IMRT dose calculation to account for intra-fractional rigid motion

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INTRODUCTION

Intensity-modulated radiotherapy (IMRT) is an effective treatment to reduce the dose organ at risk, but it has one problem. The problem is called "interplay effect". Dosimetric error is caused by interplay between MLC's motion and tumor motion. Because of this, IMRT has been rarely used to treat the moving tumor. In the other hand, IMRT is needed for some difficult cases, such as the cases that dose for OAR cannot be controlled completely to use 3D conformal radiotherapy. So in those cases, IMRT should be applicable, where interplay effect is negligible.

PURPOSE

Because the interplay effect is caused by MLC motion and tumor motion, leaf sequence should have relationship with interplay effect. So, the first purpose of this study was investigating relationship between leaf sequence and tumor motion. Our group has developed monte carlo (MC) dose calculation method to account for tumor motion. The MC method is the most accurate algorithm but takes too much time to calculate. Dose measurement also takes much time. To investigate this effect needs several times calculation or measurement, because interplay effect is a random event. Thus, shortening calculation time is required to analyze the interplay effect. Development of in-house software to analyze the interplay effect quickly is the main purpose of this study.

METHOD

In this study, fluence maps have an important role. Dose distribution is calculated based on fluence maps, and the fuluence map itself is also a target for analysis.

Fluence is accumulated on movable grids. This is the key point to account for rigid motion into dose calculation. The respiratory tumor motion was taken by air-bag system which is developed in the Miyakojima IGRT clinic. The air-bag system monitors chest movement. The data acquisition rate is 30 Hz.

Dose calculation algorithm was based on pencil beam algorithm. In addition, the electron distribution was calculated by monte carlo codes (Geant4) and included in the calculation as Gaussian filter. Note that whole body is treated as water. As a result, no inhomogeneity correction and no scattering correction were included.

C++ builder and ROOT developed by CERN were used for developing this software. Also the developed software was included in ShioRIS-2.0 developed by Dr. Shiomi.

RESULT

Figure 1 shows standard deviation (SD) of the dose difference between moving tumor and static tumor. After Drawing SD maps, leaf edges are drawn as black lines. The black lines are overwritten with all beams. It shows dose uncertainty increases around the area with high density of leaf edges. As for the result of evaluating of DVH, there was not so much difference between motion tumor and static tumor.

It took about 1 min to calculate dose distribution by single core calculation. Repeating calculation takes us too much time. So, dose calculation algorithm was improved compatible with parallel calculation. As a result, it takes about 10 sec to calculate dose distribution by 8 cores calculation. It is fast enough to analyze interplay effect.

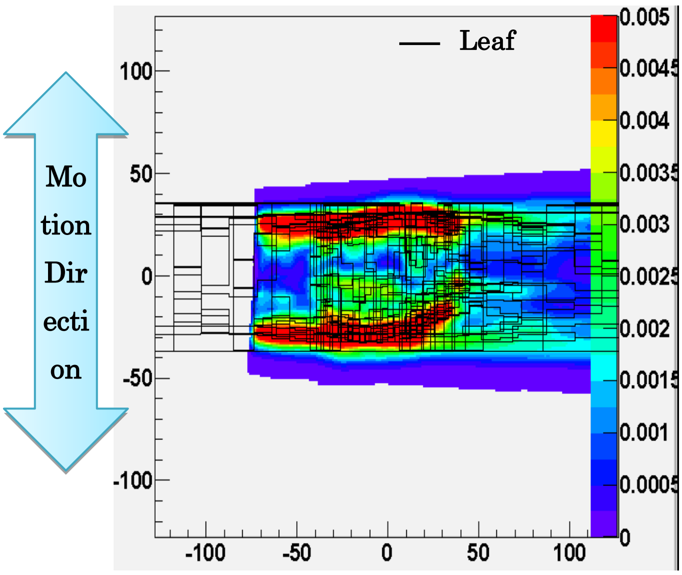

Figure 1 Relationship between leaf edges and dose uncertainty.

CONCLUTION

Overwriting of the leaf edge is useful to predict a position which tends to cause interplay effect. As for result of evaluating of DVH used clinical data, and there was not so much difference between static tumor and motion tumor. However, if the motion amplitude is large, large dose difference would be appeared. It is important to calculate the dose difference, before treatment.

