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Patient dose evaluation in computed tomography: a French national study based on clinical indications

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Abstract

Purpose. A national survey was performed to assess patient dose indicators based on clinical indication and on patient morphology for most common adult computed tomography (CT) examinations in France.

Methods. Seventeen groups of clinical indications (GCIs) for diagnostic CT in adult patients were considered based on their frequency and on image quality requirements. Data was collected for 15-30 consecutive examinations performed between 2015 and 2017, per CT scanner and GCI. Distributions of total examination Dose-Length Product (DLP) and Volume CT Dose Index (CTDI_{vol}) were assessed for each GCI as a function of patient gender or patient Body Mass Index (BMI) for head/neck and trunk examinations, respectively.

Results. 6610 examinations were analysed. Median total exam DLP values were higher for men compared to women patients for head and neck examinations: difference ranged from 6% for ear trauma indication (577 vs 543 mGy·cm, $p=0.01$) to 35% for brain tumour GCI (1472 vs 1093 mGy·cm, $p<0.01$). For trunk examinations, total exam DLP increased consistently with patient's BMI. For normal-BMI patients, median CTDI_{vol} and DLP differed significantly between different GCIs for single-phase CT of the chest (3 mGy and 112 mGy·cm, respectively, for chronic obstructive pulmonary disease group vs 5.8 mGy and 207 mGy·cm for pulmonary embolism group, $p<0.05$) and of the abdomen-pelvis (5.6 mGy and 284 mGy·cm, respectively, in renal colic group vs 9.5 mGy and 463 mGy·cm in occlusive syndrome group, $p<0.05$).

Conclusion. This study provides morphological- and clinical-based patient dose indicators in CT as a practical tool for clinical practices optimisation.

Keywords: Computed Tomography; Clinical Diagnostic Reference Levels; Radiation Protection; Nationwide Survey.

Abbreviations and acronyms:

AP: Abdomen and Pelvis

BMI: Body Mass Index

CAP: Chest Abdomen and Pelvis

COPD: Chronic Obstructive Pulmonary Disease

CT: Computed Tomography

CTDI_{vol}: Volume Computed Tomography Dose Index

DACS: Dose Archiving and Communication System

DLP: Dose-Length Product

DRL: Diagnostic Reference Level

FBP: Filtered Back Projection

GCI: Group of Clinical Indications

ICRP: International Commission on Radiological Protection

IR: Iterative Reconstruction algorithm

NDRL: National DRL

PE: Pulmonary Embolism

SFPM: French Society of Medical Physics

SFR: French Society of Radiology

USA: United States of America

Introduction

Computed tomography (CT) is a powerful clinical tool enabling faster and more accurate diagnosis than interventional techniques or conventional plain radiography. However, some epidemiological studies have associated CT during childhood with an increased risk of radiation-induced malignancies [1-4]. Even if the outcomes of these studies are still controversial [5-7], a sensible use of the modality is of common sense. It requires strict adherence to the principles of radiation protection – justification and optimisation of the patient radiation exposure [8]. At the core of the optimisation principle is the establishment of diagnostic reference levels (DRLs), first proposed by the International Commission on Radiological Protection (ICRP) [9] and subsequently introduced into European legislation [10-11]. DRLs are suggested action levels above which a facility should review its methods and determine if acceptable image quality can be achieved at lower doses. An approach to establishing DRLs in CT had been proposed by ICRP [12-13], using two primary metrics: Dose-Length Product (DLP) and Volume Computed Tomography Dose Index ($CTDI_{vol}$). National DRLs (NDRLs) in CT have been established in many countries [14-22]. Most of these NDRLs are defined for a single acquisition (*i.e. phase*), a standard patient morphology and are based on an anatomical region [15, 18, 21]. However it is evident that patient radiation dose depends on the number of acquisitions and on the patient's morphology. Likewise, patient radiation dose depends on the clinical indication, as image quality requirements are directly determined by the clinical purpose of the examination. This has been acknowledged, at least in part, by some NDRLs systems [13, 14, 16, 17, 19, 20, 22]. However, none of these NDRLs studies has simultaneously involved a large number of examinations, clinical indications and patient size.

The purpose of this national survey was to investigate current radiation doses for common clinical indications in adult CT examinations throughout France and to assess patient radiation

dose as a function of patient characteristics. This scientific pilot study did not intend to establish French national DRLs but aimed at demonstrating that clinical indications as well as patient morphology need to be taken into account in the DRLs setting for better dose optimisation. The methodology and results proposed in this study could serve as an important input for the national radiation protection authorities to future updates of French DRLs, which would need larger subgroup sample sizes.

Material and Methods

The study conformed to scientific principles and national research ethics standards. Patients' care was not modified in any manner because of this study. Data were retrospectively collected by participants on their secured radiological information systems or on their institution's medical records. Data were sent to the investigators in an anonymous form. The investigators had no access to the participants' information systems and therefore had no possibility of reidentifying the patients. Consequently, informed consent of the patients was not required by personal data protection rules at the time of the study.

Patient radiation dose survey

A national retrospective survey was conducted by the French Society of Medical Physics (SFPM) on patients aged ≥ 16 years who underwent CT examinations in France between 2015 and 2017. A list of 22 groups of clinical indications (GCIs) for diagnostic CT in 9 anatomical regions was initially defined by the SFPM, with the collaboration of the French Society of Radiology (SFR) and its associated organ sections, based on the frequency and the image quality requirements of the clinical indication. Seventeen GCIs were eventually included in the study (see Table 1 and next section for more details). A national call for volunteers for one or more GCIs was sent to the medical physicists' community. Data collection was performed

by each participant independently, using one or more of the following means: picture archiving and communication system (80% of the participants), radiological or hospital information system (61%), dose archiving and communication system (50%) or paper medical records (9%). Anonymised data were transmitted to the investigators with the help of a preformatted Excel datasheet. For each participant's CT scanner and specific GCI, 15-30 consecutive examinations were required. Collected data focused on the complete examination with details of each acquisition. Collected data included CT scanner characteristics (manufacturer, model, commissioning year and maximum collimation); patient information (age, and, optionally, gender, weight and height); acquisition parameters (use of contrast media, and, optionally, acquisition type –axial or helical–, scan length, kV, use of tube current modulation, use of patient restraint equipment and acquisition description); image reconstruction algorithm –Iterative Reconstruction (IR) or Filtered Back Projection (FBP) –; clinical information (clinical indication from the medical report and optionally, exam codification used for medical insurance) and dose data (CTDI_{vol}, DLP and phantom type – 16/32 cm diameter– for each acquisition without localizer radiograph acquisitions and without acquisitions related to the contrast media tracking as well as total examination DLP).

