Imaging and Moving Tumors in Particle Therapy

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Imaging in Particle Therapy

Stage 1: PRE-Treatment
Stage 2: DURING Treatment
Stage 3: POST-Treatment

Acta Oncologica, 2015; 54: 1254–1258

Taylor & Francis

COMMENTARY

Imaging in particle therapy: State of the art and future perspective

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- PRE-Treatment Imaging:
  - Most Important!
  - Tumor Staging: PET/CT or PET/MRI or CT
  - Stopping Power Estimation: Dual-Energy CT
  - Tumor Motion Characterization: Respiratory/Breathing Monitoring Systems
- DURING-Treatment Imaging:
  - 2nd Most Important.
  - Tumor Motion Monitoring and Adaptation: In-Room MRI or X-ray Fluoroscopy
  - Daily Treatment Setup and Alignment: CT or Cone-Beam CT or In-Room MRI
  - Beam Range Real-Time Tracking: Prompt Gamma Imaging
- POST-Treatment Imaging:
  - Treatment Response Follow-up: PET/CT or PET/MRI or CT

PRE-Treatment Imaging

PRE-Treatment Imaging

Tumor Staging: PET/MRI or CT (Responsibility of the Clinician)

Cancer is often staged twice.

- The first rating is done before treatment and is called the clinical stage (with PET/MRI/CT/Biopsy).
- The second rating is done after treatment, such as surgery, and is called the pathologic stage.

TNM (Tumor, Node, Metastasis) staging system

The TNM staging system is most often used by doctors to stage cancer.

