imagination at work

Motion Free – The Principle

Like motion can impact image resolution when you take a picture….

…Imagine what impact motion has on a moving lesion

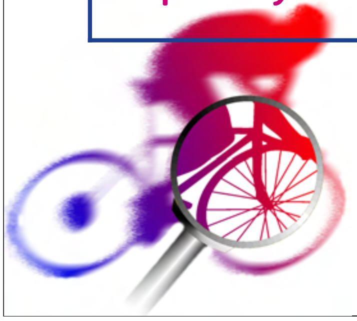
Motion impacts image resolution, when you take a picture with a photo camera.

In a moving object spatial resolution is depending on the exposure time.

Imagine, what impact a moving lesion has on image resolution in a relatively long lasting PET acquisition.

Clinically relevant challenges

Factor	FWHM Contribution
Positron range	0.5 (tissue) – 1.5mm (lung)[1]
Positron non-collinearity	1-2 mm
Detector size & sampling	2-3 mm
Reconstruction filter	2-7 mm
Displayed pixel size	2-4 mm
Effective Clinical Resolution + **Respiratory Motion**	**4–10 mm** + **10-50mm**



1. Sánchez-Crespo, et al. "Positron flight in human tissues and its influence on PET image spatial resolution", Eur J Nucl Med, Vol 31, Iss 1, Jan 2004, pp 44-51.

Taking into account positron range, positron non-collinearity, detector size and sampling, and the reconstruction filter, one can achieve an effective spatial resolution under clinical conditions of 4 to 10 mm.

The motion caused by respiration is 10 to 50 mm!

Patient Motion
is THE
Resolution Limiting factor in PET

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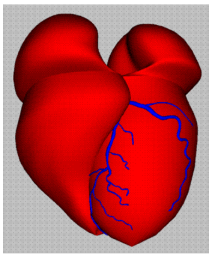
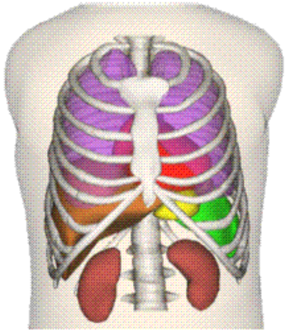
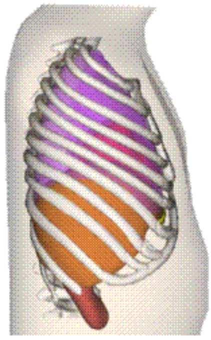
Motion in PET/CT

Motion occurs because of:

- Breathing…respiratory organ motion
- Beating…cardiac motion
- Positioning…patient motion







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Motion occurs because of :

Breathing

– the respiratory motion of organs

Beating

– the motion of the contracting heart

And positioning

– the motion, when the patient is moving by himself.

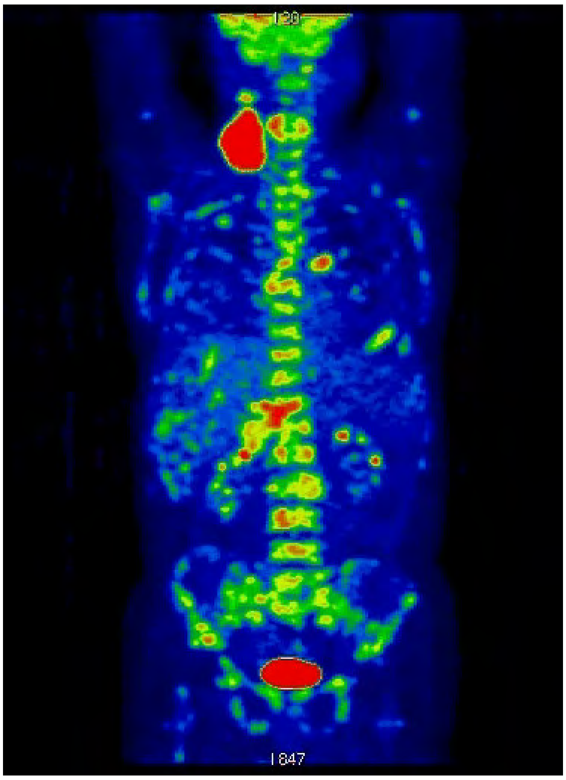
Motion in PET/CT

Motion creates challenges:

- Blurring….reduced resolution
- Artifacts…attenuation correction, misregistration
- Quantitation…uncertainty

Which translate into Clinical challenges:

- Find the smallest tumors
- Find tumor with low uptake
- Obtain the highest image quality



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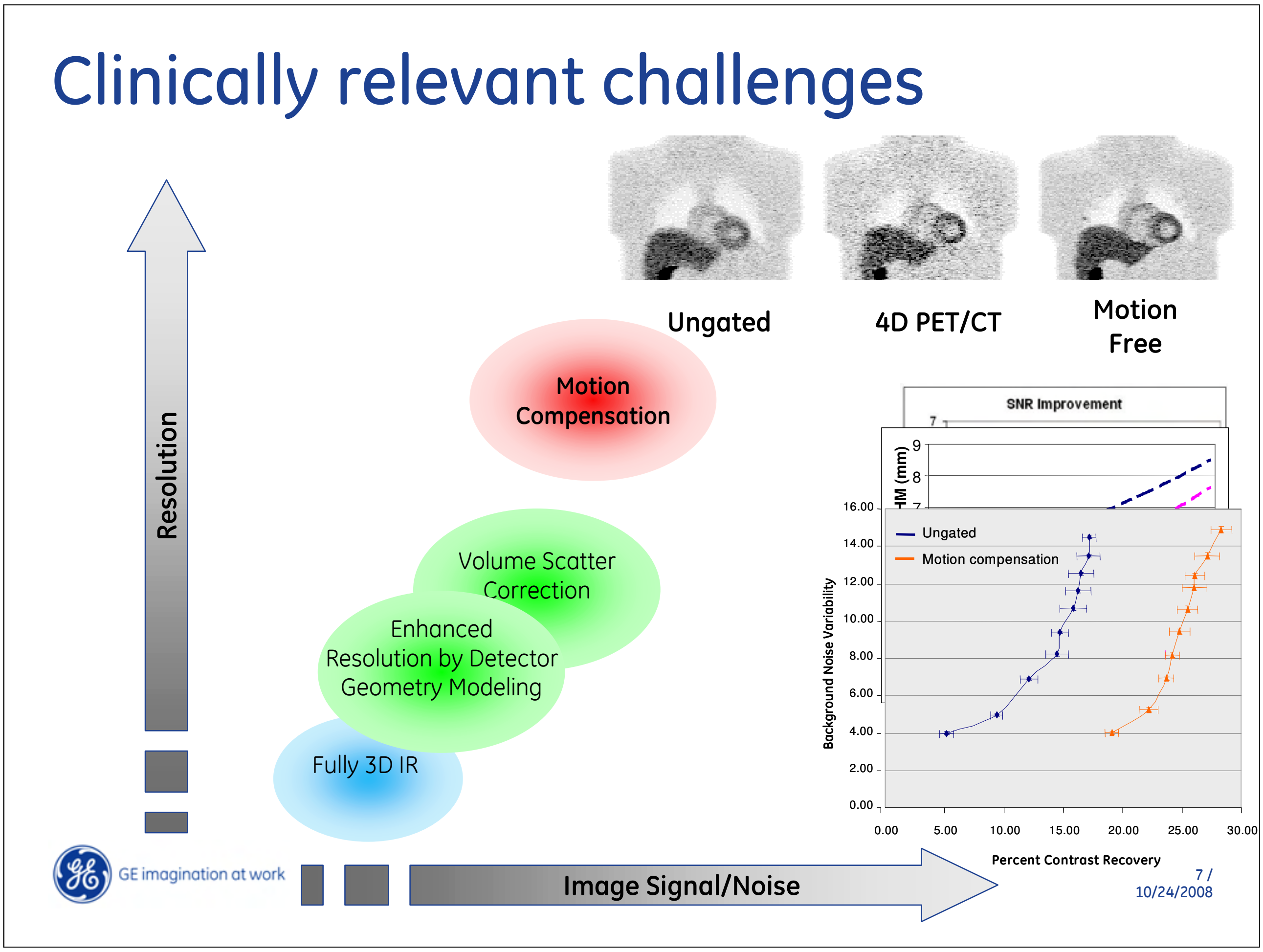
Motion creates:

Reduced lesion detectability through blurring, attenuation artifacts because of misregistration between PET and CT

And uncertain quantification.

This leads to clinical challenges like:

Detect the smallest tumor – or tumor with low uptake and obtain the highest image quality.



Basis for PET images with high signal to noise ratio is a PET/CT-scanner with highest sensitivity.

The signal to noise ratio can be increased by 60% by the use of a fully 3D iterative reconstruction with all necessary corrections in the loop.

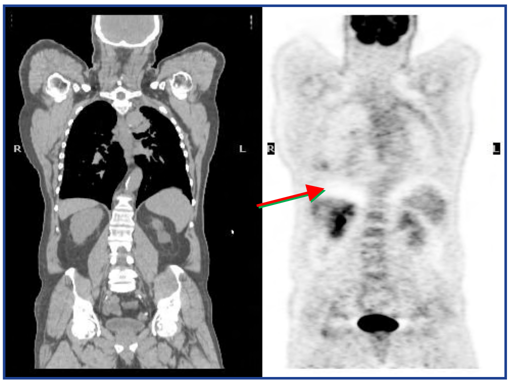
Detector geometry modeling enhances the resolution and volume scatter correction in better signal to noise ratio and resolution.

