PET-CT for Adaptive Radiation Therapy

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Outline

➢ Overall role of PET in oncology: lung cancer example
  ➢ Diagnosis/staging
  ➢ Target delineation
  ➢ Treatment response assessment
    ➢ Post-treatment imaging
  ➢ During-treatment imaging
➢ FDG-PET guided adaptive therapy
  ➢ Hodgkin’s lymphoma: chemotherapy response based
  ➢ Esophageal cancer: chemotherapy response based
  ➢ Non-small cell lung cancer: mid-radiation response based
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PET: Positron Emission Tomography

PET scan is a nuclear medicine, functional imaging technique that is used to observe metabolic processes in the body. The system detects pairs of gamma rays emitted indirectly by a positron-emitting radioactive tracer, which is introduced into the body on a biologically active molecule.

- PET is an important research tool to map normal human brain and heart function, and support drug development.
- PET, both a medical and research tool, plays an important role in clinical oncology: diagnosis, staging, treatment decision, treatment response assessment.
History of PET Quantitative Imaging

- Positron-emitting radioisotopes were first discovered in the 1930's
- Concept of tomography: David Kuhl, Luke Chapman, and Roy Edwards, U Penn, in late 1950s
- First scanner: James Robertson et al at Brookhaven National Laboratory, the first single-plane PET scan, nicknamed the "head-shrinker" in 1961
- Further technique development: Michel Ter-Pogossian, Michael E. Phelps, Edward Hoffman from Wash U, 1970-1975
- 2-fluoro-2-deoxy-D-glucose (FDG) was radiolabelled with $^{18}$F-FDG by Louis Sokoloff along with Dr. Alfred Wolf and Joanna Fowler in 1976
- The first FDG Quantitative imaging of a human reported in 1978
- FDG-PET was first covered by Medicare for NSCLC staging in Jan, 1998 (then rising CEA colon cancer and lymphoma 1999)

PET Modality

- Hypoxia PET: $^{18}$F-FMISO, $^{18}$F-FAZA, $^{64}$Cu-ATSM
- DNA PET: $[^{18}$F]$^{3'}$-deoxy-$^{3'}$-fluorothymidine (FLT) PET
- Protein PET:
  - $^{11}$C-methionine PET
  - $^{11}$C-methyl-lysergic PET
- Neuroreceptor ligand PET:
  - $[^{11}$C$]$raclopride, $[^{18}$F$]$fallypride and $[^{18}$F$]$desmethoxyfallypride for dopamine D2/D3 receptors
  - $[^{11}$C$]$ McN 5652 and $[^{11}$C$]$DASB for serotonin transporters
  - $[^{18}$F$]$Mefway for serotonin 5HT1A receptors
  - $[^{18}$F$]$Nifene for nicotinic acetylcholine receptors or enzyme substrates (e.g. $^{6}$FDOPA for the AADC enzyme).
- EGFR or other critical molecular targeted PET
- Glucose PET: $[^{18}$F$]$fluoro-2-deoxy-glucose PET (FDG-PET), the one in daily clinical practice.

Current Role of FDG-PET

Diagnosis  Staging  Response Evaluation  Restaging  Suspected Recurrence  Follow-up or Surveillance  Target Delineation for Radiotherapy Planning  Adaptive treatment
FDG-PET/CT Current Role-1
ACR Practice Appropriateness

- **Diagnosis**
  - To characterize a lesion to suggest whether it is benign or malignant
  - For the detection of a possible primary when the patient presents with metastases
  - To identify an appropriate site from which a biopsy would yield adequate representative tissue for diagnosis
  - Detection of malignancy when tumor markers are abnormal

- **Staging**
  - After the histological diagnosis, to assess the extent of disease before the start of treatment

- **Restaging**
  - Assessment of the extent of the disease after treatment or after confirmed recurrence

   Argrawal and Rangarajan, 2015

FDG-PET/CT Current Role-2
ACR Practice Appropriateness

- **Suspected Recurrence**
  - Assessment of disease following clinical or biochemical suspicion of recurrence

- **Follow-up or Surveillance**
  - Assessment of disease in the absence of critical evidence of recurrence

- **Radiotherapy Planning (RT)**
  - When the study is used for contouring and planning the radiation fields

- **Response Evaluation**
  - Assessment of response to treatment

   Argrawal and Rangarajan, 2015

FDG-PET Improves Target Accuracy

Detecting CT missed nodes

Differentiating tumor from collapsed lung

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Using PET Volume for ITV

- PET image is usually obtained in about 30 minutes. The PET volume should include all the target excursion due to internal motion, and correlates with the ITV obtained from 4D-CT (3 phases -CT).

