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Interlaboratory comparisons of the physical properties of X-ray systems and display devices in clinical conditions: whether it relates to how well we measure

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Abstract

Introduction: Polish Atomic Law requires that organizations conducting quality control checks on medical radiological equipment must participate in interlaboratory comparisons. Medical physicists who conduct these tests in their hospitals seek to validate their results by participating in interlaboratory comparisons (ILC) at least once every four years.

Material and methods: Comparisons involved measurements of physical parameters for various medical imaging equipment, including a digital X-ray unit, an angiograph, a computed tomography scanner, and a display device used to present medical images. The reference value was defined as the weighted average of the measurements performed by the participants. The En index calculation was used to assess the measurement results of each participant individually.

Results: All laboratories achieved 100% satisfactory results for computed tomography, angiography, and X-ray diagnostics, despite using mostly different research methods and various measuring equipment. During the ILC, we observed discrepancies in the results of Hounsfield Unit (HU) measurements in computed tomography (CT), which were due to the size and position of the region of interest (ROI). Additionally, there were discrepancies in the results of dose measurements in angiography, attributed to factors such as the influence of the patient's table on the measurement and the value of the backscatter factor. As a result, a standard measurement method was established. For display device measurements, two laboratories achieved 100%, two achieved over 94%, and one achieved over 88%.

Conclusions: The goals for conducting comparative research in the field of X-ray diagnostics have been met. The participants' proper use of the measuring equipment has been confirmed, and the suitability of the research methods for the intended purpose has been verified. We identify potential sources of discrepancies during ILC conducted in clinical settings. Selecting the appropriate measurement geometry and testing procedures is crucial for obtaining valuable ILC results.

Keywords: interlaboratory comparison; diagnostic radiology; quality control tests.

Introduction

Polish Atomic Law requirements for bodies performing quality control checks of medical radiological equipment include participation in proficiency testing activities, which is also in line with the ISO/IEC 17025 standard.[1] Physical measurements as a part of quality control testing of medical X-ray units (so-called *constancy tests*, performed every year or *status tests* performed after the maintenance procedures) fall within the scope of the responsibility of a medical physics expert or external testing laboratory accredited by the Polish Centre for Accreditation. Medical physicists willing to perform these tests in their hospitals are seeking confirmation for confidence in their results through participation in the interlaboratory comparison (ILC) at least every four years. ILC means *design, performance and evaluation of measurements or tests on the same or similar items by two or more laboratories in accordance with predetermined conditions (ISO/IEC 17043:2023, definition 3.4)*.[2] As a part of the quality assurance program, ILC is a monitoring tool for the validity of testing procedures and measurement results.

Authors' contribution:
A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of the article.

As well as:

a) checking the correct operation of the measuring equipment used,
b) implementation of an element of the quality assurance program to ensure the quality of test results performed by the laboratory, enabling the identification of problems in laboratories and initiating activities aimed at improving research or measurement procedures, adequate staff training, equipment calibration,
c) identification of differences between laboratories,
d) confirmation of the declared uncertainty,
e) education of participating laboratories is based on comparison results.

Systematic participation in ILC allows monitoring the results of the laboratory's activities over time, improving their quality, confirming the professionalism of the staff and the technical competence of the laboratory, and confirming to customers that the service provided to them is carried out following the principles of good laboratory practice.

Materials and methods

The ILCs were conducted at Leszek Giec Upper-Silesian Medical Centre of the Medical University of Silesia in Katowice in collaboration with the Polish Society of Medical Physics. Comparisons involved measurements of physical parameters for various medical imaging equipment, including a digital X-ray unit (Ysio Max, Siemens), an angiograph (Artis Q Ceiling, Siemens, measurements were made with the X-ray tube positioned above the patient's table), a computed tomography scanner (Somatom Force, Siemens and Optima 540, GE), and a display device used to present medical images (MDNG-3220, Barco).