These powerful improvements work perfectly in phantoms or in a patient who does not breath nor move and whose heart does not beat.

In a real living pation we need means for motion compensation to improve the spatial resolution of PET images

Attenuation Correction Artifacts

Misalignment between PET and CT due to respiratory motion

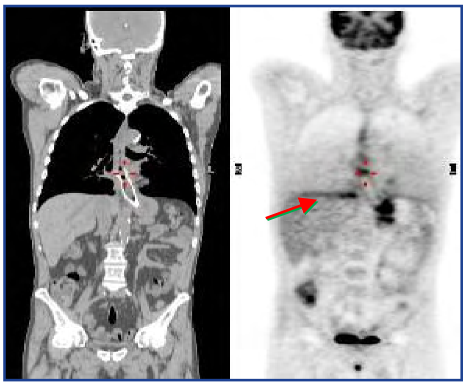


Negative Contrast

CT diaphragm position
lower than PET

False Positve Contrast:

CT diaphragm position
higher than PET



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Pan, T et.al. J Nucl Med 2005;46:1481:1487
Images Courtesy: MD Anderson Cancer Center

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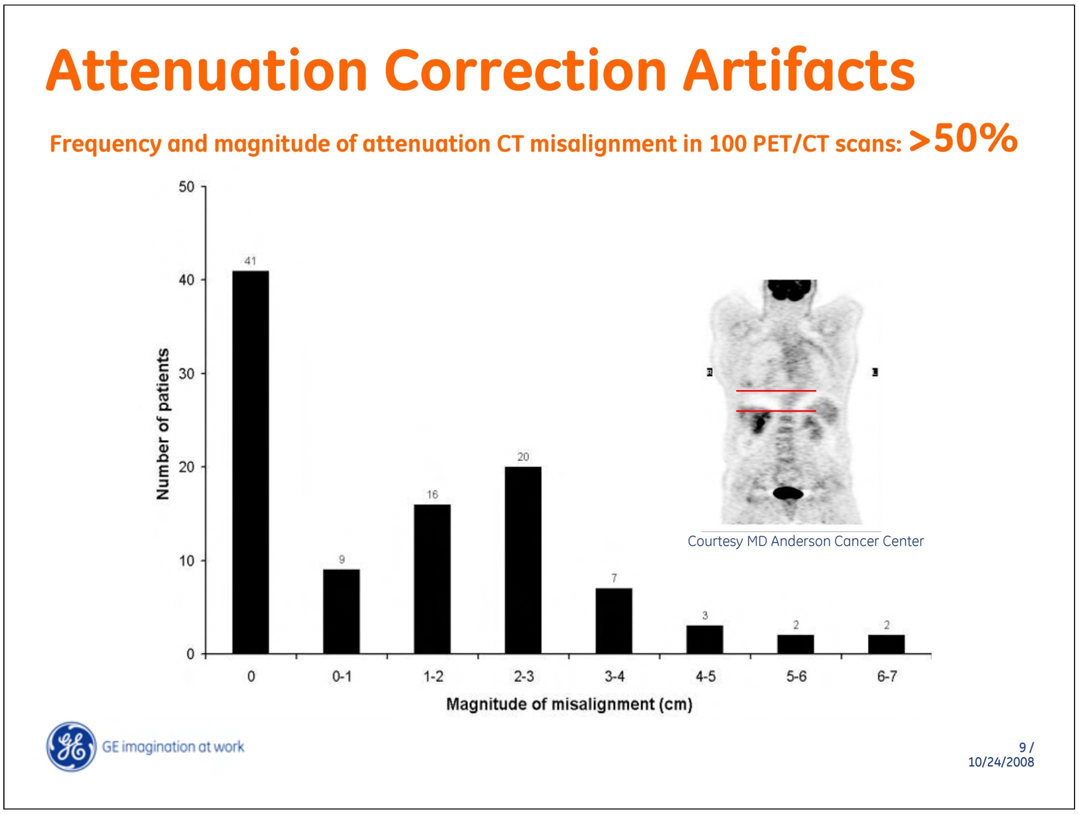
There is a principal difference regarding respiratory motion between PET- and CT-scans. The PET scan is acquired while the patient is free breathing, which resulst in an averate many breathing cycles. The CT-scan is acquired during a specific stage of the breathing cycle.

The upper panel shows a case, where the CT data has a lower diaphragm position than the PET data, resulting in a region with an underestimation of FDG uptake.

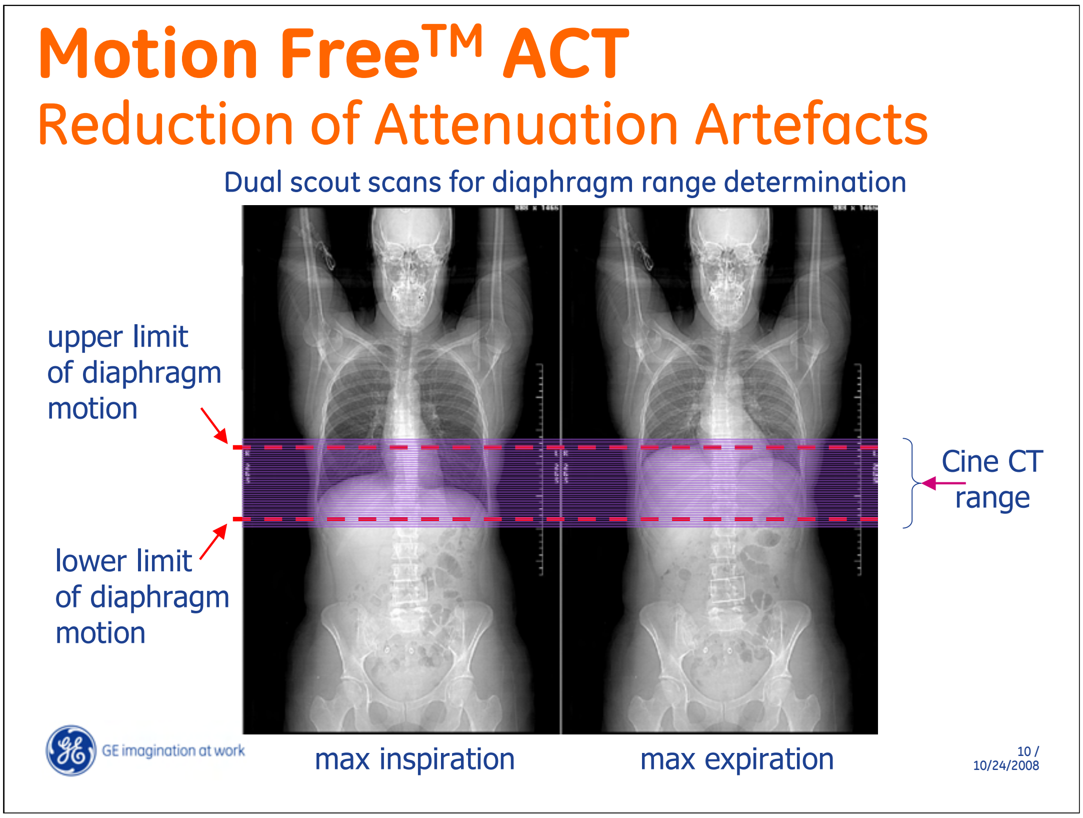
For the lower panel the diaphragm position of the CT scan is higher then the PET scan. This leads to an overcorrection, expressed by a region with an overestimation of FDG uptake.



This diagram shows the frequency over the magnitude of misaligment measured as diaphragm position between corrected image and non attenuated PET.

The displacement caused by respiratory motion can be as large as 2 to 3 cm for tumors near to the base of the lungs.

More than 50% of PET/CT acquisitions show breathing artifacts.

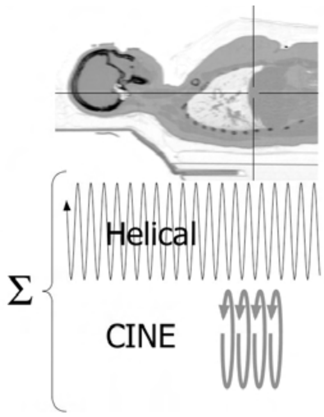


To correct for the misalignment between PET and CT is the use of a CT acquisition spanning over a respiratory cycle for the attenuation correction of the PET data.

This can be done by an additional very low-dose cine CT in the range beween upper and lower linmit of the diaphragm motion.

