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Practical Consideration for Integrating PET/CT in Radiation Therapy Planning for Patient Care

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Abstract

Over the past 20 years, PET/CT has had many technological and developmental advancements for patient care. PET/CT has evolved from solely used as a diagnosis and staging tool to now having an impact on treating cancer through a collaboration with radiation oncology. There are multiple considerations when integrating PET/CT into radiation therapy planning such as PET/CT center needs, the types of scans to offer, workflow considerations between the two centers, PET/CT center growth and demand on schedules, and the impact PET/CT will have on radiation treatment planning. Careful planning and implementation are important to offer optimum care to patients integrating PET/CT in radiation therapy planning.

Keywords: PET/CT, Radiation Therapy, Radiation Oncology, Radiation Planning, CT Therapy Planning

Introduction

Since Positron Emission Tomography (PET) was approved for clinical investigation of pulmonary nodules in 1998 (*1*), there has been unprecedented growth and development in technology and clinical applications to benefit patient care. Multiple modalities have come together including PET with Computed Tomography (CT) and more recently PET with Magnetic Resonance Imaging (MRI) to form the hybrid imaging of PET/CT and PET/MRI to assist with more accurate diagnosis, staging, therapy planning and therapy response assessment. When used correctly, PET/CT can have a great impact on the treatment planning for radiation therapy because of its unique biological target volumes when compared to other modalities. There are practical considerations to implement PET/CT in radiation therapy planning such as PET/CT center needs, the types of scans to offer, workflow considerations between PET/CT center and radiation therapy planning center, PET/CT center growth and demand on schedules, and the desired impact PET/CT will have on radiation treatment planning (*2*).

PET/CT center Needs

The first thing to consider is what needs to be in place for the PET/CT center to offer support for radiation therapy planning. There needs to be specific personnel training, hardware requirements and changes to the PET center schedule to facilitate these studies.

(a) Hardware

Specific equipment is required to be able to offer the scans needed for radiation therapy planning. Some PET/CT scanners use lower amounts of radiation to produce attention correction only CTs, and do not produce diagnostic quality CTs. To be able to use the PET/CT scanner for

radiation therapy, the CT component of the PET/CT scanner needs to be able to produce diagnostic quality CTs. Radiation therapy relies on diagnostic quality CTs for planning many of their treatments.

Some radiation therapy planning centers prefer a contrast enhanced CT for therapy planning and a pressure injector will need to be in place to allow the use of intravenous contrast. Nuclear medicine technologists need to be trained and competent in performing IV contrast CTs to offer this unique service. Anaphylactic shock is a risk anytime iodinated contrast agents are used, so a physician needs to cover this responsibility and the staff be properly trained and prepared in case of an emergency.

A radiation therapy pallet is required for scanning. Therapy treatment tables are flat, therefore any scans used for therapy planning needs to be imaged on a flat surface. The curved contour of a standard PET/CT table may interfere with planning scans, but therapy pallets are designed to slide over the curved PET/CT table to allow scanning on a flat surface that matches the radiation therapy system.

A 4D infra-red patient alignment laser system is needed to assist with the correct positioning for the scans. The exact placement of the patient's body on the table is very important, and these lasers allow for exact alignment of the patient between imaging table to treatment table (*3*).

In addition to positioning the patient's body in the exact alignment on the table, placing the actual organ or tissue that is receiving treatment in the correct position is of high importance. An assortment of positioning and stabilizing products are required. Stabilizing products such as face masks, bite blocks, and beanbags are used. Face masks are personally made for each patient

by using a plastic that when introduced to warm water will mold to the patient's face in the position that is desired. The mask then dries to a hard firm structure that will place their heads in the exact same position every time. (See Figure 1) For example, when treating a head or neck tumor the use of a face mask and bite block, which are made very similar, may be required to prevent motion and to position the tongue (*3*). If the patient were to experience some form of anatomical change like surgery or excessive weight loss, then a new mask would need to be made (*4,5*).Beanbag stabilizers are used to form around specific areas of the body to prevent motion during imaging and treatment, and are personally made for each patient as well (*3,6*). (See figure1)

Lastly, there will need to be appropriate computer systems in place to allow for the complexity of the image integration. For example, having the capability to send the images from the PET/CT system to the correct computer system for radiation therapy use. There are multiple computer workstations available on the market for this use. These workstations are not only required but also allows for the options of a collaborative method where either department can offer regions of interest or SUV values.

