Spatial fractionation of the dose in charged particle therapy: dosimetry evaluations

W. González[(1)], C. Guardiola[(1)], C. Peucelle[(2)], I. Martínez-Rovira[(1,3)] and Y Prezado[(1)].
(1). Laboratoire d'Imagerie et Modélisation en Neurobiologie et Cancérologie. CNRS-IN2P3, Orsay, France
(2). Centre Antoine Lacassagne-Institut Méditerranéen de Protonthérapie. INSTN CEA Saclay, Nice, France.
(3). UAB - Universitat Autònoma de Barcelona, Barcelona, Spain.

ecmp 2nd 2018
23-25 August 2018
Copenhagen . Denmark

Introduction

The dose tolerances of normal tissues continue being the main limitation in radiotherapy. As a strategy to overcome it, we propose to ally inherent physical advantages of heavy ions (up to Fe) with the normal tissue preservation observed when irradiated with submillimetric spatially fractionated beams (minibeam radiation therapy, MBRT) [1,2]. This would allow the use of higher and potentially curative doses in the treatment of radioresistant tumors.

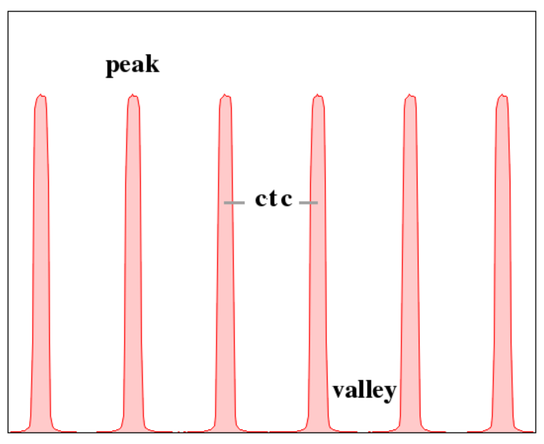
Material and methods (Monte Carlo (GATE/Geant4) codes were used to do dosimetric evaluations in hadron-MBRT)

Theorical

- **Minibeam generation: magnetic collimation assumed.**
- **Dosimetry evaluations was assessed to the optimum irradiation configuration in terms of ion species, beam widths and center-to-center distances (ctc).**
- **Dose distributions and dose averaged linear energy transfer (LET) were recorded in water phantom.**
- **The contribution of secondary fragments, Peak-to-Valley-Dose-Ratio (PVDR) and Peak-to-Valley-dose averaged LET-Ratio (PVLR) assessed.**

Hadrons

	Emax (MeV/u)
P	100
C	194
O	230
Ne	276
Si	319
Ar	351
Fe	450

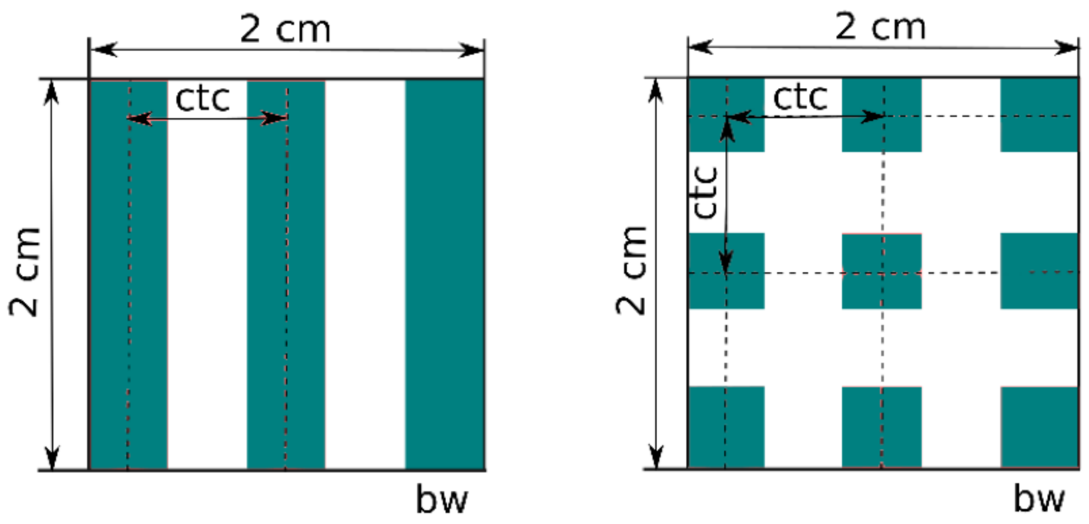


Lateral dose profile consisting in a pattern of peaks and valleys. PVDR affect the biological response.