Exclusion criteria

An essential point in this study was to have reliable data. Each participating facility was asked to check the clinical indication of the CT examination in the medical report. The working group of the SFPM and the SFR checked each collected examination data based mainly on the series description, contrast media use, phantom type (16 or 32 cm) and/or scan length.

Examinations were excluded from the analysis based on the following criteria:

- Patient's age < 16 years.

- Missing required information (*i.e.* clinical indication, CT scanner characteristics, use of contrast media, image reconstruction algorithm and dose information).
- Incoherent information, *e.g.* non correspondence between phantom type and body region or obvious mistypes.
- Incomplete examinations, *i.e.* missing one or more acquisition, as detected by comparison of the total examination DLP and the sum of all acquisition's DLP.
- Mixed indications, *i.e.* examinations not focusing exclusively on the initial clinical indication(s), such as extension assessments with respect to the normal practice protocol(s) of the considered GCI (*e.g.* brain exploration in ear trauma indication or abdominal exploration in pulmonary embolism indication). Even if these examinations correspond to the right initial clinical indication and to justified radiological practices, they could have introduced a bias in the calculation of the GCIs' dosimetric indices and were therefore excluded from the analysis.

Ultimately, sets of data counting less than 10 examinations per CT scanner and per GCI at the end of the exclusion process were excluded from the analysis. Likewise, GCIs having less than 10 contributing CTs were also excluded from the study. Consequently, 5 GCIs were abandoned (aortic dissection, suspicion of a lung cancer, screening for secondary liver cancer, suspicion of a kidney cancer and haematuria). Table 1 indicates the 17 GCIs retained for this study, together with the correspondent body part and the abbreviated name, which will be used thereafter in the paper.

CT dose indices analysis

Current CT scanners provide $CTDI_{vol}$ (in mGy) and DLP (in mGy·cm) for each acquisition, which are measured in 16 or 32 cm diameter acrylic phantoms [23]. Given their ease of collection, they were the main parameters selected for this study. By also taking into account

the number of scan acquisitions used, total exam DLP is directly related to patient risk.

Therefore, it may be used to set DRLs for CT-examinations [12-13] and hence was the primary parameter recorded in this study.

Total exam DLP based on the number of acquisitions per examination n_a was analysed as a function of gender for head and neck GCIs. For trunk/body regions, a refined analysis per body mass index (BMI) groups was possible for 11 GCIs using the international classification of adult underweight ($\text{BMI} < 18.5 \text{ kg/m}^2$), normal ($18.5 \leq \text{BMI} < 25 \text{ kg/m}^2$), overweight ($25 \leq \text{BMI} < 30 \text{ kg/m}^2$) and obesity ($\text{BMI} \geq 30 \text{ kg/m}^2$) [24].

Examinations characteristics (kV, mA, image reconstruction type, CTDI_{vol} and DLP) between different GCIs relative to the same body part were compared. This analysis was restricted to single-acquisition examinations and, for trunk examinations, to normal-BMI patients in order to overcome the influence of the number of acquisitions and the patient morphology on dose.

Statistical analysis

Statistical analysis was performed using R version 3.4.3 (R Foundation for Statistical Computing, Vienna-Austria). Categorical variables were expressed as percentages of the number of examinations, which was systematically indicated. Dose indices data were found to be non-normally distributed. Therefore, differences between median values were assessed using a non-parametric test (Wilcoxon rank-sum). The significance level was set to 0.05. The maximum p value was quoted when more than two GCI subgroups were compared.

Twenty-fifth, 50th and 75th percentile values of total exam DLP were calculated once on the distribution of pooled data for all facilities and once again, without BMI or n_a stratification, on the distribution of median values per facility according to ICRP recommendations [13].

The two methods gave mean(min-max) differences of 14(1-41)%, 7(0-16)% and 9(1-24)% in resulting 25th, 50th and 75th percentiles of total exam DLP for each GCI, respectively. The

mean differences being within or very close to the mandatory accuracy on displayed values of DLP ($\pm 20\%$), we chose to present only results of the first method with pooled data distribution for all sub-groups (examination DLP per GCI, per gender/BMI as a function of the number of acquisitions per examination n_a). This was possible because of the similar number of examinations submitted by all CT scanners, which gives them an equivalent weight.

Only descriptive comparisons were possible with published data from other countries because of the variability in methods among countries and of insufficient clinical or patient information in other studies for statistical comparisons.

Results

A total of 9667 acquisitions, corresponding to 7102 examinations included in the 17 selected GCIs, was collected from 88 CT scanners in 53 facilities. After the data validation process, 6610 examinations (8620 acquisitions, 86 CT scanners, 53 facilities) were analysed. This included 24% chest, 21% head, 14% abdomen and pelvis (AP), 11% chest, abdomen and pelvis (CAP), 9% pelvis, 6% ear, 5% mandible/maxilla, 5% cervical spine and 5% body CT-examinations (Table 1). 87% of participating facilities were public hospitals (59% academic and 41% non-academic), 9% comprehensive cancer care institutes and 4% private centres. All French regions were represented. Figure 1 shows the distribution of collected examinations by scanner manufacturer, commissioning year and GCI. The median commissioning year was 2013. Examinations were performed on CT scanners from different manufacturers: General Electric Healthcare (49%), Siemens Healthineers (35%), Philips (9%) and Canon Medical Systems Corporation, formerly Toshiba Medical (7%). Table 1 shows the distribution over the 17 GCIs of the number of centres, CT scanners and examinations collected and validated. Mean number of acquisitions per examination $\langle n_a \rangle$ and clinical practices distribution in terms

of n_a value and contrast media use are also presented. $\langle n_a \rangle$ ranges from 1 (Pelviscan) to 3.67 (Polytrauma). Fifteen GCIs out of 17 gave a majority of single-acquisition CT examinations. Two GCIs had a majority of CT examinations with two acquisitions (Head/Tumour) or three acquisitions (Polytrauma). Fully unenhanced or fully contrast-enhanced examinations were dominant amongst all but the same two GCIs (Head/Tumour, Polytrauma) where mixed studies (*i.e.* including both unenhanced and enhanced acquisitions) were dominant.