Motion Free^{TM} ACT

Helical CT + CINE CT =
Average CTAC

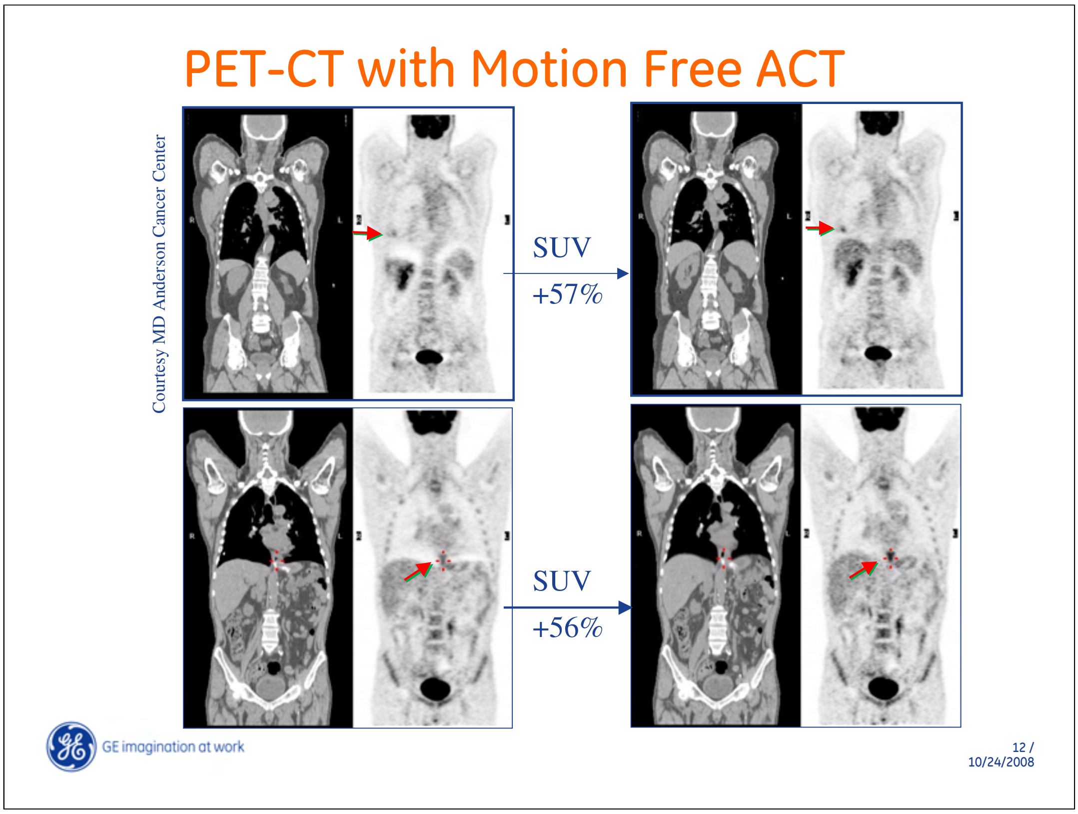


Addresses artifacts caused by respiratory motion over liver's upper lobe.
Improve quantitation

Capability to acquire cine CT and automatically generate average CTAC.
Do not require gating.

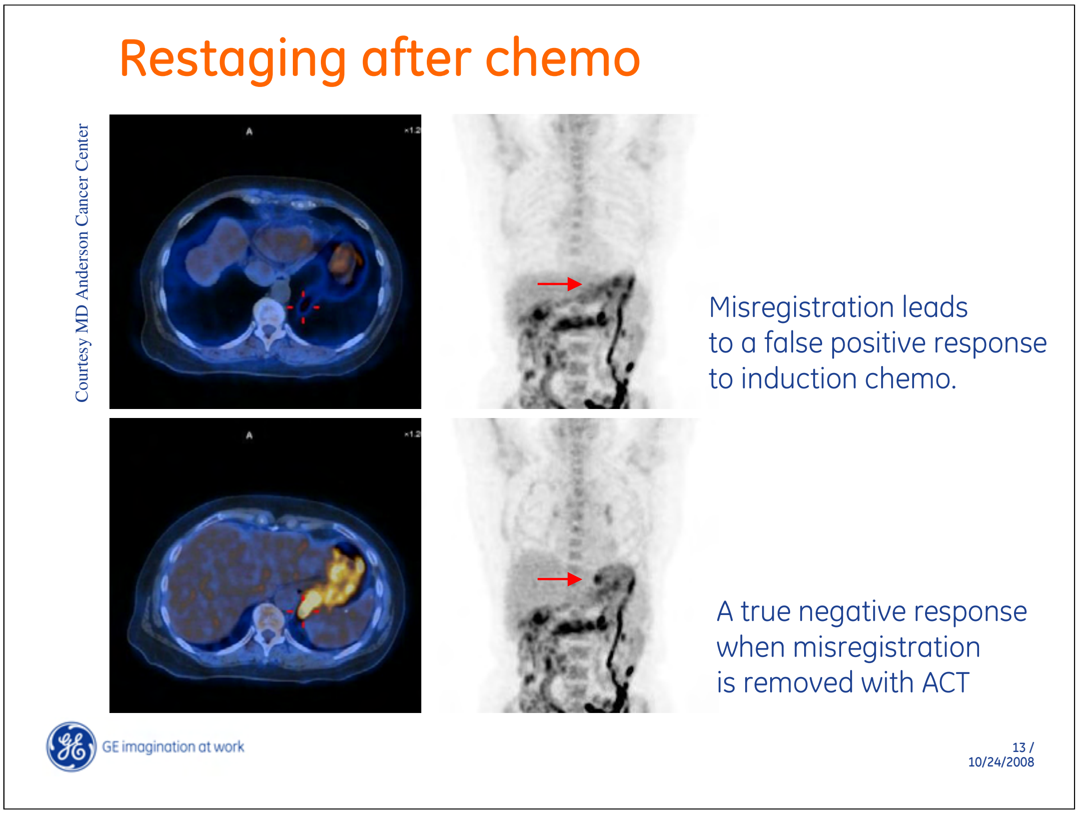
Motion Free CT attenuation correction adresses the artifacts caused by respiratory motion especially over the upper lobe of the liver.

This correction technique does not require respiratory gating. It takes only a few seconds additional acquisition time.



Removing the artifacts caused by respiratory motion may result in greater than a 50% difference in quantitative accuracy – here the standard uptake value.

This potentially provides more accurate monitoring of the treatment response.



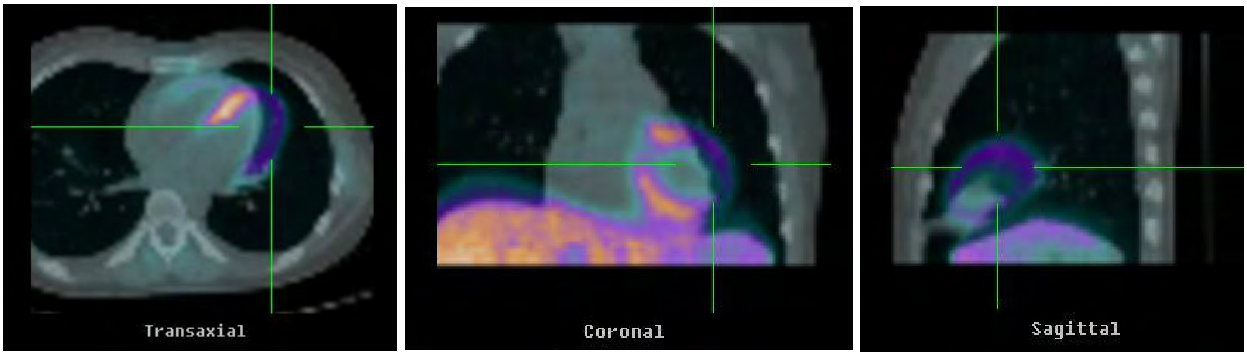
This patient is for restaging after chemo therapy.

The misregistration caused by respiration leads to a false positive therapy response.

With motion free attenuation correction the lesion can be clearly seen, which stands for the true negative response to chemo therapy.

Attenuation Correction Artifacts

Patient Motion: misregistration between CT
and PET emission scan

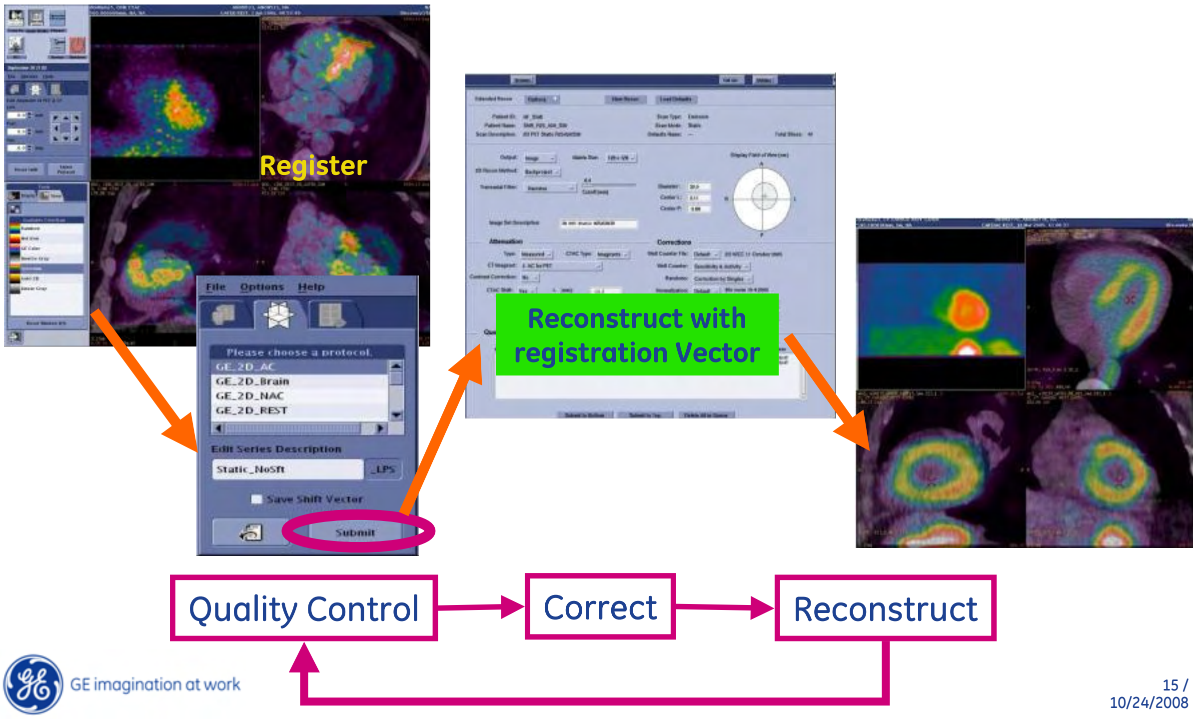


For cardiac PET around 30% of PET perfusion studies show patient motion resulting in misregistration of PET and CT.

