# Optimisation of abdomino-pelvic CT protocols:

## Presentation of a recently published comprehensive and up-to-date inventory of pertinent metrics for the perusal of the clinical medical physicist

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SPTAR MATER DEI

# Introduction

Clinical protocol optimisation traditionally considered only desired image quality (clinical task dependent) and radiation risk/dose.

But, body shape and size (habitus) impact image quality and dose.

Hence, the process of optimisation is dependent on the appropriate selection of metrics from three categories:
patient **body habitus** (BH), **image quality** (IQ), and **risk/dose** (RD).

Various metrics for each of the three categories are found in literature, however a single inventory bringing them all together is still lacking.

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# Introduction

Inventories of metrics risk/dose:

*Ria et al (2021)* listed **12** surrogates for risk/dose

*Avramova-Cholakova (2022) et al* compared **17** methods for calculating effective dose

Listing of metrics for image quality and body habitus are virtually non-existent.

The purpose of this work was to establish a comprehensive inventory for all three categories of metrics and to propose a way forward for its use.

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# Method

A literature search was conducted on PubMed for the period 2010–2024.

The keywords used were:

> ‘comput* tomography’, ‘CT’, ‘abdom*’, ‘dose’, ‘risk’, ‘SSDE’, ‘image quality’, ‘water equivalent diameter’, ‘size’, ‘body composition’, ‘habit*’, ‘BMI’, ‘obes*’, ‘overweight’

Inclusion criteria were applied specific to each category of metrics.

# Inclusion criteria

# Inclusion criteria

## Body habitus

| Criterion | Rationale |
|---|---|
| Within or related to the abdomino-pelvic region | This is dictated by the scope of the study |
| Would possibly act as a predictor of dose or image quality metrics & as such can be determined pre-scan or via post-localiser radiograph | Required for making pre-exposure patient habitus specific optimisation possible |

# Inclusion criteria

## Image quality

| Criterion | Rationale |
|---|---|
| Objective metrics as evaluated by the radiologist in patient images*, as opposed to device performance | This qualifies the term ‘image quality metric’ as used in this study |
| Can be calculated solely from ‘for presentation’ image data | Data readily available to the physicist (i.e. not metrics requiring access to raw data or vendor agreements) |
| Can be automated in principle and be available immediately post-scan | To avoid the need for reader time and to be useful in objectively assessing whether a rescan is required |
| Adult and patient specific | Required by the increased emphasis on personalised medicine |

*i.e. sharpness, contrast, noise quantity/texture

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# Inclusion criteria

## Risk/dose

| Criterion | Rationale |
|---|---|
| Can be calculated solely from DICOM header and image data | All such data is available to the clinical medical physicist |
| Can be automated in principle | To avoid the need for human input and for ongoing dose monitoring |
| Adult and patient specific | Required by the increased emphasis on personalised medicine |

# Results

The literature search retrieved **439** articles.

After applying the inclusion criteria, the inventory consisted of:

- **11** Body habitus metrics
- **9** Image quality metrics
- **6** Risk/dose metrics

# Body habitus metrics

# Body habitus metrics

| Metric | Symbol & unit | Definition | Measurement instant |
|---|---|---|---|
| Patient weight | W (kg) | Global metric and a general indicator of patient size. | Pre or post scan. |
| Body Mass Index | BMI (kg/m$^2$) | Global whole body metric. | Pre-scan. |
| T-shirt size | XXS to XXL | General indicator of patient size and/or degree of obesity. | Pre-scan. |
| Sagittal, lateral diameters | PA, LAT (cm) | Regional metric. Thickness and width of patient. | post-scout or post-scan images using digital callipers. |
| Waist circumference | WC (cm) | Regional metric measured at umbilicus. Measure of abdominal obesity. | Pre-scan (direct measure using tape measure);<br>Post-scan (contour tracing). |
| WC to hip circumference ratio | WHR | Regional metric. WHO defines WHR obesity as >0.90 for men and >0.85 for women. | Pre-scan (direct measure using tape measure);<br>Post-scan (contour tracing). |

# Body habitus metrics

| Metric | Symbol & unit | Definition | Measurement instant |
|---|---|---|---|
| Effective diameter | $D_E$ (cm) | Regional metric measured typically at the centre of the body region being scanned. | Post-scout or post-scan based on AP and LAT measurements. |
| Ellipticity ratio | r | Regional metric measured as the average over the entire scanned volume. | Post-scout or post-scan based on AP and LAT measurements. |
| Water equivalent diameter | Dw (cm) | Measured per axial slice or averaged over the entire scanned volume. | Post-scout or post-scan (although latter is more reliable). |
| Cross-sectional area | A ($cm^2$) | Regional metric measured typically at the level of the umbilicus. | Approximate estimate pre-scan from waist circumference. More accurately post-scan. |
| Area of circumscribing ellipse | $A_{cir}$ ($cm^2$) | Regional metric measured typically at the level of the umbilicus. | Measured post-scout or post-scan based on AP and LAT measurements. |

