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Type Testing Validation of Dose Calculation Accuracy for Intensity-Modulated Proton Therapy (IMPT) for a newly developed Treatment Planning System CuraProton

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ABSTRACT

Objective: To validate the accuracy of CuraProton, a domestically developed proton therapy treatment planning system (TPS), through comprehensive type testing of central axis depth dose distributions and transverse dose profiles across multiple clinically complex scenarios, in strict compliance with the Chinese medical device industry standard YY/T 1905-2023 Requirements for Calculation Accuracy of Planned Dose in Light Ion Beam Radiotherapy.

Methods: Three phantom configurations representing various clinical complexity were evaluated: R14M10FS10 and R33M10FS10 in solid water phantoms (simple cases), R20M10FS10 in a double-wedge phantom (moderate complexity), and R15M10FS10 in an anthropomorphic head phantom (high complexity). Test plans generated by a newly developed CuraProton TPS and were transferred to and delivered on the ProBeam® (Varian Medical Systems) proton therapy system at our center. Dosimetric validation was performed by measuring depth dose distributions with a PPC05 ionization chamber along the beam central axis (CAX) and acquiring transverse dose profiles using an IBA Matrixx PT 2D detector array at the center plane of the spread-out Bragg peak (SOBP).

Results: CuraProton TPS demonstrated high dosimetric accuracy across all test cases, meeting YY/T 1905-2023 requirements. For depth dose distributions, absolute dose deviations were within ±1.8% in the entrance region, ±2.0% in the high-dose plateau region,±1.2% in the out-of-field region， and ±5.0% in the proximal and distal fall-off regions. For transverse dose profiles, deviations were within ±1.8% in the high-dose plateau, ±1.2% in the out-of-field region， and ±8.7% in the penumbra,. All measured dose deviations in the proximal and distal fall-off regions and penumbra regions fully complied with the scenario-adaptive tolerance criteria stipulated in YY/T 1905-2023：
deviations within±10% for simple scenarios and ±15% for medium/complex scenarios.

Conclusion: The rigorously validated results demonstrated that the new TPS CuraProton is in full compliance with YY/T 1905-2023 standards with adequate dose calculation accuracy. It establishes a solid foundation for the subsequent clinical trials of the CuraProton system in China.

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INTRODUCTION

The development of a newly proton therapy TPS is driven by urgent necessity:

1. **Economic Accessibility**: Mainstream imported TPS platforms (e.g., RayStation, Eclipse, Pinnacle) incur prohibitive acquisition and maintenance costs, creating a significant financial barrier for widespread clinical implementation.
2. **Optimization Efficiency**: Existing commercial systems often exhibit limitations in optimization algorithms and computational efficiency, leaving substantial room for improvement in plan quality and workflow speed.
3. **Technological Adaptability**: The emergence of advanced delivery techniques—specifically Pencil Beam Scanning (PBS) IMPT, Proton Arc Therapy, and FLASH radiotherapy—has outpaced the development capabilities of legacy systems.

To validate the accuracy of CuraProton, a domestically developed proton therapy treatment planning system (TPS), through comprehensive type testing of central axis depth dose distributions and transverse dose profiles across multiple clinically complex scenarios, in strict compliance with the Chinese medical device industry standard YY/T 1905-2023 requirements for Calculation Accuracy of Planned .

METHODS AND MATERIALS

- Three phantom configurations representing various clinical complexity were evaluated:
  1. **Simple cases**: R14M10FS10 and R33M10FS10 in solid water phantoms
  2. **Moderate complexity**: R20M10FS10 in a double-wedge phantom
  3. **High complexity**: R15M10FS10 in an anthropomorphic head phantom.
- Test plans generated by CuraProton TPS and were transferred to and delivered on the ProBeam® proton therapy system (Varian Medical Systems) at our center.
- Dosimetric validation was performed by measuring depth dose distributions with a PPC05 ionization chamber along the beam central axis (CAX) and acquiring transverse dose profiles using an IBA Matrixx PT 2D detector array at the center plane of the spread-out Bragg peak (SOBP).

RESULTS

- CuraProton TPS demonstrated high dosimetric accuracy across all test cases, meeting YY/T 1905-2023 requirements.
- For depth dose distributions, absolute dose deviations were within ±1.8% in the entrance region, ±2.0% in the high-dose plateau region,±1.2% in the out-of-field region， and ±5.0% in the proximal and distal fall-off regions.
- For transverse dose profiles, deviations were within ±1.8% in the high-dose plateau, ±1.2% in the out-of-field region， and ±8.7% in the penumbra.
- All measured dose deviations in the proximal and distal fall-off regions and penumbra regions fully complied with the scenario-adaptive tolerance criteria stipulated in YY/T 1905-2023： deviations within±10% for simple scenarios and ±15% for medium/complex scenarios.