Two different irradiation geometries were considered:

Rectangular (1D-Grid or minibeams (MBRT))

Squared (2D-Grid (GRT))



Martínez-Rovira et al. 2015, Peucelle et al. 2015b, Guardiola et al. 2017, González and Prezado 2018

Experimental

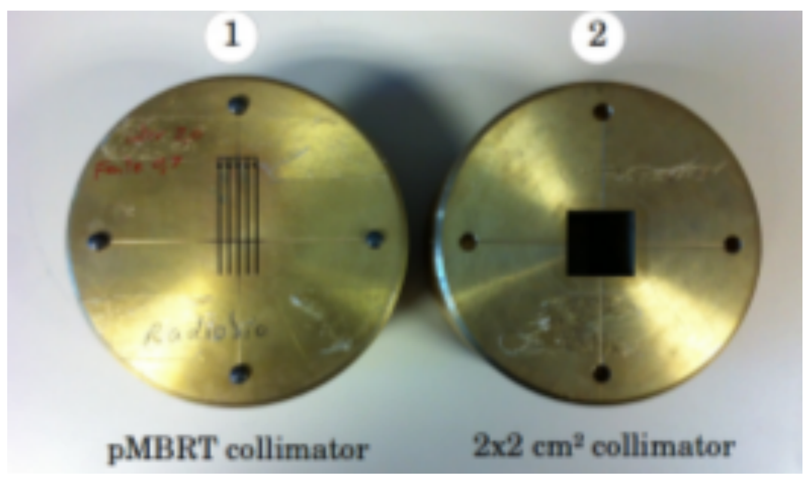
- **Full proton beam line of the Orsay Proton Therapy Center simulated and benchmarked with experimental data.**
- **Complete dosimetric dataset acquired to guide the preclinical studies.**

Peucelle et al. 2015a, Prezado et al. 2017

Source

	Emax (MeV/u)	bw (um)	ctc (um)
P	100	700	3500

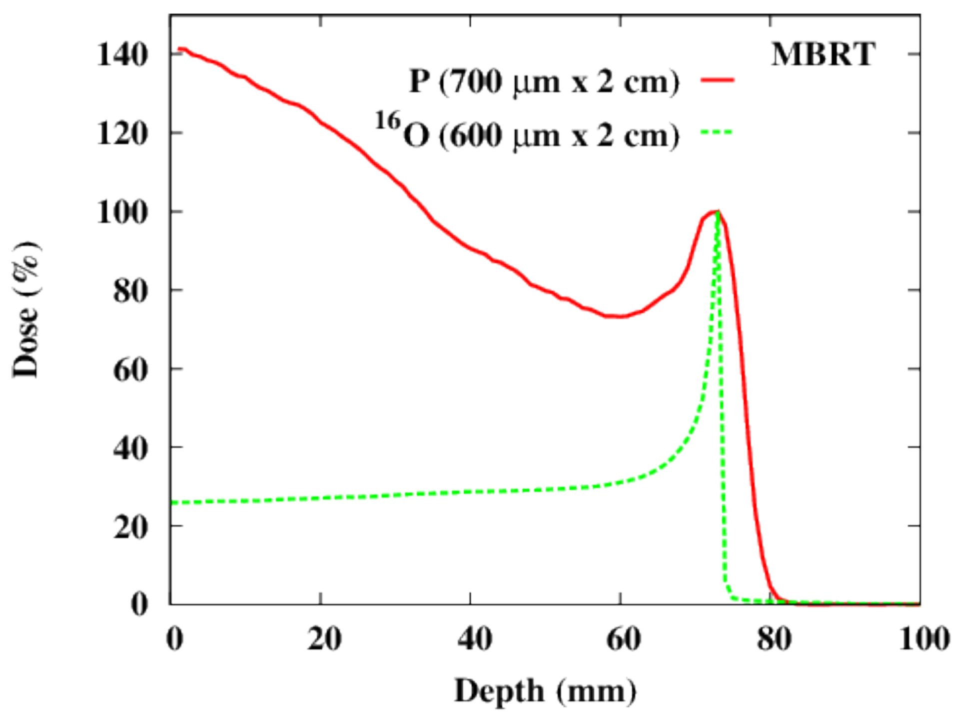
bw: beam width
ctc: center-to-center distance