The tests were performed on April 5 - April 11, 2022 (1st part of ILC, three participants, x-ray unit, angiograph), February 17, 2023 (2nd part of ILC, participant A, measurement of voltage and X-ray tube output in computed tomography), March 31 - April 1, 2023 (2nd part of ILC, four participants, excluding participant A, computed tomography scanner, display device), June 22, 2023 (2nd part of ILC, participant A, display device) and on August 8, 2023 (2nd part of ILC, participant A, $CTDI_{vol}$). All measurements were performed in the presence of independent observers.

Participants measured using their measuring and computational equipment based on their previously developed measurement procedures (e.g. for high voltage, a method based on PPV or kVp, for HVL using Al filter sets and/or using the algorithm available in the measurement meter). Participants confirmed that the equipment they use has valid calibration certificates. The list of equipment used and participation in a specific part of the ILC is provided below (**Table 1**).

The participant's task was to determine the values/parameters described in **Table 2** and **Table 3**.

Method of determining the assigned/reference value

Reference values were determined as the weighted mean of the measurement results received by the organizer and all participants. The inverse squares of the corresponding standard uncertainties were used as weights.[3]

The reference values were calculated from **Equation 1**:

$$y_w = \frac{\sum_{i=1}^{n} \frac{y_i}{u^2(y_i)}}{\sum_{i=1}^{n} \frac{1}{u^2(y_i)}} \quad \text{Eq. 1}$$

the uncertainties of the reference values ($u(y_w)$) were calculated from **Equation 2**:

$$u(y_w) = \sqrt{\frac{1}{\sum_{i=1}^{n} \frac{1}{u^2(y_i)}}} \quad \text{Eq. 2}$$

where:

y_i – result obtained by the i-th participant,

$u(y_i)$ – a value of the standard uncertainty of the i-th participant's result.

The uncertainties of the assessed parameters were determined in accordance with Evaluation of Measurement Data, Guide to the Expression of Uncertainty in Measurement (GUM) JCGM. 100:2008 GUM 1995 with Minor Corrections, Tech. Rep, 2008. Joint Committee for Guides in Metrology.[4]

Then, the obtained uncertainties of participants' measurement results and calculated reference values were expressed as expanded standard uncertainties ($U(y_w)$ and $U(y_i)$) of measurement with a coverage factor k = 2, which corresponds to a confidence level of approximately 95%.

Table 1. List of equipment used in interlaboratory comparisons.

Laboratory	Equipment	ILC part
A	Barracuda (RTI Electronics AB, MPD, DCT 10RS LEMO), LXcan (IBA Dosimetry)	1st, 2nd
B	Piranha BLACK 657 (RTI Electronics AB, DCT10RS, Dose Probe), RaySafe X2 Light Sensor	1st, 2nd
C	Piranha BLACK 657 (RTI Electronics AB, DCT10, Piranha Light Probe)	1st, 2nd
D	CD LUX (Pehamed)	2nd
E	RaySafe X2 (8251010-6 RaySafe X2 Base Unit, 8252010-6 RaySafe X2 R/F Sensor, 8252030-3 RaySafe X2 CT Sensor, 8252040-4 RaySafe X2 Classic Light Detector)	2nd

Table 2. Description of measurement in the in 1st part of the ILC.