Figure 2 shows the distribution of total examination DLP for all studied GCIs, independently of n_a value and without patient grouping per gender or size. Median examination DLP varied from 25 mGy·cm for Pelviscan to 3184 mGy·cm for Polytrauma. Tables 2a and 2b summarize total exam DLP interquartile ranges based on the number of acquisitions per examination n_a and on patient gender for 6 head and neck GCIs or patient BMI for 11 trunk/body GCIs.

Examinations were evenly distributed between men and women patients (49.7% men, 50.3% women) and total exam DLP median values were higher in men patients for all head and neck GCIs. Median DLP difference ranged from 6% in Ear/Trauma to 35% in Head/Tumour, this difference being statistically significant for all head GCIs ($p < 0.01$), for Ear/Trauma ($p = 0.01$), and Neck/Trauma ($p = 0.03$) (Table 2a).

For trunk/body examinations (Table 2b), 45% of examinations were in normal-weight patients, 34% in overweight, 15% in obese and 6% in underweight patients. Total exam DLP median values increased dependably with patient BMI for all GCIs and all n_a sub-groups. In general for every GCI in any body part, total exam DLP increased consistently with the number of involved CT acquisitions, n_a (Tables 2a and 2b).

Table 3 shows the variation of single-acquisition examinations characteristics and dose indices between different GCIs relative to the same body part. Characteristics of unique GCIs (Ear/Trauma, Dental, Neck/Trauma, Pelviscan) are also summarized. Distribution of CTDI_{vol} values and examination DLP are represented in Figure 3 for head GCIs (3a, 3c) and thorax, AP and CAP GCIs (3b, 3d). All GCIs but Ear/Trauma (33%), Dental (16%) and Pelviscan (23%) examinations were mostly done with automatically modulated current (mA). IR algorithms were mostly used in all GCIs examinations except for AP/occlusion (50% IR and 50% FBP). For head and neck examinations, 110/120 kV were dominant in all GCIs except for Ear/Trauma where 130/135/140 kV were mostly used. For chest and AP examinations, kV values varied between 100 kV and 110/120 kV. For the 2 GCIs in CAP examinations, 110/120 kV were dominant. For Head GCIs, Median CTDI_{vol} was slightly higher in Head/Hemo ($p = 0.03$) and median examination DLP for Head/Tumour was lower ($p = 0.01$) than the two other head GCIs. The analysis for chest examinations showed that both CTDI_{vol} and examination DLP median values for Chest/PE were significantly higher than the other GCIs ($p < 10^{-3}$) and significantly lower for Chest/COPD ($p = 0.03$ and 0.01 for CTDI_{vol} and DLP respectively). Every AP GCIs showed a significant difference from one another both in median CTDI_{vol} ($p < 0.01$) and examination DLP ($p = 0.01$). Lastly, no significant difference was observed between CAP/Tumour and CAP/Infectious.

Discussion

CTDI_{vol} (for single-acquisition) and total exam DLP (per number of involved acquisitions) national distributions were assessed on 17 GCIs as a function of patient gender or BMI for head and neck or trunk examinations respectively. For head and neck GCIs, total exam DLP values were higher for men compared to women patients, considering the same number of acquisitions within a same examination (Table 2a). This is likely due to larger size [25] and

more dense head and neck of men compared to women's, especially when analysed examinations were mostly performed with automatically modulated current (Table 3). For all trunk/body GCIs, total exam DLP increased consistently with patient BMI for all examination groups (Table 2b). Thus, our results confirmed the strong dependence of dose estimators on patient morphology.

When comparing different GCIs within same body region, $CTDI_{vol}$ and DLP for single-acquisition examinations showed significantly higher values for Chest/PE compared to other GCIs in chest region. This can be explained by the high image quality requirements for this indication, reflected in CT examination characteristics mostly performed with contrast media in Chest/PE, compared to other GCIs (Table 1). Conversely, the lower dose indices values observed for Chest/COPD are related to the lower image quality requirement of this indication that is always performed without contrast media and takes advantage of the high natural contrast of the lung parenchyma. The analysis for AP examinations showed significantly lower values for AP/Colic compared to other GCIs. Lower dose protocols mostly performed without contrast enhancement (Table 1) and lower kV (mostly 100 kV) (Table 3) were used in AP/Colic compared to AP/Pain and AP/Occlusion. In these latter GCIs, contrast-enhanced examinations and higher kV (110/120 kV) were mostly used. These findings could be related to the fact that CT for AP/Colic is commonly performed in low dose thanks to the high natural contrast between kidney stones and tissues. The higher values observed for AP/Occlusion could be related to the high percentage of FBP reconstruction (50%) when compared to other GCIs. However, the low number of examinations (18) in this subgroup limits the significance of this difference. A small but statistically significant difference in $CTDI_{vol}$, respectively DLP, was observed between Head/Hemo, respectively Head/Tumour, and other GCIs in head examinations. However the small gap in dose indices between head GCIs tends to indicate

that similar protocols are used whatever the indication. The same interpretation stands for CAP examinations where differences between two GCIs are moderate and statistically non-significant. Indeed, for these body parts, more homogeneous practices were noticed in kV use (mostly 110/120 kV) and modulated mA (Table 3).

