Current Worldwide Practice in Calibration of Small Leksell Gamma Knife Radiosurgery Fields – Intermediate Results from the International Calibration Survey

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Leksell Gamma Knife

• Leksell Gamma Knife 4C



• Leksell Gamma Knife PERFEXION



Collimator System for LGK 4C

- 4, 8, 14, 18 mm collimators
- Collimator helmets
- 201 Co-60 sources
- Hemispherical source geometry











Collimator System for LGK PERFEXION

- -4, 8, 16 mm collimators
- No collimator helmets
- 192 Co-60 sources
- Cylindrical source geometry









• Largest collimator size 18 mm (LGK B, C, 4C) 16 mm (LGK Perfexion)

• Calibrated ion chamber at the unit center focus point

• All other collimator output values are measured relatively to the largest collimator

• ABS ELEKTA spherical phantom





• ELEKTA solid water spherical phantom



Calibration of the Gamma Knife using a new phantom following the AAPM TG51 and TG21 protocols								
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• Water filled clear urethane plastic phantom (diameter 160 mm) and

AAPM TG 51 protocol



Air kerma based dosimetry calibration for the Leksell Gamma Knife

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• PMMA (acrylic) "Lucy phantom" (diameter 140 mm) and in-air measurement following modified AAPM TG 21 protocol





International Leksell Gamma Knife

Calibration Survey

- To collect information on calibration procedures including protocols, instrumentation (e.g. phantoms, ion chambers and etc.) used and other information related to calibration (e.g. independent verification of calibration, person responsible for calibration and etc.)
- To measure output of the Leksell Gamma Knife unit with alanine dosimetry and compare measured value with treatment planning system value

Goal for this project: survey 100 LGK units worldwide

Leksell Gamma Knife[®] 279 Units installed Worldwide- July 2010



International Leksell Gamma Knife

Calibration Survey

- Cover letter.
- Leksell Gamma Knife Calibration questionnaire.
- Instructions for alanine dosimeter handling and irradiation in the ELEKTA ABS spherical phantom.



International Leksell Gamma Knife

Calibration Survey

- ELEKTA ABS spherical phantom cassette specially adapted for alanine dosimeter. The cassette has hole drilled at its center and small plug to cover inserted alanine dosimeter. Special tool for plug and alanine dosimeter insertion into cassette and also removal from cassette is also included.
- 5 alanine dosimeters. These dosimeters have diameter of 4.8 mm and height of 3.0 mm. All dosimeters are already marked.



Assessment of variation in Elekta[®] plastic spherical-calibration phantom and its impact on the Leksell Gamma Knife[®] calibration Josef Novotny, Jr.^{a)} and Jagdish P. Bhatnagar Department of Radiation Oncology, University of Pittsburgh Cancer Institute, Pittsburgh, Pennsylvania 15213 Hyun-Tai Chung Department of Neurosurgery, Seoul National University College of Medicine, Seoul 110-744, South Korea Jonas Johansson Elekta Instrument AB, Stockholm SE-10393, Sweden Greg Bednarz Department of Radiation Oncology, University of Pittsburgh Cancer Institute, Pittsburgh, Pennsylvania 15213 Liiun Ma Department of Radiation Oncology, University of California, San Francisco, California 94143 M. Saiful Hug Department of Radiation Oncology, University of Pittsburgh Cancer Institute, Pittsburgh, Pennsylvania 15213

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Results: The mean measured deviation in diameter from expected nominal 160 mm for 13 phantoms was 0.51 mm (range of 0.09–1.51 mm). The mean measured phantom mass density for 13 phantoms was 1.066 ± 0.019 g/cm³ (range of 1.046-1.102 g/cm³). The percentage deviation of output for individual phantom from mean of 13 phantom outputs ranged from -0.37% to 0.55% for LGK PerfexionTM. Similarly, the percentage deviation of output for individual phantom from mean of 13 phantom of 13 phantom outputs ranged from -0.72% to 0.47% for LGK 4C.

Conclusions: This study demonstrated that small variations in terms of phantom size and mass density of the phantom material do not have a significant impact on dose-rate measurements of the Leksell Gamma Knife[®]. Also, date of manufacture of the phantom did not show up to be a significant factor in this study. © 2010 American Association of Physicists in Medicine. [DOI: 10.1118/1.3481508]

Leksell Gamma Knife Calibration Questionnaire

Leksell Gamma Knife Model



□ C 1.1 or C 1.2

$\Box 4C$



Protocol used for calibration

□ AAPM TG21

□ AAPM TG51

□ IAEA TRS 277

 \Box IAEA TRS 398

□ OTHER, please specify_

Phantom used for calibration

□ ELEKTA ABS plastic spherical phantom

□ ELEKTA solid water spherical phantom

□ OTHER, please specify _____

Ion chamber used for calibration

□ Manufacturer____

□ Model _____

 \Box Volume [cm3] _____

□ Last date of ion chamber calibration _____

□ Calibration laboratory _____

Leksell Gamma Knife calibration performed by

□ On-site physicist

□ ELEKTA INSTRUMENT, AB physicist

□ Other, please specify _____

Date of LGK calibration

Independent verification of calibration, please

include result if available



□ **RPC** audit

□ IAEA TLD audit

□ National TLD or ion chamber mandatory audit

 \Box OTHER, please specify _

Collimator relative output factors used

- □ ELEKTA default values
- □ Values measured by on-site physicist
- □ Other, please specify_