Modality	Test	Measurement conditions
X-ray unit	High voltage (HV)	Large focus, current-time product: 10 mAs, exposure time: 100 ms, distance to measurement detector: 100 cm, without additional filtration. Tested voltage values: 50, 81, 121 [kV].
	X-ray tube output (TO)	Large focus, high voltage: 81 kV, current-time product: 10 mAs, exposure time: 100 ms, distance to measurement detector: 100 cm, without additional filtration.
	Half value layer (HVL)	Large focus, high voltage: 81 kV, current-time product: 10 mAs, exposure time: 100 ms, distance to measurement detector: 100 cm, without additional filtration.
	Exposure time (T)	Large focus, high voltage: 81 kV, current-time product: 10 mAs, exposure time: 100 ms, distance to measurement detector: 100 cm, without additional filtration.
	Geometry of the beam field (G)	Participants determined the sum of the distance differences between the edge of the X-ray field and the edge of the image recorder's field of view in the directions of the two main axes of the image recorder for fixed field size.
	X-ray field illumination (Il)	Participants, at a specific point, determined the intensity of a light field simulating an X-ray field. Illuminance has been corrected for background measurement.
	Perpendicularity of the X-ray beam axis	Participants determined the angle of deviation of the X-ray beam axis from the axis perpendicular to the plane of the image recorder derived from the intersection of the light cross.
Angiography	High voltage (HV)	Large focus, tube current: 100 mA, exposure time: 100 ms, distance to measurement detector: 100 cm, without additional filtration. Tested voltage values: angiograph - 50, 81, 121 [kV].
	X-ray tube output (TO)	Large focus, high voltage: 81 kV, tube current: 100 mA, exposure time: 100 ms, distance to measurement detector: 100 cm, without additional filtration.
	Half value layer (HVL)	Large focus, high voltage: 81 kV, tube current: 100 mA, exposure time: 100 ms, distance to measurement detector: 100 cm, without additional filtration.
	Exposure time (T)	Large focus, high voltage: 81 kV, tube current: 100 mA, exposure time: 100 ms, distance to measurement detector: 100 cm, without additional filtration.
	Dose rate at the phantom input surface (DR)	Protocol used in clinical practice (full automatic selection of exposure parameters), using a PMMA phantom (polymethyl methacrylate, transverse dimensions: 30 cm × 30 cm, thickness: 20 cm).
	Input dose per image (ID)	Protocol used in clinical practice (full automatic selection of exposure parameters), using a PMMA phantom (polymethyl methacrylate, transverse dimensions: 30 cm × 30 cm, thickness: 20 cm).

Table 3. Description of measurement in the in 2nd part of the ILC.

Modality	Test	Measurement conditions
CT	High voltage (HV)	Service mode (100 mA, measurement detector in the isocenter of the tomograph). Tested voltage values: 100 kV. Somatom Force CT scanner.
	X-ray tube output (TO)	Service mode (100 mA, 100 kV measuring detector in the isocenter of the tomograph). Somatom Force CT scanner.
	Thickness of the image layer	The layer thickness was measured on previously prepared DICOM images of the Catphan 600 phantom (clinical protocol called Routine Head, high voltage: 140kV, mA selected automatically, thickness of the imaged layer: 2.5 mm). Optima 540 CT scanner.
	Dose index $CTDI_{vol}$	Clinical mode - clinical protocol called HeadSeq (100 kV was used). Somatom Force CT scanner.
	HU value	HU value was measured on previously prepared DICOM images of the Catphan 600 phantom (clinical protocol called Routine Head, high voltage: 140kV, mA selected automatically, thickness of the imaged layer: 2.5 mm). Optima 540 CT scanner. The established sizes and locations of ROIs in material inserts with different densities (**Figure 1**).
	Image uniformity	HU value was measured on previously prepared DICOM images of a GE service phantom (service protocol - high voltage: 120kV, 120 mA, thickness of the imaged layer: 10 mm). Optima 540 CT scanner.
Display device	Luminance	Measurements were performed with test images TG18-LN12 (version 8.0).

Statistical evaluation of results

The participant's result were evaluated based on the PN-EN ISO/IEC 17043:2011 document titled Conformity assessment — General requirements for the competence of proficiency testing providers.[5] For this article, we have confirmed the conformity assessment with the latest edition of these standards.[2]

The calculated E_n index was used to evaluate the participants' individual measurement results. The index was calculated according to the **Equation 3**:

$$E_n = \frac{y_{lab} - y_{ref}}{\sqrt{U_{lab}^2 + U_{ref}^2}} \quad \text{Eq. 3}$$

where:

y_{lab} – result obtained by the participant,

y_{ref} – reference value designated by the organizer,

U_{lab} – expanded uncertainty of the participant's result,

U_{ref} – expanded uncertainty of the reference value assigned by the organizer.

Criteria for assessing results based on the E_n indicator:

$|En| \leq 1.0$ indicates a "satisfactory" result,

$|E_n| > 1.0$ indicates an "unsatisfactory" result.