NDRLs implemented in many countries [15, 18, 19, 21] are only based on an anatomic region, for single CT acquisition. Few studies involved the influence of patient size [19] or clinical indication [14, 16, 17, 20, 22]. The impact of patient size on radiation dose was well established in the United States of America (USA) recent study on their NDRLs [19]. Nevertheless, patient grouping was done in terms of water equivalent diameter for body examination and lateral thickness for head examination. These settings are not easily accessible for local benchmarking neither for national assessment. Moreover, USA NDRLs were developed based on examination type not on clinical indication. NDRLs were proposed in few studies for few clinical indications and for standard sized patients [14, 16, 17, 20, 22]. These studies showed that patient radiation dose depends on the number of CT acquisitions within same examination and on image quality requirements for diagnosis. Recently, the European Commission launched a tender project on clinical DRLs (EUCLID - European Study on Clinical Diagnostic Reference Levels for X-ray Medical Imaging [26]). The project is led by the European Society of Radiology and started in August 2017. The aim of this project is to provide up-to-date clinical DRLs for the most important, from a radiological perspective, x-ray imaging tasks in Europe. The 75th percentile dose indices for normal-weight patients in this study were compared with those of other clinical NDRLs (Table 4). Our results were generally lower than other reported data or within the lowest values. One reason might be the evolution of techniques and professional practices within the time gap between different surveys. Modern CT scanners with dose-reduction options (current

modulation and IR) were generally used in this study. Another possible explanation is that, with a few exceptions, this study relied on voluntary medical physicists. It seems reasonable to consider that facilities where a medical physicist is involved tend to have lower dose protocols. Proposed French NDRLs based on CT examinations grouped by anatomical regions were also indicated in Table 4. All CTDI_{vol} and DLP values of this study were similar or lower than the proposed French NDRLs except for traumatic brain injury and CAP infectious foci examinations where DLP value was a little higher.

Morphology and clinical based patient dose indicators are useful to benchmark CT imaging protocols and optimise patient radiation dose as a function of image quality need. Twenty-fifth, 50th and 75th percentiles (Tables 2a and 2b) of total examination DLP per n_a value are provided to encourage facilities to optimize dose as low as reasonably achievable by taking into consideration the image quality. Ideally, facilities should analyse and compare their median, size-grouped dose indices by clinical indication with the respective clinical and size based 25th, 50th and 75th percentiles values. If size-grouped dose indices are not available, facilities should compare their overall median indices with the “all Genders”, “all BMIs” and/or “all acquisitions” 25th, 50th and 75th percentiles values. The implementation of this optimisation process is most effective if the facility has a Dose Archiving and Communication System (DACS) that automatically monitors patient radiation dose indices.

This study comes with some limitations. First, no strict image quality analysis was carried out but the patient radiation dose data corresponded to examinations performed in the institutions according to their normal practice of image quality selection for the given indication. We have to assume that the vast majority of the collected examinations met image quality standards because we assume the vast majority were interpreted. The second limitation concerns the

representativeness of this survey. First, a little number of CT scanners contributes to some GCIs (Head/Tumour, Chest/Infectious, Chest/Metastases and CAP/Infectious) resulting from grouping examinations by patient size and number of acquisitions within examination.

Second, less than 20 % of the facilities were private centres. However, numerous general public hospitals (i.e. non-academic) share their equipment with the private sector in so-called “economic interest groups” regional organization (GIE for *groupements d'intérêt économique*). Third, this study relied on voluntary medical physicists involved in university imaging departments in France, who represent a small proportion of facilities in France. Therefore, the results of this pilot study cannot be considered as representative of the whole French radiological practice.

In addition, the recent ICRP recommendations [13] could not been generalised in establishing dose distributions for all sub-groups by using the median of each CT scanner. Nonetheless, the two calculation methods were tested and gave acceptable differences. Moreover, we accepted that no correction was applied to the recorded CTDI_{vol} values. We assumed that CTDI_{vol} values were in agreement with the national quality criteria (within $\pm 20\%$ deviation) checked annually and after tube replacement. Lastly, the manual process for patient size data and examination dose information in some departments not using a DACS, led to missing data in some cases. Moreover, the use of an Excel sheet to manually collect the data limited the number of examinations compared to an automatic collection with dedicated software, such as in the US DRLs study [19]. However, the verification of the clinical indication was more feasible with the Excel sheet.

Conclusion

This study was, to our knowledge, the first national survey based on clinical indication and patient size and evaluating CT dose. Results provide a tool for CT dose optimisation that is

better adapted to clinical practices and to the variability of patients' morphology. In order to capture continual future trends in CT technologies and practices evolution, this study should be periodically updated. This study could serve as an important input for the national radiation protection authorities to future updates of French DRLs after taking into account the study limitations.

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Table legends:

Table 1: List of 17 groups of clinical indications (GCIs). Number of centres, CT scanners and examinations (n_e) included in the national survey. Description of clinical practices in terms of mean number of acquisitions per examination ($\langle n_a \rangle$), percentage distribution of n_a and contrast media use.

Table 2a: Number of CT examinations (n_e) and total exam DLP range (50th (25th-75th percentile)) based on the number of acquisitions per examination (n_a) and on patient's gender for 6 head and neck GCIs. Non-significant (--) sub-groups counting less than 20 examinations are not presented. Total exam DLP values are given for the 16-cm diameter phantom in head, ear and mandible/maxilla examinations and the 32-cm diameter in cervical spine examinations. p results of the Wilcoxon rank sum test between women and men values are presented (p < 0.05 are marked with *).

Table 2b: Number of CT examinations (n_e) and total exam DLP range (50th (25th-75th percentile)) based on the number of acquisitions per examination (n_a) and on patient's BMI range for 11 trunk or full-body GCIs. Non-significant (--) sub-groups counting less than 20 examinations are not presented. Total exam DLP values are all given for the 32-cm diameter phantom, except for the Polytrauma GCI where the examination DLP value can be a sum of 16-cm and 32-cm DLP values for full-body examinations.

Table 3: Comparison of dosimetric indices and acquisition characteristics between different GCIs relative to the same body part. Only single-acquisition examinations are considered for all GCIs. Only normal BMI patients are considered for trunk and full-body examinations. DLP and CTDI_{vol} values are given for the 16-cm diameter phantom in head, ear and mandible/maxilla examinations, 32-cm for other body parts. This analysis was not possible for Polytrauma GCI because of a non-significant number of single-acquisition examinations.

* indicates a p-value < 0.05 for every Wilcoxon rank sum tests calculated with other GCIs of the same body part.