# Image quality metrics

# Image quality metrics – Noise

| Metric | Symbol & unit | Definition | Application |
|---|---|---|---|
| Noise standard deviation | SD (HU) | Regional noise magnitude measure. SD (HU) of HU values over a manually placed ROI on homogenous tissue (2D or 3D). | Traditional assessment of magnitude of image noise. |
| Tian & Samei noise | TSN (HU) | Whole-slice noise magnitude measure. Modal value in HU of the values of SD. | Objective and automated monitoring of noise as part of routine quality control and for comparing noise across protocols and scanners. |
| Global noise level | GNL (HU) | Global, whole-slice, or tissue-specific noise magnitude measure. Modal value in HU of SD values of a noise map of homogenous tissue. | Suitable for automated monitoring of noise over predefined segmented homogenous areas in the abdomino-pelvic image slice relevant to the clinical query. |
| Local task-based auto-covariance | ACV | Regional noise structure measure. Auto-covariance in the spatial domain of a sub-ROI in a uniform region of the task-based ROI. | The shape, peak position and area under the ACV curve may be used to compare noise textures. |

# Image quality metrics – Contrast

| Metric | Symbol & unit | Definition | Application |
|---|---|---|---|
| Contrast to noise ratio | CNR | Mean difference in MPV in HU between the feature of interest (e.g. lesion) and MPV of adjacent tissue with respect to the value of the uncertainty in the difference. | The minimum value of the CNR for detectability is still a subject of research. Three levels of CNR may be defined: |

1. The CNR level above which a detection can be considered a true-positive and a non-detection a true-negative at a given level of significance.

2. The minimum CNR level that may be expected a priori to lead to detection can be used to set noise indexes at exposure such that lesions would be detected by the Radiologist or CAD software.

3. The CNR level beyond which a quantitative measurement of contrast can be performed with a stated uncertainty.

# Image quality metrics – Sharpness

| Metric | Symbol & unit | Definition | Application |
|---|---|---|---|
| Margin sharpness | MS | Gradient at the inflection point of the sigmoid function describing the pixel values (in HU) along the normal to the boundary between a feature and its adjacent tissue. | To quantify image sharpness across a boundary. The range of MS values for acceptable image quality is a subject of research and may be radiologist dependent. |
| Image blur metric | IBM | Defined as a range between 0 (minimum blur, maximum sharpness) and 1 (maximum blur, minimum sharpness). | Can be applied to quantify the sharpness of a whole image or specific ROIs. |
| Structure sharpness index | SSI | Median of the set of gradients of HU profiles along normal cross-boundary across the boundary of interest. | To quantify image sharpness across a boundary. The range of SSI values for acceptable image quality is a subject of research and may be radiologist dependent. |

# Risk/dose metrics

# Risk/dose metrics

| Metric | Symbol & unit | Definition | Measurement instant and application |
|---|---|---|---|
| Dose length product | DLP (mGy·cm) | A measure of the total energy imparted to the standard phantom under the same exposure parameters as the patient. | Pre-scan as length defined prior to scan. Since defined on a non-anthropomorphic phantom of fixed size, the DLP has little relevance to the actual energy imparted to the individual patient. |
| Size specific dose estimate | SSDE (mGy) | Provides a better estimate of the total energy imparted to the patient by replacing the standard 32 cm PMMA phantom with a virtual disc water phantom having the same total attenuation as the patient slice (Dw). | post-scout or post-scan (latter being more accurate as it uses the measured values of linear attenuation of coefficient of patient voxels as inputs for the calculation of Dw). |
| Individual organ dose | OD (mGy) | Energy imparted per unit mass of an organ. | May be measured directly in anthropomorphic phantoms. In patients, may be estimated via Monte Carlo. |

# Risk/dose metrics

| Metric | Symbol & unit | Definition | Measurement instant and application |
|---|---|---|---|
| Effective dose (or 'organ dose based effective dose') | E or $ED_{OD}$ (mSv) | Measure of stochastic risk from an exposure to a reference individual representing a population. Does not consider age and sex. | Many approaches exist to estimate E either pre-scan or post-scan. Useful for comparing risks between different protocols particularly when there are significant differences in absorbed dose distribution in the body. |
| Risk index | RI | $ED_{OD}$ with consideration of age and sex. This index is considered as the most reflective of the real patient risk and therefore would be considered the gold standard. | May be estimated post scout or post scan depending on approach used. This would be the ideal metric to use. |
| Relative effective dose | $ED_r$ (mSv') | The RI relative to a 20-year old patient. | May be estimated post scout or post scan depending on approach used. |