(b) Scheduling

Once the PET/CT center has all essential hardware and trained personnel, it is time to look at the schedule. There needs to be dedicated time slots on the PET/CT schedule to support radiation therapy scans. Most of the scans will require scheduling PET imaging and radiation therapy resources so they can be available at the same time. A strong communication channel needs to be in place between the PET center, radiation oncology center, and the scheduling team to prevent logistical errors.

Typically, therapy scans take 15-30min of table time depending on the body region being imaged. This makes therapy scans compatible with most PET/CT time slots which consist of 30min. Occasionally a patient may need a larger time slot due to a specific patient prep.

Once the radiation oncologists and therapists are on board with the collaboration, encourage them to discuss with the referring physician the need to order the PET/CT and the radiation therapy planning at the same time. This will allow for the PET/CT and CT therapy planning combination scan, which produces the best images for planning a therapy. This will also be of assistance to patients by getting the two scans done on the same day instead of traveling two separate days.

Scans to offer

With appropriate equipment and communication channels in place, it is possible to support radiation oncology with multiple imaging services using a PET/CT imaging system. For initial therapy planning, routine follow-up, and disease progression a standard wholebody PET/CT scan is used. Once the radiation oncologists use the standard wholebody PET/CT for initial treatment planning, then disease progression will be monitored by using follow-up wholebody PET/CTs scans.

A diagnostic quality CT therapy planning scan can be offered on the PET/CT system and used to plan a patient's initial radiation treatment. For this scan, a combination team of a PET/CT technologist and a radiation therapist is needed. The PET/CT technologist will facilitate operating the PET scanner, while the radiation therapist will set the patient up with the appropriate restraints, stabilizing products, and positioning.

For lesions in an area with a lot of motion, a 4D gating scan using CT or PET can be used to assess accurate motion and changes in fiducial marker movement over the course of therapy. Depending on the type of treatment the patient will receive, tumor motion can be a big factor. Specific types of radiation planning benefit from seeing the full range of motion of the tumor, and other areas involved due to the motion. Fiducial marker placement and the movement of the fiducials are very important for treatment planning. For accurate treatment, the fiducials need to be in the accurate place and move in the same motion as the tumor.

Patients entering the outpatient imaging workflow and are known with certainty that they will be treated by the same institution, offering a combined PET/CT and CT radiation therapy planning study is a great option. The patient's PET/CT scan and CT radiation therapy scan will be scheduled on the same day in consecutive time slots. The workflow starts with the PET/CT scan. At the end of the PET/CT scan, the radiation therapist would position the patient appropriately with the face mask or any other stabilizing products needed. Their CT radiation therapy planning scan is completed. Then immediately following, an additional PET image in the same position can be completed over the area of interest. This workflow offers initial treatment planning standard wholebody PET/CT scan, a CT radiation therapy planning scan, and a PET image of only the area of interest that matches spatially with their CT planning scan.

PET/CT Center Growth

Once the collaborative workflows begin, there may be an increase in the PET/CT requests from referring physicians and radiation oncologists, which require additional logistics considerations for outpatient PET/CT imaging. Discussions with the radiation oncology group during collaboration development should include determining expected referral numbers as well as information on radiation oncology anticipated growth. Potential radiation oncology PET/CT

referral growth should be included in outpatient imaging department numbers to enable appropriate planning of imaging services, staffing, and scheduling to adequately handle the increased imaging load without creating unacceptable wait times for imaging. Although the cost for hardware, equipment, and new technology needed will vary, and can be expensive, the PET/CT growth that comes from this type of collaboration can, over time, absorb that cost and even help bring in more profit for the PET/CT center. Our first year collaboration results (shared below) indicate the potential growth that can be observed with such collaborations.

In the first year of radiation oncology PET/CT collaborations, radiation oncologists directly added 108 PET/CT procedures to our outpatient workflow. During the first half of the year, forty PET/CT procedures were ordered with sixty-eight added in the second six month period. Over the course of the first year, we experienced growth of 70% from the first half of the year to the second, thus suggesting the potential growth capabilities of this type of collaboration. This data does not include any indirect referrals that came from other oncology groups that may have been influenced by consults with radiation oncology.

