Clinical Implementation of the TG-51 Protocol

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Educational Objectives

- Improve your understanding of how to implement TG-51 to determine the dose accurately.
- Provide details on how to make your job easier to yield accurate doses from TG-51.
- Reduce the possibility of errors in beam calibrations.
Current Implementation Status

TOTAL 1494 of 1623 ACTIVE INSTITUTIONS (92%)

Only 8% to go
What’s the Holdup?

- New Air Kerma standard
  - TG-51 ≈ TG-21 depending on the chamber
- Time and effort required (everyone is very busy)
- New equipment requirements (chambers and phantoms)
New Protocols and Havoc

BEAM CALIBRATION
RPC Onsite Visits

Photons
Electrons
TG-21 Implementation
TG-51 Implementation

Percent within 3% Criterion

YEAR

Why the problems?

- Most modern accelerators/beam energy combinations have the same dosimetry parameters
- The one parameter that changes with time and is subject to human intervention is beam calibration
  - Training
  - Protocol interpretation/misunderstandings
  - Lack of practice (once a year)
Equipment Needs

- Properly sized “liquid” water phantom (30x30x30 cm³)
  - Don’t use the scanning tank
  - Adequate scatter conditions
  - Easy reproducible setup
Chamber Holder and Positioner

- **Holder**
  - Versatile to hold different chambers
  - Rigid (sensitive volume parallel to water surface)
  - No lateral displacement with depth
  - Accurate sub-millimeter placement at any depth
  - Verify accuracy prior to initial use
  - Remote electronic control is nice
Ion Chambers

- TG-51 ion chambers vs NEW ion chambers
  - Most are similar in design but now waterproof
    1. Wall material
    2. Radius of air cavity
    3. Presence of Al electrode
    4. Wall thickness
  - AAPM working group to determine the $k_Q$, $k_{R50}$, $k_{ecal}$ for new chambers
Ion Chambers - Photons

- **ADCL calibrated 0.6 cm³**
  - Smaller volume chambers (> 0.1 cm³) okay if traceable to another 0.6 cm³
  - **NO parallel plate chambers**
  - Waterproof (Go ahead and get one)
    - Most common: Exradin A12, PTW 30013
  - Non waterproof needs a 1mm PMMA sleeve that does not leak!
Ion Chambers - Electrons

- Parallel-plate or cylindrical chambers okay
  - Cylindrical for energies > 6 MeV per protocol \((R_{50} \geq 2.6 \text{ cm})\)
  - Cylindrical = parallel plate if care in placement

<table>
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<th></th>
<th>P11</th>
<th>PTW Roos</th>
<th>Welhoffer Roos</th>
<th>Marcus</th>
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<td>6</td>
<td>1.002 ± 0.1% (n=3)</td>
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<td>0.996 ± 0.3% (n=2)</td>
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<td>9</td>
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<td>0.998 (n=1)</td>
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<td>1.000 (n=1)</td>
<td>1.000 ± 0.1% (n=2)</td>
<td>1.000 (n=1)</td>
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- Always use a parallel plate chamber for 4 MeV beams
- Caution as to where the inside surface of the front window is located
Ion Chambers - Electrons

- All chambers must have an ADCL calibration coefficient EXCEPT PARALLEL PLATE CHAMBERS

  - AAPM recommendation is to cross calibrate parallel plate chamber with cylindrical chamber in a high energy electron beam (worksheet C *a la* TG-39)

  - ADCL $N_{D,w}$ – **good**   TG-51 $k_{ecal}$ – **bad**

  - Use of $(N_{D,w} \cdot k_{ecal})$ results in an error of 1-2%

  - ONE EXCEPTION – Exradin P11 seems to be okay

  - AAPM working group determining new $k_{ecal}$ values
Measurement Techniques

- Accurate placement of cylindrical ion chamber at depth
  - Whether manual or electronic motor driven there must be a starting reference point