Results

All laboratories received 100% satisfactory results for computed tomography, angiography, and X-ray diagnostics despite using mostly different (own) research methods and various measuring equipment. During ILC, discrepancies were noticed in the results of HU measurements in computed tomography (the effect of the size and position of the ROI) as well as in the results of dose measurements in angiography (the influence of the patient's table on the measurement, the value of backscatter factor). Therefore, a standard measurement method was established. For display device measurements, two laboratories obtained 100%, two more than 94%, and one more than 88%.

The reference values, expanded uncertainties of reference values, range of En index and range of uncertainties determined by the participants for specific measurement parameters in a specific part of the ILC (1st and 2nd) is provided below (**Tables 4-7**). The following symbols are used in the tables: y_w - reference values, $u(y_w)$ - uncertainty of assigned value, y_i – result obtained by the i-th participant, $u(y_i)$ – value of the standard uncertainty of the i-th participant's result

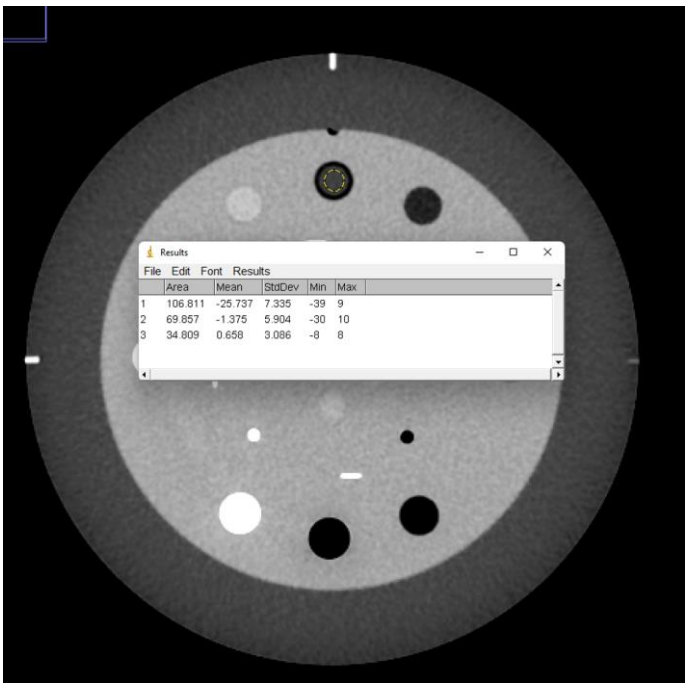

Figure 1. Locations of ROIs in material inserts with different densities for 'HU value' test in CT

Table 4. Reference values, participants' measurement results with expanded standard uncertainties, and the values of the En conformity indexes for measurements of the X-ray unit (1st part of the ILC).

Test	Ref. value	Laboratory A		Laboratory B		Laboratory C	
	$y_w \pm u(y_w)$	$y_i \pm u(y_i)$	E_n	$y_i \pm u(y_i)$	E_n	$y_i \pm u(y_i)$	E_n
High voltage [kV]	49.3 ± 0.5	49.5 ± 0.8	0.19	49.1 ± 0.8	-0.19	49.3 ± 0.9	0.00
	80.9 ± 0.8	80.6 ± 1.2	-0.16	80.8 ± 1.3	-0.03	81.1 ± 1.4	0.17
	121.1 ± 1.1	120.9 ± 1.8	-0.07	120.7 ± 2.0	-0.19	121.7 ± 2.1	0.24
X-ray tube output [µGy/mAs]	58.0 ± 1.7	57.9 ± 2.9	-0.03	57.9 ± 3.1	-0.02	58.2 ± 2.9	0.06
Half value layer [mmAl] - algorithm available in the measurement meter	3.19 ± 0.19	3.19 ± 0.32	0.01	3.18 ± 0.33	-0.02	3.19 ± 0.32	0.00
Exposure time [s]	99.1 ± 0.6	99.3 ± 1.0	0.14	99.0 ± 1.0	-0.11	99.1 ± 1.2	-0.02
Geometry of the beam field - distance measurement [cm]	0.7 ± 0.2	0.8 ± 0.6	0.21	0.8 ± 0.1	0.51	0.4 ± 0.4	-0.57
X-ray field illumination [lx]	318.4 ± 7.2	327.9 ± 6.4	0.99	311.1 ± 11.7	-0.53	308.8 ± 17.0	-0.52
Perpendicularity of the X-ray beam axis [°]	0.3 ± 0.1	0.4 ± 0.1	0.44	0.2 ± 0.3	-0.25	0.3 ± 0.1	0.11