As new software and imaging technology are added to the PET/CT system, it is important to provide information to the radiation oncology group on how that technology is used in imaging and have discussions on how the new technology might be used with radiation therapy planning. Technologies that are specific to radiology and PET/CT imaging may not be familiar to radiation oncology teams. Having discussions and educational reviews regarding new features will assist with their adoption and may improve image quality or increase efficiency of imaging workflows for both radiology and radiation oncology services.

Another recent potential growth area for PET/CT and radiation oncology collaborations, is the use of newly approved radiopharmaceuticals for PET imaging. Fluorodeoxyglucose (FDG)

has been the primary radiopharmaceutical used to diagnose, stage, and monitor cancer in patients by imaging glucose utilization in the body. Within the last two years, new radiopharmaceuticals for imaging neuroendocrine tumors and prostate lesions have been approved for use in the United States with more specific tumor seeking agents on the horizon. Access to these compounds will create additional opportunities for collaborative PET/radiation oncology services and provide more individualized imaging and radiation therapy planning.

PET/CT Impact on Radiation Treatment

The collaboration between PET/CT and radiation oncology allows for PET/CT imaging to have an impact on diagnosis, staging, treatment care path, target delineation, clinical trials, research, and follow up. The patient's treatment planning begins by physicians discussing the diagnosis and staging aspect, typically as part of tumor board discussions. To stage a patient, a radiation oncologist will utilize the PET/CT to determine the gross tumor volume, metastatic disease, or nodal involvement. The physician will discuss with medical oncologist, surgical oncologist, and other physicians to determine the best treatment plan for the patient involving chemo and radiation; this is referred to as the treatment care path. If radiation therapy is prescribed, the physician can begin his treatment plan process immediately and will delineate the target volume for treatment planning. For some patients, the patient's performance status or disease involvement make palliative care the best option for overall outcome.

PET/CT collaboration may improve the treatment planning workflow for the initial patient's treatment and for patients who have had prior radiation treatment. Use of integrated PET/CT radiation therapy workflows result in similar patient position between modalities enabling a number of key radiation therapy workflow benefits:

- Rigid registration between modalities can be used instead of more error-prone deformable registration
- Lesion contours can be more easily transferred reducing inaccuracies in radiation therapy plans
- Evaluation of the dose with respect to critical structure and tumor volume can be completed more rapidly. This leads to a more efficient process for treatment planning by reducing the registration time, fusion review time, and contouring time.
- Less radiation exposure to the patient because a single scan workflow can be employed. Robust collaboration between radiation oncology and PET/CT imaging services can enable a more efficient and effective pre-treatment and treatment planning process.

Tables 1 and 2 summarize the differences in efficiency that may be realized in the radiation therapy workflow when incorporating PET/CT imaging versus not using PET/CT imaging studies for therapy planning. With collaboration, times for initial and prior treatment are improved with maximum time savings of approximately 157min and 54min, respectively.

The clinical relevance of imaging and therapy collaborations for radiation oncology patients can be appreciated by reviewing several clinical examples. Three cases are presented below: a pre-treatment case, an intra-treatment case, and a post-treatment case. The institutional review board did not require consent from the patients below because the images are being used for educational case study purposes.

(a) Pre-Treatment Case

In this abdominal mass example, PET/CT imaging was used to aid in drawing treatment planning contours. A typical planning workflow will define three primary volumes: gross tumor volume, clinical tumor volume, and planning target volume (*7*). Gross tumor volume when using PET describes the extend of disease visible on imaging. In this example, the FDG uptake visualized by PET/CT is used to determine the gross tumor volume shown in yellow.

The clinical tumor volume is the area included in the gross tumor volume plus some additional margin related to sub-clinical disease. This volume is highly variant and complex to determine, as the disease extent cannot be accurately measured. The area in dark blue is the clinical tumor volume defined by the gross tumor plus the microscopic disease.

