Materials and Methods: Fourteen patients treated at our facility with passively scattered proton beams were selected. Acceptance areas ranged from 3 to 35 cm². Aperture sizes < 3 cm² were not considered in this study because aperture scattering effects might outweigh effects from patient heterogeneities. Dose distributions predicted by our pencil beam (PB) algorithm were verified against MC dose calculations using TOPAS—a TTool for Particle Simulation layered on top of GEANT4. Open field dosimetry was corrected based on the clinical guidelines for small fields to consider aperture scattering and dose equilibrium. DTVs were analyzed and differences in the dose to the 50% of the GTV (D50) were assessed on a field-by-field basis. We developed a simple and fast methodology to quantify the tissue inhomogeneity traversed by a single beam using a heterogeneity index (HI). The implementation was based on the dose calculation approach taken by our PB algorithm. Finally, we evaluated the potential correlation between the errors made by our PB algorithm in D50 for each field and the level of tissue heterogeneity traversed by the proton beam given by HI.

Results: Discrepancies up to 5.4% were found in D50 ([D50_MC—D50_Pb]/D50_MC). The discrepancies found for each field exhibited a strong correlation to their associated HI-values (Spearman's $r = 0.8, p <0.0001$); the higher the level of tissue heterogeneities for a particular field, the larger the dosimetric error by the analytical algorithm. With the established correlation a threshold for HI could be set by choosing a tolerance level; requiring an absolute difference for D50 < 2.5% for clinical routines suggests recalculating patient treatments for HI $> 1.7$.

Conclusions: The HI as defined in this study appeared to be a good indicator for the accuracy of proton field delivery in terms of GTV prescription dose coverage. Each HI-value was obtained in less than 3 minutes allowing the implementation of this methodology in the clinical routine. For HI-values exceeding the threshold, either a change in beam direction (if feasible) or a recalculation of the dose with Monte Carlo would be highly recommended.

OC-0438
Experimental validation of monte carlo pencil beam scanning model in heterogeneous media for proton therapy.
J. Sorriaux1, S. Rosomme1, J.A. Lee1, D. Bertrand3, S. Vynckier3, E. Sterpin1
1Université Catholique de Louvain, Center of Molecular Imaging Radiotherapy and Oncology, Brussels, Belgium
2Ion Beam Applications s.a, R&D, Louvain-la-Neuve, Belgium
3Cliniques Universitaires Saint-Luc, Département de Radiothérapie, Brussels, Belgium

Purpose/Objective: To validate experimentally a GATE/GEANT4-based(G4) Monte Carlo (MC) model in heterogeneous media for dedicated pencil beam scanning in proton therapy. Comparisons between measurements and MC simulations using G4 and PENELOPE-proton are presented. A comparison against analytical modeling from commercial TPS is also investigated. This work evaluates the impact of heterogeneities on range prediction, beam shape and depth dose changes.

Materials and Methods: The MC model for pencil beam based on G4 has been validated in water and PMMA phantoms (Grevillot et al Phys. Med. Biol.(2011)) reproducing pristine Bragg peaks for a series of individual energies (from 100 to 226.7 MeV) with 0.7 mm range and 0.2 mm spot size accuracy. The same optical model was implemented in PENELOPE-proton. In order to validate the beam model in heterogeneous media, phantoms made of stacked slabs with different densities and known compositions were used. Two experimental test cases including solid water (SW), lung (LN-300) and bone (SB3) tissue-equivalent material were investigated. Depth-dose distributions for a monoenergetic single spot and 10x10cm² composite fields were measured using Gafchromic EBT3 films and the ionization chamber (IC) PPC05 in all configurations. To measure accurately the Bragg peak position, a stack of films of 2x2cm² was inserted in the last centimeter of the proton range.

Results: Figure 1 shows results for one heterogeneous configuration. All doses-to-medium were converted to dose to water using stopping power ratios. Dose distributions were arbitrarily normalized in the middle of the second SW region. Bragg peak positions are reproduced by MC simulations within 1mm in both configurations (Table 1). IC measurements, G4 (binary-cascade) and PENELOPE-proton simulations are within 2%/2 mm. Point-to-point mean difference of 1.2% is observed between G4 (precompound) and measurement in the first 15 cm of the phantom and increased to 7.2% after bone insert until 286.5mm depth. In lung and bone slabs, EBT3 films and G4 binary-cascade are in agreement within 0.77% while a mean point-to-point difference up to 1.26% is observed with G4 precompound model. The uncertainty (1σ) on EBT3 films was evaluated to be at 2.75% which included readout process and dose calibration against IC (TRS-398). A statistical uncertainty of 0.1% was achieved for MC simulations.

Conclusions: The Bragg peak position is predicted with 1mm precision for all MC simulations, even though ionization potential values for phantom slabs were calculated using classical additive rules. G4/GATE beam model reproduce depth-dose behavior of proton transport regarding both IC and EBT3 measurement in heterogeneities.

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OC-0439
Proton dose calculation using the macro Monte Carlo method M.K. Fix1, D. Frei1, W. Volken1, E.J. Born1, D.M. Aebersold1, P. Manner1
1Division of Medical Radiation Physics and Department of Radiation Oncology, Inselspital Bern University Hospital and University of Bern, Bern, Switzerland

Purpose/Objective: Currently, pencil beam dose calculation algorithms are commonly used in treatment planning for radiotherapy with protons. These algorithms are of limited accuracy in some situations such as patient heterogeneities, which could be overcome when using Monte Carlo (MC) methods. However, MC suffers from long