PET Target Can Include Motion

- 15 patients with NSCLC, tumor 233±237cc (ranged 30-876cc)
- Three phase scan CT simulation: inhale, exhale, and free breathing
- Composite GTV of both inhale and exhale
- FDG-PET on treatment position
  - PET volume: multiple threshold PET volume
- Comparison of CT GTV vs PET volume
  - 15±5 % PET GTV matched best with CT composite GTV

Fernando (Kang) et al. 2005

PET Target May Include CT-CTV

- 15 patients with NSCLC, tumor 233±237cc (ranged 30-876cc)
- Three phase scan CT simulation: inhale, exhale, and free breathing
  - Composite GTV of both inhale and exhale
  - ITV (Internal target volume)=composite GTV + 8mm expansion
- FDG-PET on treatment position
  - PET volume, multiple threshold PET volume,
- Comparison of CT GTV vs PET volume
  - 14±4 % PET GTV matched best with ITV

Fernando (Kang) et al. 2005
Methods Used for PET-MTV Delineation

- 1. Visual Inspection: Nuclear medicine physician set windows and levels, target delineated manually by radiation oncologists; Pro: expert’s hands; Con: subjective, difficult to reproduce
- 2. Absolute SUV cut-off (2.5)
  - Pro: easy, objectively follow the number
  - Con: SUV varies with scanners, injection amount, time between injection and many other factors; RT plan systems do not have SUV
- 3. Tumor background/mediastinum ratio
  - Pro: objective
  - Con: What is the right threshold? What do you do with the adjacent normal tissue
- 4. Relative threshold method (% maximum)
  - Pro: objective
  - Con: can not find a fixed threshold for every tumor; the most commonly used 40% is wrong in 80% cases
- 5. “Gradient method”
  - Pro: objective
  - Con: Requiring specific program software? What do you do with the adjacent normal tissue

Contouring Tumor Target on PET

<table>
<thead>
<tr>
<th>Tumor Size</th>
<th># of Lesions</th>
<th>Threshold Method</th>
<th>Max SUV</th>
<th>CT Volume (cc)</th>
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</thead>
<tbody>
<tr>
<td>&gt;5 cm</td>
<td>9</td>
<td>40% threshold</td>
<td>12 ± 4</td>
<td>18 ± 9</td>
</tr>
<tr>
<td>&lt;3 cm</td>
<td>3</td>
<td>40% threshold</td>
<td>2.9 ± 0.3</td>
<td>11 ± 7</td>
</tr>
<tr>
<td>All</td>
<td>20</td>
<td>40% threshold</td>
<td>12 ± 8</td>
<td>200 ± 277</td>
</tr>
</tbody>
</table>

The 40% Threshold Is Not Correct for Majority Patients

Lung lesions surrounded by lung parenchyma

The 40% PET threshold underestimated CT tumor volume in 17/20 (85%) lesions. The mean threshold was 24% for CT sized tumor.
RTOG1106 Recommendation PETMTV

- Metabolic tumor volume (MTV) should be generated using a fixed tumor background ratio
  - 1.5 times of the mean activity of aorta
- This can be done through various systems, such as MIM PET edge.
- The key issue is consistency between scans and patients.

- Example steps from University of Michigan functional image analysis tools (FIAT) can be found:

Delineation of PETMTV Step-1

- Contour an aortic structure of 1.2 cm in diameter (1 cc in volume, about 3 slices) in the middle of ascending aorta in CT scan
- Transfer aortic structure to PET scan which is already registered with CT scan.

Delineation of PETMTV Step-2

- Check aorta volume on PET and fused PET-CT image
- Calculate the mean intensity of 1cc aortic structure in PET image
- Autotrack the tumor volumes by thresholding at 1.5*mean intensity of the aortic structure

Delineation of PETMTV Step-3

- MTV can be done in one click depending on the contouring tool
- Check the MTV slice by slice in fused PET-CT image
- Identify normal structure incidentally included in the MTV


Delineation of PETMTV Step-4

- Manually remove normal structures such as heart and esophagus (dark in the white circle) incidentally included in MTV
- PETMTV (yellow arrows) delineation is now complete.


