CAT·ClinART

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Catalan Clinical Audit Network for Quality Improvement in Radiotherapy

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MANUAL FOR DOSIMETRY AUDITS

D4.4

T4.4

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SUMMARY SHEET

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Summary	Describes the methodology for carrying out dosimetry audits.

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1. Executive Summary

1.1. Context

The CAT-ClinART project, co-funded by the EU4Health programme, aims to enhance the quality and safety of radiotherapy practices in Catalonia. A key aspect of this mission is establishing a robust clinical audit framework based on the QUATRO methodology. Dosimetry audits are a fundamental component of clinical audits in radiotherapy, as they ensure that treatment unit calibrations are traceable to primary dose standards and verify the accuracy of dose delivery in both magnitude and spatial positioning. By identifying potential discrepancies in reference dosimetry and treatment delivery, they play a critical role in maintaining consistency across centres and contribute directly to the overall quality management system in radiotherapy.

1.2. Objectives

The CAT-ClinART project will include dosimetry audit as part of its clinical audit strategy. This deliverable outlines the procedures for conducting these audits, ranging from basic audits under reference conditions to advanced end-to-end audits. It also includes the process for auditing contouring and dose planning in prostate radiotherapy.

The primary objective of this deliverable is to define a consistent approach for conducting dosimetric audits across radiotherapy departments in Catalonia. Specific goals include:

- **Definition of dosimetry audits**. The manual will define two complementary types of dosimetric audit exercises:
    - Planning (or virtual) audits, which assess the accuracy of contouring, prescription and treatment planning. These exercises will be based on provided clinical cases, which include CT and MR images, as well as clinical data
    - Irradiation (or treatment delivery) audits, which will evaluate whether centres can accurately deliver the planned dose, going from reference to advanced end-to-end conditions
- **Standardisation of procedures and tools**. It will include guidance on how to conduct and interpret the results of the audits.
- **Ensuring measurements traceability**. Guidelines will ensure that all dose measurements performed as part of the audits are traceable to national or international standards.
- **Definition of evaluation criteria**. The manual will establish clear action levels and passing criteria for both planning and irradiation audits. By including these components and meeting these objectives, the CAT-ClinART project will enable participating centres to demonstrate compliance with dosimetric quality standards, reinforce the accuracy and safety of radiotherapy delivery and foster a culture of continuous improvement and collaboration across institutions

1.3. Outline

Chapter 1: Executive Summary

Provides an overview of the CAT-ClinART project and the specific role and objectives of dosimetric audits in achieving high-quality radiotherapy care.

Chapter 2: Virtual dosimetry audit

Describes the required materials, methodology, and action levels.

Chapter 3: Treatment delivery audit

Describes the required materials, methodology, and action levels.

2. Virtual dosimetry audit

2.1. Purpose

This audit exercise includes two representative prostate clinical cases: one with curative intent and the other involving post-operative radiotherapy. Each audited centre will contour a set of structures for each case, including organs at risk and treatment volumes. In addition, each centre must provide a treatment prescription for both cases according to its local protocol and prepare the corresponding treatment plan.

This is not a competitive exercise, and there is no gold standard or ground truth, thus precluding direct comparison or ranking. Rather, the aim is to analyse potential variability in contouring, prescription, treatment planning and beam modelling parameters among participating centres.

2.2. Material

The audited centre will use the same Treatment Planning System (TPS) it uses routinely for its own patients, as well as the contouring software employed in daily clinical practice (if contours are not delineated manually). An online survey will also be distributed to the audited centres to gather additional insights and support the overall analysis. The survey will collect relevant information such as local treatment planning system, dose calculation algorithms, and contouring procedures/software. Finally, a generic beam model will be used for part of the data analysis

2.3. Methodology

For each of the two anonymised clinical cases, the audited centre will receive clinical information (unstructured text) and CT and MR images (in DICOM format). Each participating centre must submit to the auditors, for each of the two cases, a set of structures, a treatment plan, and a dose distribution. These must be prepared according to the local protocol, exactly as if the patients were being treated at the centre's own clinic. Detailed instructions will be provided to complete this exercise, including the clinical information for each case.