Gafchromic© films irradiated in the phantom using the collimator.

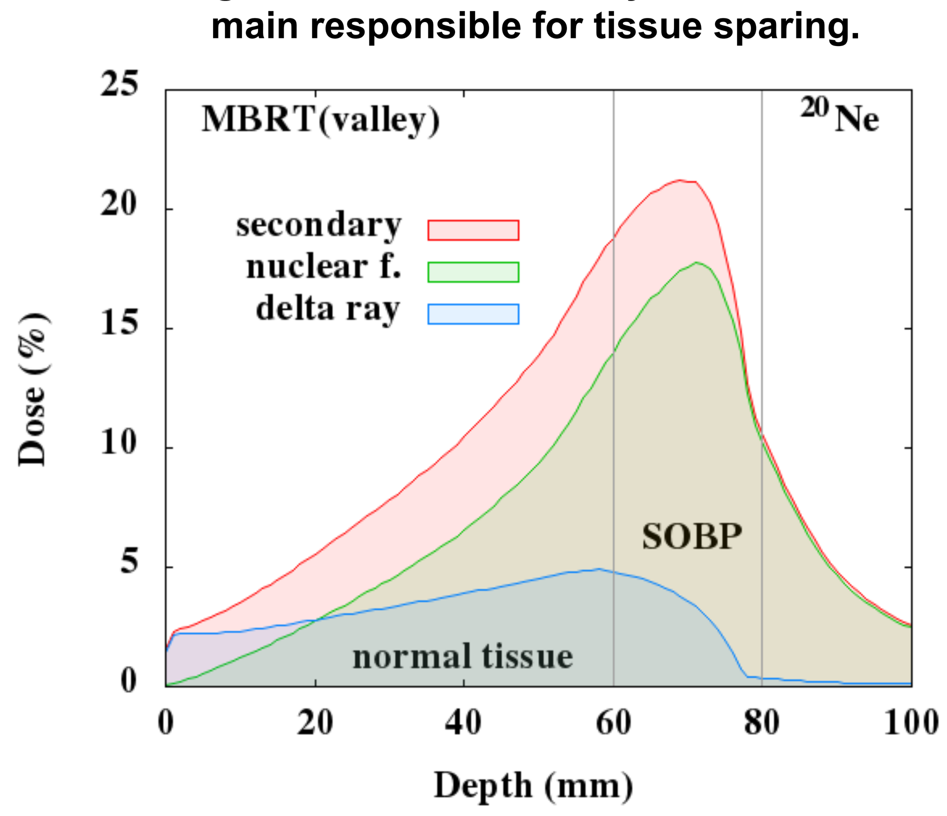
Results

Depth dose distributions.