CT attenuation correction applied with misregistration yields in false positive defects.

Motion Free ACQC

Addresses artifacts caused misalignment between PET and CT for attenuation correction.

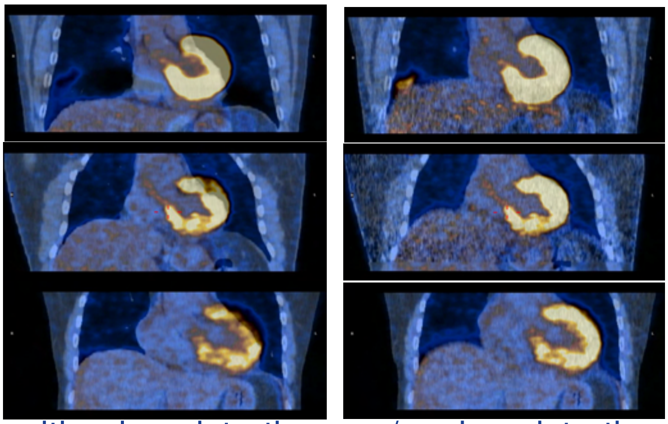


For the correction of cardiac misregistration between PET and CT the PET data can be registered to the CT data and reconstructed with the registration vector.

If the quality concerning the PET/CT registration is insufficient, registration and reconstruction are processed again.

Motion Free ACQC for cardiac PET

Do not require gating



with misregistration   w/o misregistration

Pan et al, Med. Phys. 2006

^{15}O

Turku PET Center

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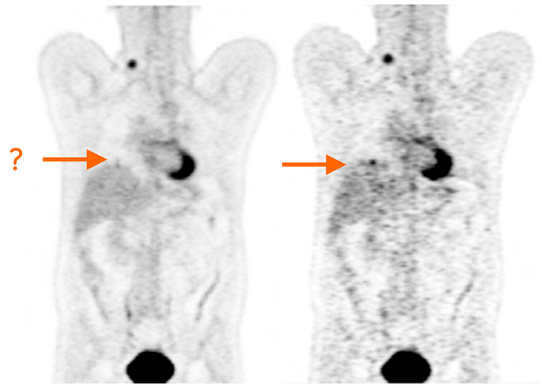
The result of motion free attenuation correction with quality control is an artifact free cardiac perfusion PET, fused with a CT coronary angiogram.

Blurring caused by respiratory Motion

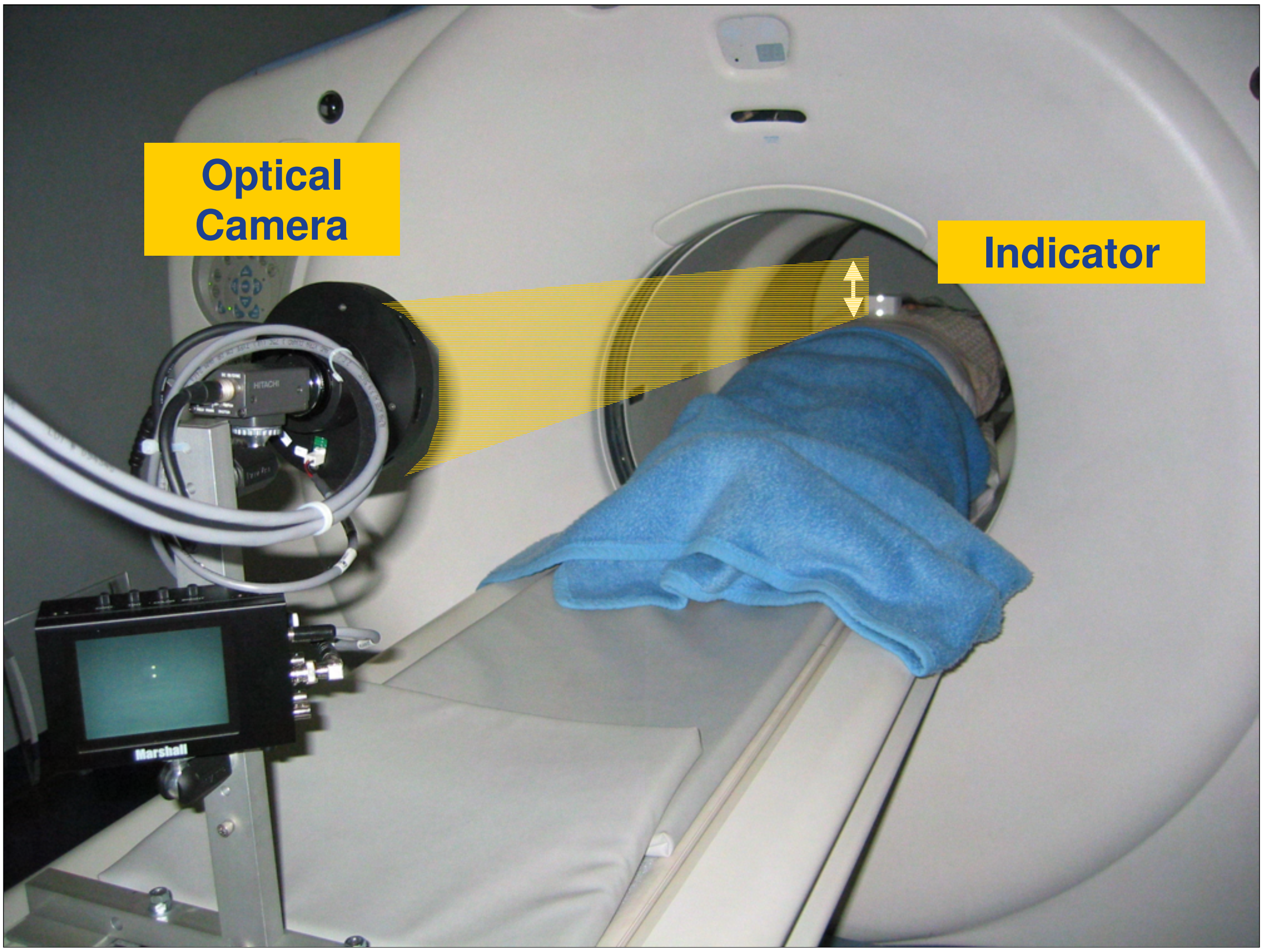


Motion adds blurring effect, therefore reduces lesion detectability…
in lung cancer this is key for patient survival

Images Courtesy: MD Anderson Cancer Center

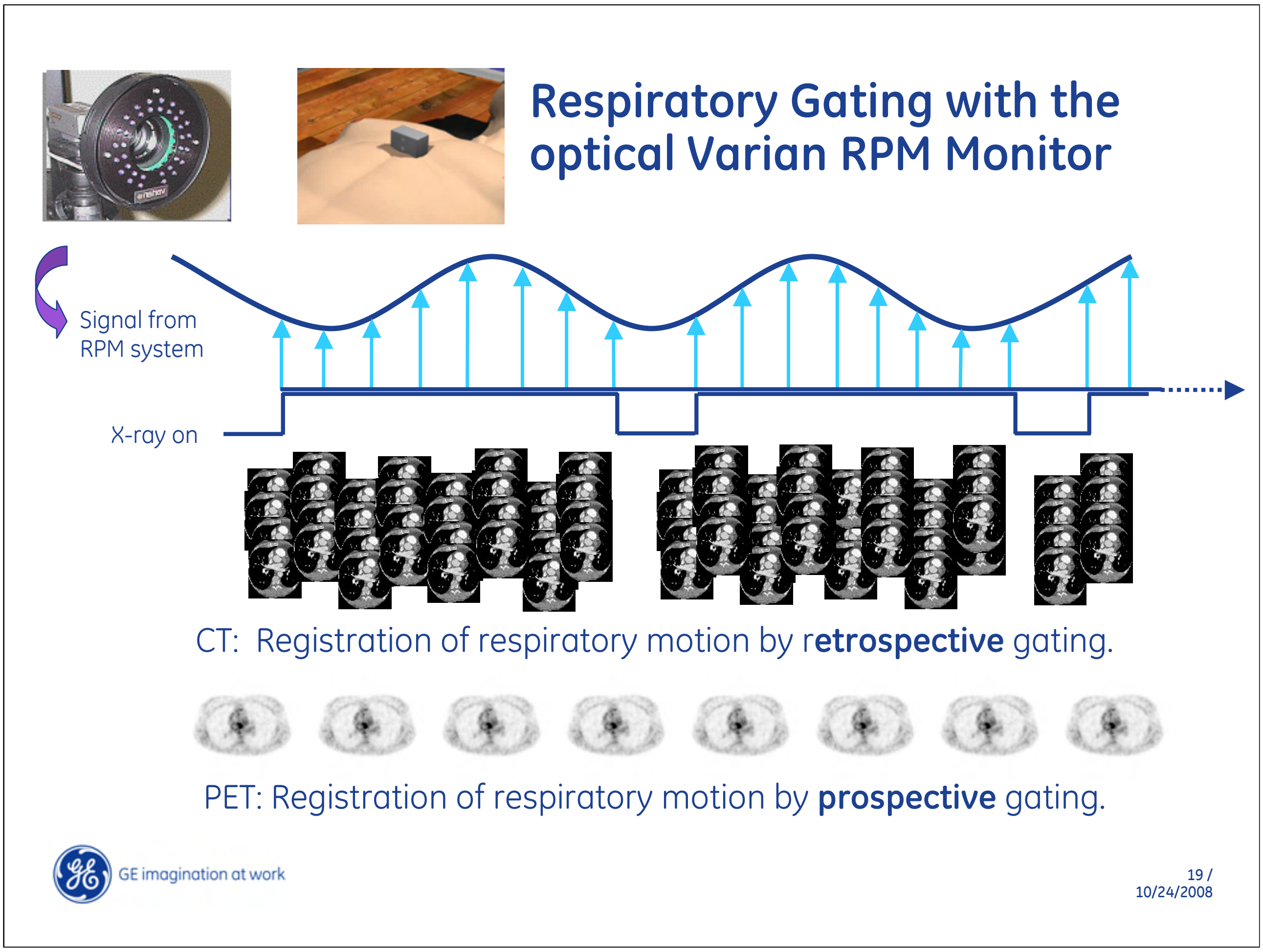
The blurring caused by respiratory motion sometimes reduces the tumor signal to noise ratio so that the tumor becomes invisible.