IMRT dose calculation to account for intra-fractional rigid motion

Collaborating with the Miyakojima IGRT Clinic

Osaka University Graduate School of Medicine
Masaki Suga

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- Purpose
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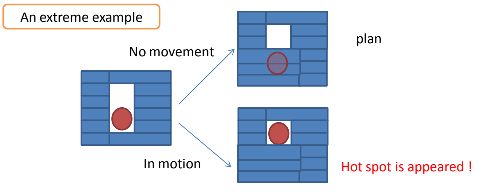
Introduction

- Interplay between the IMRT delivery technique and tumor motion can lead to dosimetric error.
  - It is hard to use IMRT for moving tumor.
  - Interplay effect is reduced by reduction of dose rate or fraction.



Introduction of the miyakojima IGRT Clinic

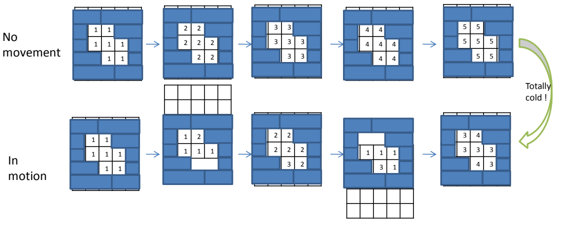
- Using Novalis
- Using the Air-Bag System to monitor the breathing
- Low fraction treatment

Purpose

- Analysis of relationship between leaf sequence and interplay effect
- Development of in-house software to analyze the interplay effect quickly
  - measurement by film takes lot of time (at least ~10min)

Method

1. Making Fluence map.



2. Calculating of dose distribution
3. Evaluating of DVH

Breathing waveform

Breathing waveform is as target motion CC direction

Fig.1 RPM breathing waveform data

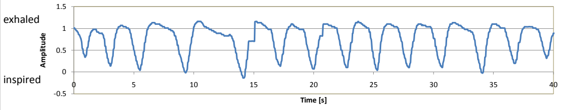
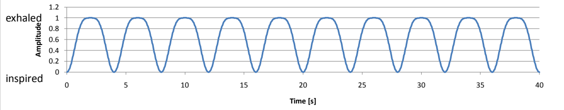


Fig.2 cos⁴ model waveform data*

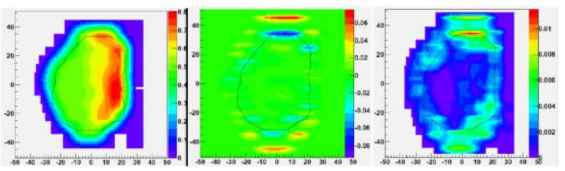


* Seppenwoolde *et al.* Int. J. Radiat. Oncol. Biol. Phys. 53 822–34

2D ANALYSIS

Analysis patterns of 2D fluence map

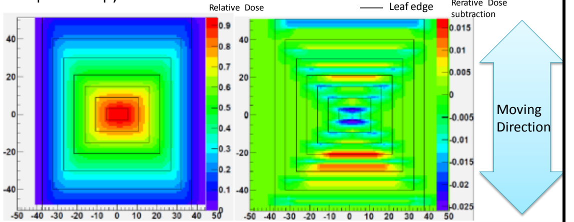
- 2 analysis mode
  - Averaging the dose difference between moving tumor and static tumor
  - SD of the dose difference between moving tumor and static tumor



Left : No movement , Center : mean of dose subtraction, right : SD of dos subtraction

Dependency of leaf sequence and interplay effect

Dependency of leaf sequence and interplay effect is verified by fluence map shaped like a pyramid



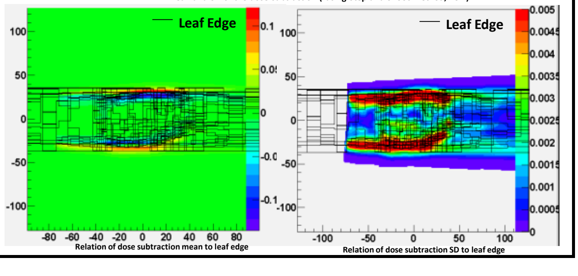
Left : Fluence map shaped Pyramid Right : Subtraction of fluence map shaped Pyramid