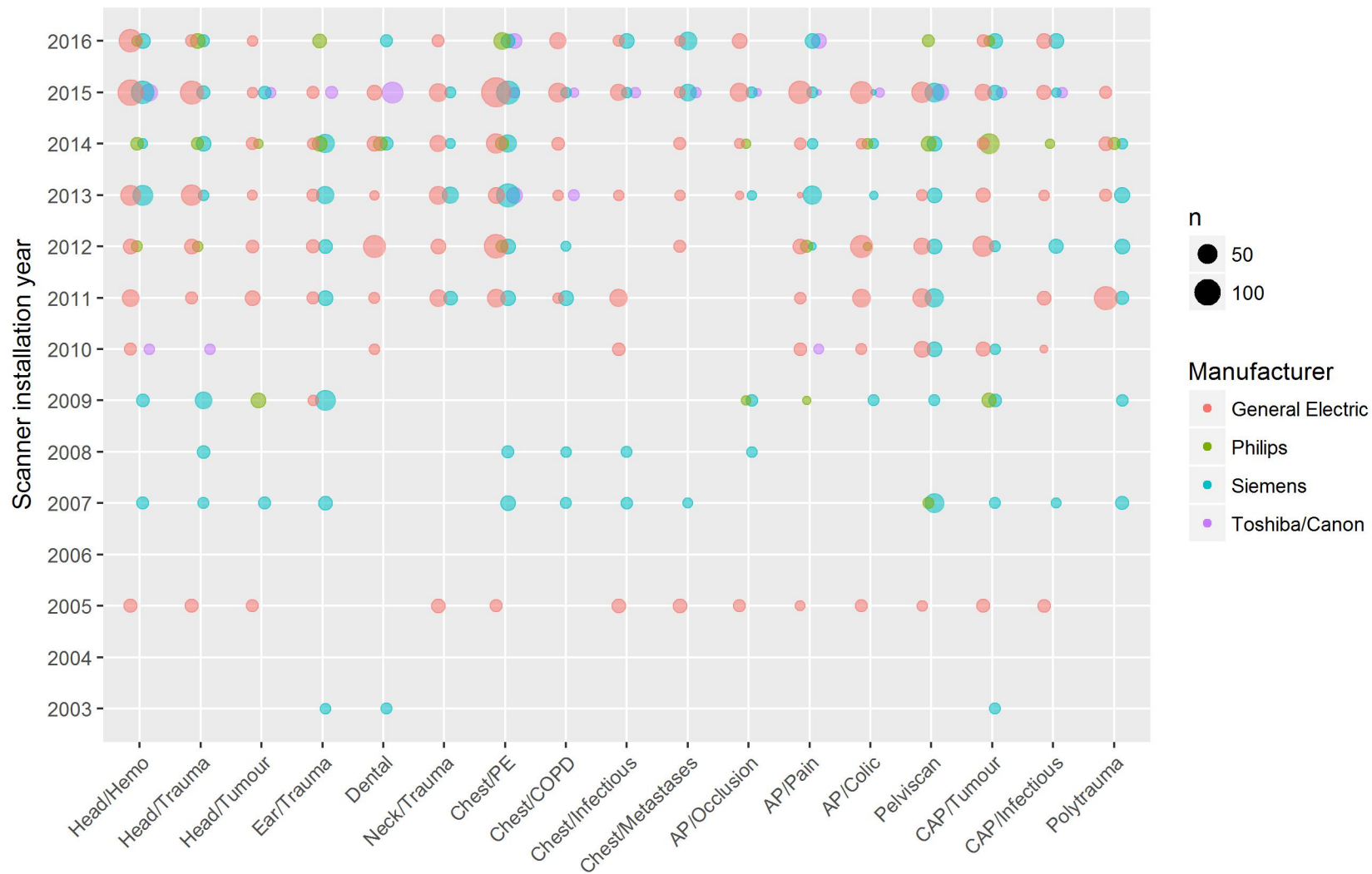
Table 4: Comparison of this study's results with published international DRLs. Rounded values of the 75th percentile of CTDI_{vol} (mGy) and DLP (mGy·cm) for normal-weight patients (except for head & neck examination) are considered for this study. CTDI_{vol} and DLP values are given for the 16-cm diameter phantom in head, ear and mandible/maxilla examinations, 32-cm for other body parts.

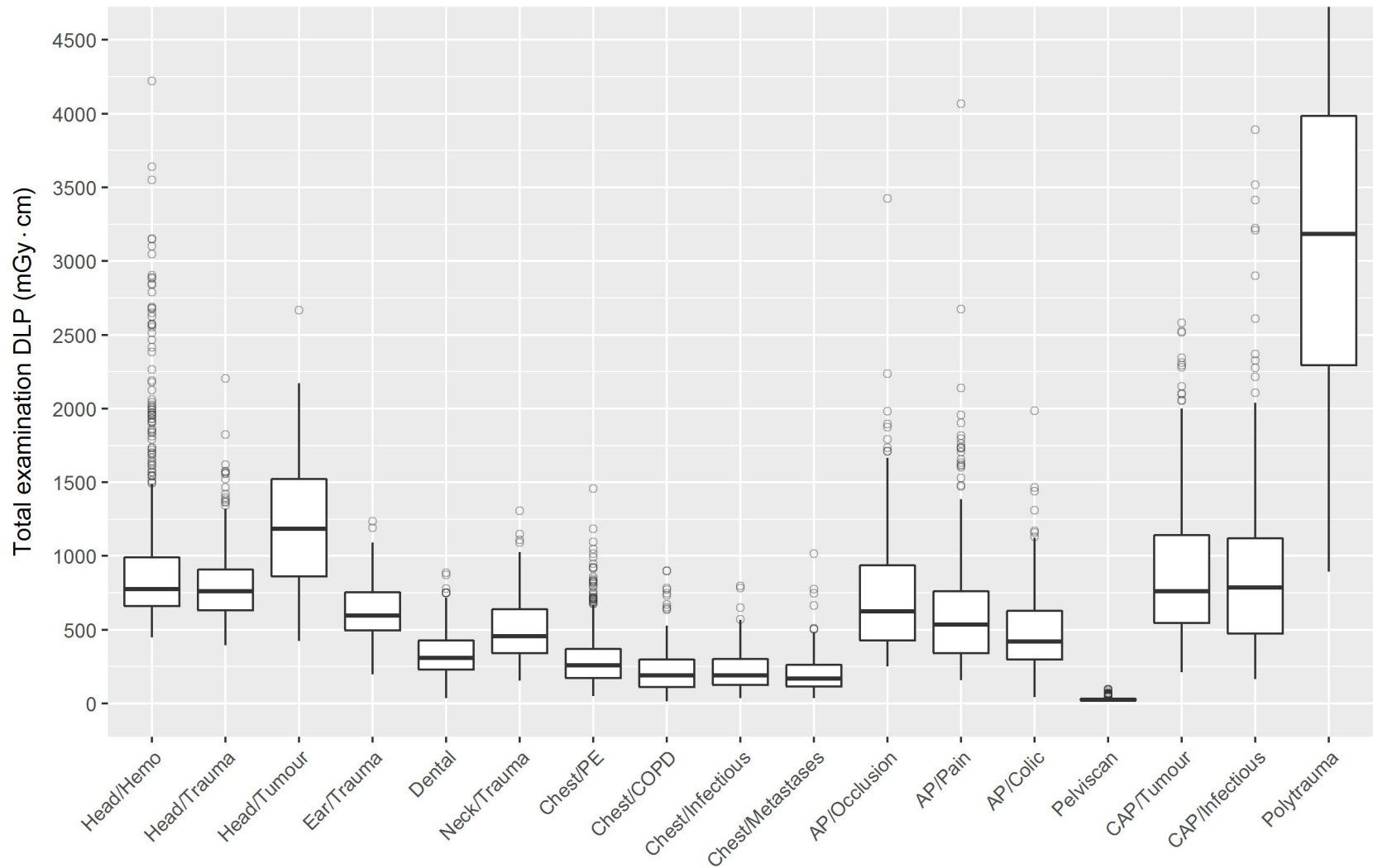
Figure captions:

Figure 1: Distribution of collected examinations by scanner manufacturer, commissioning year and GCI. The size of the dots is proportional to the number of examinations. Scanner manufacturer is colour coded.

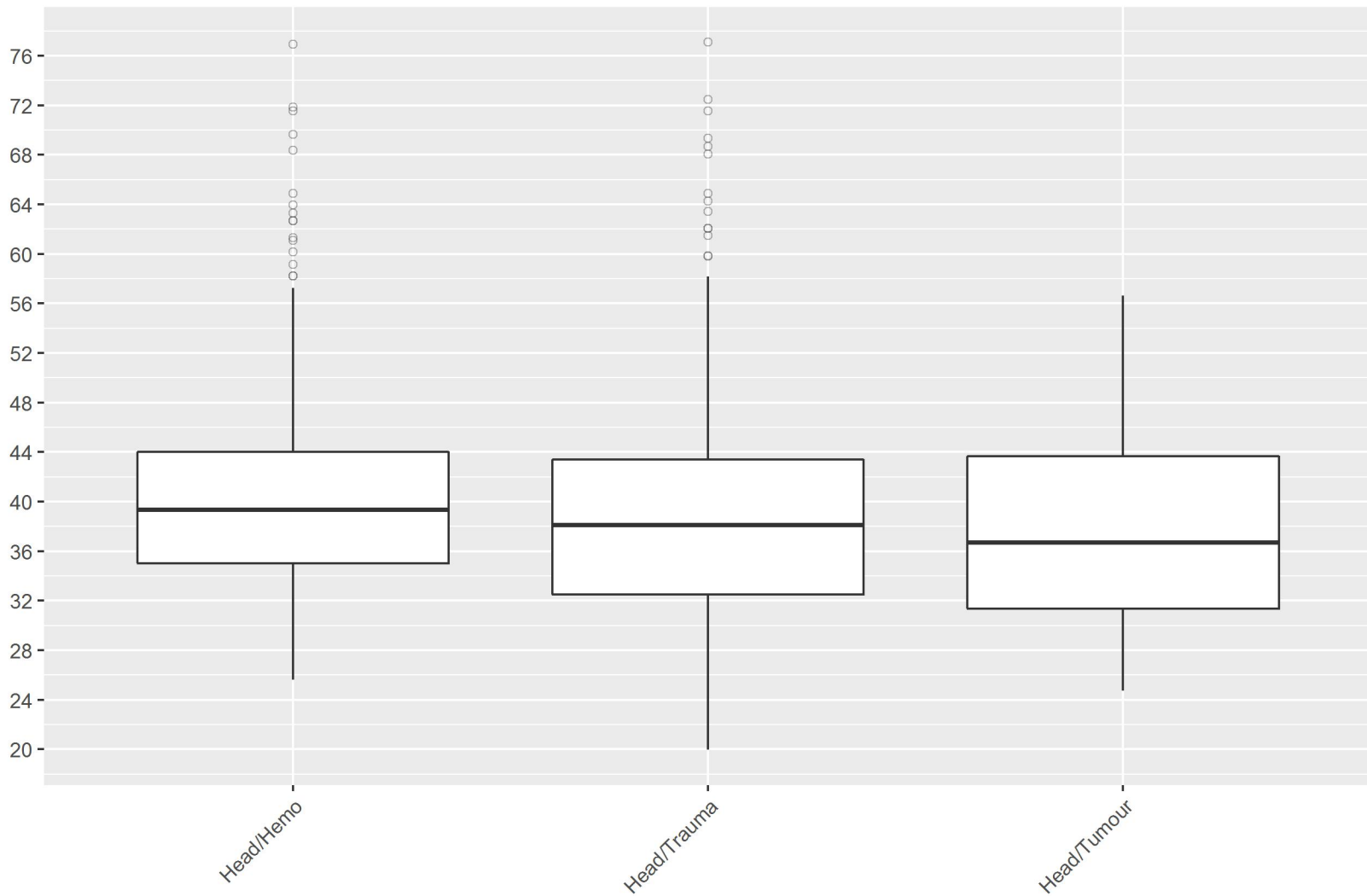
Figure 2: Distributions of multi-acquisitions examination DLP for 17 studied GCIs in 9 anatomical regions in all BMIs patients. The boxes represent the inter-quartile range (IQR, distance between the 1st and 3rd quartiles), the black lines in between mark the median value. The upper (lower) whiskers extend to the largest (smallest) value no further than $1.5 \times \text{IQR}$ from the boxes. Data falling outside the whiskers range are plotted individually as outliers.

Figure 3: Distribution of CTDI_{vol} (a, b) and DLP values (c, d) for single-acquisition examination in Head, Thorax, AP and CAP GCIs. Only normal BMI patients are considered for trunk examinations. CTDI_{vol} and DLP values are given for the 16-cm diameter phantom in head examinations, 32-cm for other body parts. The boxes represent the inter-quartile range (IQR, distance between the 1st and 3rd quartiles), the black lines in between mark the median value. The upper (lower) whiskers extend to the largest (smallest) value no further than $1.5 \times \text{IQR}$ from the boxes. Data falling outside the whiskers range are plotted individually as outliers.