The cyan outline is the planning target volume, which includes the clinical tumor volume plus a margin for daily treatment setup and patient positioning. The purpose of a properly defined planning target volume is to make sure that the defined clinical tumor volume receives the appropriate radiation dose prescription. These volumes are used in defining the patient treatment plan. (See Figure 2)

(b) Intra-Treatment Case

This example shows an intra-treatment use of PET/CT imaging for a head and neck patient who presented with initial disease. The therapy path was planned using PET/CT with a mask molded to fit the patient and increase positional accuracy between the imaging and therapy systems. During treatment, the patient lost weight requiring a new setup and the creation of a new face mask. For this study, the patient's previous PET/CT was registered to their follow-up CT scan using deformable registration. This methodology is used to determine adjusted treatment volumes

quickly as previous contours can be deformed to match contours on the new imaging studies. Using this methodology, the patient was able to continue their full course of radiation without having to build in any breaks. (See Figure 3)

(c) Post-Treatment Case

In this example, a head and neck case is shown with the top images visualizing pre-treatment volumes. The middle image shows the individual's PET/CT follow up scan acquired approximately 1 year after beginning therapy. The follow-up PET/CT study is fused to the initial plan allowing delineation of the new tumor volumes to treat. The bottom image shows the new treatment volumes, where the knowledge of the previous treatment and contour placement allowed us to treat a reoccurring tumor next to prior treatment. (See Figure 4)

Conclusion

When the PET/CT center forms a collaboration with the radiation oncology center, there are multiple considerations that need to be considered such as PET/CT center needs, the types of scans to offer, workflow considerations between the two centers, PET/CT center growth and demand on schedules, and the impact PET/CT will have on radiation treatment planning. Imaging and therapy collaborations will contribute to the better patient course of treatment, increased efficiency in workflow and time management within the centers, and positive effects in the pre-treatment, intra-treatment, and post treatments of radiation oncology patients.

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References

1. Center of Medicare and Medicaid Services. Regulations and Guidance. Retrieved From: https://www.cms.gov/RegulationsandGuidance/Guidance/Transmittals/downloads/R136CIM.pdf

2. Acuff S, Jackson S, Osborne D. Clinical considerations for using PET/CT in Radiation Therapy. *Society of Nuclear Medicine and Molecular Imaging. San Diego.(2016)*

3. Verhey L, Goitein M, McNulty P, Munzenrider J, Suit H. Precise positioning of patients for radiation therapy. *Int J Radiat Oncol Biol Phys,* Volume 8, 289 – 294.

4. Schoenfeld JD, Kovalchuk N, Subramaniam RM**,** Truong MT. PET/CT of cancer patients: part 2, deformable registration imaging before and after chemotherapy for radiation treatment planning in head and neck cancer. *AJR Am J Roentgenol*. 2012 Nov;199(5):968-74. doi: 10.2214/AJR.12.8562

5. Kovalchuk N, Jalisi S, Subramaniam RM**,** Truong MT. Deformable registration of preoperative PET/CT with postoperative radiation therapy planning CT in head and neck cancer. *Radiographics*. 2012 Sep-Oct;32(5):1329-41. doi: 10.1148/rg.325125008

6. Bentel G, Marks L, Sherouse G, Spencer D, Anscher M. The effectiveness of immobilization during prostate irradiation. *Int J Radiat Oncol Biol Phys,* Volume 31 , 143 – 148

7. Burnet NG, Thomas SJ, Burton KE, Jefferies SJ. Defining the tumor and target volumes for radiotherapy. *Cancer Imaging*. 2004;4(2):153-161. doi:10.1102/1470-7330.2004.0054.

TABLE 1

Workflow without Collaboration from PET/CT for Initial Treatment		**Workflow with Collaboration from PET/CT for Initial Treatment**	
Task	Time (min)	Task	Time (min)
Import Images	3	Import Images	3
Image registration (Deformable Registration Required)	20	Image Registration (Native Registration)	3
Verify Registration	20	Verify Registration	4
Import Images into the planning software	4	Contour	120
Contour	240	Planning	1,440
Planning	1,440		
Total Time	1,727	Total Time	1,570

