# A Multi-Institutional End-To-End Dosimetry Mail Audit for Orthovoltage Small Animal Irradiators

M. Gronberg[1], R. Tailor[1], S. Smith[1], S. Kry[1], D. Followill[1], S. Stojadinovic[2], J. Niedzielski[1], P. Lindsay[3], S. Krishnan[1], F. Aguirre[1], T. Fujimoto[1], C. Taniguchi[1], R. Howell[1]

1The University of Texas MD Anderson Cancer Center, Houston, Texas
2The University of Texas Southwestern Medical Center, Dallas, Texas
3Princess Margaret Cancer Centre, Toronto, Ontario

JULY 12–16 2020 VIRTUAL JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

## INTRODUCTION

- Preclinical animal studies often directly influence the design of radiation oncology clinical trials for human subjects
- There are currently no standardized methods to ensure reliable dose delivery in small animal irradiators
- A widely available, mail audit independent peer review service can greatly improve dosimetric standardization in preclinical studies, leading to improved clinical trials

## AIM

- Develop a mail audit independent peer review system to verify dose delivery among institutions using X-RAD 225Cx irradiators

## METHODS

**Mouse Phantoms**
- Two mouse phantoms were machined out of high impact polystyrene; one accommodated three thermoluminescent dosimeters (TLD) (Figure 1a) and the other an Exradin A1SL ionization chamber (Figure 1b)

**Dosimeter Characterization and Determination of the TLD Energy Correction Factor in the Mouse Phantom**
- Ionization chamber measurements were taken at the machine isocenter free "in-air" according to TG-61[1] (Figure 2a) and in the mouse phantom on the animal stage (Figure 2b&c) to determine the dose rate in the mouse phantom
- Using the dose rate in the mouse phantom, a known dose was delivered to the TLD mouse phantom (Figure 3)
- The TLD were read, and the energy correction factor was calculated using the TLD dose formula

**Statistical Analysis and Uncertainty**
- An uncertainty analysis for the developed service was computed by means of the TLD dose formula[2]
- This approach takes into account uncertainties in the measured thermoluminescent signal, the system calibration coefficient, and the k-correction factors

**Multi-Institutional Mail Audit Study**
- A feasibility study of the developed service was conducted at our institution
- A mail audit of three outside institutions was performed
- Participating institutions received the TLD mouse phantom, TLDs to be used for acquiring images for treatment planning, and TLDs to be used for delivering the treatment
- Institutions were instructed to deliver 3 Gy to the mouse phantom at 1 cm depth at the isocenter using equally-weighted AP/PA beams using a tube potential of 225 kVp, a current of 13 mA, a focal spot size of 5 mm, and a field size between 20 mm x 20 mm and 100 mm x 100 mm
- Institutions were asked to report their calibration conditions

## RESULTS

**Mouse Phantoms**
- Dimensions based on measurements of 5 C57BL/6J mice at 8, 10, 12 weeks age
- Dimensions
  - Width- 25 mm diameter partial cylinder
  - Height- 20 mm
  - Length- 85 mm

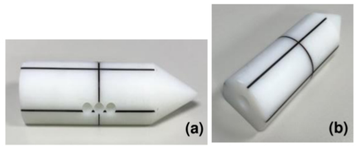


*Figure 1. High-impact polystyrene TLD (a) and ionization chamber (b) mouse phantoms*

**Dosimeter Characterization and Determination of the TLD Energy Correction Factor in the Mouse Phantom**

- The TLD energy correction factor in the mouse phantom was 0.821 ±0.006 for equally-weighted AP/PA beams

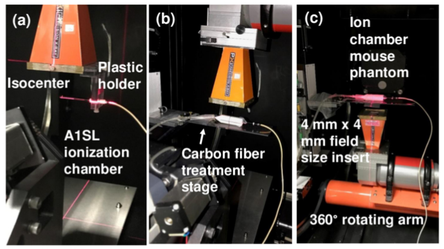


*Figure 2. Photographs of ionization chamber measurements at isocenter (a) in-air, (b) in phantom with AP field orientation, and (c) in phantom with PA field orientation*

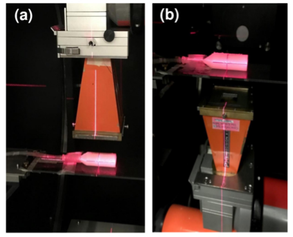


*Figure 3. Experimental setup for delivering a known dose to the TLDs in the mouse phantom using equally weighted (a) AP and (b) PA beams*