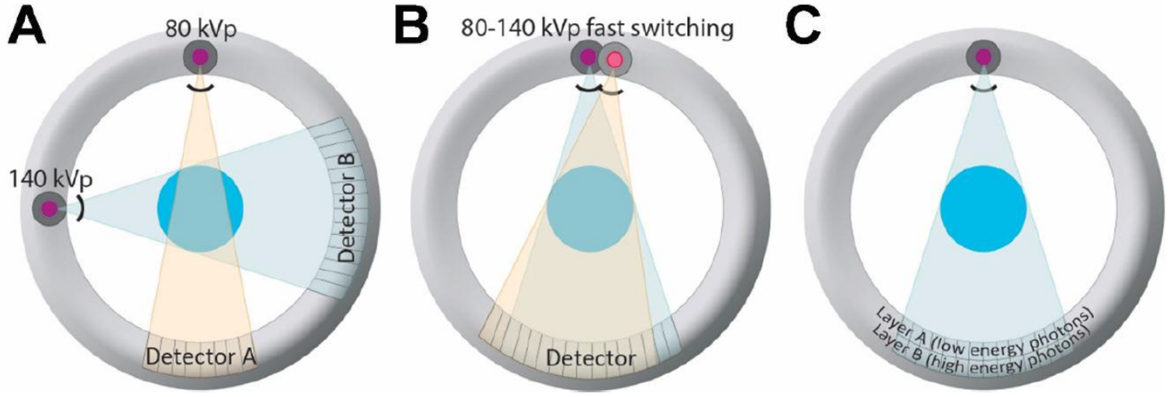
Responsibility of the Clinician

PRE-Treatment Imaging

❖ Stopping Power Estimation: Dual-Energy CT

Dual-Energy CT Scanners

SIEMENS | **GE Healthcare** | **PHILIPS**

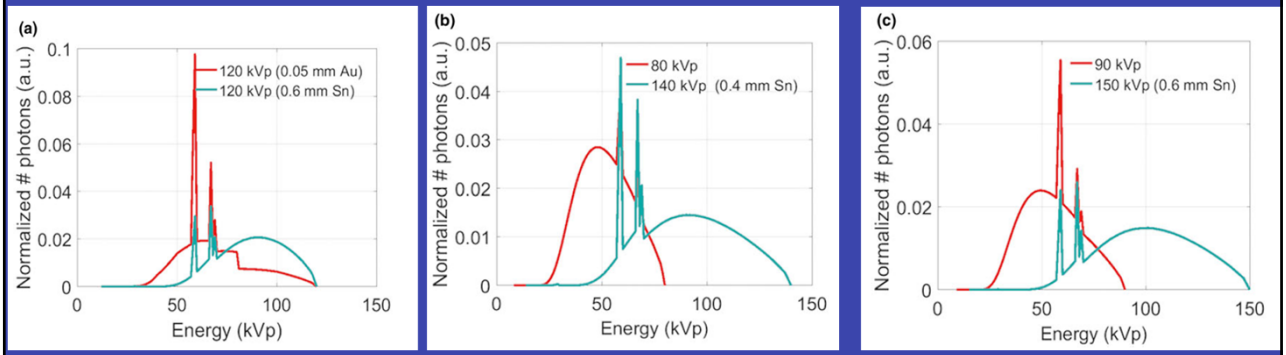


PRE-Treatment Imaging

❖ Stopping Power Estimation: Dual-Energy CT

SIEMENS DECT Scanners: X-ray Spectrum

EDGE | **FLASH** | **FORCE**



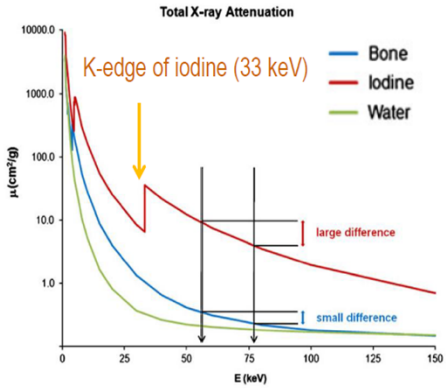
3rd Generation Twin-Beam scanner | 3rd Generation Dual-Source scanner | 2nd Generation Dual-Source scanner

PRE-Treatment Imaging

❖ Stopping Power Estimation: Dual-Energy CT

Generally 2 types of Parameterization of Attenuation Coefficient (μ_{eff}) in DECT

- *Electron density (ρ_e) and effective atomic number (Z_{eff})*



PRE-Treatment Imaging

❖ Stopping Power Estimation: Dual-Energy CT

Bethe-Bloch formula

$$SPR = \frac{\varrho_{e,medium}}{\varrho_{e,water}} \cdot \frac{\ln\left(\frac{2m_e c^2\beta^2}{(I_{medium}/eV)(1-\beta^2)}\right) - \beta^2}{\ln\left(\frac{2m_e c^2\beta^2}{(I_{water}/eV)(1-\beta^2)}\right) - \beta^2}$$

Relative Electron Density

Mean Excitation Energy (I_{medium})

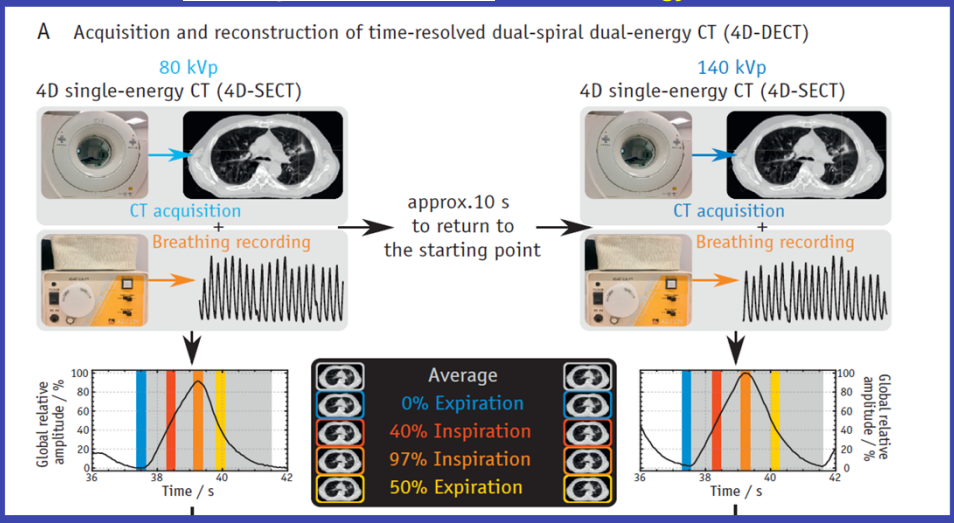
Yang et al

Effective Atomic Number (Zeff)