Sam#1 RTOG1106 uses which of following methods to define FDG-PET scan to guide adaptive treatment in non-small cell lung cancer:

- 1) threshold SUVmax at 2.5
- 2) threshold at 40% of SUVmax
- 3) manual drawing per treating physician
- 4) tumor background ratio


The Traditional Approach of Treatment Response Assessment

- CT (PET)
- "Watch and see", assess the response after completion of RT

Diagnosis & RT Planning  Radiation Therapy  Months to years

Post-treatment outcome

CT  PET  Perfusion (Q) SPECT

Post-Tx CT-PET Imaging for Tumor Control

- Post-Tx CT response is the standard practice in most disease
- Post-Tx PET is better than CT as it can tell scars from active tumor
- Post-Tx PET is highly correlated with pathologic response.
- Post-Tx PET may be predictive of pattern of failure
- Post-Tx PET, as a biomarker, is predictive of long term survival.
  * post-Tx metabolic response is the most significant factor in predicting long term survival.

But, post-Tx PET tumor response does not provide an opportunity to change the treatment plan. NO use for ART.

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MDTx PET-CT to Assess Individual Response

If long term outcome can be predicted before treatment completion, the remaining treatment can be adapted in each individual patient.

FDG-PET in Hodgkin’s Lymphoma-1

- Prognostic value of early interim PET response after chemotherapy cycles. No treatment modification was made based on PET response:
  - Danish prospective analysis, 77 patients:
    - 15 out of 14 (105%) PET+ patients relapsing or progressing
    - PET+ patients relapse vs. ongoing response (OR 6.6; P < .05)
    - PET2 response was a significant predictor for both DFS and OS (P < .05).
  - An Italian prospective trial, 108 patients (mostly advanced stage) treated with ABVD with 54% receiving IFRT.
    - PET2 response correctly predicted treatment outcome in 95% of patients, with a positive predictive value of 90% and a negative predictive value of 97%.
  - A combined analysis of the above two prospective trials:
    - The 2-year DFS was 82% for PET2-positive patients compared to 61% if PET2-negative (P < .001).
    - PET2 response was the only significant predictor of outcome on multivariate analysis (P < .0001).
    - Both the negative predictive value (NPV) and positive predictive value (PPV) of PET2 response were excellent (92% and 93%, respectively).

FDG-PET in Hodgkin’s Lymphoma-2

- Chemotherapy modification based on PET response, chemo based on PET2 response:
  - A study from Haifa/Israel, 108 patients:
    - PET-2-negative patients receiving standard BEACOPPh
    - PET-2-positive patients receiving BEACOPPh (both 4 cycles).
    - Radiation therapy, given to 30% of patients, included initial bulky disease (>10 cm) and a single PET-positive site after completing chemotherapy.
    - Interim PET-based treatment was effective and feasible, with 5-year event-free survival (EFS) and OS of 85% and 90%, respectively.
  - A phase II study from Hadassah University Hospital, Jerusalem:
    - 43 advanced stage HL, a favorable PET response after 2 cycles of BEACOP received an additional 4 cycles of ABVD. Results comparable to similar patients (high-risk, advanced HL) treated in the German HD9 trial with 8 cycles BEACOPPh.

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FDG-PET in Hodgkin’s Lymphoma-3

- Consolidative radiation therapy based on PET response
  - HD15 trial of the German Hodgkin Study Group (GHSG): 817 patients (Stage IB bulky or Stage II B) underwent 2 cycles of BEACOPP chemotherapy and randomized for response by PET CT at completion (6 to 8 cycles).
  - Patients with PET positive residual disease (≥2.5 cm in size) received 30 Gy IFRT. The PFS for patients with PET negative residues treated with chemotherapy alone was 96% compared to 86% for PET positive patients treated with chemotherapy and IFRT (P = .011).
  - One published randomization from Italy: 260 patients with bulky HL (>5 cm, all stages) with VE-BEP (vinblastine, etoposide, bleomycin, epirubicin, prednisone) chemotherapy for 6 cycles, randomized to versus no IFRT.
  - PET CR: EFS 86% compared to 96% with IFRT, P = .03.
  - PET residual disease: treated with high-dose chemotherapy and stem cell transplant, 50% EFS.
  - Picardi et al, 2007

- Judge is still out for the role of FDG-PET on RT decision for Hodgkin’s lymphoma.
  - Sam#2: Which of the following is correct regarding PET-guided adaptive treatment in Hodgkin’s lymphoma?
    - 1) Current standard RT in lymphoma is tailored treatment based upon PET assessment.
    - 2) There is consensus regarding the appropriate treatment of PET-avid disease (interim or after completion of therapy): i.e. more intensive treatment for poor responders.
    - *3) PET response is strongly prognostic for treatment outcome
    - 4) PET guided adaptive trial has demonstrated superiority of such treatment in lymphoma.


