. Saudi Food and Drugs Authority. National Diagnostic Reference Levels; 2022. p. 1-8. Available from: https://www.sfda.gov.sa/sites/default/files/2023-02/NDRL-En.pdf. [Last accessed on 2024 Apr 29].
47. Dimov A, Tsanev I, Ivanova D, Simeonov F. Elaboration of New NDRLs as Part of Third National Patient Dose Radioprotection and Nuclear Safety Institute. Analysis of Data for Updating Diagnostic Reference Levels in Radiology and Nuclear Medicine. 2019 – 2021 Report. 2021. Available from: https://nrd.asnr.fr/sites/nrd/files/2023-12/2019-2021%20Report%20on%20DRLs.pdf. [Last accessed on 2024 May 12].
48. Compagnone G, Padovani R, D'Ercole L, Orlacchio A, Bernardi G, D'Avanzo MA, *et al.* Provision of Italian diagnostic reference levels for diagnostic and interventional radiology. Radiol Med 2021;126:99-105.
49. Japan Network for Research and Information on Medical Exposure (J-RIME). National Diagnostic Reference Levels in Japan. Japan Network for Research and Information on Medical Exposure (J-RIME); 2020. Available from: https://ndrecovery.niph.go.jp/trustrad/images/DRL/DRL2020_Engver.pdf. [Last accessed on 2024 Apr 29].
50. Schegerer A, Loose R, Heuser LJ, Brix G. Diagnostic Reference Levels for Diagnostic and Interventional X-Ray Procedures in Germany: Update and Handling. Fortschr Röntgenstr 2019;191:739-51.
51. Do KH, Jung SE. Current status of medical radiation exposure in Korea – Recent efforts to develop a radiation exposure control system focussed on justification and optimisation. Ann ICRP 2016;45:113-21.
52. EC: Directorate-General for Energy. European guidelines on diagnostic reference levels for paediatric imaging. Radiation Protection N 185. Luxembourg: Publications Office of the European Union; 2018. Available from: https://data.europa.eu/doi/10.2833/486256. [Last accessed on 2024 Jul 07].
53. Dasegowda G, Kalra MK, Abi-Ghanem AS, Arru CD, Bernardo M, Saba L, *et al.* Suboptimal chest radiography and artificial intelligence: The problem and the solution. Diagnostics (Basel) 2023;13:412.
54. Stevens BJ, Skermer L, Davies J. Radiographers reporting chest X-ray images: Identifying the service enablers and challenges in England, UK. Radiography (Lond) 2021;27:1006-13.
55. Hart D, Hillier MC, Shrimpton PC. Doses to Patients from Radiographic and Fluoroscopic X-Ray Imaging Procedures in the UK – 2010 Review. HPA-CRCE-034. Health Protection Agency, Centre for Radiation, Chemical and Environmental Hazards. Chilton, England. 2012.
56. Karami V, Zabihzadeh M, Keshtkar M. Evaluation of the Entrance Surface Dose (ESD) and radiation dose to the radiosensitive organs in pediatric pelvic radiography. Int J Pediatr 2017;5:5013-22.
57. Vodovatov AV, Balonov MI, Golikov VY, Shatsky IG, Chipiga LA, Bernhardsson C. Proposals for the establishment of national diagnostic reference levels for radiography for adult patients based on regional dose surveys in Russian federation. Radiat Prot Dosimetry 2017;173:223-32.
58. Masood M, Aggarwal A, Reidpath DD. Effect of national culture on BMI: A multilevel analysis of 53 countries. BMC Public Health 2019;19:1212.
59. Dolenc L, Petrinjak B, Mekiš N, Škrk D. The impact of body mass index on patient radiation dose in general radiography. J Radiol Prot 2022;42:041505. [doi: 10.1088/1361-6498/ac9f1f].
60. Matthews K, Brennan PC. Optimisation of X-ray examinations: General principles and an Irish perspective. Radiography 2009;15:262.
61. Ruiz Santiago F, Láinez Ramos-Bossini AJ, Wáng YX, Martínez Barbero JP, García Espinosa J, Martínez Martínez A. The value of magnetic resonance imaging and computed tomography in the study of spinal disorders. Quant Imaging Med Surg 2022;12:3947-86.
62. Özdemir M, Das JM. Skull imaging. In: StatPearls. StatPearls Publishing, Treasure Island, Florida: 2023. Available from: https://www.ncbi.nlm.nih.gov/books/NBK556122/. [Last accessed on 2024 May 03].