The submitted contours will be analysed against a reference derived from the combined submissions of all participating centres. The treatment plans and resulting dose distributions will be assessed to evaluate practice variability and the dosimetric impact on the reference contours. Finally, as part of the virtual audit, the treatment plan used for the end-to-end beam delivery audit will be recalculated using a generic beam model to help identify potential dose modelling errors.

At the end of the audit exercise, each centre will receive a report summarising the results, enabling it to compare its performance with that of other centres. Report will be anonymised—each centre will only be able to identify its own data.

The results will be analysed according to the following procedure.

2.3.1. Computation of reference structures

Each structure submitted will be compared against a reference structure created by aggregating all submissions using a consensus approach. Specifically, this consensus segmentation will follow the majority class rule: each voxel is assigned to the structure selected by more than 50% of participants. For example, if a given voxel is included in the rectum by six specialists and excluded by four, that voxel will be included in the consensus rectum structure. If this results in anomalous contours, a subset of experts will be selected to generate these contours.

2.3.2. Evaluation of contours using geometric metrics

The geometric metrics that will be used to compare each centre's structures with the reference structure set are shown in Table 1.

Table 1. Geometric metrics to compare each centre's structures with the reference..

Metric	Type	Measurement	Sensitivity	Clinical Usefulness
DSC (Dice Similarity Coefficient)	Volumetric Overlap	Overlap between two volumes	Size-dependent	Easy to interpret; good overall indicator of overlap
sDSC (Surface Dice, τ = 3 mm)	Surface Agreement	% of contour within 3 mm tolerance	High (to small shifts)	Detects small but clinically relevant surface discrepancies
MDA (Mean Distance to Agreement)	Surface Distance	Mean shortest distance between surfaces	Moderate	Measures average proximity; not symmetric
HD95 (95th Percentile Hausdorff)	Extreme Distance	Robust max distance (ignores outliers)	High	Detects large discrepancies; highlights critical differences
Volume Variation	Volumetric Variation	Relative and absolute volume difference	Size-dependent	Simple volume comparison; good for systematic size evaluation

Where the metrics are defined as:

- **DSC – Dice Similarity Coefficient**

$$DSC = 2 \times |A \cap B| / (|A| + |B|)$$

where $|A|$ and $|B|$ are the voxel sets (in voxels or mm³) of the reference and evaluated contours.

DSC measures the degree of overlap between the reference and evaluated contours. It ranges between 0 (no overlap) to 1 (perfect match).

- **sDSC – Surface Dice with Tolerance (τ = 3 mm)**

$$sDSC_\tau = \frac{|S_A^\tau \cap S_B| + |S_B^\tau \cap S_A|}{|S_A| + |S_B|}$$

where S_A and S_B are contour surfaces, and S_B^τ is the region of S_B within τ mm of S_A.

sDSC is a variation of DSC focused on surface agreement. It introduces a spatial tolerance (typically 3 mm in clinical settings), within which two surface points are considered matching. It indicates the portion of the contour's surface that lies within 3 mm of the reference surface. It ranges between 0 and 1 (best agreement).

- **MDA – Mean Distance to Agreement**

$$MDA = \text{mean}(\text{min distance from each point in } S_A \text{ to } S_B),$$

where S_A and S_B are the surfaces.

MDA measures the average shortest distance between the surfaces of the evaluated and reference contours. Lower values indicate closer agreement. It is useful for detecting minor systematic shifts and is not strongly influenced by outliers. It ranges from 0 (perfect agreement) to ∞ (no proximity).

- **HD95 – 95th Percentile Hausdorff Distance**

$$HD95 = 95\text{th percentile of all point-to-surface distances.}$$

It captures the largest significant deviation between surfaces, excluding outliers. It represents the distance within which 95% of the evaluated contour's surface lies relative to the reference. It ranges from 0 to ∞.