FDG-PET in Hodgkin’s Lymphoma-4

- Ongoing clinical trials
  - CALGB trials 50604 and 50801 (non bulky and bulky Stage I/II, resp.) assess for PET response after an initial 2 cycles of ABVD (clinicaltrials.gov ID NCT01132807 and NCT01118026, resp.).
  - The German HD16 comparing 2 cycles of ABVD and 30 Gy IFRT compared to the same regimen with PET response-guided radiotherapy.
  - The H10 EORTC/GELA study is recruiting patients with stage I/II disease.
  - Trials from Cancer Research UK (stage IIb-IV) and Southwest Oncology Group (SWOG, stage III/IV) treat PET-2-positive patients after ABVD with BEACOPP-based regimens (NCT00678327 and NCT00822120, resp.).
Sam#3: Regarding the PET adapted MUNICON I trial in esophageal cancer:

- 1) This phase II trial is a PET adaptive study that involved adaptive radiation therapy.
- 2) Of 110 patients enrolled, 54 patients had more than 35% reduction in SUV after 2 weeks of chemotherapy.
- 3) Due to the use of PET adapted treatment, the metabolic non-responders had achieved similar survival than that of responders.
- 4) The non-metabolic responders on PET showed no histological response.

FDG-PET in Esophageal Cancer
MUNICON II Trial

Comparison of Major Findings of MUNICON I and MUNICON II Trials

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MUNICON I</th>
<th>MUNICON II</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET</td>
<td>Responded</td>
<td>Nonresponders</td>
</tr>
<tr>
<td>Response</td>
<td>69%</td>
<td>51%</td>
</tr>
<tr>
<td>Enlargement</td>
<td>1</td>
<td>15%</td>
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<tr>
<td>2</td>
<td>20%</td>
<td>4%</td>
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<td>3</td>
<td>22%</td>
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<tr>
<td>Response</td>
<td>99%</td>
<td>74%</td>
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<tr>
<td>4</td>
<td>9%</td>
<td>26%</td>
</tr>
<tr>
<td>5</td>
<td>19%</td>
<td>17%</td>
</tr>
<tr>
<td>Survival</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Median TTP: 12.3 mo, 14.3 mo, Not reached 15.4 mo
Median HD: Not reached 15.8 mo, Not reached 16.3 mo

FDG-PET/CT
Within 2 wks

Pre-RT

FDG-PET/CT, 45 Gy
During RT

Tx response, Local control, Overall survival

Long term

Weeks

Months to years
Hypothesis-1
Tumor Functional Imaging to Guide Individualized Adaptive RT

- The tumor response on FDG-PET during-RT is correlated with post-treatment response, and predictive of progression free, local progression free and overall survivals.
- PET during-RT response can guide individualized adaptive RT.

General Study Design

Blood markers

Primary Tumor  FDG-Activity During & Post RT

NSUV= Max SUV of the Region of Interest / Mean SUV of Aortic Arch

Kong et al, JCO, 2007
PET-Activity and Volume During-RT

PET Activity and Volume During-RT PET Activity and Volume During-RT

During-RT PET and Overall Survival

During-RT PET and Overall Survival

PET Variables for Survival

PET Variables for Survival

During-treatment volumetric factors are most significant for survival while FDG activity alone were not.

