Managing Motion in Conventionally Fractionated Lung Cancer Radiation Therapy: A Summary of "Good Practice" Guidelines from the Michigan Radiation Oncology Quality Consortium (MROQC) Working Group on Lung Motion Assessment.

Introduction

In early 2014, the Practice Patterns Quality Improvement Project Group within the Michigan Radiation Oncology Quality Consortium (MROQC) was initiated. The goal of the group was to identify areas within the realm of practice patterns in breast and lung cancer radiation therapy treatment with higher than expected variability across the State of Michigan that could potentially benefit from quality improvement measures and interventions. The first project tackled by the group was the use of accelerated whole breast fractionation in eligible breast cancer patients. The results from this work have been reported elsewhere. In early 2015, a second working group was initiated targeting the use of motion assessment for lung cancer patients as a potential area for quality improvement. Based on data gathered from institutions treating definitive lung cancer patients with conventional fractionation, we found that motion assessment was only being performed in approximately 50% of patients and only 56% of patients with lower lobe tumors. National recommendations by the American Society of Radiation Oncology and the American Association of Physicists in Medicine suggest the use of motion assessment for patients where respiratory motion displacing the target is expected to have a potential impact on treatment[1,2]. Several publications have comprehensively studied the motion of lung tumors and found that tumor excursions of up to 3-4 cm are not uncommon. While the extent of motion, on average, is increased in non-attached and lower lobe tumors, it can be difficult to predict which tumors may benefit from motion management techniques during treatment planning and/or delivery[2-4]. Given the high variability across institutions and the perceived underutilization of motion assessment techniques in MROQC, a working group was formed to study the potential reasons for the underutilization of motion assessment, identify barriers to efficient use of motion assessment techniques, and suggest "good practices" that may help institutions improve their rate of motion assessment and use of motion management technologies.

In April 2015, the working group had an initial conference call to discuss the goals and timeline for the project. The mission of the working group was to "*Improve the overall utilization of motion assessment for MROQC lung patients through collaboration of institutions. We will promote and provide education* *on the use of "good practices" and create shared resources to improve workflow and efficiency*." The group proposed to meet this mission by performing and analyzing a detailed motion assessment and motion management survey of participating institutions, carrying out site visits to institutions with varying motion assessment equipment and methods to gain experience, observe good practices, identify areas for shared improvement, and finally to present and create a report on good practices for motion assessment and management that could serve as a reference for MROQC institutions.

Survey and Results

A survey of motion assessment and management practices was distributed to participating MROQC physics site leaders in June 2015. Of the participating 21 institutions in MROQC at the time, 16 sites responded to the survey. Below we report a subsample of relevant questions as well as MROQC patient data in different areas of motion management and assessment.

Motion assessment at time of simulation

The motion assessment survey asked several questions regarding the determination for, strategy used, and supervision of motion assessment at simulation. The first question was "**How do you determine if a patient needs a motion management strategy, such as breath hold or gating?"** The responses, shown in Figure 1, suggest that the majority of decisions are based on a case by case decision or institutional policy. Along similar lines, Figure 2 shows the response for the question, "**Do you have a written policy to guide motion assessment**?" Half of the sites that responded (8/16) had a written policy that they followed regarding motion assessment while 4/16 had a non-formalized policy.