Table 5. Reference values, participants' measurement results with expanded standard uncertainties, and the values of the En conformity indexes for measurements of the angiography unit (1st part of the ILC).

Test	Ref. value	Laboratory A		Laboratory B		Laboratory C	
	$y_w \pm u(y_w)$	$y_i \pm u(y_i)$	E_n	$y_i \pm u(y_i)$	E_n	$y_w \pm u(y_w)$	E_n
High voltage [kV]	49.7 ± 0.5	49.9 ± 0.8	0.25	49.3 ± 0.8	-0.45	49.9 ± 0.9	0.18
	79.8 ± 0.8	79.4 ± 1.2	-0.25	79.9 ± 1.3	0.07	80.0 ± 1.4	0.15
	119.3 ± 1.1	119.5 ± 1.8	0.13	119.0 ± 1.9	-0.13	119.3 ± 2.1	0.01
X-ray tube output [µGy/mAs]	55.3 ± 1.6	55.0 ± 2.8	-0.10	55.5 ± 3.0	0.05	55.5 ± 2.8	0.05
Half value layer [mmAl] - algorithm available in the measurement meter	3.31 ± 0.19	3.32 ± 0.33	0.01	3.32 ± 0.34	0.02	3.30 ± 0.33	-0.04
Half value layer [mmAl] - Al filter sets	3.26 ± 0.15	3.32 ± 0.01	0.40	—	—	3.20 ± 0.30	-0.18
Exposure time [s]	99.9 ± 0.6	100.0 ± 1.0	0.09	99.9 ± 1.0	-0.01	99.8 ± 1.2	-0.08
Dose rate at the phantom input surface [mGy/min]	2.68 ± 0.21	2.80 ± 0.16	0.67	2.53 ± 0.22	-0.61	2.70 ± 0.10	0.16
Input dose per image [mGy/min]	5.72 ± 0.21	5.90 ± 0.29	0.50	5.56 ± 0.48	-0.30	5.70 ± 0.30	-0.05

Table 6. Reference values, participants' measurement results with expanded standard uncertainties, and the values of the En conformity indexes for measurements of the computed tomography (2nd part of the ILC).