Kong et al. 16th World Lung Congress, 2015

<table>
<thead>
<tr>
<th>Variable</th>
<th>HR</th>
<th>95% CI</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre SUVmean (per unit)</td>
<td>1.14</td>
<td>(0.85, 1.54)</td>
<td>0.375</td>
</tr>
<tr>
<td>During SUVmean (per unit)</td>
<td>1.12</td>
<td>(0.694, 1.8)</td>
<td>0.645</td>
</tr>
<tr>
<td>During-Pre SUVmean (per unit)</td>
<td>0.934</td>
<td>(0.637, 1.37)</td>
<td>0.727</td>
</tr>
<tr>
<td>Pre SUVmax (per unit)</td>
<td>1.06</td>
<td>(0.993, 1.13)</td>
<td>0.0793</td>
</tr>
<tr>
<td>During SUVmax (per unit)</td>
<td>1.11</td>
<td>(0.974, 1.26)</td>
<td>0.121</td>
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<tr>
<td>During-Pre SUVMax (per unit)</td>
<td>0.939</td>
<td>(0.857, 1.03)</td>
<td>0.17</td>
</tr>
<tr>
<td>Pre TLG (per 10 units)</td>
<td>1.01</td>
<td>(1, 1.01)</td>
<td>0.00708</td>
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<tr>
<td>During TLG (per 10 units)</td>
<td>1.03</td>
<td>(1, 1.06)</td>
<td>0.0315</td>
</tr>
<tr>
<td>During-Pre TLG (per 10 units)</td>
<td>0.992</td>
<td>(0.986, 0.998)</td>
<td>0.00993</td>
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<tr>
<td>Pre MTV (per 10 units)</td>
<td>1.02</td>
<td>(1, 1.04)</td>
<td>0.021</td>
</tr>
<tr>
<td>During MTV (per 10 units)</td>
<td>1.08</td>
<td>(1.01, 1.15)</td>
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<tr>
<td>During-Pre MTV (per 10 units)</td>
<td>0.971</td>
<td>(0.947, 0.995)</td>
<td>0.0187</td>
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<tr>
<td>Pre CTGTV (per 10 units)</td>
<td>1</td>
<td>(1, 1)</td>
<td>0.0563</td>
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<tr>
<td>During CTGTV (per 10 units)</td>
<td>1</td>
<td>(1, 1)</td>
<td>0.0409</td>
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<tr>
<td>During-Pre CTGTV (per 10 units)</td>
<td>0.976</td>
<td>(0.946, 1.01)</td>
<td>0.143</td>
</tr>
</tbody>
</table>

J Wang (Kong) et al. 2012

J Wang (Kong) et al. 2012

Li et al. (Kong), ASTRO, 2013

Li et al. (Kong), ASTRO, 2013

Kong et al., 16th World Lung Congress, 2015

Kong et al., 16th World Lung Congress, 2015
Advantages of during-PET ART

- Tumor dose can be escalated by 19% more if the lung normal tissue complication probability (NTCP) is kept same
- Lung NTCP could be decreased by 18% if the tumor dose is unchanged
- Example:
  - Pt Mr. B, keep lung NTCP unchanged (this case was 9%)
  - Re-simulation at 40 Gy, start boost RT at 50 Gy
  - GTV reduced by 50%
  - Tumor dose escalated by 11 Gy
  - Code dose decreased by 12 Gy

Feng (Kong), Red Journal, 2009
Using FDG-PET Acquired During the Course of Radiation Therapy to Individualize Adaptive Radiation Dose Escalation in Patients with NSCLC

Adaptive plan individualized to each tumor

Using FDG-PET Acquired During the Course of Radiation Therapy to Individualize Adaptive Radiation Dose Escalation in Patients with NSCLC
Pre-RT PET-CT individualized plan: 17.2% NTCP, 70 Gy to tumor.

During-RT PET-CT adapted plan: 17.2% NTCP, 86 Gy to residual PET tumor.

Long-Term Local Tumor Control

Pt #1

Primary tumor shrank from 5 cm at 12 mo to 3 cm at 18 mo, though brain mets at 8 mo.

She lived 33 months.

Long-Term Tumor Control

Pt #2

Primary tumor shrank from 5 cm at 12 mo to 3 cm at 18 mo, though brain mets at 8 mo.

She lived 33 months.
Midtreatment PET volume based adaptive RT improved local tumor control (infield) to 82% 2-year tumor control from 34% historical control, 65% of RTOG617 for stage III NSCLC
Kong et al., JAMA Oncol., 2017 Jun 1.

RTOG 1106/ACRIN 9967 Schema

The Primary Endpoint: 2 year local regional tumor control
Randomization stratified by primary tumor, nodal disease, and histology.

