GAMMA KNIFE: TREATMENT PLATFORM, QA, AND TREATMENT UNCERTAINTY

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DISCLOSURES

- No conflicts of interest to disclose
**OUTLINE**

- Calibration and commissioning
- Treatment prep and image acquisition
  - How do I determine imaging modality?
  - What potential sources of error arise due to imaging?
- Treatment planning and delivery
- QA
- Sources of uncertainty
- Gamma Knife ICON
- SAMS

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**Gamma Knife Program**

- 1st GK patient treated January 2010
- 2 physicists, 2 neurosurgeons (1 primary), 4 radiation oncologists (1 primary)
- Source reload August 2014
**Gamma Knife Program**

- Over 1500 treatments provided to date
- 273 in 2016
- Wide range of indications
  - Metastatic disease
  - Surgical cavity
  - Primary malignant brain tumor
  - Acoustic neuroma
  - Meningioma
  - Trigeminal neuralgia
  - AVM
  - Glomus tumor
  - Essential tremor

**Calibration and Commissioning**

- Single output measurement required for commissioning!
- No clear guidelines on calibration methodology
- McDonald et al in Med Phys: *Calibration of the Gamma Knife Perfexion using TG-21 and the Solid Water Leksell Dosimetry Phantom*
  - TG-21 using solid water phantom + A14SL ionization chamber
- Verify Monte-Carlo-based output factors
TREATMENT PREPARATION

- Stereotactic frame-based system
- Neurosurgeon positions frame on morning of treatment
- Patient receives:
  - MRI and/or
  - CT and/or
  - Angiogram (AVM only)
- Each imaging modality has dedicated localizer
- At MUSC 90% of patients receive MRI only
- Typical sequences
  - T1 volume scan w/ gado (1mm slice)
  - T2 Drive (0.7mm slice)
  - Time-of-flight (0.7mm slice)

IMAGING AND LOCALIZATION

- Consider inherent MR distortion
  - Gradient non-linearity largest cause
  - Increases with distance from imaging center
  - Ensure vendor distortion correction is activated
    - Beware of outside MRs
  - Standard diagnostic QA/PMs may not be sufficient
    - ACR requires ± 2mm
  - Dedicated phantoms available to help quantify MR distortion
    - Pictured – Modus Medical Quasar Grid3D™
MR distortion due to Leksell frame

- E P Pappas in Physics in Med and Bio: *Characterization of system-related geometric distortions in MR images employed in Gamma Knife radiosurgery applications*
  - GK frame base can introduce additional MR distortion
  - Up to 5mm adjacent to frame base
  - Distortion decreases with distance from frame base
  - Frame related distortion eliminated 9cm superior to base
  - Distortion reduced at center of coordinate space

Consider registration accuracy

- Kenneth Ulin in Int. Journal of Rad Onc Bio Phys: *Results of a Multi-Institutional Benchmark Test for Cranial CT/MR Image Registration*
  - Graph result of benchmark study of CT/MRI cranial rigid registration
  - Average error found to be 1.8mm
  - Manual registration found to be more accurate than automatic

- MR distortion affects registration accuracy
IMAGING AND LOCALIZATION

- Consider GK skull measurement
  - “Bubble measurement” external contour
    - Generated by model
    - Fails to capture extreme/unusual head shapes
    - Fails to accurately represent surface below the cerebellum
    - Historically sufficient for older-model GKS
  - CT-based external contour
    - More accurate
    - Requires day-of-tx CT
    - Can represent surface below the cerebellum
- Patient anatomy and target location dictate need for CT-based contour

TREATMENT PLANNING

- MUSC procedure
  - Physicist imports and prepares images for planning
    - Definition of in-frame images
    - Registration of out-of-frame images
    - Creation of external (“skull”) contour
  - Neurosurgeon reviews registrations, contours tumor volumes and OARs
  - Physicist creates treatment plan
  - Radiation Oncologist determines prescription, reviews and approves plan
TREATMENT PLANNING