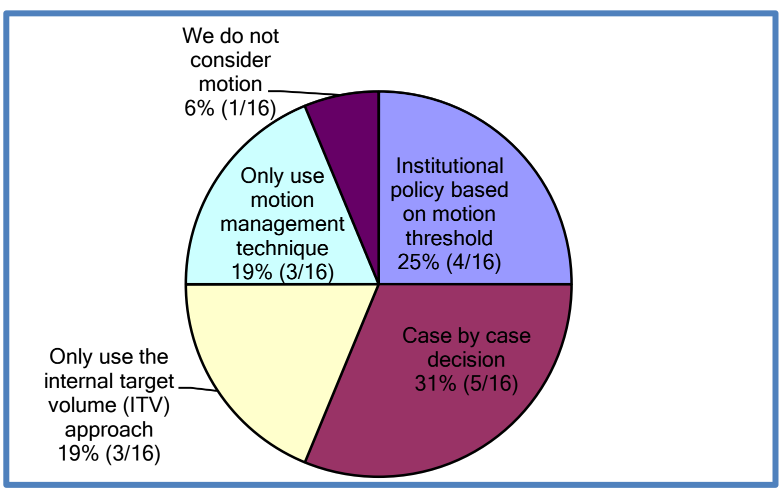


Figure 1. Responses for how sites determine if a patient needs a motion management strategy (such as breath hold or gating).

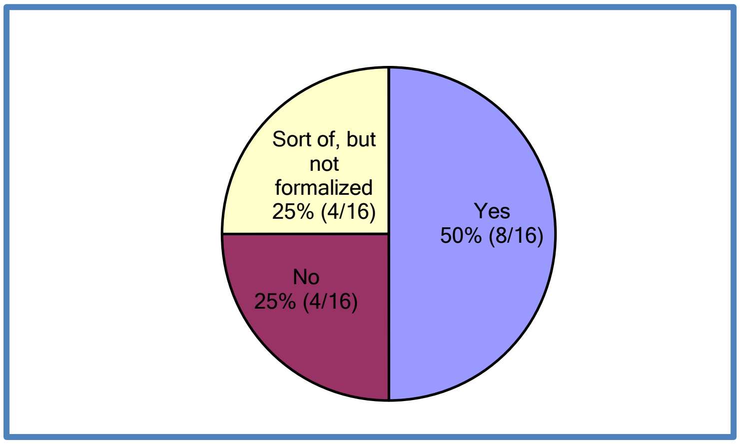


Figure 2. Responses for "Do you have a written policy to guide motion assessment?"

Regarding the type of motion assessment used during simulation, institutions were asked the question, **"Describe your utilization of respiratory motion assessment or management at the time of simulation for conventionally fractionated lung patients."** The results from 16/21 institutions in MROQC, shown in Figure 3, represent the general institutional practices and capabilities regarding the use of the motion assessment strategy. This survey suggested that all sites had the capability and intention to perform some type of motion assessment at the time of simulation for patients.