Dual Energy CT scan

PRE-Treatment Imaging

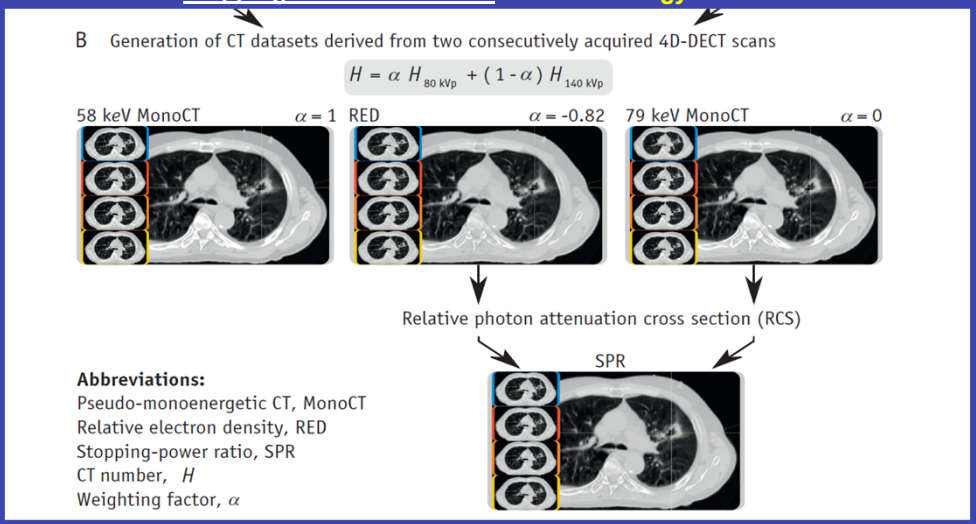
❖ Stopping Power Estimation: 4D Dual-Energy CT



Wohlfahrt et al (2018) Clinical feasibility of single-source dual-spiral 4D DECT for proton..” IJROBP

PRE-Treatment Imaging

❖ Stopping Power Estimation: 4D Dual-Energy CT



Wohlfahrt et al (2018) Clinical feasibility of single-source dual-spiral 4D DECT for proton..” IJROBP

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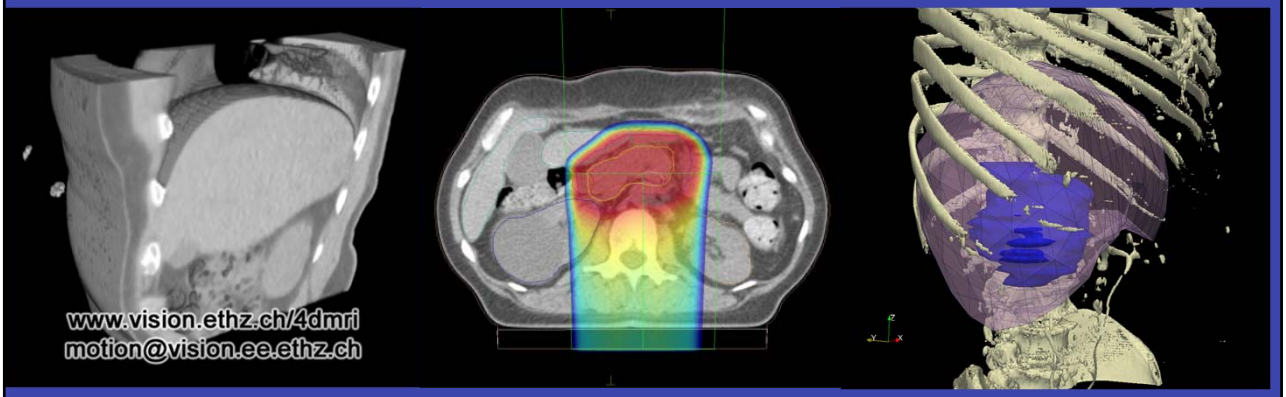
PRE-Treatment Imaging

❖ Tumor Motion Characterization: Respiratory/Breathing Monitoring Systems

image plan **Breathing motion.**

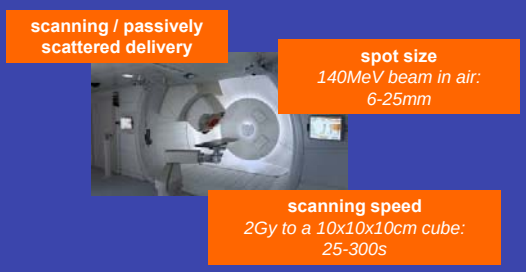


For several tumor sites we cannot assume the patient geometry is static during the delivery of a treatment fraction.