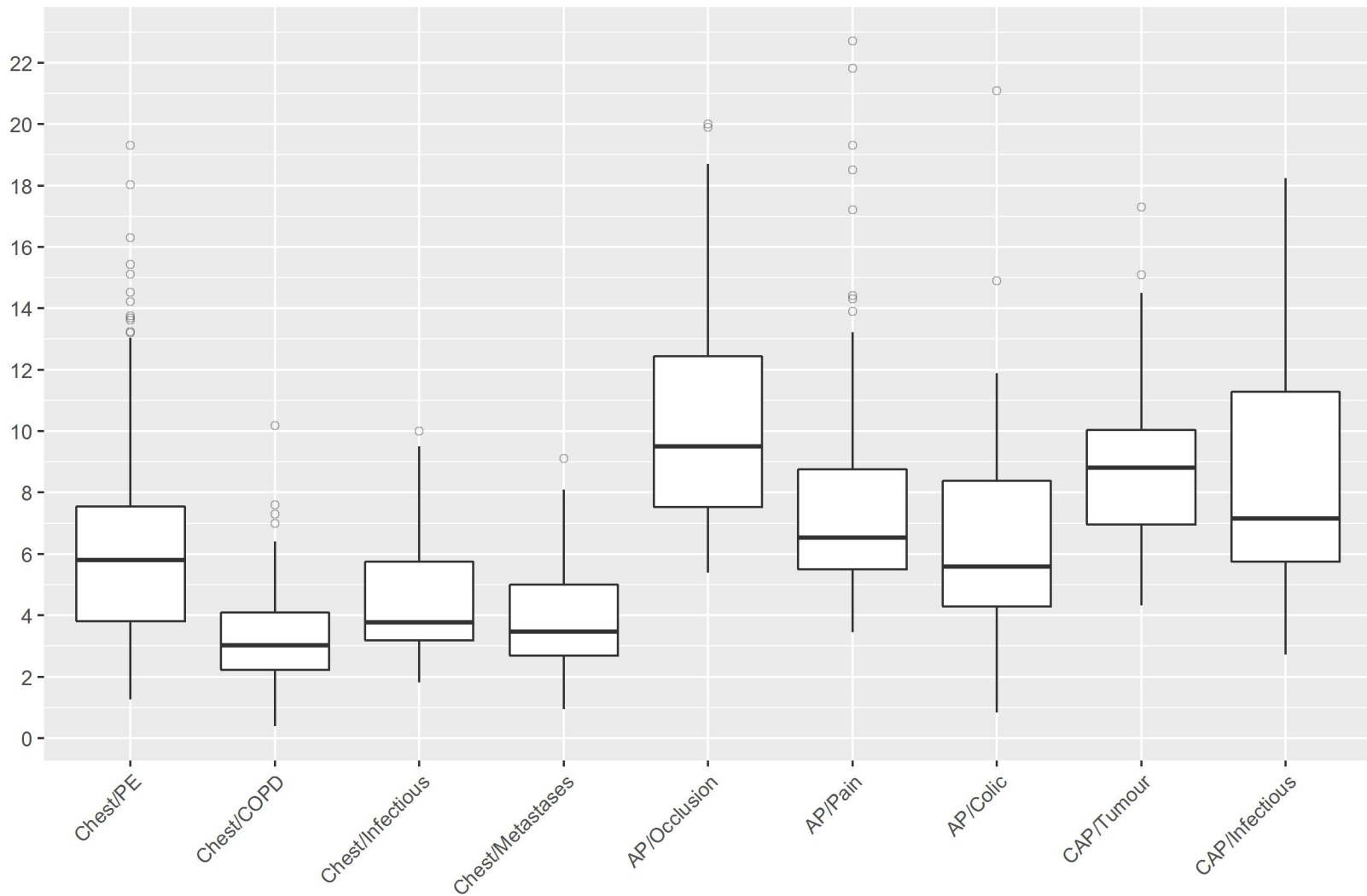




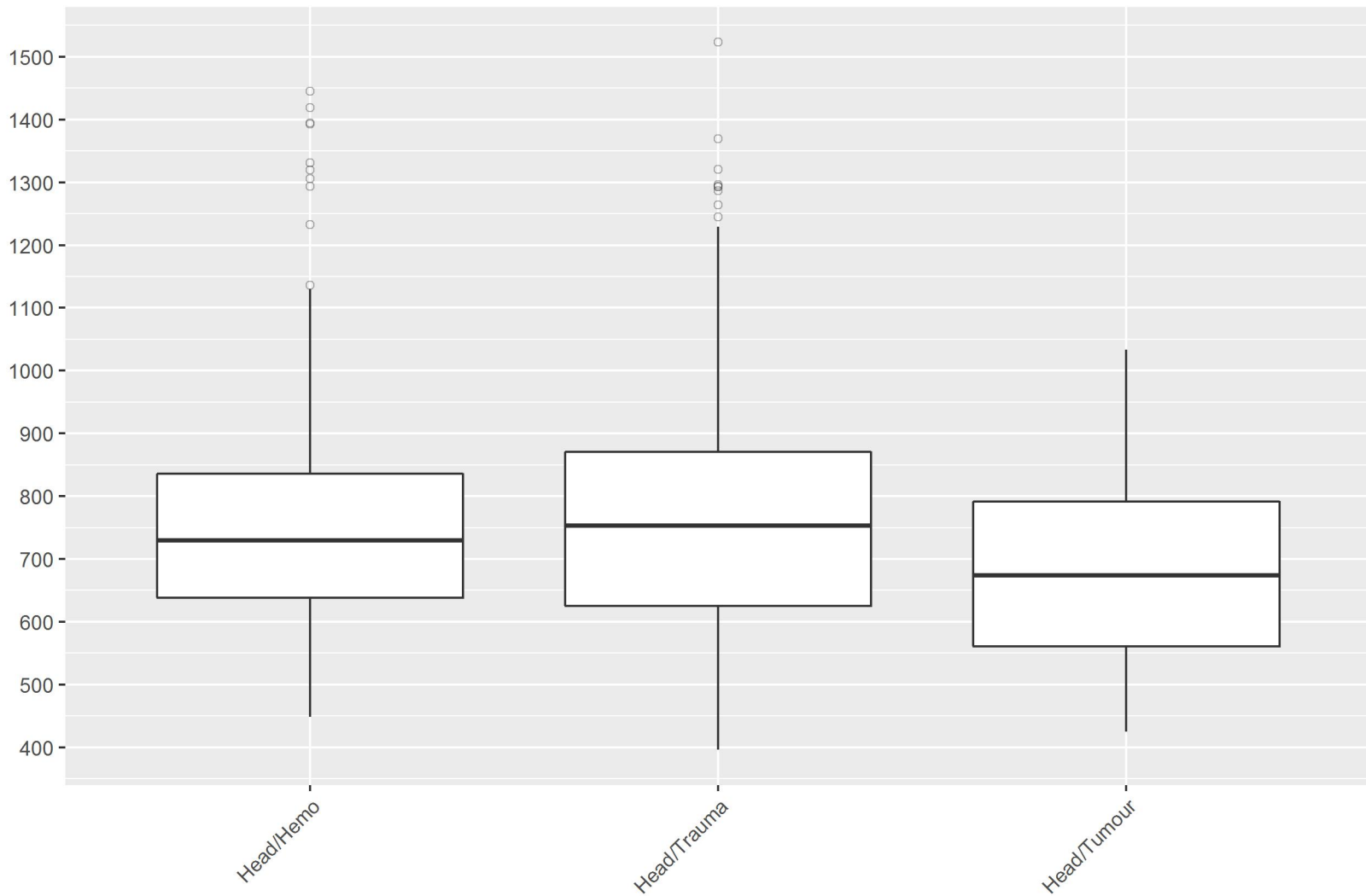
CTDI_{vol} (mGy)