Depending on the location of the tumor, motion displacement is greater for tumors located close to the liver and in the outer sections of the lungs versus those tumors located close to the mediastinum.



For the registration of the respiratory motion gating of the PET- and CT-acquisitions is necessary.

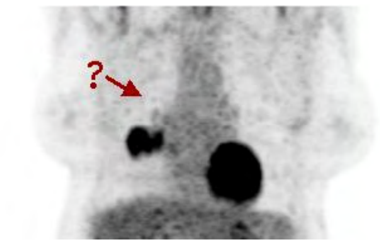
The trigger device is a infreed sensitive video camera facing to an infrared reflector, which is positioned on the chest of the patient and moving withe the respiratory cycle.

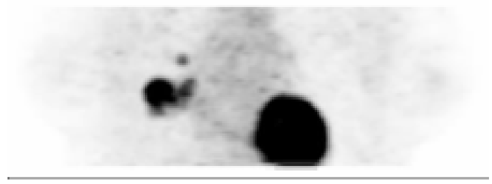


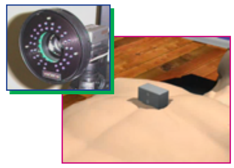
The signal from the trigger device reflects the respiratory motion over time and can be used for retrospective gating of the CT data and for the prospective gating of PET.

The result is a dynamic PET/CT dataset spanning over a mean respiratory cycle.

MotionFree
for Improved Lesion Visualization







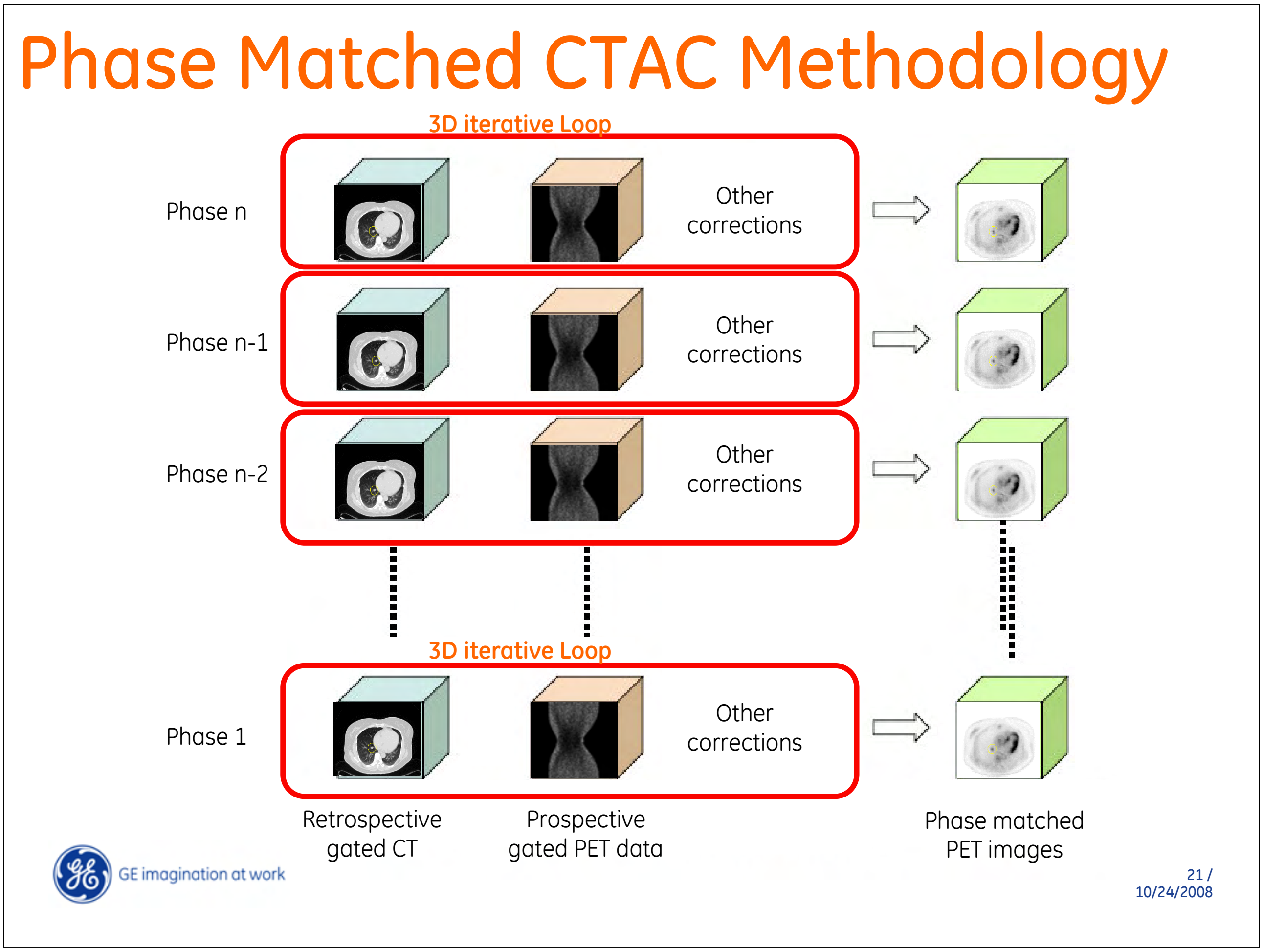
Static Image:

Only the primary tumor can be seen

Respiratory gated PET images for lesion visualization clearly show the mastasis

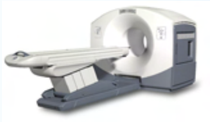
In the conventional static PET image only the primary tumor can be seen.

The respiratory gated PET images clearly show the matastasis, which is blurred by motion in the static scan, so that ist signal is inside the noise.



For the phase matched CT attenuation correction each PET time bin is corrected with the correspondent CT time bin.

Clinical Workflow



Gantry Design/Patient Handling

Interface and Workflow

Reconstruction Engine

- Better access to accessories (RPM, IV)
- Dual cardiac and respiratory gating

- Motion management on acquisition console
- Enhanced gating interface

- Prospective gated reconstruction available while scanning
- Data management for advanced reconstruction techniques

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So the complete iterative reconstruction must be worked out for each respiratory phase.

For a sufficient clinical work flow high reconstruction power is needed for prospective reconstrucion available while scanning.