TABLE 2

Workflow without Collaboration from PET/CT for Prior Treatment		**Workflow with Collaboration from PET/CT for Prior Treatment**	
Task	Time (min)	Task	Time (min)
Import Images	3	Import Images	3
Image registration (Deformable Registration Required)	20	Rigid Registration	10
Verify Registration	20	Verify Registration	20
Transfer/Deform Contours	30	Transfer Contours	10
Verify Contours on New CT	10	Verify Contours on New CT	10
Deform Prior Dose to Current CT	10	Contour	240
Verify the Dose Transfer to New CT	10	Planning	1,440
Import Images into the planning software	4	Insert Plan Sum	5
Contour	240	Evaluate Plan Summation	10
Planning	1,440		
Insert Plan Sum	5		
Evaluate Plan Summation	10		
Total Time	1,802	Total Time	1,748

Figure1: Radiation pallet placed on the PET/CT table with face mask and bean bag stabilizer. 4D Laser system also seen. This is what a common setup looks like when using a PET/CT system to create radiation therapy imaging.

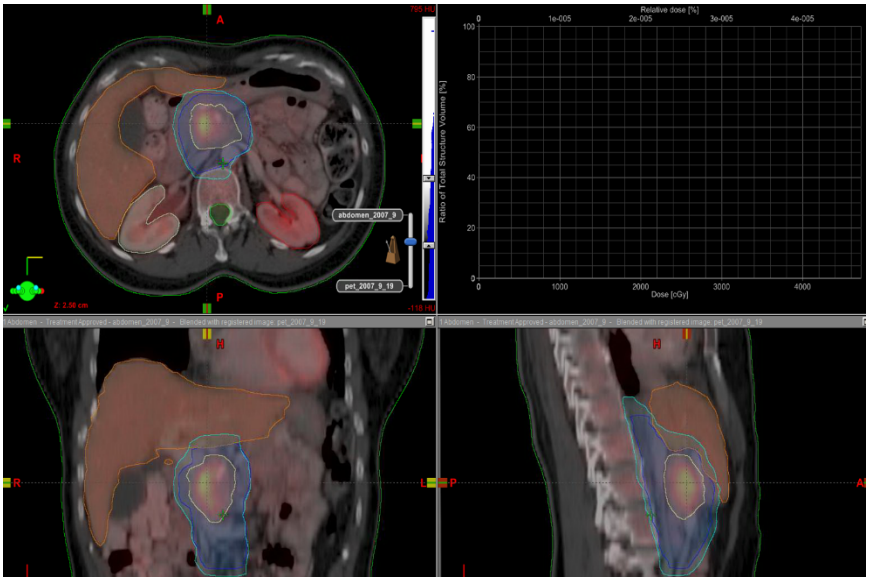

Figure 2: In this abdominal mass example, PET/CT imaging was used to aid in drawing treatment planning contours. The FDG uptake visualized by PET/CT is used to determine the gross tumor volume (GTV) shown in yellow. The area in dark blue is the clinical tumor volume (CTV) defined by the gross tumor plus the microscopic disease. The cyan outline is the planning target volume (PTV), which includes the CTV plus a margin for daily treatment setup and patient positioning.

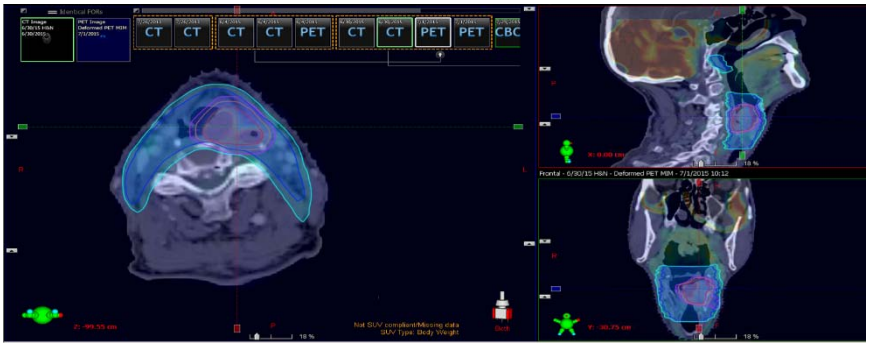

Figure 3: This example shows intra-treatment use of PET/CT imaging for a head and neck patient who presented with initial disease. Due to weight loss, the patient had to have a new face mask made and a follow up CT. The original PET/CT imaging was registered to new CT allowing the patient to continue treatment without any breaks.

