Measuring radiation dose through the detection of radiation-induced acoustic waves

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Dosimetry in radiation therapy

- Variety of dosimetry techniques and protocols required to ensure patients receive the correct dose in the desired location

- Development of advanced delivery techniques presents a dosimetry challenge

- Novel fast and accurate dosimetry techniques are required
Overview of x-ray acoustic computed tomography (XACT)

- Pulsed photon beam deposits energy
- Acoustic waves generated through thermoacoustic effect
- Acoustic waves detected by ultrasound transducers
- Image of initial pressure distribution reconstructed

Xiang et al., Med Phys 40(1), 2013
Theory: Thermoacoustic effect

- Thermoacoustic wave equation:

\[
\nabla^2 p(r, t) - \frac{1}{v_s^2} \frac{\partial^2}{\partial t^2} p(r, t) = -\frac{\beta}{C_p} \frac{\partial}{\partial t} H(r, t)
\]

- \( p \) = Pressure
- \( v_s \) = Speed of sound
- \( \beta \) = Isobaric expansion coefficient
- \( C_p \) = Specific heat capacity
- \( H \) = Heat energy
- \( \Gamma \) = Grüneisen coefficient
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• Initial pressure distribution

$$p(\mathbf{r})|_{t=0} = H(\mathbf{r}) \cdot \Gamma(r)$$

where

$$\Gamma = \frac{v_s^2 \beta}{C_p}$$

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- Initial pressure distribution
  \[ p(\mathbf{r})|_{t=0} = H(\mathbf{r}) \cdot \Gamma(\mathbf{r}) \]

- Relating pressure to dose
  \[ p(\mathbf{r}) = D(\mathbf{r}) \cdot \rho(\mathbf{r}) \cdot \Gamma(\mathbf{r}) \]

Terms:
- \( p = \) Pressure
- \( v_s = \) Speed of sound
- \( \beta = \) Isobaric expansion coefficient
- \( C_p = \) Specific heat capacity
- \( H = \) Heat energy
- \( \Gamma = \) Grüneisen coefficient
Project objective

- Previous work has demonstrated feasibility of using XACT as a dosimetry tool through simulations
- Experimental work has been limited to irradiation of metal blocks
- Present work aims to demonstrate ability of XACT to act as a relative dosimetry technique in water
Experimental set-up

Beam’s eye view

- Primary field
- Transducer
- Preamplifier
- Oscilloscope

Transducer

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Radiation parameters

- 10 MV flattening filter free photon beam produced by clinical radiotherapy linac (Varian TrueBeam)

- At 10 cm depth (imaging plane):
  - Dose per pulse = 0.77 mGy
  - Temperature increase per pulse = 185 nK

- Pulse repetition frequency = 180 Hz

- Pulse length = 4 μs
Typical transducer signal

Transducer

11.5 cm

4.4 cm
Typical transducer signal

Transducer

11.5 cm

4.4 cm
Imaging parameters

- Signals acquired at 60 angles
- Image reconstructed from sinogram using back projection algorithm
- XACT images are relative dose images
Simple field: Dose comparison

XACT

Film

Percent difference map

[a.u.]

Introduction · Methods · Results · Conclusion
Simple field: Dose comparison

Percent difference map

XACT

Film

Root mean square error = 12.2%
Resolution test: XACT image

Field diagram

- 2.5 mm gap
- 6 cm
- 3 cm

XACT image

[a.u.]
Resolution test: Dose comparison

XACT image

Extracted profiles
MLC field: Dose comparison

XACT image

Extracted profiles

Root mean square error = 13%
Complex field: XACT image

Field diagram

XACT image

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Complex field: Dose comparison

XACT image

Extracted profiles

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Complex field: Dose comparison

XACT image

Extracted profiles

Root mean square error = 10.9%
Outlook: XACT as a dosimeter

- **Motivation for XACT dosimetry:**
  - Real-time
  - Volumetric
  - No beam perturbation
  - Energy independent
  - Potential to combine with ultrasound imaging

- **Future potential applications:**
  - 3D dose mapping
  - Small field dosimetry
  - *In vivo* dosimetry
  - Absolute dosimetry
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