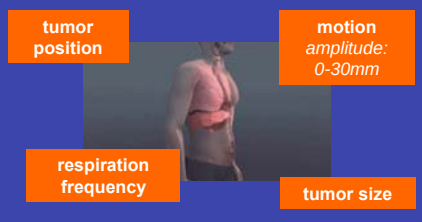
Tumor Motion Characterization

- Currently:
  - Not many proton facilities treat moving targets.
  - Experience is often based on passively scattered protons, while new centers are scanning facilities.
  - Simulation studies are often not conclusive as results are patient and facility specific.

facility characteristics



patient characteristics



Tumor Motion Characterization

Intra-fractional changes happen due to:

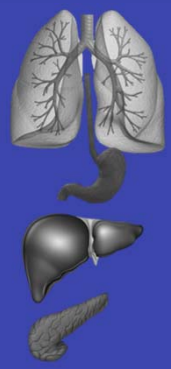
→respiration
periodic motion
12-15 cycles per min

→ heartbeat
periodic motion
60-90 beats per min

→ relaxation
drift motion
settling after 5-10 min

Motion effects cannot be resolved completely by fixation devices.
Targets in the whole thorax have to be considered mobile.

Tumor Motion Characterization



Lung
Liver

→ **Whithout motion mitigation, a limited number of patients shows motion <5mm.**
→ **Motion variations are difficult to predict.**

Pancreas
Esophagus

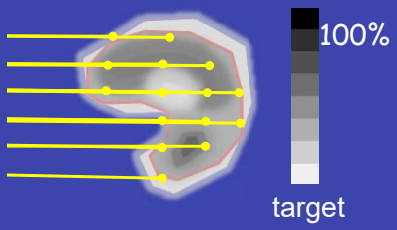
→ Almost all patients show motion >5mm.

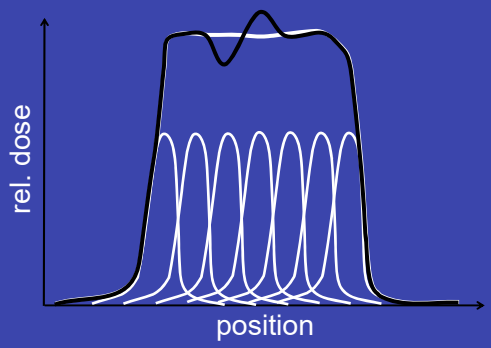
→ Main motion direction superior-inferior (S-I).

If we want to treat all patients with targets in the thorax and abdomen with proton therapy we need specific solutions!

Tumor Motion Characterization

Motion effects include target miss, dose blurring and the interplay effect.

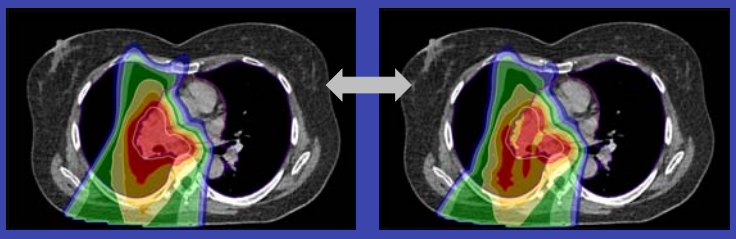




Due to the interplay-effect, margins won't solve the motion problem for protons treatments!

DURING-Treatment Imaging

Motion Monitoring / Adaptation
(DURING-treatment Imaging)



planned dose

delivered dose

Are the differences significant?

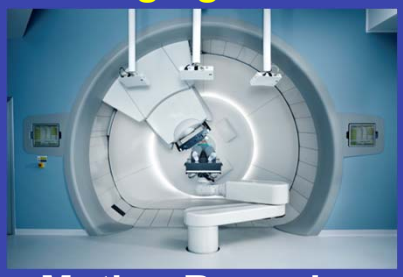
↓

Adaptation!

→ day-specific anatomy
→ day-specific motion
→ day-specific delivery characteristics

→ Motion mitigation aims to minimize motion effects on a daily basis.