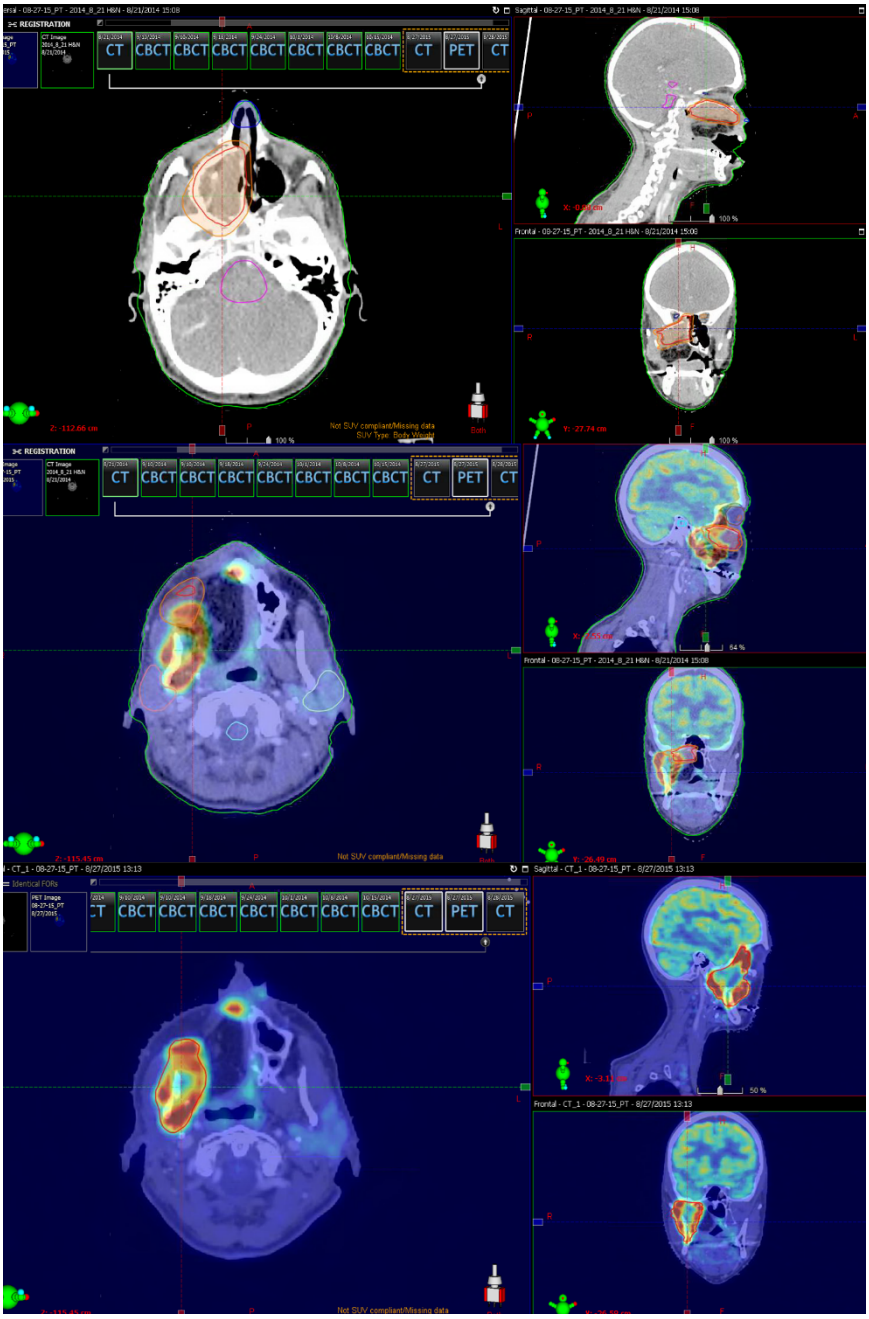

Figure 4: In this example, a head and neck case is shown with the top images visualizing pre-treatment volumes. The middle image shows the individual's 1 year PET/CT follow up. The bottom image shows the new treatment volumes while using a PET/CT image.