Test	Ref. value	Laboratory A		Laboratory B		Laboratory C		Laboratory E	
	$y_w \pm u(y_w)$	$y_i \pm u(y_i)$	E_n	$y_i \pm u(y_i)$	E_n	$y_i \pm u(y_i)$	E_n	$y_i \pm u(y_i)$	E_n
High voltage [kV]	99.3 ± 1.7	99.4 ± 1.5	0.09	99.3 ± 1.6	0.01	97.7 ± 1.7	-0.83	101.3 ± 2.1	0.91
X-ray tube output [µGy/mAs]	111.5 ± 5.2	112.7 ± 5.6	0.14	109.8 ± 5.9	-0.31	110.2 ± 6.4	-0.23	112.9 ± 4.1	0.24
Thickness of the image layer [mm]	2.48 ± 0.04	2.43 ± 0.24	-0.19	2.45 ± 0.13	0.13	2.41 ± -0.39	-0.04	2.48 ± 0.02	0.07
Dose index $CTDI_{vol}$ [mGy]	22.38 ± 0.43	22.36 ± 0.89	-0.02	22.80 ± 1.10	0.36	22.44 ± 0.65	0.08	21.90 ± 1.00	-0.44
HU value [HU]									
Air	-970.34 ± 0.91	-970.27 ± 0.94	0.06	-970.38 ± 0.88	-0.03	-970.45 ± 0.93	-0.08	-970.27 ± 0.91	0.06
PMP	-172.58 ± 0.67	-172.59 ± 0.69	-0.01	-172.46 ± 0.67	0.13	-172.64 ± 0.68	-0.06	-172.63 ± 0.64	-0.05
LDPE	-82.79 ± 0.83	-82.69 ± 0.84	0.08	-82.87 ± 0.80	-0.07	-82.85 ± 0.84	-0.05	-82.74 ± 0.83	0.04
Water	0.66 ± 0.52	0.66 ± 0.53	-0.01	0.66 ± 0.51	0.00	0.67 ± 0.54	0.01	0.66 ± 0.52	0.00
Polystyrene	-28.56 ± 0.89	-28.58 ± 0.89	-0.02	-28.56 ± 0.88	0.00	-28.66 ± 0.92	-0.08	-28.43 ± 0.89	0.10
Acrylic	124.84 ±0.72	124.70 ± 0.76	-0.14	124.79 ± 0.70	-0.06	125.02 ± 0.72	0.17	124.87 ± 0.71	0.02
Delrin	363.12 ± 0.86	363.41 ± 0.84	0.24	363.03 ± 0.87	-0.08	363.04 ± 0.90	-0.07	363.00 ± 0.84	-0.10
Teflon	950.29 ± 0.87	950.12 ± 0.90	-0.14	950.24 ± 0.85	-0.04	950.52 ± 0.88	0.19	950.27 ± 0.84	-0.01
Image uniformity [HU][1]	0.51 ± 0.06	-0.17 ± 4.61	-0.15	0.60 ± 4.60	0.02	0.63 ± 0.37	0.31	0.51 ± 0.06	-0.04

[1] *- HU difference between the center and the edge image (12 o'clock direction)*

Table 7. Reference values, participants' measurement results with expanded standard uncertainties, and the values of the En conformity indexes for measurements of the display device (2nd part of the ILC).