Motion Monitoring / Adaptation
(DURING-treatment Imaging – Clinical Reality TODAY)



Motion Record

ANZAI belt

Mechanical Ventilator

VisionRT

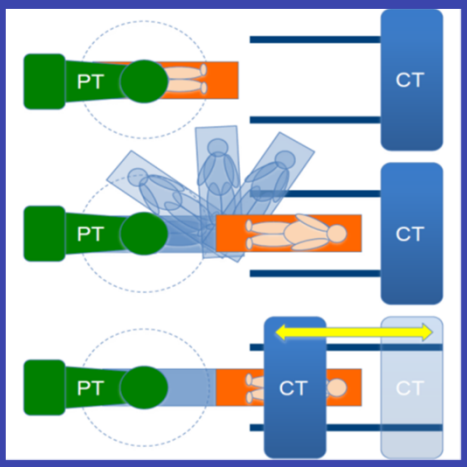
Hokkaido Proton Center

Kanehira et al. 2017 International Journal of Radiation Oncology*Biology*Physics 100(1) 173-181

DURING-Treatment Imaging

- Daily Treatment Setup and Alignment: CT or Cone-Beam CT or In-Room MRI

In-room CT-on-rails in proton therapy



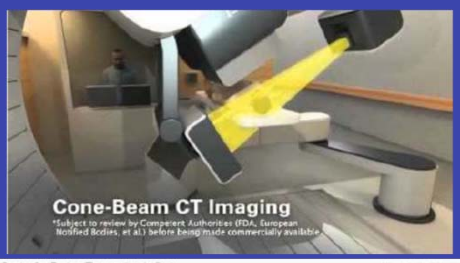
In-Room CT on Rails. Patient is rotated from treatment position to CT

DURING-Treatment Imaging

- Daily Treatment Setup and Alignment: CT or Cone-Beam CT or In-Room MRI

1999: 1st CBCT integrated with X-ray Linac

2016: 1st Proton-Gantry mounted CBCT



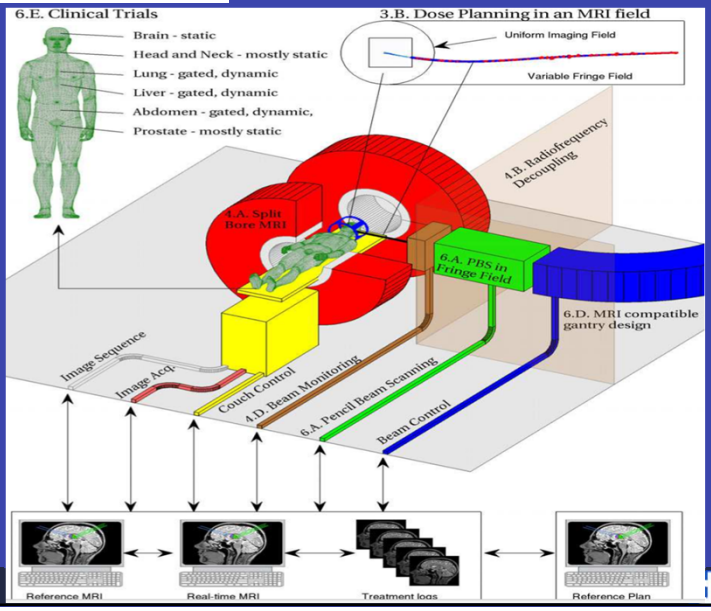
DURING-Treatment Imaging

- Daily Treatment Setup and Alignment: CT or Cone-Beam CT or In-Room MRI

Addressing in-room Movement

with PROTON MRI

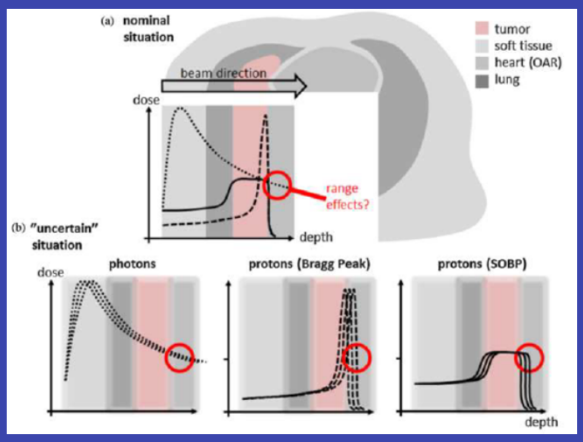
FUTURE of PROTON THERAPY (?)