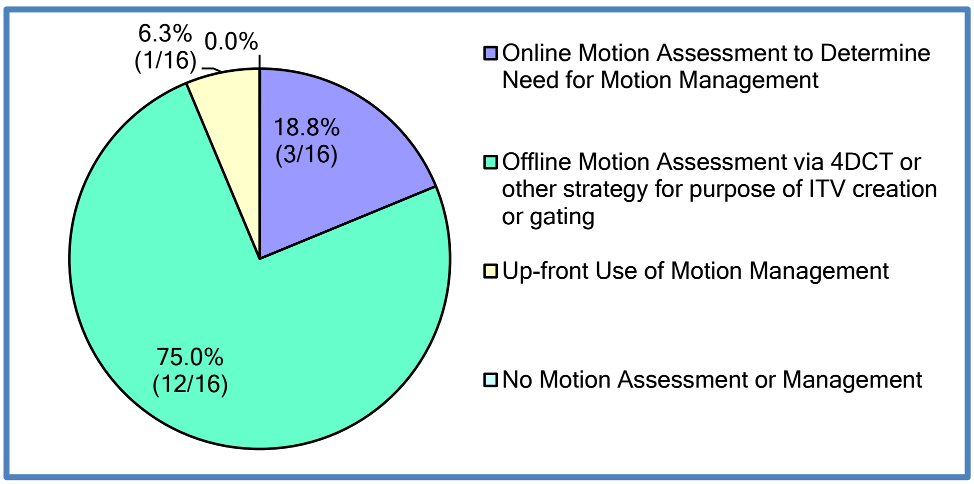
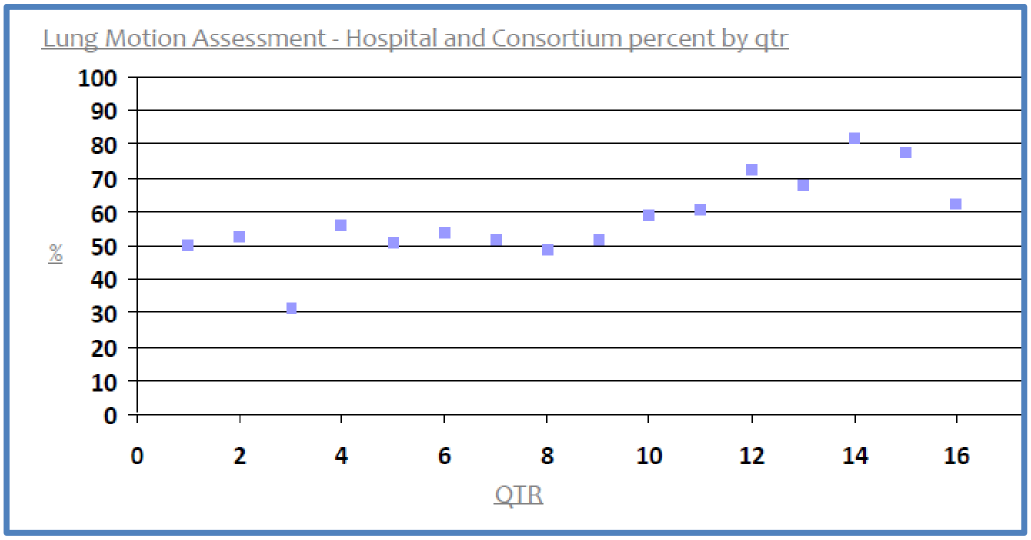
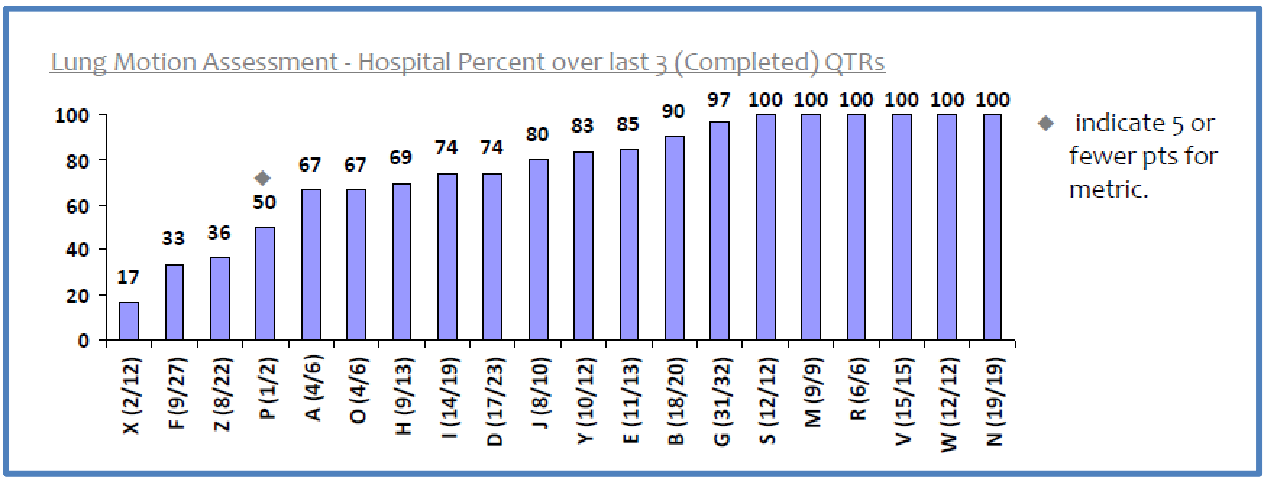


Figure 3. Survey results for the utilization of motion assessment at time of simulation for conventionally fractionated lung patients.