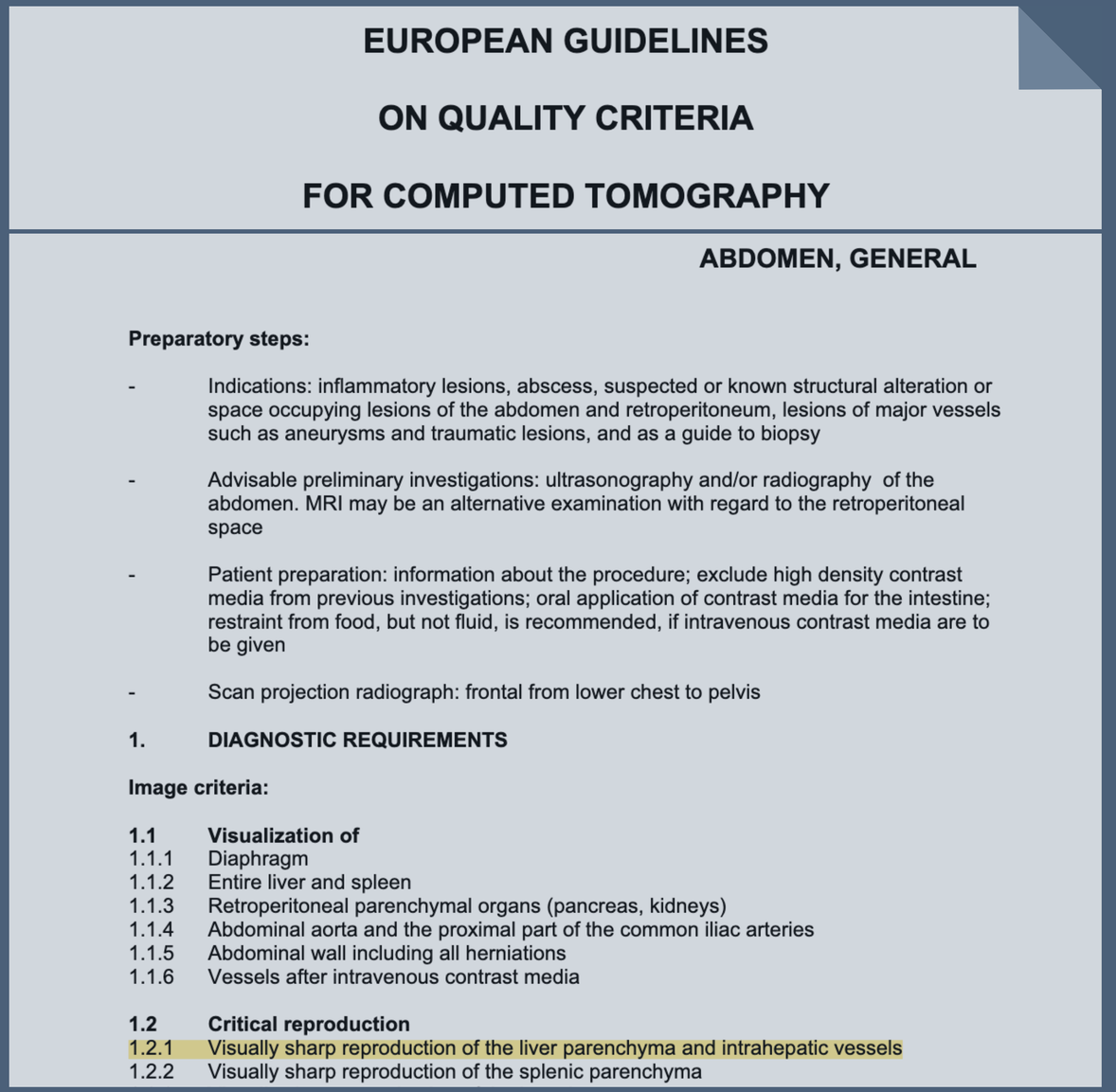
# Example usage

# Using the inventory

This inventory is intended to assist the clinical medical physicist in the optimisation of protocols.

Such optimisation should ideally be targeted at addressing the image quality criteria for specific clinical tasks.

The metrics from the inventory can be mapped to the specific image quality criteria from these documents.