Two techniques

1. Surface method
2. “Cowboy” method

- Accuracy depends on cutting ruler
- Used for reference starting point
- Periodic check of depth

Cut ruler down to minimize surface area
U-shape plastic attached flush with end of ruler
Weights
Ion chamber
Cut ruler by the chamber radius and wall thickness
Measurement Techniques

- Parallel plate ion chambers
  1. Flat surface makes it easy to measure depth
  2. Accurate ruler needed
  3. Must know where the inside surface of the front window is located

**Spokas Parallel Plate Chamber**
*Model A11, P11 or T11*

- Collecting Volume: 0.8 cc
- Nominal Calibration Factor: 5.5 R/nC (TG-21)
- Nominal Calibration Factor: 48.3 Gy/μC (Air Kerma)

**Centroid of Collecting Volume:** 2.0 mm from window surface
**Collector Diameter:** 20.0 mm
**Window-Collector Gap:** 2.0 mm
**Window Thickness:** 1.0 mm
**Window, Collector and Guard Material:**
  - A11 – CS52 Styrofoam air-equivalent plastic
  - P11 – D400 pc
  - T11 – A150 Sh
  - Stem: 11.1 mm OD cm long; removable
  - Waterproof: Yes, a
  - Venting: Through T body and running th inside tubing.
  - Buildup Caps Avai chamber window

- Model 11
Effective Point of Measurement and Beam Quality

**Photons**

- **10 cm** calibration depth

“point of measurement” is the center electrode of a cylindrical chamber and the front window of a parallel plate chamber

- \(\%dd(10)_x\) beam quality

**Electrons**

- \(d_{ref}\)

Beam quality should always be measured using the “effective point of measurement”

- \(0.6r_{cav}\) shift to effective point
- **100 cm** beam quality SSD
- \(R_{50}\)
- **10 x 10 cm\(^2\)** field size

- \(0.5r_{cav}\)
- **100 cm**

\(\geq 10 \times 10 \text{ cm}^2\)
Effective Point of Measurement

Water surface

Effective depth

Physical depth

Cylindrical

Parallel plate
“Get the lead out”

- Photon beams ($\geq 10$ MV)
  - Lead sheet 1 mm $\pm$ 0.2 mm
  - 30 or 50 cm from phantom surface
  - Determine $\%dd(10)_{Pb}$ (percent values not fractional)
    - $\%dd(10)_x$ should be within 2.5% of $\%dd(10)_{Pb}$

- Interim alternative (No Lead Sheet)
  - Measure $\%dd(10)$ without lead and use TG-51 eq 15
  - Introduces only 0.1-0.2% error in $k_Q$
  - Saves time and minimizes chance of damage to chamber
Beam Quality Conversion Factors

- Photons
- Tabular values much easier to read
- My favorite part
- Figures have a great deal of overlay
- For spreadsheets plot the tabular data
- Be sure to have an independent check
Beam Quality Conversion Factors

- Electrons

Only small figures, no tables

Good figures at:

Beam Quality Conversion Factors

- Electrons – 4 MeV beams ($R_{50} < 2.0$ cm)
  - Only use parallel plate chamber
  - Need to extrapolate curve

- Equation good down to 1 cm
Charge Measurements

\[ M = P_{ion} \cdot P_{TP} \cdot P_{elec} \cdot P_{pol} \cdot M_{raw} \]

- \( P_{TP} \) correction factor
  - Mercury thermometers and barometers most accurate
    (but they are no longer kosher)
  - Hg barometers T&G corrections needed
  - Quality aneroid or digital can be used
    - Check annually against a standard
    - Digital purchased with a calibration does not mean accurate
      but rather what it read at certain pressures or temperatures
Charge Measurements

- **$P_{\text{elec}}$** correction factor
  - ADCL calibration for each scale needed