Vertical Leaf edge is more risky than horizontal one.
~ at most a few %

Relation of Leaf Sequence to Interplay Effect

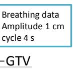
- Interplay effect has a tendency to be occurred around leaf edges

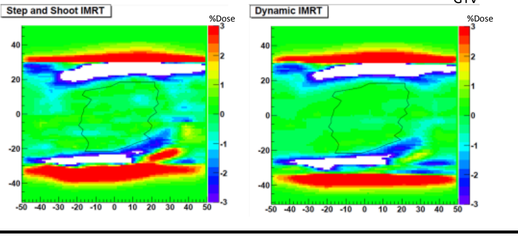
Mean and SD of the dose subtraction.(using Step and Shoot method, 13fr)



Analysis of 2D Fluence map

- These figures show comparison between Step and Shoot IMRT and Dynamic IMRT.
  - % Dose Difference is at most 1% in GTV.





3D ANALYSIS

3D Dose Calculation

- Algorithm based on measurement
  - Using PDD and OCR
  - Secondary electron distribution is described as Gaussian
    - Gaussian is estimated by monte carlo simulation
  - Voxel size : 1 x 1 x 1 mm^3
  - Voxel space : 256 x 256 x 256(default)
    - Variable voxel space 64x64x64,128x128x128,512x512x256
    - Whole body is treated as water
      - ➢ No inhomogeneity correction
    - No scattering correction.
      - ➢ Absolute dose has uncertainty

Relative dose is important this study.

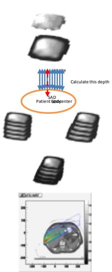
Calculation time
Step and Shoot ~ 30 s
Dynamic ~ 1 min

Parallel calculation — 8 core

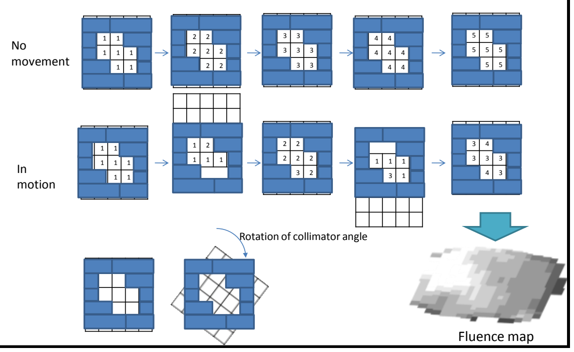
Calculation time
Step and Shoot ~ 5 s
Dynamic ~ 10 s

Calculation procedure

1. Making fluence map
2. Smoothing of fluence map
3. Depth calculation
4. Making Fan beam
5. TMR and OCR correction
6. Rotation of gantry angle and summation of all beams

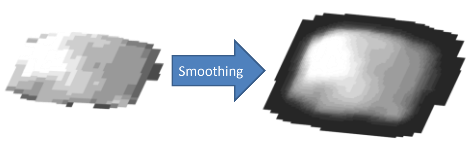


Making fluence map

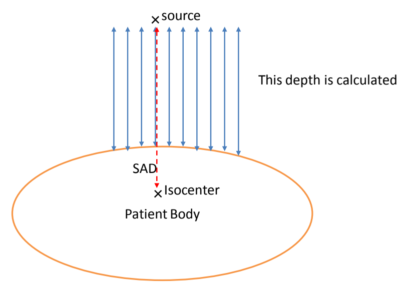


Smoothing of fluence map

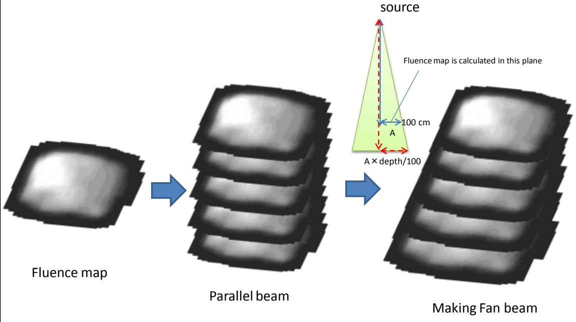
- Using Gaussian filter
  - Gaussian filter is calculated by monte carlo