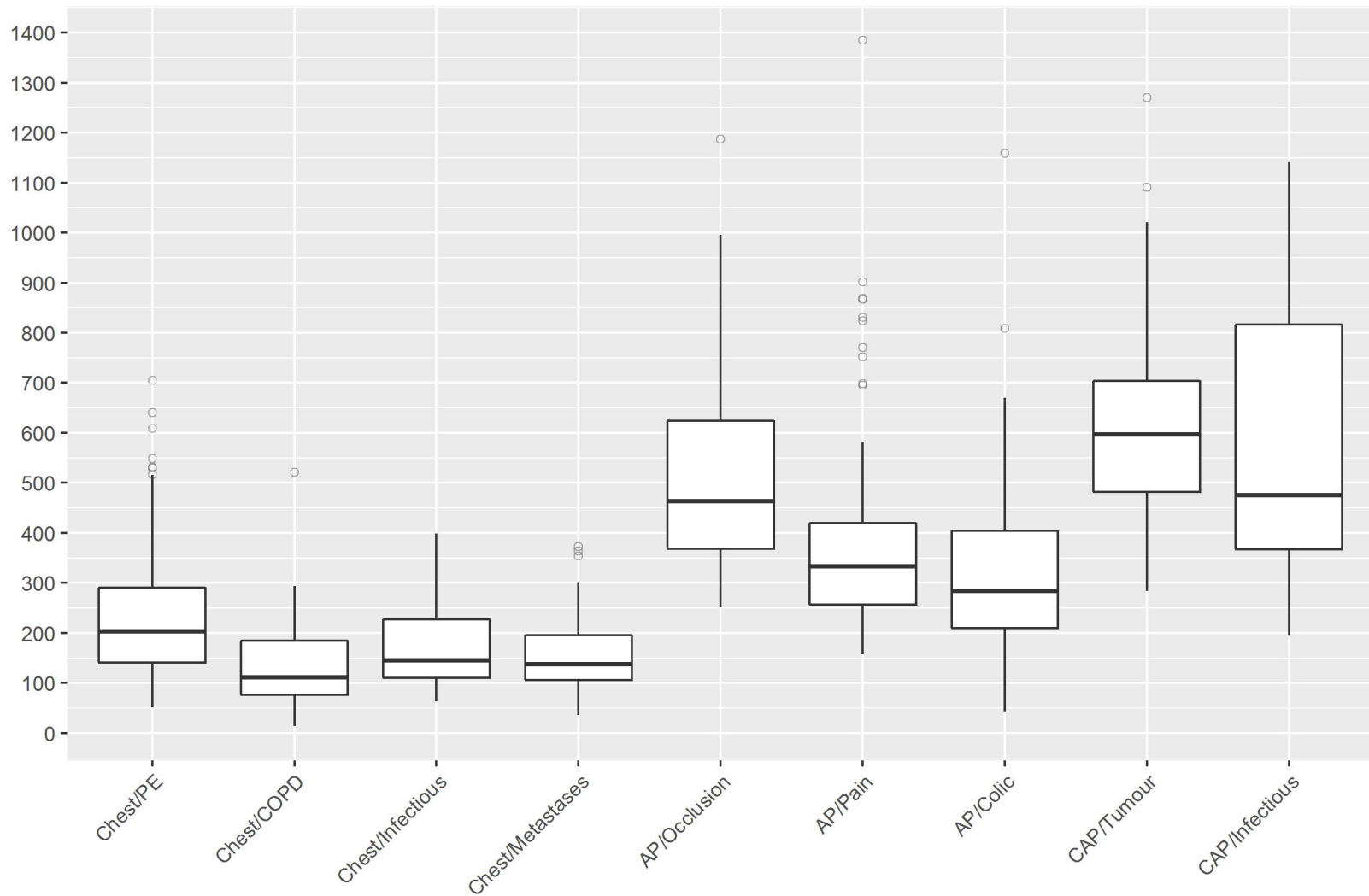
CTDI_{vol} (mGy)



DLP (mGy · cm)



DLP (mGy · cm)



Highlights

- Patient morphology- and indication-based CT dose indices were assessed nationwide.
- Dose indices differed significantly between some indications in the same body region.
- For head & neck examinations, dose indices were higher for male patients.
- For trunk examinations, dose indices increased consistently with patient BMI.
- This study provides a tool for CT dose optimisation adapted to clinical practices.