- Plans created by placing “shots”
- Each “shot” consists of:
  - Table position
  - Collimator selection
  - Weighting (time)
- 192 sources divided onto 8 movable plates
- Each plate can be positioned over the 4, 8, or 16mm collimator, or blocked completely
- Plates positioned independently (4^8 possible patterns per shot!)
- 3 head tilt positions (Gamma Angles) available
  - 70 (chin back), 90 (neutral), 110 (chin down)

TREATMENT DELIVERY

- Patient docked to treatment couch
- Treatment couch moves patient around fixed isocenter to create desired dose distribution
- Source plates simultaneously move 192 Co-60 sources over desired collimators
MACHİNE SPECIFICATIONS

- Available collimator sizes
  - 4, 8, 16mm – 8 independent source plates
- Radiological accuracy
  - <0.25mm
- Positioning accuracy
  - <0.20mm
- Number of radiation sources
  - 192
- Total activity at loading
  - 5100-6300Ci
- Max dose rate (16mm coll) at loading
  - >3Gy/min
- Treatment timer accuracy
  - <0.2%
- Couch weight limit
  - 500lbs

QUALİTY ASSURANCE

- Daily QA
  - Focus precision
    - Verification of radiation isocenter vs couch position
    - Automatic routine
    - Diode detector mounted to couch using clinical frame adapter
    - 4mm collimator used
    - 0.1mm tolerance
  - Emergency alarm
  - AV
  - Gamma angle sensor
  - Radiation survey
  - Interlocks (Door, Lt and Rt patient protection, frame docked)
  - Pause, emergency stop, door open
  - Radiation monitor and warning lights
QUALITY ASSURANCE

Monthly QA
- All daily checks +
- Ion-chamber output check
  - GK solid water phantom
  - A14SL ion-chamber
- Timer check

Annual QA
- All daily and monthly checks +
- Output factor verification
- Radiation isocenter centricity
  - $X$, $Y$, and $Z$ directions
- Radiation profile vs baseline for each collimator
- All tests utilize Gafchromic film

**Isocenter Centricity Check 16mm**

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## Profile Comparison

- Annual vs Baseline

## Treatment Uncertainties

- **Mechanical performance of treatment unit**
  - Daily verification of radiation iso vs couch position
  - Couch position sensors stop tx at >0.1mm deviation
  - Plate motion and collimator design minimize opportunity for wear and error
  - Positioning accuracy guaranteed through service contract and verified during bi-annual PM
  - Novotny et al in Med Phys: *Long-term stability of the Leksell Gamma Knife® Perfexion™ patient positioning system (PPS).*
    - Measurements collected over 4 years
    - Average deviations 0.1mm or less
TREATMENT UNCERTAINTIES

- **Frame integrity**
  - Once images are obtained, frame placement is assumed to be invariant
  - Improper frame placement could lead to frame shift which may not be caught prior to treatment
  - **Experienced neurosurgeon extremely important**
    - Frame assembly
    - Frame position
    - Pin entry angle
    - Pin pressure
    - Patient history
  - If in doubt – re-image!

- **Uncertainty due to image distortion or registration**
  - MR distortion always present
    - Increases with distance from imaging isocenter
    - Increased near GK frame
  - CT/MR registration introduces error
    - Carefully verify automatic registration results
    - Consider MR distortion during registration
      - Avoid focusing on areas of known MR distortion
GAMMA KNIFE ICON

- Newest Gamma Knife platform
- Perfexion body with added CBCT
- Includes infrared tracking for frameless treatment
- May:
  - Expand GK use to include more fractionated treatments due to frameless tracking
  - Allow for quick verification of frame integrity prior to treatment for traditional patients
  - Track frame integrity throughout treatment with infrared system

REFERENCES

SAM QUESTION 1

Uncertainty during treatment on the Gamma Knife Perfexion is predominantly due to:

- Mechanical performance of the treatment machine
- MLC positioning error
- Frame integrity and planning image registrations and distortions
- Machine output fluctuation

References

**SAM QUESTION 2**

- **MR Distortion Due to the GK Frame Base is:**
  - Minimal compared to distortion already inherent in MR imaging
  - Significant adjacent to the frame base, decreasing as distance from the frame base increases
  - Corrected during the localization process
  - Minimal compared to mechanical uncertainty of the treatment unit

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**SAM QUESTION 2**

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**References**