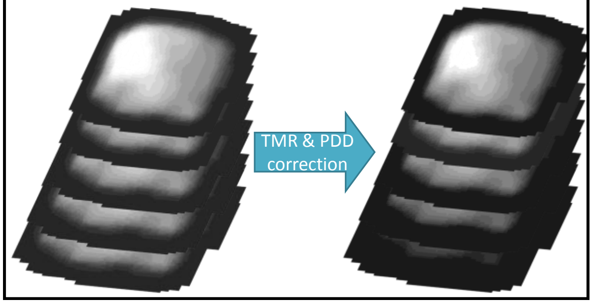
Depth Calculation



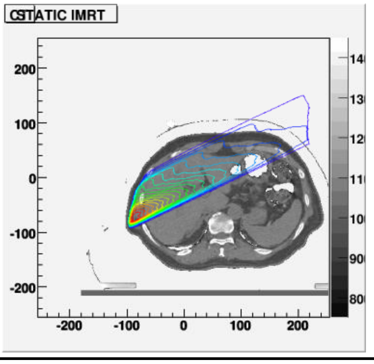
Making Fan beam



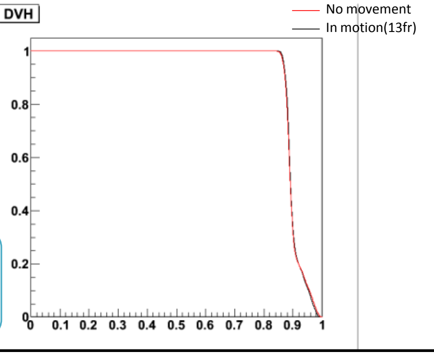
TMR and PDD correction



Summation of all beams



DVH (GTV)

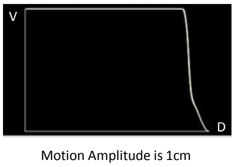


Step and Shoot
1segment
4 s + 2 s
Breathing wave
Amplitude : 1cm
Cycle ~ 4 s

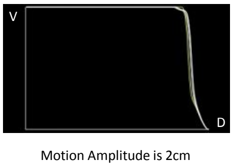
Dependency of DVH and Amplitude

- Comparing two DVHs.
  - Breath amplitude : 1cm , 2cm
  - Delivery type : Step and Shoot.
  - ROI : GTV(ITV)
    - Dose difference is not negligible
      - Leaking dose from Boost region
      - PTV cannot be covered, when the amplitude is 2 cm.

PTV margin is 8mm



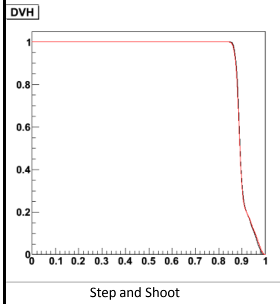
Motion Amplitude is 1cm



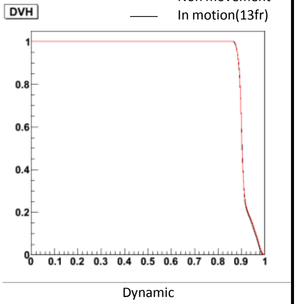
Motion Amplitude is 2cm

Comparing Step and Shoot IMRT and Dynamic IMRT in GTV

Non movement
In motion(13fr)



Step and Shoot



Dynamic

Development of QA software

- Analysis function
  - Detection of Leaf edge
  - Mean of 2D Fluence map subtracted
  - SD of 2D Fluence map subtracted
  - DVH

    etc.
- Variable value
  - Breath amplitude and cycle
  - Delivery time per a segment (Dose Rate)

etc.

ShioRIS Start

Summary

- Overwriting of the leaf edge is useful to predict a position which tends to cause interplay effect.
- % Dose difference is at most 1% when breath amplitude is about 1 cm.

Future

- Commissioning
- Dose calculation using higher precision algorithm
  - Convolution or Super position
- Dose calculation using each phase of 4DCT
- Taking account for AP-, RL-motion.

etc.

Thank you for your attention.