Ln[1]	Ref. value	Laboratory A		Laboratory B		Laboratory C		Laboratory D		Laboratory E	
	$y_w \pm u(y_w)$	$y_i \pm u(y_i)$	E_n	$y_i \pm u(y_i)$	E_n	$y_i \pm u(y_i)$	E_n	$y_i \pm u(y_i)$	E_n	$y_i \pm u(y_i)$	E_n
1	0.46 ± 0.02	0.38 ± 0.04	**-1.66**	0.44 ± 0.02	-0.61	0.44 ± 0.03	-0.59	0.59 ± 0.04	**2.81**	0.47 ± 0.02	0.42
2	1.31± 0.06	1.19 ± 0.14	-0.78	1.25 ± 0.05	-0.72	1.19 ± 0.08	**-1.19**	1.43 ± 0.09	**1.09**	1.38 ± 0.05	0.94
3	2.79 ± 0.13	2.71 ± 0.32	-0.22	2.71 ± 0.12	-0.47	2.58 ± 0.17	-0.97	2.91 ± 0.19	0.54	2.89 ± 0.10	0.64
4	4.97 ± 0.23	4.98 ± 0.58	0.02	4.87 ± 0.21	-0.33	4.61 ± 0.30	-0.96	5.08 ± 0.33	0.28	5.14 ± 0.18	0.59
5	8.22 ± 0.38	8.21 ± 0.96	-0.01	8.10 ± 0.35	-0.24	7.66 ± 0.51	-0.88	8.25 ± 0.53	0.05	8.49 ± 0.30	0.57
6	12.66 ± 0.58	12.58 ± 1.46	-0.05	12.55 ± 0.55	-0.14	11.86 ± 0.78	-0.82	12.43 ± 0.80	-0.23	13.10 ± 0.46	0.59
7	18.75 ± 0.86	18.49 ± 2.15	-0.11	18.60 ± 0.79	-0.13	17.50 ± 1.20	-0.85	18.41 ± 1.18	-0.23	19.40 ± 0.68	0.59
8	26.58 ± 1.24	26.31 ± 3.06	-0.08	26.55 ± 1.14	-0.02	24.60 ± 1.60	-0.98	26.33 ± 1.69	-0.12	27.50 ± 1.00	0.58
9	37.53 ± 1.74	36.85 ± 4.29	-0.15	37.40 ± 1.61	-0.06	35.10 ± 2.30	-0.84	37.27 ± 2.39	-0.09	38.70 ± 1.40	0.52
10	52.41 ± 2.50	51.52 ± 5.99	-0.14	52.20 ± 2.54	-0.06	49.40 ± 3.30	-0.73	52.77 ± 3.38	0.08	53.50 ± 1.90	0.35
11	71.13 ± 3.28	69.62 ± 8.10	-0.17	70.90 ± 3.21	-0.05	66.90 ± 4.40	-0.77	72.11 ± 4.62	0.17	72.50 ± 2.50	0.33
12	95.98 ± 4.46	93.37 ± 10.86	-0.22	95.60 ± 4.34	-0.06	90.30 ± 6.00	-0.76	98.02 ± 6.27	0.26	97.70 ± 3.40	0.31
13	127.02 ± 5.92	123.90 ± 14.41	-0.2	126.0 ± 5.80	-0.12	120.10 ± 7.90	-0.70	131.11 ± 8.39	0.4	129.00 ± 4.50	0.27
14	166.84 ± 7.66	163.20 ± 18.98	-0.18	166.0 ± 7.37	-0.08	156.50 ± 10.00	-0.82	171.44 ± 10.97	0.34	170.00 ± 5.90	0.33
15	217.69 ± 10.08	213.80 ± 24.87	-0.14	216.5 ± 9.77	-0.08	204.00 ± 13.00	-0.83	223.60 ± 14.31	0.34	222.00 ± 7.80	0.34
16	284.38 ± 13.09	279.60 ± 32.52	-0.14	283.5 ± 12.47	-0.05	266.00 ± 18.00	-0.83	291.56 ± 18.66	0.32	289.00 ± 10.00	0.28
17	368.50 ± 16.96	361.90 ± 42.10	-0.15	367.0 ± 16.17	-0.06	345.00 ± 23.00	-0.82	377.51 ± 24.16	0.31	375.00 ± 13.00	0.30
18	474.34 ± 21.92	467.00 ± 54.32	-0.13	473.5 ± 20.83	-0.03	443.00 ± 29.00	-0.86	485.71 ± 31.09	0.30	483.00 ± 17.00	0.31

[1] *- Luminance TG18-LN12-01-18*

Tables 4-7: y_w - reference values, $u(y_w)$ - uncertainty of assigned value, y_i – result obtained by the i-th participant, $u(y_i)$ – value of the standard uncertainty of the i-th participant's result

Discussion

The interlaboratory comparisons for X-ray diagnostics have been successful. The participating laboratories have demonstrated their competence in conducting tests and delivering accurate results. The measurement equipment and methods used by the participants have been confirmed to be appropriate for assessing the physical parameters of radiological devices in X-ray diagnostics. This comparison also allowed the laboratories to monitor their performance against other laboratories, as required by the ISO/IEC 17025 standard (sub-clause 7.7.2). The consistency in measurement and determination of set values has been demonstrated.

The ILC organisers have applied the appropriate requirements of ISO/IEC 17043 *"General requirements for the competence of proficiency testing providers"* standard that are relevant for the assessment of a small ILC (definition of small ILC according to EA-4/21 INF: 2018[6]).