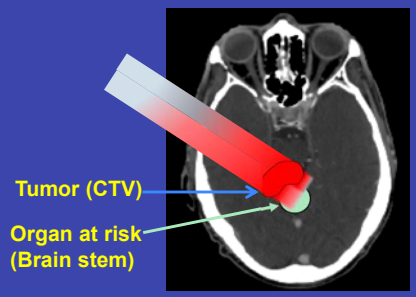


DURING-Treatment Imaging

- Beam Range Real-Time Tracking: Prompt Gamma Imaging

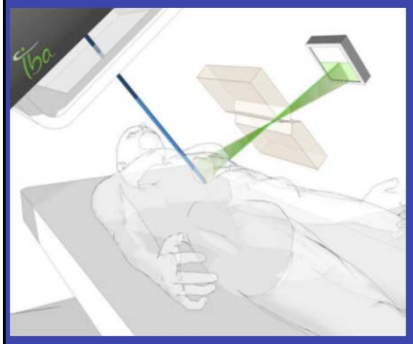
Range Uncertainties in Particle Therapy





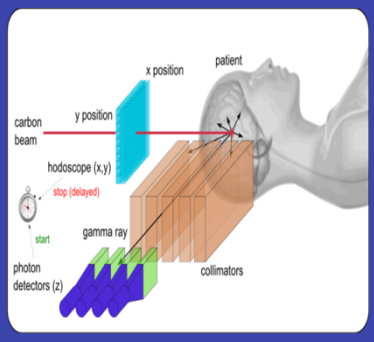
DURING-Treatment Imaging

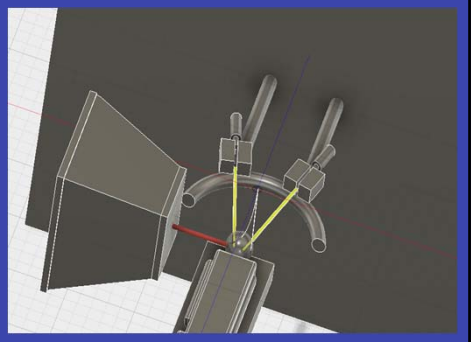
- Beam Range Real-Time Tracking: Prompt Gamma Imaging



Slit-Camera design

Smeets J et al. Prompt gamma imaging with a slit camera for real-time range control in proton therapy. Phys. Med. Biol 57.11 (2012),





Prompt Gamma Spectroscopy

Verburg JM and Seco J. Proton range verification through prompt gamma-ray spectroscopy. Phys. Med. Biol 59.23 (2014)

POST-Treatment Imaging

POST-Treatment Imaging

- Treatment Response Follow-up: PET/CT or PET/MRI or CT

Followup Imaging "Watching for recurrence"

One goal of follow-up care is checking for a recurrence. Recurrent cancer is cancer that has come back after treatment. Cancer recurs because small areas of cancer cells may remain undetected in the body. Followup focuses on the detection of local, regional, or distant recurrence

Followup Imaging "Watching for Side Effects"

Long-term side effects may occur as a result of any part of management of the cancer. The type and severity of these side effects vary according, in part, to the type of therapy that have been given.

Current Clinical Practice Follow-up Imaging involves the use of PET/CT or CT or MRI

Future Clinical Practice will include the use of PET/MRI

Conclusions

- Imaging plays a major role in particle therapy.
- There are 3 stages in which imaging can be adopted in particle therapy
  - Stage 1: PRE-Treatment
  - Stage 2: DURING-Treatment
  - Stage 3: POST-Treatment

- The PRE-Treatment Stage is the most important since it involves all the needed preparation for treatment, from the dose calculation to tumor staging and involving the organ contouring.
- The DURING-Treatment Stage is the 2nd most important and involves all the daily imaging performed during treatment
- The POST-Treatment Stage involves the treatment response assessment and plays a vital role in understanding the success or not of the therapy.

Thank You for Your Attention ☺

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Relaxing!

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