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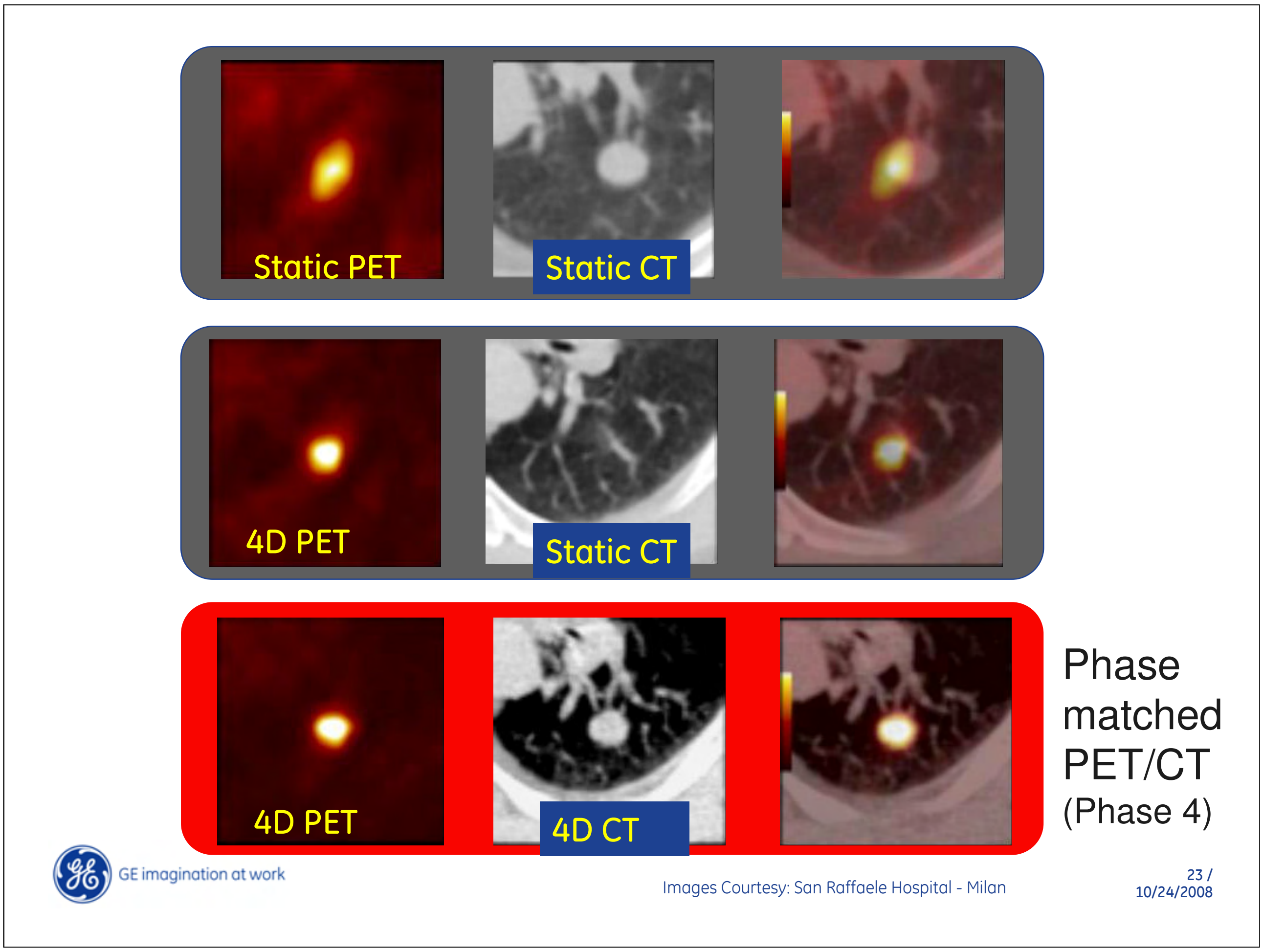
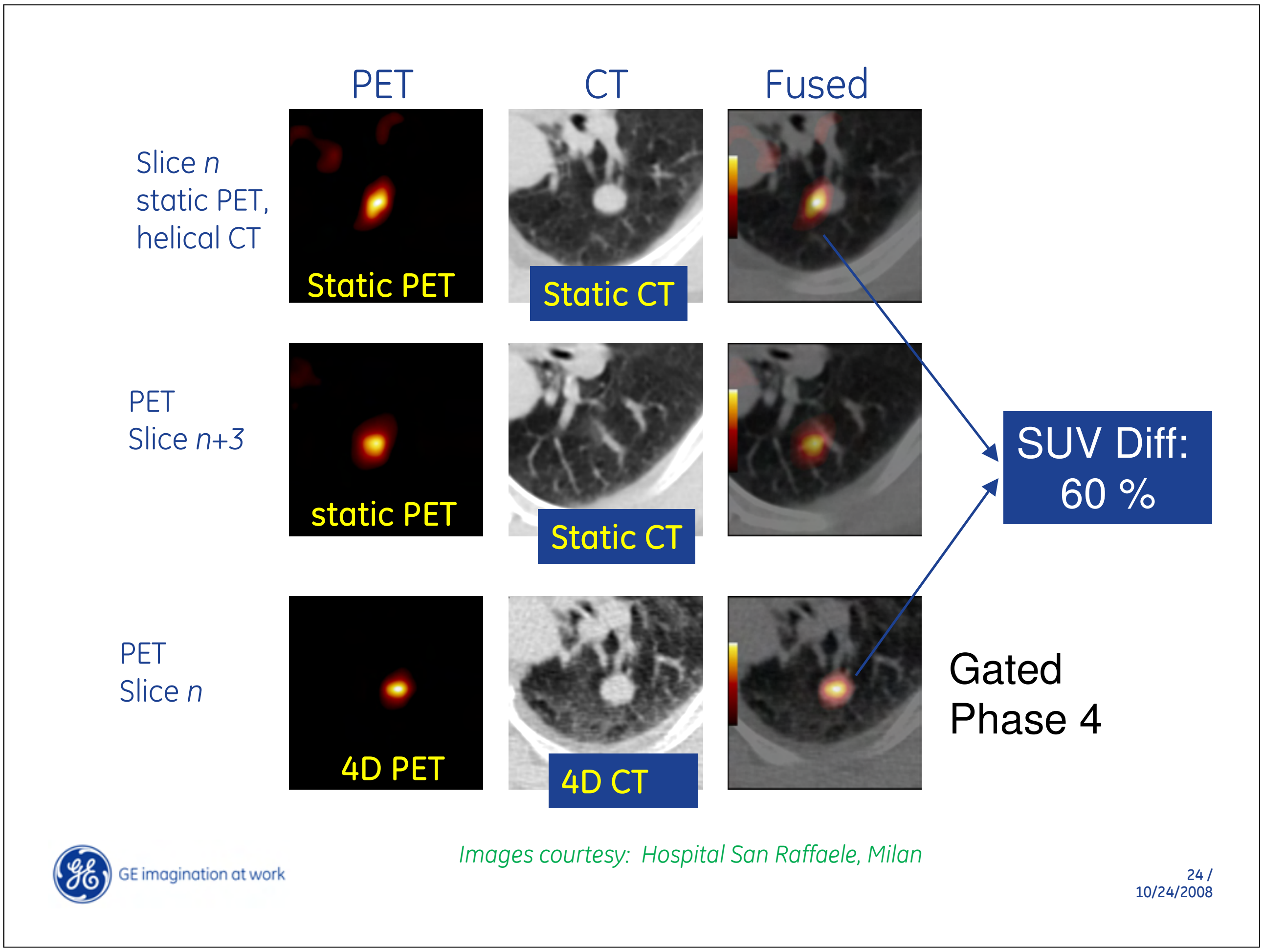


The necessity of phase matched PET/CT is demonstrated here:

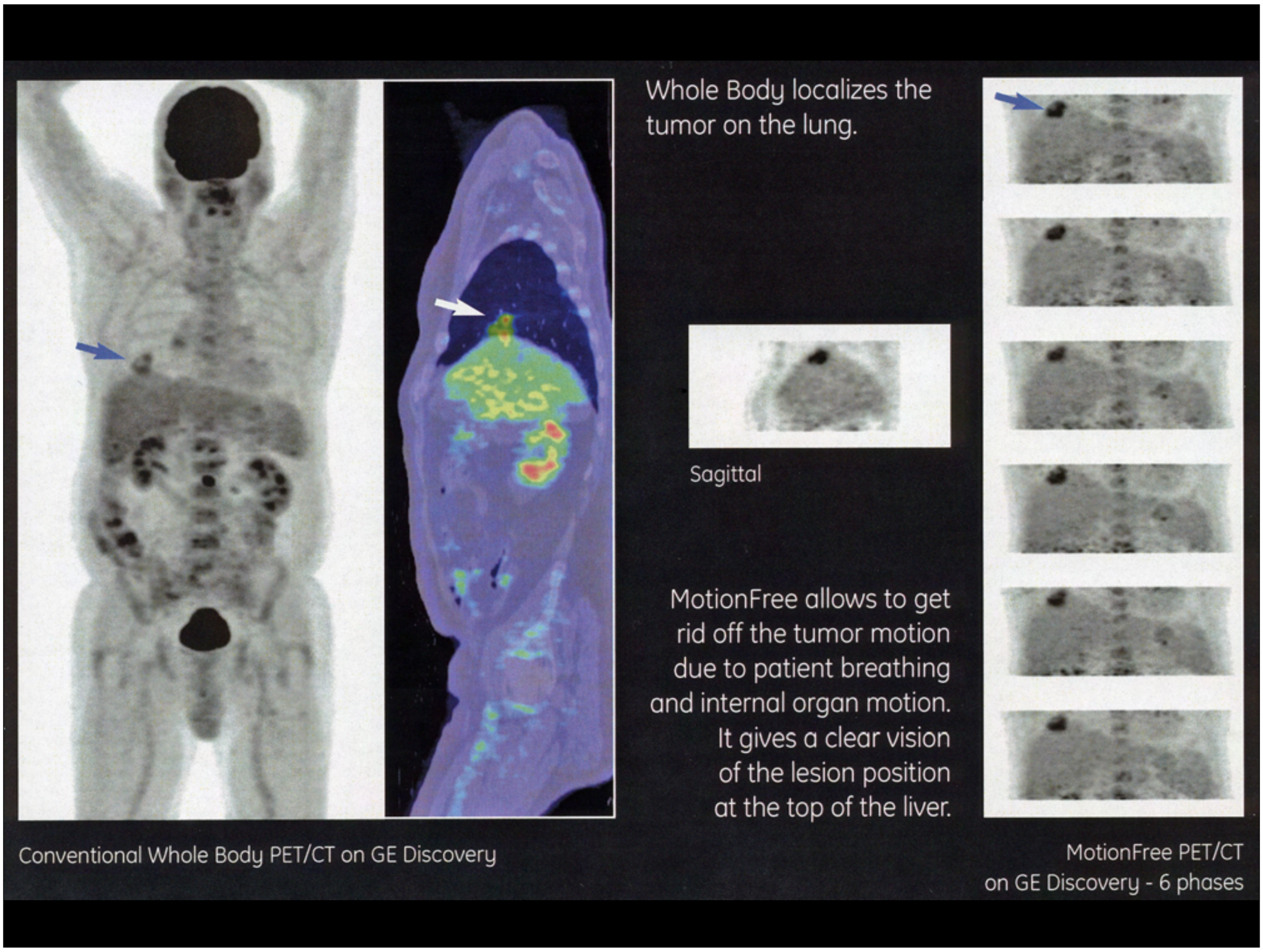
The upper panel shows the blurred lesion in static PET, sharp in static CT, and unsharp in the fused display.