Alanine dosimeters irradiation

Gamma	Knife	Data

Calibration dose	3.633 Gy/min at 2007-09-20		
Days since calibration at treatment date	623		
Treatment dose rate (2009–06–04)	2.902 Gy/min		
Effective output factors (4, 8, 16)	0.805 0.924 1		
Ring 1 output factors (4, 8, 16)	0.799, 0.957, 0.961		
Ring 2 output factors (4, 8, 16)	0.815, 0.946, 1.000		
Ring 3 output factors (4, 8, 16)	0.792, 0.901, 0.986		
Ring 4 output factors (4, 8, 16)	0.725, 0.808, 0.920		
Ring 5 output factors (4, 8, 16)	0.663, 0.730, 0.851		

Deliver 50.0 Gy













Advantages of alanine dosimetry

- Near water equivalence
- Low energy dependence of the response over a wide energy range
- Small correction factors compared to e.g. TLD
- Low fading
- Non-destructive measurement
- Relatively small dosimeter size



• Can be produced in different shapes and dimensions

Alanine structure

• Alanine is an α -amino acid with the chemical formula $CH_3CH(NH_2)COOH$





Alanine dosimetry

- Paramagnetic centers (molecules or atoms with unpaired electrons) are produced by ionizing radiation
- Created paramagnetic centers are proportional to the absorbed dose
- Concentration of created paramagnetic centers is measured by electron paramagnetic resonance (EPR)
- Irradiated materials are placed in a magnetic field and electron spin transitions are induced by an electromagnetic field of the appropriate frequency (typically GHz range)





NIST evaluation of alanine dosimeters

- Three to five alanine pellets (4.8 mm in diameter and 3.0 mm in height)
- Alanine dosimeters measured with a Bruker ECS106 EPR spectrometer using the protocol described in the NIST Ionizing Radiation Division Quality System Manual

http://www.physics.nist.gov/Divisions/Div846/QualMan/procedures.html



Initial Results

Participation in the project up to date

- North America 18 out of 120(15 %)
- Europe 11 out of 40 (28 %)
- Asia 11 out of 109 (10 %)

Total No. 40 LGK units surveyed Total No. 38 LGK centers participated Total No. 11 countries participated



Calibration protocols used

- AAPM TG 21
- AAPM TG 51
- IAEA TRS 277
- IAEA TRS 398

16 (40.0 %)

2 (5.0 %)

1 (2.5 %)

16 (40.0 %)

• OTHER (NPL Code of Practice)

5 (12.5 %)

Phantoms used for calibration

• ELEKTA ABS spherical phantom 37 (92.5 %)

• ELEKTA solid water phantom

3 (7.5 %)

Ion chambers used for calibration

Ion chamber manufacturer and type	Ion chamber volume [cm ³]	Frequency in this study	
PTW 31010	0.125	16	40.0 %
Exradin A16	0.007	7	17.5 %
Capintec PR-05P	0.070	5	12.5 %
PTW 31006	0.015	3	7.5 %
Exradin A1SL	0.057	3	7.5 %
PTW 31002	0.125	3	7.5 %
Exradin A14SL	0.016	2	5.0 %
Wellhoffer IC-10	0.125	1	2.5 %

Calibration performed by



• OTHER (Consulting physicist) 1 (2.5 %)

Independent verification of calibration

• None

20 (50.0 %)

• RPC

6 (15.0 %)

• National TLD or ion chamber audit 3 (7.5%)

• Other

11 (27.5 %)

Relative output factors used

• ELEKTA default values

40 (100 %)

• Values measured by on-site physicist 0(0%)

North American LGK calibration model



European LGK calibration model







Asian LGK calibration model





Ratio of planned dose to alanine dosimetry measured dose



Plan/Measured Dose Ratio range 0.963 – 1.030

Distribution of deviations worldwide



Mean deviation 0.9 %

Distribution of deviations North America



Mean deviation 0.2 %

Distribution of deviations Europe



Mean deviation 1.7 %

Distribution of deviations Asia



Mean deviation 1.1 %

Conclusions

- It is obvious that different calibration procedures, especially different calibration protocols are used worldwide (North America AAPM TG21, Europe and Asia IAEA TRS398).
- Despite of this heterogeneity in Leksell Gamma Knife calibration procedures, observed deviations between planned and measured dose were of small magnitude with mean value of 1.413 ± 0.962 %. The range of planned to measured dose ratio was 0.963 1.030.
- All surveyed centers at this time are using ELEKTA default values for relative output factors.

Conclusions

- Small systematic deviation in calibration is observed for sites in Europe and Asia where IAEA TRS398 protocol is used.
- Calibration in Europe and Asia is systematically lower by approximately 1.4 %.
- ELEKTA ABS phantom is considered to be a water equivalent when performing calibration in Europe and Asia.

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A few comparisons can be made with the literature. The Gamma Knife manual says that the polystyrene ball underestimates the dose to water by about 1%.³ Our measurements using the A16 ionization chamber indicate that use of the polystyrene ball underestimates the dose compared to water by 0.8%. Therefore, our value agrees with those stated by Elekta to within 0.2%.

No direct comparison of TG51 to TG 21 dose calibration values is available in the literature for the Exradin A16 chamber. We refer, therefore, to the 2002 paper by Taylor

Calibration of the Gamma Knife using a new phantom following the AAPM TG51 and TG21 protocols

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Conclusions

- There is currently no nationally or internationally recognized specific protocol for the Leksell Gamma Knife calibration
- Hopefully new activities related to small field dosimetry will bring standardized procedure also for the Leksell Gamma Knife calibration



Medical Physics Letter

A new formalism for reference dosimetry of small and nonstandard fields

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AAPM TG 178 Gamma Stereotactic Radiosurgery Dosimetry and Quality Assurance

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Future research in alanine dosimetry

• Application of miniature alanine dosimeters in small radiation fields.

Alanine Dosimeters New therapy-optimized prototypes currently being tested. "Commercial" "Prototype" 2 x 2.5 mm 5 x 3 mm A 3 x 3 mm prototype is also available.

Thank You!