Table 1. Measured TLD energy correction factor in the mouse phantom for a combined AP/PA technique

| Irradiation Session | $k_Q$ AP/PA |
|---|---|
| 1 | 0.800 ± 0.008 |
| 2 | 0.830 ± 0.007 |
| 3 | 0.826 ± 0.005 |
| 4 | 0.828 ± 0.001 |
| Average | 0.821 ± 0.006 |

**Statistical Analysis and Uncertainty**
- Uncertainty in $k_Q$ was taken as the standard deviation in the measured values
- All other uncertainties are from TG-191[3]
- Estimated total uncertainty: 2.1%
- Action criterion of 10% selected due to strong dependence of the TLD energy correction factor on the half-value layer in the orthovoltage energy range

Table 2. Uncertainty Budget for the Developed Independent Peer Review System for the X-RAD 225Cx

| Variable | 1-sigma Uncertainty (%) |
|---|---|
| $D_0$ | 0.6 |
| $M_0$ | 0.7 |
| $M_{raw}$ | 1.7 |
| $k_L$ | 0.1 |
| $k_F$ | 0.7 |
| $k_\beta$ | 0.0 |
| $k_Q$ | 0.6 |
| Total (1-sigma) | **2.1** |

**Multi-Institutional Mail Audit Study**
- All institutions passed the mail audit
- Mail audit results agreed much better with the Monte Carlo calculations
- There was variability in reported calibration methodology and conditions

Table 3. Multi-Institutional Mail Audit Results

| Institution | Field Size (mm) | Treatment Planning Calculation Algorithm | Irradiation Time (s) | Specified Dose (Gy) | Measured Dose (Gy) | % diff |
|---|---|---|---|---|---|---|
| MD Anderson | 40 x 40 | Look-up tables | 58.0 | 3.00 | 3.12 | +4.0% |
| A | 20 x 20 | Look-up tables | 58.0 | 3.00 | 2.83 | -5.7% |
| B | 20 x 20 | Look-up tables | 64.0 | 3.00 | 2.79 | -7.0% |
| | | Monte Carlo | 64.0 | 2.83 | 2.81 | -0.7% |
| C | 40 x 40 | Monte Carlo | 68.4 | 3.00 | 3.02 | +0.6% |

Table 4. Reported Calibration Conditions

| Institution | HVL (mm Cu) | Calibration Methodology | Calibration Measurement Field Size (mm) | Backscatter Conditions | Calibration Dose Rate (Gy/min) to water |
|---|---|---|---|---|---|
| MD Anderson | 0.857 | TG-61 | 40 x 40 | TG-61 $B_w$ | 3.72 |
| A | 0.910 | TG-61 | 20 x 20 | 10 mm depth in solid water | 3.10 |
| B | 1.014 | TG-61 | 40 x 40 | TG-61 $B_w$ | 2.99 |
| C | 0.966 | TG-61 | 40 x 40 | TG-61 $B_w$ | 3.26 |

## CONCLUSIONS

- A mail audit small animal orthovoltage dosimetry service between multiple institutions was shown to be feasible
- To our knowledge, this is the first end-to-end (image, plan, treat) dosimetry test of orthovoltage small animal irradiators
- This methodology can be applied to other common irradiators
- A widely available, mail audit independent peer review service has the potential to greatly improve dosimetric standardization in preclinical studies, leading to improved clinical trials

## ACKNOWLEDGEMENTS

We would like to thank the following people for participating in the feasibility study:
- Strahinja Stojadinovic at UT Southwestern Medical Center
- Pat Zanzonico and James Russell at Memorial Sloan Kettering Cancer Center
- Patricia Lindsay and Robert Heaton at Princess Margaret Cancer Centre

We would also like to thank John Costales and Charles Kingsley at UT MD Anderson Cancer Center.

## REFERENCES

1. Ma et al. AAPM protocol for 40 – 300 kV x-ray beam dosimetry in radiotherapy and radiobiology. 2001.
2. Kirby, Hanson, and Johnston. Uncertainty analysis of absorbed dose calculations from thermoluminescence dosimeters. Med Phys 19(6), 1427–1433, 1992
3. Kry, SF et al. AAPM TG 191 Clinical Use of Luminescent Dosimeters: TLDs and OSLDs. Med Phys. 2019
4. Gronberg et al. A Mail Audit Independent Peer Review System for Dosimetry Verification of a Small Animal Irradiator. Radiat Res. 193, 341-350, 2020

## CONTACT INFORMATION

mpeters1@mdanderson.org @MaryGronberg