The proper statistical evaluation for a small ILC might be quite challenging, as the number of participants is low, and identification of distribution to detect outliers is difficult, so that derivation of assigned values is important. For this ILC the reference values (assigned values) were determined as the weighted average of the measurements performed by the organizer and all participants where the inverse squares of the corresponding standard uncertainties were used as weights. A weighted average was chosen as the reference value because the measurements were performed by different participants using different tools with varying standard uncertainties. Therefore, a measurement method with higher uncertainty should not have the same impact on the reference value as a method with lower uncertainty. On the day the ILC was conducted, all participants' measuring devices had valid calibration certificates issued by Secondary Standard Laboratories (SSLs). Considering the above and in analogy to key comparisons between the National Metrology Institutes (NMIs), the reference value (assigned value) was determined as a weighted average.[3] Both the assigned value and the reported values have stated uncertainties (estimated in the same way as the expanded uncertainty) and all measurements were performed in one laboratory under the same conditions, thus the En number has been used as a performance scoring (according to ISO/IEC17043 standards). It is important to note that the ILC being discussed took place before the new edition of the ISO/IEC 17043 standard was introduced. As a result, the selection of the En indicator was influenced by a provision in this edition of the standard, which specifies that this indicator should be used when participants assess uncertainty using the same method.[5] The participants are experienced laboratories that, on the regular basis, take part in proficiency testing from the proficiency testing (PT) provider that operates according to ISO/IEC17043 standards and uses the referenced X-ray sources. Also, the equipment used in the described comparisons is regularly calibrated in SSLs. Participants' measurement competencies have been confirmed by the low values of the En index and low assigned uncertainties. The obtained values of the En index were well below 1.0 for most of the tested parameters. The obtained uncertainties for measurements performed with the use of meters were generally below 5%, which confirms the measurement competence and reliability of testing. The documents and recordings related to the organisation of this small ILC were managed in conformity with the ISO/IEC 17025 quality management system of the organiser.[1] Medical physicists who took part in this ILC are competent laboratory personnel authorised to perform this kind of measurement in the field of X-ray diagnostics and interventional radiology. The methods and measurement arrangements used by the participants were documented and assessed. As the lessons learned from the participants' results of different measurement arrangements, changes in the measurement geometry and backscatter corrections are suggested as a recommendation for the organisation of the future ILC. Research has also revealed a significant impact of the size and location of the ROI in the measurement of the HU value for computed tomography (therefore, a standard procedure was established), as well as some discrepancies in the luminance measurements for the lowest values. The greatest differences for the lowest luminance values were observed between the LXcan (IBA Dosimetry) and CD LUX (Pehamed) meters. The CD LUX meter is equipped with a mechanical spacer, so the luminance measurement is performed at a certain distance from the display, and additional ambient light is recorded. In contrast, other meters are applied directly to the display surface, measuring luminance only from the display. This difference in measurement methods explains the significant differences in the measurement results. The literature demonstrates variations in the responses of different luminance meters used for quality control in radiodiagnosis.[7]

Conclusion

The goals set for carrying out comparative research in the field of X-ray diagnostics have been achieved. The correct operation of the measuring equipment used by the participants was confirmed and the adequacy of the relevant research methods for the intended purpose was confirmed.

Possible sources of discrepancies during ILC performed in clinical conditions may be:

– the type of luminance meter (the location of the active area) for measurements of radiology display devices,
– the size and location of the ROI in the measurement of the HU value for computed tomography,
– different measurement arrangements (changes in the measurement geometry) and backscatter corrections in the angiography unit measurement.

Therefore, the proper selection of measurement geometry and testing procedures are important steps on the way to valuable ILC results.

Disclosure of interest

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References

1. EN ISO/IEC 17025:2017. General requirements for the competence of testing and calibration laboratories.
2. ISO/IEC 17043:2023 Conformity assessment — General requirements for the competence of proficiency testing providers.
3. Cox MG, Harris PM. The evaluation of key comparison data using key comparison reference curves. Metrologia 2002;39:589-5–95. https://doi.org/10.1088/0026-1394/39/6/10
4. Working Group 1 of the Joint Committee for Guides in Metrology (JCGM/WG 1). Evaluation of measurement data — Guide to the expression of uncertainty in measurement. Int Organ Stand Geneva ISBN 2008;50:134.
5. PN-EN ISO/IEC 17043:2011 Conformity assessment — General requirements for the competence of proficiency testing providers.
6. EA-4/21 INF: 2018. Guidelines for the assessment of the appropriateness of small interlaboratory comparisons within the process of laboratory accreditation.
7. Garcia I, Navarro M, Macêdo E, Jesus D, Leite H. Response of luminance meters used for radiodiagnostic applications. J Phys Conf Ser 2021;1826(1):012054. https://doi.org/10.1088/1742-6596/1826/1/012054