As some institutions weren't represented in the motion assessment survey, we also analyzed data from the MROQC database to determine the true rate of motion assessment for all participating institutions (Figure 4). We also expect the results in Figure 3 to represent the most common and intended ideal workflow at each institution (but not necessarily what is realized in practice).



(A)



(B)

Figure 4 Utilization of motion assessment in the MROQC patient database (A) as a time trend per quarter and (B) by institution over the most recent 3 quarters.

Rates of motion assessment over time within MROQC show a promising trend towards increased utilization overall. However, Figure 4B still demonstrates a lower rate of utilization at several MROQC institutions, which suggests that there may remain barriers to successful motion assessment at these sites. Based on discussions within the motion assessment working group and at quarterly consortium meetings with the MROQC institutions, barriers to routine motion assessment included:

- Lack of software or hardware resources
- Lack of knowledge on efficient implementation
- Lack of motivation that it was necessary and beneficial

While we believe use of motion assessment has been well established in the literature, the lack of knowledge and resources available to perform motion assessment safely, effectively, and efficiency, is a concern.

Sites were also surveyed to determine who was responsible for reviewing the motion assessment simulation. As shown in Figure 5, there was a split of responsible parties including physicians, physicists, dosimetrists, and therapists. At the majority of institutions (10/16 and 11/16), the physician and physicist, respectively, were responsible for reviewing the motion assessment in simulation.

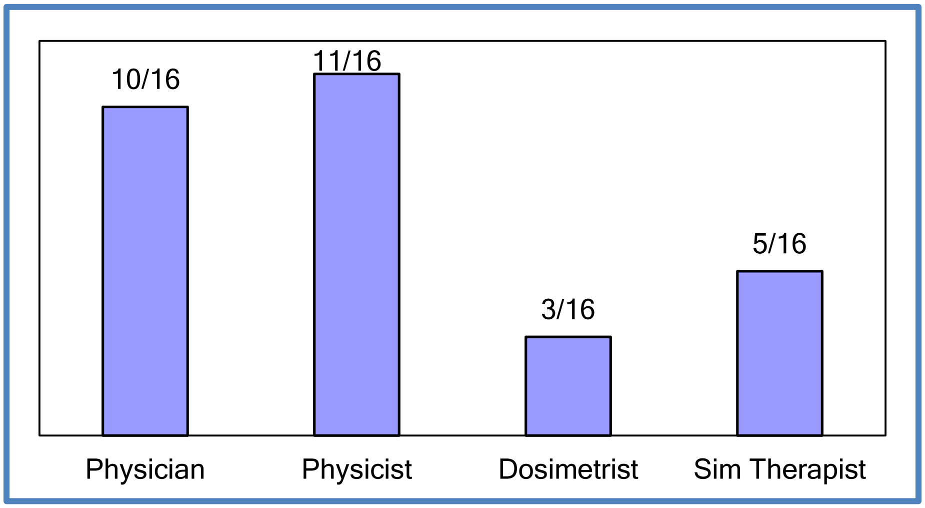


Figure 5. Results of the survey question, "Who is responsible for reviewing the motion assessment in simulation (Choose all that apply)?"