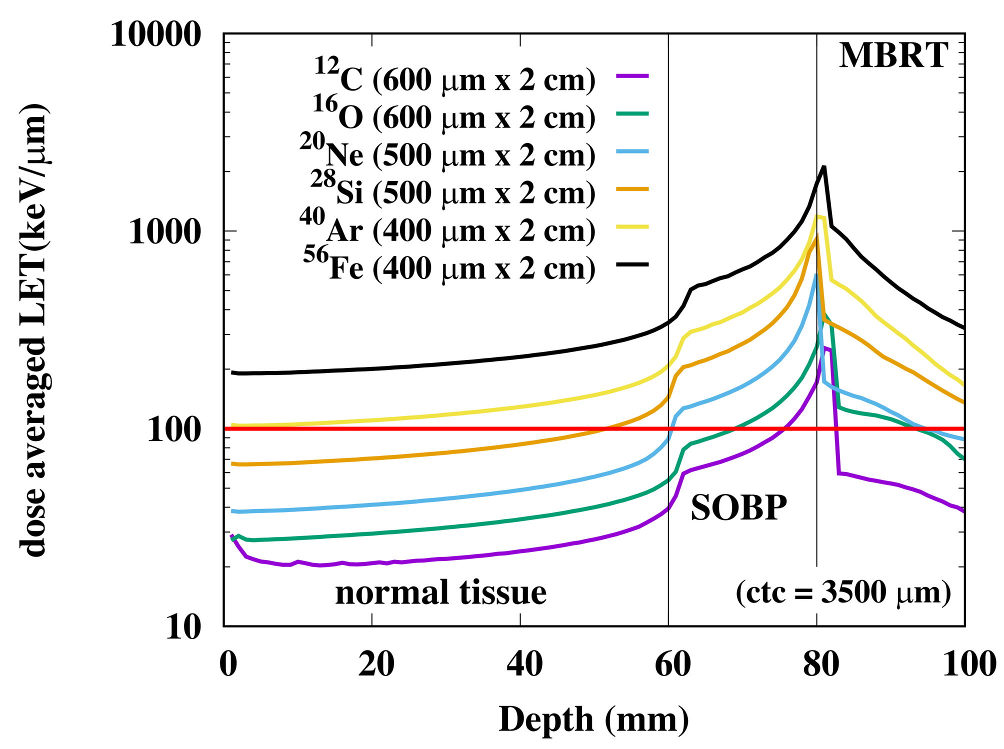
Comparison of depth dose distributions of protons and oxygen minibeams. Due to the reduced scattering for higher ions, the characteristic shape of the depth dose curve is maintained.

Contribution of secondary products of nuclear fragmentation to the valleys, which is the main responsible for tissue sparing.



Until 20 mm of depth, the delta rays represent the principal contribution to the secondary particles in the valleys. (ctc = 3500 μm.)

Dose-averaged LET (peak region) as a function of depth for the different ions.



In normal tissues, LET values remains below 100 keV/μm threshold where biological effects starts being significant, except for iron.

Conclusions

- **Heavy ions MBRT could offer some advantages with respect to proton MBRT, in particular, the possibility of using thinner beams.**
- **A possible drawback of heavy ions MBRT is influence by the fragmentation, but large ctc (3500 μm) would lead to valley doses composed of lighter nuclear fragments and lower dose averaged LET which minimizes the possible biological effects of heavier ions in the valleys in normal tissues.**
- **Ne stands out as the one leading to the best balance between high PVDR and PVLR in normal tissues.**

References

[1]. Y. Prezado, et al., J. Synchr. Radiat. 16, 582-586 (2009)
[2]. Y. Prezado, et al., Rad. Research. 184, 314-21 (2015)
[3]. I. Martínez-Rovira et al., Med. Phys. 42, 685-93 (2015)
[4]. C. Peucelle et al., Med. Phys. 42, 5928-36 (2015a)
[5]. C. Peucelle et al., Med. Phys. 42, 7108-13 (2015b)
[6]. C. Guardiola et al., Med. Phys. 44, 1470-8 (2017)
[7]. W. González and Y. Prezado, Med. Phys. 45, 2660-7 (2018)
[8]. Y. Prezado et al., Med. Phys. 42, 3675-6 (2017)

Acknowledgment
The authors acknowledge the calculation time granted at Centre de Calcul de Lyon (IN2P3) and at Grand Equipement National de Calcul Intensif (in particular at the supercomputer Curie of CEA). We warmly thank the access to Castilla y León Supercomputing Center (Calendula) awarded by the Red Española de Supercomputación. We also acknowledge PRACE for awarding us access to resource MareNostrum Barcelona Supercomputing Center based in Spain.