- **$P_{\text{pol}}$** correction factor
  - Change polarity requires irradiation (600 to 800 cGy) to re-equilibrate chamber
  - Use of eq 9 in TG-51 requires that you preserve the sign of the reading or
  
  \[
  P_{\text{pol}} = \frac{|M_{\text{raw}}^+| + |M_{\text{raw}}^-|}{2|M_{\text{raw}}|}
  \]
  - $P_{\text{pol}}$ should be near unity for cylindrical chambers and slightly larger correction for parallel plate chambers
Charge Measurements

Monitor's drift due to Ktp & machine fluctuation
(All other chamber data are norm to monitor)
Charge Measurements

- $P_{\text{ion}}$ correction factor
  - Use eqs. 11 and 12 to calculate $P_{\text{ion}}$
  - As a check if using $V_H/V_L = 2$ (within 0.1%)
    - Pulsed beam: $P_{\text{ion}} = \frac{M_H}{M_L}$ if $M_H/M_L < 1.02$
    - Continuous beam: $P_{\text{ion}} = \{(M_H/M_L - 1)/3\} + 1$

$P_{\text{ion}}$ depends on chamber, beam energy, linac and beam modality
  - Tends to increase with energy
Electron beam gradient \((P_{gr})\) correction factor

- No correction for photon beams since correction included in \(k_Q\)
- Only for cylindrical ion chambers
- Ratio of readings at two depths

\[
P_{gr} = \frac{M(d_{ref} + 0.5r_{cav})}{M_{raw}(d_{ref})}
\]

The reading at \(d_{ref} + 0.5r_{cav}\) should have the same precision as the reading at \(d_{ref}\) since:

\[
\text{Dose} = M(d_{ref}) \cdot \text{(many factors)} \cdot \frac{M(d_{ref} + 0.5r_{cav})}{M(d_{ref})}
\]
Charge Measurements

- Electron beam gradient ($P_{gr}$) correction factor
  - $E < 12$ MeV; $P_{gr} > 1.000$
  - $E \geq 12$ MeV; $P_{gr} \leq 1.000$
  - Why? Because for low electron energies $d_{ref} = d_{max}$ and this places the eff. pt. of measurement in the buildup region thus a ratio of readings greater than 1.000.
  - At higher electron energies $d_{ref}$ is greater than $d_{max}$ and as such the eff. Pt. of measurement is on the descending portion of the depth dose curve thus a ratio of readings less than 1.000.
Charge Measurements

Physical depth

Effective depth

\[ \text{Effective depth} = \frac{M(d_{\text{ref}} + 0.5r_{\text{cav}})}{M_{\text{raw}}(d_{\text{ref}})} \]
Charge Measurements

Physical depth

Effective depth

\[ \frac{M(d_{\text{ref}} + 0.5r_{\text{cav}})}{M_{\text{raw}}(d_{\text{ref}})} \]
Clinical Depth Dose

- Always measured using the effective point of measurement
  - Re-measurement not suggested for existing Linacs
  - New Linacs or beams should incorporate shift
- Always use the clinical depth dose to make the correction from the calibration depth to the reference depth
  - Measurement at depth will always equal calculation at the same depth (use same data to go to d_{max} as is used to go back down to reference depth)
%dd(10)_x = 67.0%
Annual QA %dd_{10} = 67.4%
TPS %dd_{10} = 66.6% (mu calc)
Clinical Depth Dose

- For photons – do not use the beam quality value \( \%dd(10)_x \) to take dose from 10 cm to \( d_{\text{max}} \)

- For electrons – depth dose correction for \( \geq 16 \) MeV is significant (\(~98.5\% - 16 \text{ MeV} \) and \(~95.5\% - 20 \text{ MeV}\))

  - Caution!!! Super big problem if you use \% depth ionization data (3-5\% error for high energy electron beams)
Summary

- Implementation is straightforward
  - Must read the protocol and follow the prescriptive steps
  - Many suggestions to clarify confusion have been made
  - RPC will assist you and answer questions

- Differences between TG-51 and other protocols such as TG-21 and TRS 398 are minimal.