4D respiratory gated PET depicts a sharp lesion but located in a different slice.

Only phase matched PET/CT shows the lesion sharp in both modalities in the same volume.



Phase matched pET/CT has a strong influence on quantification demonstrated here in a SUV difference of 60% between static and 4D PET/CT.



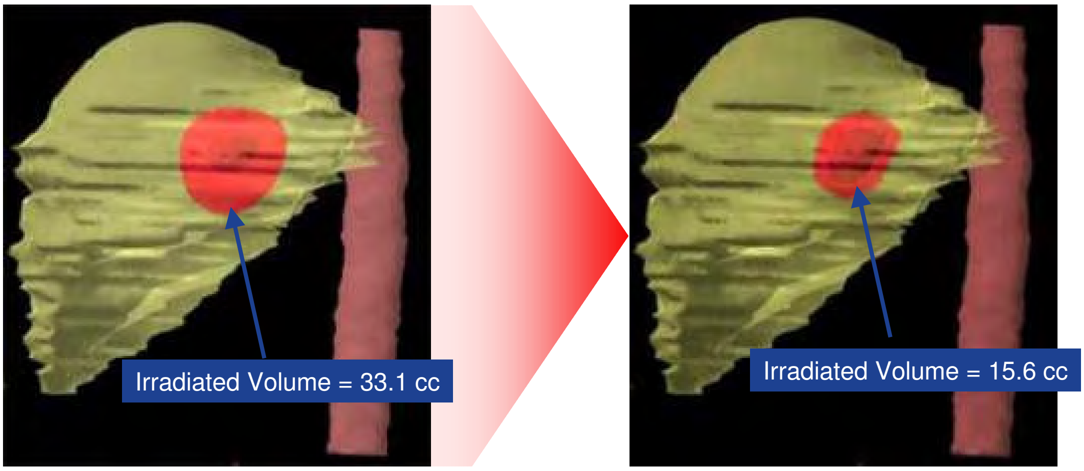
4D phase matched pET/CT improves also the localisation of a lesion as this patient study shows:

The static whole body PET localizes the tumor in the lung.

Using 4D phase matched PET/CT gisves a clear vision of the lesion position at the top of the liver.

Motion Free for improved Radiotherapy Planning

Courtesy Prof. F.Fazio HSR-Milano



Without MotionFree **With MotionFree**

Detecting tumor motion in RT planning improves the efficiency of treatment and limits side effects on patients

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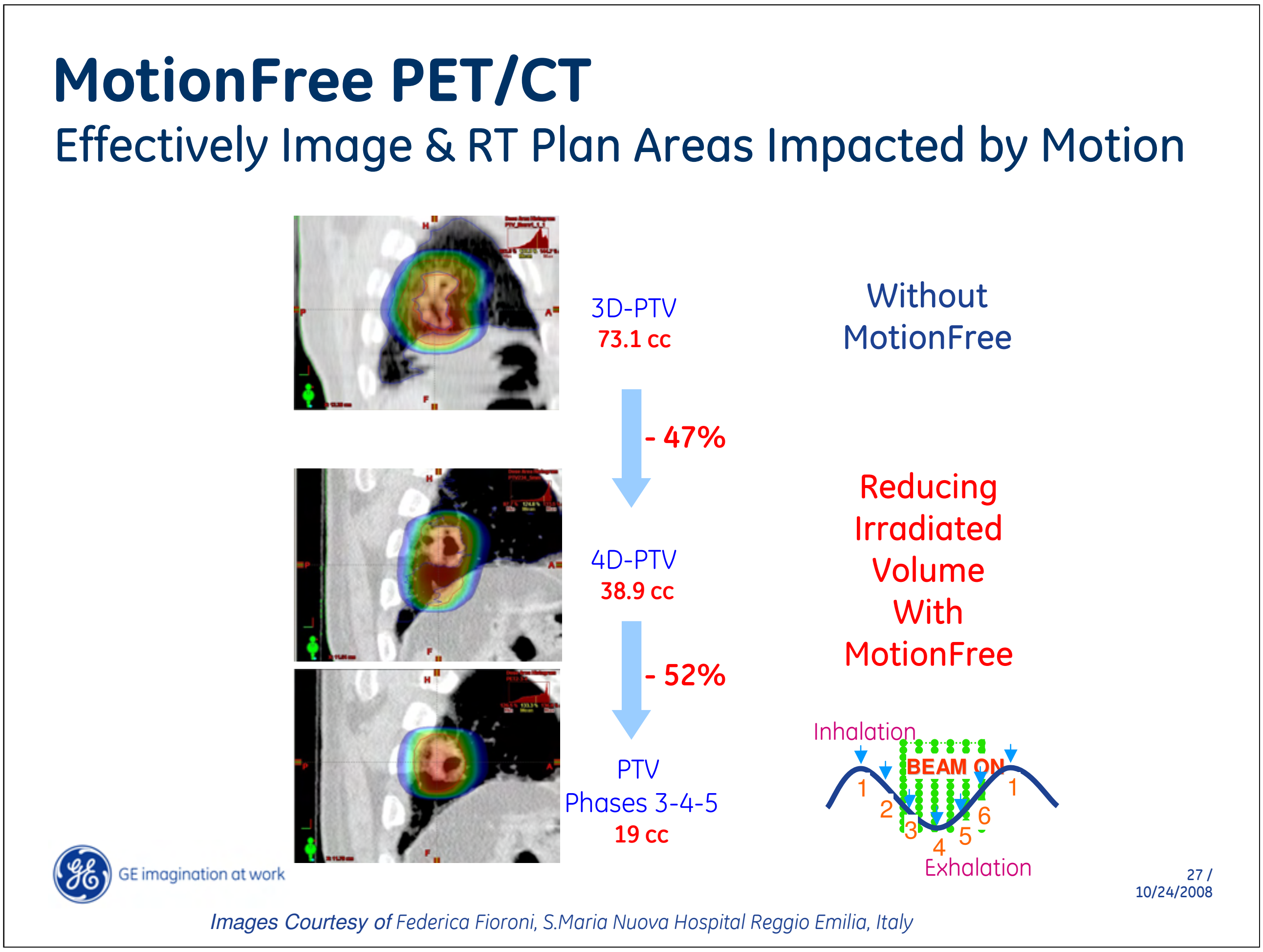
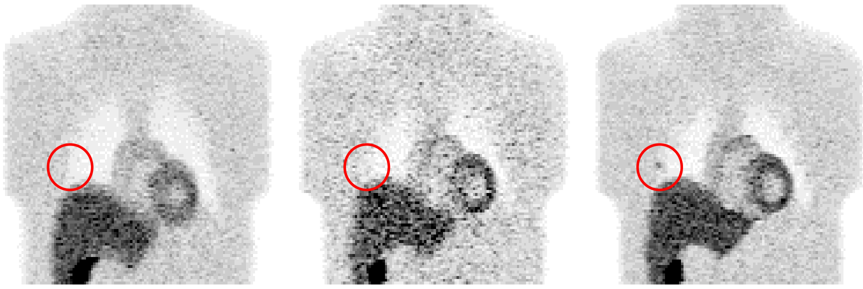
The exact knowledge of the tumor motion improves the efficiency of radiation therapy planning by limiting the side effects on patients.



With the knowledge of the tumor motion the 3D planning target volume can be reduced by 47%.

By the use of respiratory gating of the therapy beam the PTV again is reduced by 52%.



Static PET | 4D PET | Motion Freeze

Respiratory gated 4D PET/CT has the disadvantage, that the countrate statistic is inferior because of the shorter acquisition time per time segment.

Present lesions with low contrast can be hidden by the reduced signal-to-noise ratio.

Registering and summing of all phases increase the countrate statistic and freeze the motion.

Freezing Motion

1 Single Gate Reconstruction
- Reconstruct only gate of interest
- Significant loss of SNR – Most of data thrown away!

2 Reconstruct and Add
- Reconstruct all gates independently
- Register all other gates to gate of interest and average

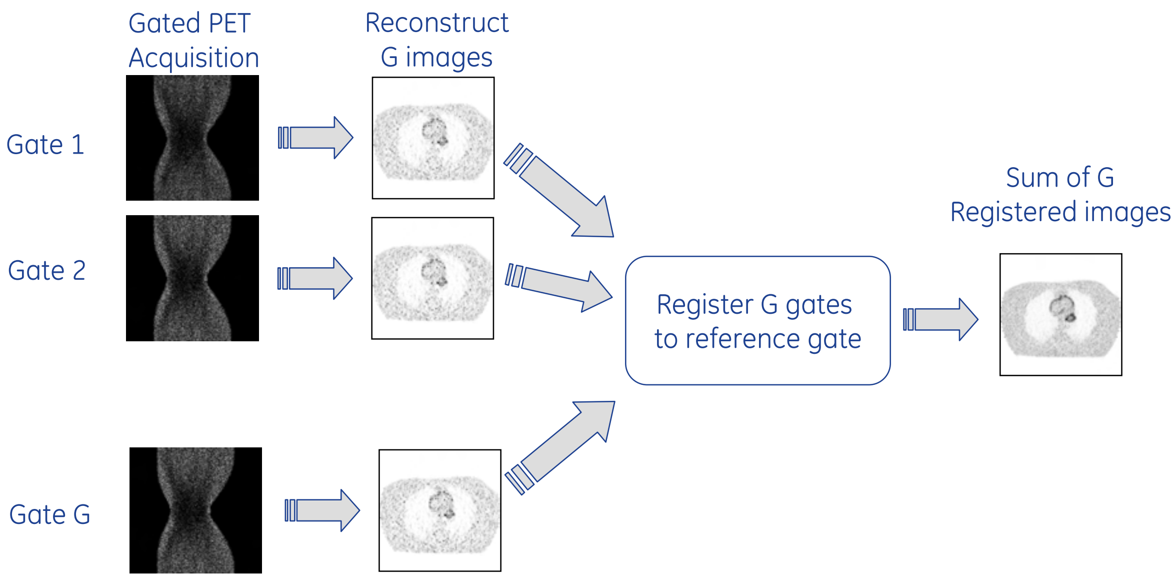
3 Model Based Motion Correction
- Incorporate motion information into system model
- Provides superior bias, variance and lesion contrast

Methods 2 and 3 require accurate motion information

Freezing the motion can be done very simple by single gate reconstruction. Here only the phase of interest is reconstructed. Because most of the PET data are thrown away, there is a significant loss of signal to noise ratio.