- **Volume Variation**

$$\text{Relative Diff.} = 100 \times (1 - V / Vref)$$

$$\text{Absolute Diff.} = V - Vref$$

where V is the evaluated volume and Vref is the reference volume.

This is a measure of the difference between the evaluated and reference volumes. It ranges from – ∞ to + ∞, with 0 indicating perfect volume agreement.

2.3.3. Evaluation of prescription, treatment plans and dose metrics

Prescriptions for PTVs, dose constraints for organs at risk, and the fractionation schemes will be compared among centres. Treatment plan parameters (i.e., number of arcs, beam energy, modulation factors, and dose calculation settings) will also be compared.

Using the dose distribution provided by the audited centre, dosimetric metrics will be calculated for both the centre's own structures and the consensus reference structures. These results will be compared to assess how contouring variability affects dosimetric outcomes.

The following dosimetric indicators will be evaluated:

- **Homogeneity Index (HI) and Coverage Index (CI)** for the PTVs, defined as:

$$HI = (D2\% - D98\%) / D50\%$$

$$CI = V95\% / (\text{Target Volume})$$

- **Equivalent Uniform Dose (EUD)** for organs at risk. It represents the uniform dose value that would have the same biological effect as the actual inhomogeneous dose. It will be calculated as:

$$EUD = \left(\sum_i v_i D_i^a \right)^{1/a}$$

where:

  - v_i = the fraction of the organ or target volume receiving dose D_i

- D_i = dose to subvolume i (often from a DVH bin)
- α = tissue-specific parameter

2.3.4. Impact of beam modelling parameters on the calculated dose distributions

Atypical beam configuration parameters in the TPS may impact the results of the end-to-end audit exercise. Therefore, a 'virtual' audit exercise is combined with the end-to-end test. Participating centres will report their beam configuration values in the TPS (MLC configuration and source model parameters). Then:

- Plans provided for the end-to-end assessment will be re-calculated using a 'generic' beam model defined with Golden Beam Data for that energy and community values for the MLC configuration. MUs will be rescaled to account for different calibration conditions between local beam model and common beam model using the reference beam conditions calculations with both beam models. The recalculated dose D_{recalc} will then be compared with the submitted dose distribution D_{local}.
- A second recalculation will be obtained with the same generic beam model but with matching MLC configuration parameters $D_{recalc\text{-}MLC}$ to the values reported by the centre. This recalculation separates the effects from the beam model and the MLC configuration.

2.4. Action levels

No tolerances are set for these results. Instead, comparison with results from other centres will help identify variations and support improvements in consistency and quality across participating centres.

3. Treatment delivery audit

3.1. Purpose

The aim of this audit is to verify beam output and beam quality under reference and non-reference conditions. This exercise will also include an end-to-end test, covering imaging, treatment planning, and dose delivery. The aim is to ensure that prescribed doses are delivered as planned.

In particular, the proposed audits include:

- Measurements under reference conditions (audit level I).
- Measurements under non-reference conditions (audit levels II).
- An end-to-end audit (audit level III).

These audits will be performed in all hospitals participating in the consortium and for all photon beams used clinically to treat prostate patients. If a hospital uses twin linacs, only one photon beam from one of them needs to be measured. Optionally, centres may also request to audit additional photon beams if they wish.

3.2. Material

The required materials depend on whether the audit is performed remotely or on-site. The dosimetric equipment for each audit type is shown in Table 2.

Table 2. Equipment for each audit type.

Dosimetry equipment		Audit levels I and II	Audit level III
Detectors	Luminescence dosimeter or ionization chamber + electrometer	√	√
	Radiochromic film + film scanner		√
Phantom	Geometric solid water with inserts for the ionisation chamber or LD, or water tank with holder for the ionisation chamber or LD	√	
	Anthropomorphic with inserts for the detectors		√

Measurements in reference and non-reference conditions will be carried out in a water tank using an appropriate ionisation chamber or luminescent dosimeters (if available). For the end-to-end audit, an anthropomorphic phantom containing both film and an ionisation chamber or LD holder will be provided. This allows simultaneous assessment of dosimetric and spatial accuracy, as well as the verification of planning, alignment, and delivery processes. The phantom will include a structure mimicking a prostate target volume, an organ at risk, and external alignment marks.