RTOG1106 Dose Prescription

Isotoxicity for adaptive arm
Pre-RT CT-PTV
Adaptive Arm
≤50 Gy
Pre-RT CT-PTV
≤60 Gy
During RT PTV dose is escalated.
Pre-RT PTV dose is de-escalated.
RTOG1106 Technology

- Must use PET for RT planning:
  - Use tumor background ratio of 1.5, using mediastinum blood pool as background, plus manual edits
- Demands 4D motion assessment for every patient:
  - Use average scan for lung dosimetry
  - IGTV for GTV
- Must use imaging guidance for daily treatment, CBCT recommended
  - The trial reached accrual goal of 138 patients in Spring of 2017

Hypothesis-2
Changes in Normal Tissue on PET to Guide Adaptive RT

- The activity of FDG-PET during-RT is predictive of treatment toxicity
- PET during-RT response can guide adaptive RT to spare organs at risk and decrease treatment toxicity

Background:
PET to Assess Post-RT Lung Changes

Post-RT lung changes associated with survival
Hicks et al, 2004
Post-RT Lung Changes and Dose Response

36 esophageal patients, 4-12 wks s/p RT+chemo

There is a remarkable individual difference in dose response relationships

Post-RT Changes Can Be Remarkable on PET

Changes on During-RT PET?

- Feb 2004 to June 2005, a pilot study from University of Michigan (UMCC-200376)
- FDG-PET scans were performed within 2 weeks prior to, at 45 Gy during and 3 months after RT in 15 patients (14 pts with FDG-Avid tumors) with NSCLC
- 2/15 patients had mild increased FDG-Activity During-RT, 7/15 had remarkable increase post-RT.
Lung FDG Activity During-RT

<table>
<thead>
<tr>
<th>Grade</th>
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<th>2</th>
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<td>155</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>161</td>
</tr>
</tbody>
</table>

Fisher’s exact P value = 0.001

3/4 patients had changes during RT developed clinical pneumonitis.
During-RT PET may predict post-RT pneumonitis.
Li et al (Kong), ASTRO, 2013

During-RT Changes in FDG Uptake and RILT

- 84 patients with pre- and during-RT PET-CT, and RILT
- Of 9 patients with increased FDG uptake during-RT, 5 (55.6\%) developed RILT
- Of 11 patients developed clinical RILT, 88\% had FDG uptake on the post-RT PET images.
- 89\% RILT patients had notable changes of FDG uptake on post-RT PET images.
- There was a significant correlation between the incidence of RILT and FDG uptake changes on during-RT (P=0.002) and post-RT (p<0.001) PET images.

Li et al (Kong), ASTRO, 2013

During-RT FDG Uptake and Clinical RILT

Li et al (Kong), ASTRO, 2013
Sensitivity and Specificity of Hick’s Grading Scale for Esophagitis

- FDG uptake during-RT to predict post-RT RILT
  - Sensitivity=45.5%, Specificity=94.5%
  - Positive predictive value=55.6%
  - Negative predictive value=92.0%
- FDG uptake post-RT and RILT post-RT
  - Sensitivity=87.5%, Specificity=65.9%
  - Positive predictive value=33.3%
  - Negative predictive value=96.4%

A patient with negative findings on during-RT PET is most likely at low risk for RILT, during-RT PET may thus guide adaptive planning to decrease clinical RILT.

PET for Heart Function

High FDG accumulation in the high-dose irradiated myocardium at five months after chemoradiotherapy are decreased markedly of heart function in the region (arrows). (Jingu et al, 2006)
Radiation Induced Esophagitis

A Patient with Grade 4 Esophagitis
Another Patient with Grade 4 Esophagitis

Example Patient without Esophagitis

PET Guide Esophagus Sparing RT
During-RT PET Guided Esophagus Sparing

Without during-RT PET guided esophagus sparing  
With PET esophagus sparing

Max esophagus dose: 85 Gy  
Max esophagus dose: 65 Gy

Effect of Esophagus Avoiding RT

PET-CT may predict each individual’s RT response, the dose prescription can be individualized for a maximized therapeutic gain.

PET guided ART to Improve Outcome
PET as quantitative imaging tool plays an important role in ART and the modern era of personalized medicine!

**Future: PET Radiomics Feature Guided ART**

average geodesic distances (AGD) map

Standardized moment = 0.58
OS is 67.23 months volume is 24332 mm³

Zhang, Jin, Kong

**Acknowledgement**

- **Medical physicists**
  - Randall Sinibaldi
  - Timmy Ritter
  - Jean Moran
  - Max Kessler
  - James Baker
  - Daniel Mcshan
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