Better are the methods which reconstruct all phases and add them together or which use a model based motion correction.

Reconstruct, Register and Add



- Sort data into multiple "gates" based on motion information
- Independently reconstruct all gates
- Register to a reference gate and (weighted) add

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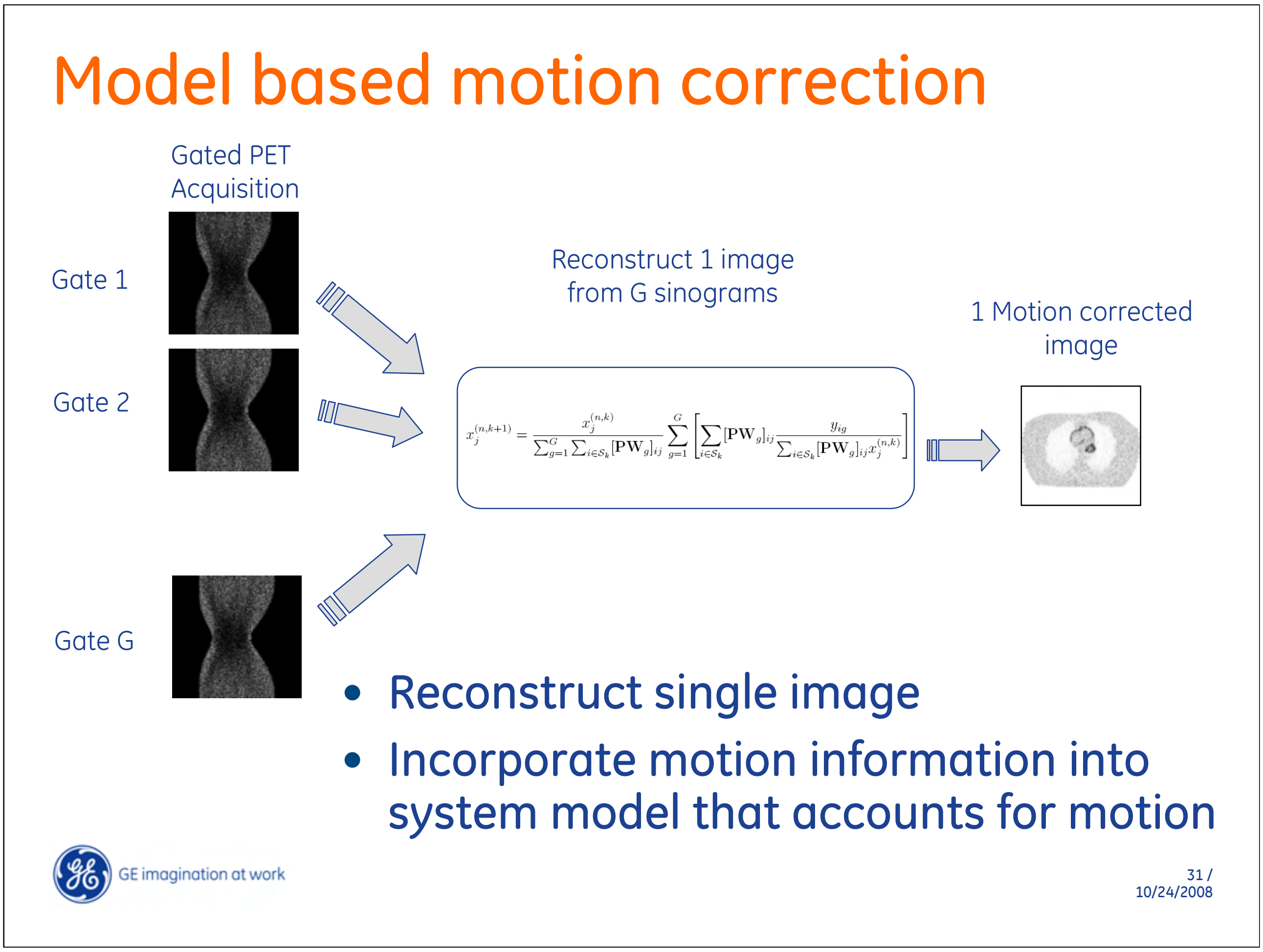
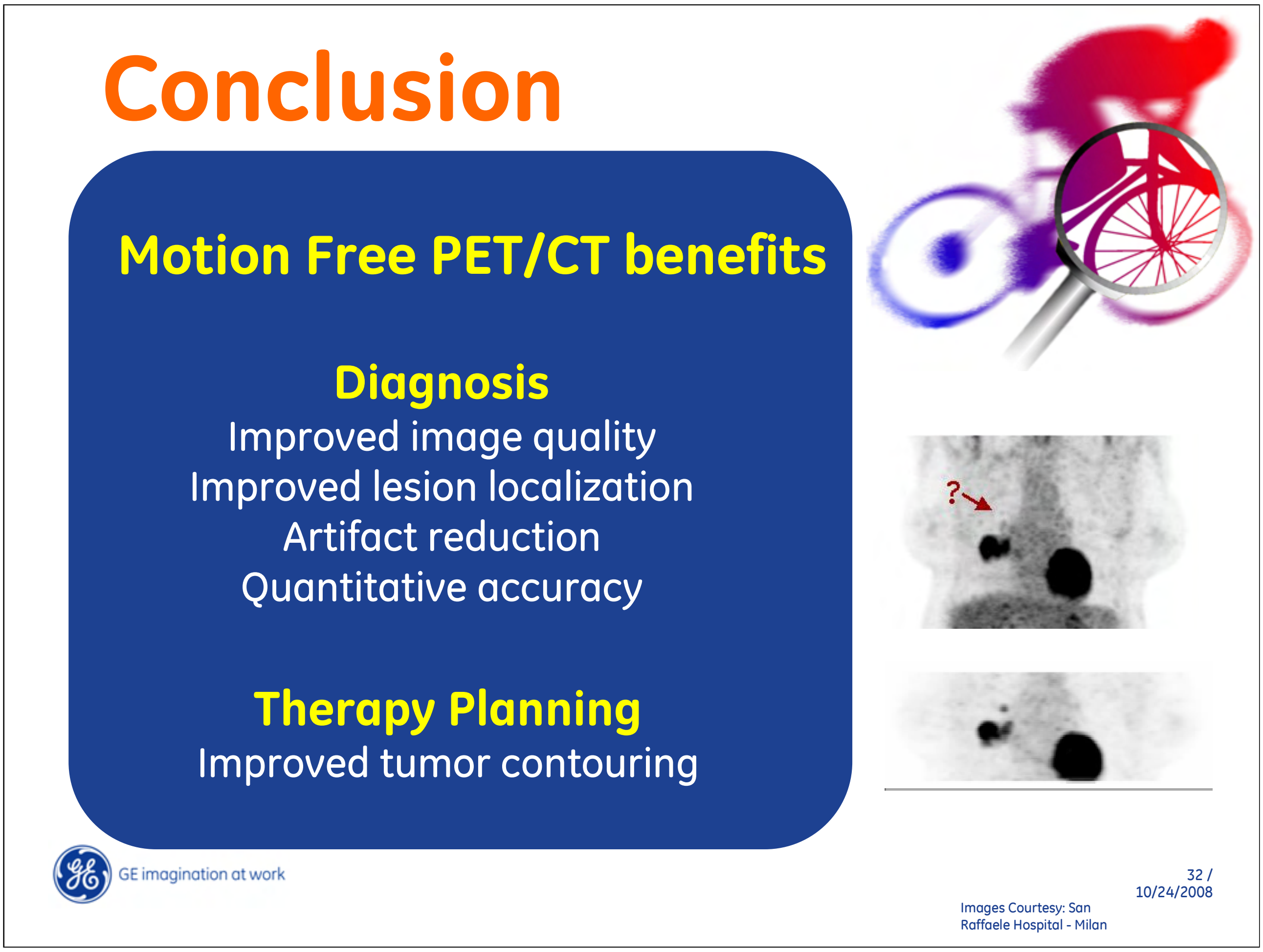
The method Reconstruct, Register and Add sorts all data into multiple gates and reconstructs them all independently.

Finally all respiratory phases are registered to a reference phase and added together.



The model based motion correction is works in progress.

Only a single PET dataset is reconstructed but with incorporated motion information into the system model.



Conclusion

The benefits of motion free PET/CT are
For Diagnosis:
-improved image quality
-Improved localization of lesions
-Artifact reduction
-Quantitative accuracy

For therapy planning:
-improved tumor contouring