Minimum requirements:

- A minimum of two reference ionometric systems (ionisation chamber and electrometer), traceable to a Primary or Secondary Standard Dosimetry Laboratory (PSDL or SSDL) are required for absorbed dose intercomparison measurements.
- A Farmer-type chamber is needed for audits under reference and non-reference conditions, and an ionization chamber with a volume of ≤ 0.125 cc is required for the end-to-end audit.
- The audited institution must provide its own water tank and chamber holder to avoid shipping these items.
- Presence of the audit team during dose measurements. If not present, clear instructions must be provided.

3.3. Methodology

3.3.1. Traceability of the dose measurements

- Ionisation chambers must have been calibrated within the last two years in a Primary or Secondary Standard Dosimetry Laboratory (PSDL or SSDL).
- A designated reference institution will verify the performance of the ionisation chamber between uses by intercomparing the travelling dosimetry system with a system established at the reference centre. This comparison will be carried out under identical conditions, using either with a water tank or solid phantom. Differences between dose responses between the dosimetry system that travels and the one that stays at the reference institution must be less than 1% under the same conditions.

- At least one hospital from the consortium will serve as a reference centre for film dosimetry. The reference centre will generate its own calibration curve and use local protocols to cover doses from 0 to 8 Gy. The system must have passed an external audit or intercomparison before providing audit services. Ideally, a second reference centre with its own calibration curve and software will be available to cross-check results. Both reference centres will intercompare results before starting audits.
- The film dosimetry system must pass at least the following quality assurance checks:
    - Mean dose error of the calibration curve <2%. This is the mean difference between nominal dose of the irradiated film and the dose calculated with the calibration curve of the dosimetry software used.
    - A film irradiated to a known dose of around 6 Gy and a non-exposed film will be scanned with the audited film. Calculated doses must be within 2% for the irradiated film and <0.1 Gy for non-exposed film.
- For luminescence dosimeters, the *Centro Nacional de Dosimetría* (CND) will act as an accredited dosimetry laboratory if its dosimetry system for audits in radiotherapy is ready by the end of the project. LD system calibration will be performed through irradiation of reference dosimeters in a PSDL or SSDL. The system must be re-calibrated at each reading session.

3.3.2. Audits for photon beams in reference and non-reference conditions

This audit exercise includes:

- Measurements under reference conditions (SSD = 90 cm, depth = 10 cm, field size = 10 x 10 cm2) in a water phantom, following the IAEA TRS-398 Code of Practice.
- Measurement of the quality index $TPR_{20,10}$, also according to IAEA TRS-398.
- The following tests will be also measured under the same conditions (SSD = 90 cm, depth = 10 cm, field size = 10 x 10 cm2) in a water phantom with a Farmer chamber's active volume centered at the isocenter and its long axis perpendicular to the leaf motion direction:
    - Transmission for carriages A and B.
    - Sweeping gaps of 5, 10, 20 and 30 mm.
    - Asynchronous sweeping gaps for the 20 mm gap and 's' values of 2, 5, 10 and 20 mm.

  These tests will be distributed in DICOM format to all participants, who will have to import them on the TPS ahead of the audit visit and calculate them with 200 MUs per field.
- These measurements can be conducted on-site with support from local medical physicists, or remotely if LDs are available.

Measurements with an ionization chamber

The auditors, in collaboration with medical physicists from the audited hospital, will complete provided worksheets (e.g. TRS-398 dose determination forms) and apply corrections for daily output variations.