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**ON QUALITY CRITERIA**

**FOR COMPUTED TOMOGRAPHY**

**ABDOMEN, GENERAL**

**Preparatory steps:**

- Indications: inflammatory lesions, abscess, suspected or known structural alteration or space occupying lesions of the abdomen and retroperitoneum, lesions of major vessels such as aneurysms and traumatic lesions, and as a guide to biopsy
- Advisable preliminary investigations: ultrasonography and/or radiography of the abdomen. MRI may be an alternative examination with regard to the retroperitoneal space
- Patient preparation: information about the procedure; exclude high density contrast media from previous investigations; oral application of contrast media for the intestine; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given
- Scan projection radiograph: frontal from lower chest to pelvis

**1. DIAGNOSTIC REQUIREMENTS**

**Image criteria:**

**1.1 Visualization of**
1.1.1 Diaphragm
1.1.2 Entire liver and spleen
1.1.3 Retroperitoneal parenchymal organs (pancreas, kidneys)
1.1.4 Abdominal aorta and the proximal part of the common iliac arteries
1.1.5 Abdominal wall including all herniations
1.1.6 Vessels after intravenous contrast media

**1.2 Critical reproduction**
1.2.1 Visually sharp reproduction of the liver parenchyma and intrahepatic vessels
1.2.2 Visually sharp reproduction of the splenic parenchyma

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# Using the inventory

As an example, a quality criterion for general abdomen CT in the EU quality criteria is the **visually sharp reproduction of the liver parenchyma and intra-hepatic vessels**.

Such 'visually sharp reproduction' would be mapped to the **Structure Sharpness Index (SSI)**.

A tolerance range could then be developed in collaboration with radiologists.

This tolerance range would serve to ensure that only images of acceptable quality are presented to the radiologist for analysis, a process that is in principle automateable.

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# Conclusion

Optimisation requires consideration of body habitus.

Metrics from three categories as identified in literature were collected into a single inventory.

Inventory includes 11 body habitus; 9 image quality; 6 risk/dose metrics.

Consensus favours the use of Dw for BH, GNL for generic IQ and SSDE for RD.

Inventory useful for the clinical medical physicist to *map quality criteria for a particular clinical task to objective, physical metrics*.

Working with radiologists and radiographers, mapped metrics may be measured to identify thresholds of acceptability.

As the metrics are objective and automateable, they can be implemented in routine practice, ensuring only images of acceptable quality are presented to the radiologist.

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# Key references


**American Association of Physicists in Medicine** (2011). *Size-Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations (AAPM Report 204)*. American Association of Physicists in Medicine. https://doi.org/10.37206/143

**American Association of Physicists in Medicine** (2014). *Use of Water Equivalent Diameter for Calculating Patient Size and Size-Specific Dose Estimates (SSDE) in CT (AAPM Report 220)*. American Association of Physicists in Medicine. https://doi.org/10.37206/146

**Avramova-Cholakova S**, Dyakov I, Yordanov H, O'Sullivan J. *Comparison of Patient effective doses from multiple CT examinations based on different calculation methods*. Phys Med 2022;99:73–84. https://doi.org/10.1016/j. ejmp.2022.05.014.

**Burton CS**, Szczykutowicz TP. *Evaluation of AAPM reports 204 and 220: Estimation of effective diameter, water-equivalent diameter, and ellipticity ratios for chest, abdomen, pelvis, and head CT scans*. J Appl Clin Med Phys 2018;19: 228–38. https://doi.org/10.1002/acm2.12223.

**Christianson O**, Winslow J, Frush DP, Samei E. *Automated technique to measure noise in clinical CT examinations*. Am J Roentgenol 2015;205:W93–9. https:// doi.org/10.2214/AJR.14.13613.

**European Commission**. *European Guidelines on Quality Criteria for Computed Tomography*. EUR16262. 2000.

**Ria F**, Fu W, Hoye J, Segars WP, Kapadia AJ, Samei E. *Comparison of 12 surrogates to characterize CT radiation risk across a clinical population*. Eur Radiol 2021;31:7022–30. https://doi.org/10.1007/s00330-021-07753-9.

**Szczykutowicz, T. P.** (2020). The CT Handbook: Optimizing Protocols for Today's Feature-Rich Scanners. Medical Physics Publishing.


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# Thank you

# Related publications

Pace, E., et al (2024). **An inventory of patient-image based risk/dose, image quality and body habitus/size metrics for adult abdomino-pelvic CT protocol optimisation**. Physica Medica, 125. https://doi.org/10.1016/j.ejmp.2024.10343

Pace, E., et al (2022). **CTContour: An Open-Source Python Pipeline for Automatic Contouring and Calculation of Mean SSDE Along the Abdomino-Pelvic Region for CT Images; Validation on Fifteen Systems**. Physica Medica, 103, 190–198. https://doi.org/10.1016/j.ejmp.2022.10.027

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