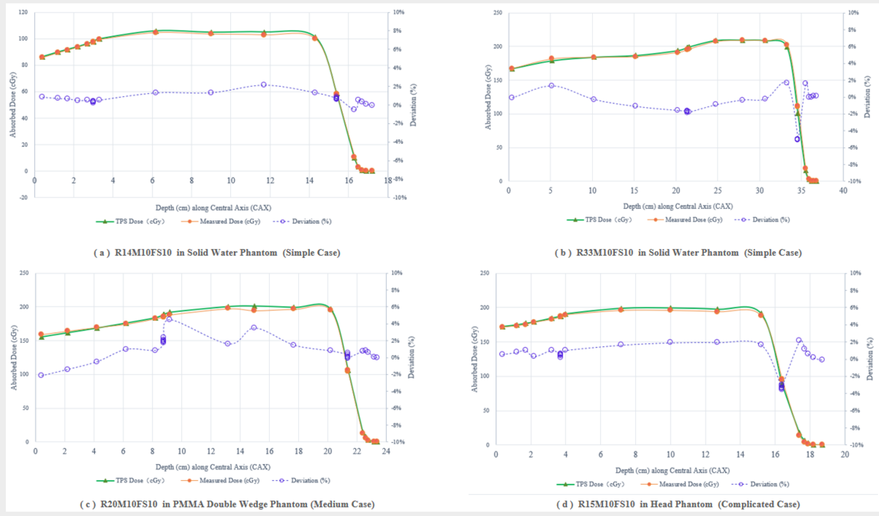

Figure 2. Validation of Calculation Accuracy for Beam Depth Dose Distributions: (a) (b)R14M10FS10, R33M10FS10 in Solid Water Phantom; (c) R20M10FS10 in PMMA Double Wedge Phantom (d) R15M10FS10 in Head Phantom

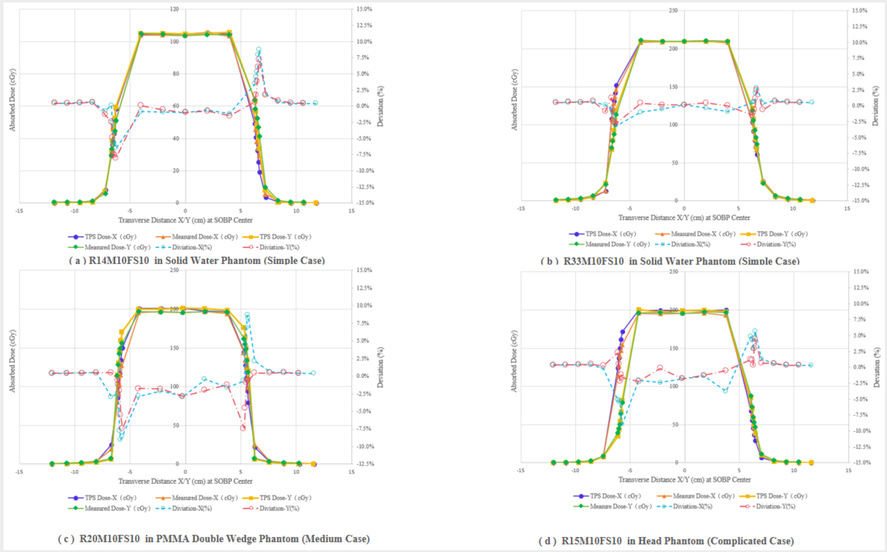

Figure 3. Validation of Calculation Accuracy for **Transverse Dose Distributions**: (a) (b)R14M10FS10, R33M10FS10 in Solid Water Phantom; (c) R20M10FS10 in PMMA Double Wedge Phantom (d) R15M10FS10 in Head Phantom

DISCUSSION

- This study confirms that CuraProton TPS meets the dosimetric accuracy requirements of the YY/T 1905-2023 standard. However, passing these standard-based type tests only demonstrated the correctness of calculation algorithms under simplified situations, and a more comprehensive verification remains necessary to ensure clinical safety and accuracy.
- Subsequent validation tests are planned for

  1)rigorous clinical beam model commissioning and validation against specific hardware data;

  2)verification to diverse clinical scenarios involving complex anatomical heterogeneities, alongside a robust Patient-Specific Quality Assurance (PSQA) program; and

  3)clinical trials and evaluations to demonstrate workflow efficiency and safety, fully establishing the system's reliability for clinical applications.

CONCLUSIONS

The rigorously validated results demonstrated that the new TPS CuraProton'is in full compliance with YY/T 1905-2023 standards with adequate dose calculation accuracy., and built a solid foundation for the subsequent clinical trials of the CuraProton system in China.

REFERENCES

1. YY/T 1905-2023 Requirements for Calculation Accuracy of Planned Dose in Light Ion Beam Radiotherapy
2. Arjomandy B, Taylor P, Ainsley C, Preciado-Walters F, Kooy H, Engelsman M, et al. AAPM Task Group 185: Clinical commissioning of proton pencil beam scanning algorithms: An AAPM Task Group Report. Med Phys. 2021;48(1):e1–e26.

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