Measurements with a luminescence dosimeter

Absorbed dose can also be determined with mailed luminescence dosimeters and the appropriate holders. LDs will be sent to the hospitals by the dosimetry laboratory with the holders, instructions and data sheets. Centres will irradiate the dosimeters in their own water phantom under reference conditions. Corrections for daily output variations must be applied. The dosimeters will then be returned to the dosimetry laboratory, which will read the luminescent signal and apply relevant corrections. Absorbed dose to water, D_w, will be calculated by the dosimetry laboratory using:

$$D_w = M_{corr} \cdot N \cdot f_{lin} \cdot f_{en} \cdot f_{fad} \cdot f_{hol}$$

Where:

M_{corr} [counts] is the LD corrected response (e.g. background subtraction and re-reading correction if applicable);

N [Gy/counts] is the calibration coefficient system;

f_{lin} is the non-linearity dose-response correction factor;

f_{en} is the energy correction factor;

f_{fad} is the fading correction factor;

f_{hol} is the holder correction factor.

A detailed report will be provided, including combined relative standard uncertainty.

3.3.3. End-to-end dosimetric audit

Preparation of the treatment plan

Prior to the auditors' visit, CT images of the anthropomorphic phantom together with the corresponding structure set will be sent to the audited centre, who will import them into the TPS. The audited centre will then prepare an IMRT-VMAT plan using the centre's standard process and parameters for a prostate treatment (e.g. number of arcs, beam energy, complexity). The dose constraints for one fraction will be:

- PTV: 2.0 Gy prescribed to at least 95% of the PTV volume; 99% to receive at least 93% of the prescription dose; and <5% to receive >105%.
- OAR: a maximum dose will be set, with specific values depending on the phantom used.
- Maximum dose anywhere in the plan: ≤ 2.2 Gy.

CT scan and preparation of the final plan

On the day of the audit, a CT of the phantom will be performed at the audited hospital and imported into the TPS. The structures and treatment plan previously prepared will be transferred and recalculated on the new dataset. Fine adjustments to the dosimetry may then be applied as required.

The electron or mass density (depending on which is used in the dose calculation algorithm) of a reference material within the phantom, as represented in the TPS, will be validated against the reference value provided by the manufacturer.

Pre-treatment QA

Local pre-treatment patient-specific QA checks will be performed according to the local protocol.

Phantom irradiation

The phantom will be set up on the treatment couch using the alignment marks. The plan will be delivered by the staff usually treating patients. Dose from the IGRT irradiation will be neglected.

Three fractions of the IMRT-VMAT treatment plan will be delivered to the phantom. If using an ionisation chamber, it will be pre-irradiated before setting up the phantom, and will be reset after each treatment fraction such that three dose measurements are recorded. LDs (if used) and a radiochromic film will remain in place for all three fractions.

Analyses of the results

The audited centre will submit datasheets provided by the auditors and the axial dose distribution in the film position calculated with the TPS.

The results will be reported as:

- Ratio of the stated dose to the measured dose (with the ionization chamber or LD).
- Gamma analysis between film measurements and the planned dose.

Correction factors may be applied if the audited centre reports dose-to-medium.

3.4. Action levels

Any results outside the action levels below will be reviewed with the local medical physicists. These action levels are referred to the difference between the measured value and the one provided by the audited centre. If necessary, measurements will be repeated to confirm the results.

Action levels for audits in reference and non-reference conditions

- ±3% for D(SSD=90cm, z=10cm, A=10x10cm^2)
- ±4% for $TPR_{20,10}$
- No action levels are set for the transmission and sweeping gaps tests. Instead, results will be compared with those from other centres.

Action levels for the end-to-end audit

- ±3% for the ionisation chamber or LD measurements in homogeneous dose regions (PTV).
- ±5% for the ionisation chamber or LD measurements in the non-homogeneous dose region (organ at risk).
- It is expected that >90% of pixels pass the gamma criterion 5%/2 mm with a 25% low dose threshold. However, other gamma criteria and tolerance levels may be considered based on the results of the uncertainty evaluation and pilot study.
- Dose profiles will be compared to TPS-calculated profiles, without pre-defined action levels.
- ±2% for the relative electron density or mass density in the reference material.