Motion assessment simulation equipment

Sites were also surveyed regarding "**What equipment is used for motion assessment?**" Results demonstrated that of the 16 sites responding, all had four-dimensional CT in use for motion assessment (see Figure 6). Using 4DCT, snapshots of the CT at various breathing phases, binned either by the amplitude or phase of respiration, are reconstructed in order to gauge the motion of the tumor and surround normal tissues. Other methods, such as CT and inhale and exhale or fluoroscopy, were not selected by any sites participating in the survey. Specific equipment noted by different sites for 4DCT binning included:

- Philips Big Bore with Bellows
- General Electric Scanner with Varian RPM
- Siemens with Anzai pressure sensor
- C-Rad Sentinel surface imaging

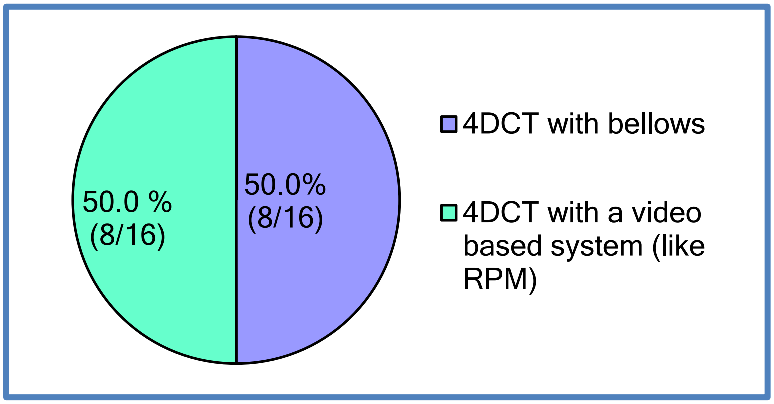


Figure 6. Equipment used for motion assessment at the time of simulation. Sites were also asked to give details on the specific equipment. Responses are listed.

In order to compare the actual usage of motion assessment techniques at different institutions, Figure 7 shows the strategies used for motion assessment at the time of simulation per institution for MROQC patients entered between January 2014 and September 2015.

Figure 7. Motion assessment strategies applied at the time of simulation for MROQC patients per site from January 2014 to September 2015.

Motion Management Strategies

The survey also asked "**which motion management strategies were in use for lung cancer patients**" at the different sites. Figure 8 shows the survey responses. The survey responses are expected to show the capability of each of sites, but likely do not represent the actual usage. For example, several sites selected tracking, which may suggest the site has a machine with tracking capabilities, such as a robotic linear accelerator. Currently, these devices are limited to stereotactic body radiation therapy (SBRT) for lung, which is not included in MROQC.

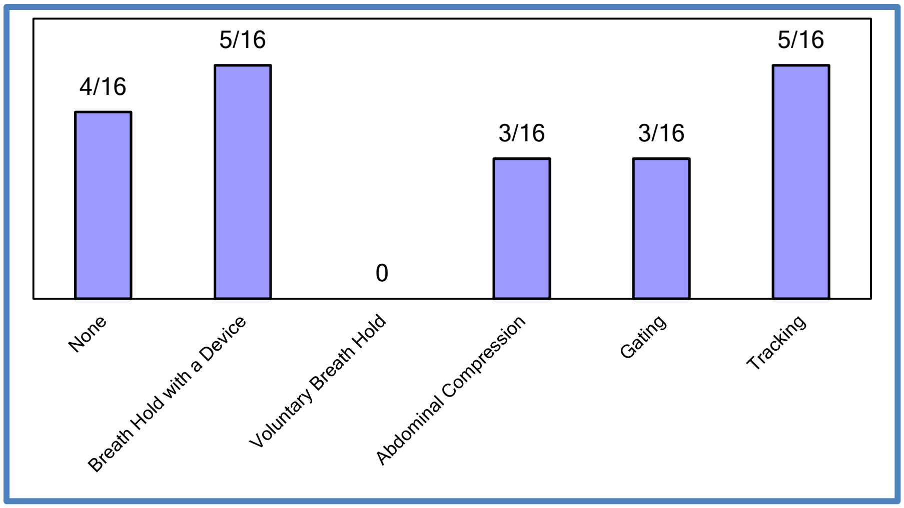


Figure 8. Results of question on which motion management strategies were used for lung patients at each institution.

In order to appreciate the actual usage, Figure 9 shows the use of motion management strategies at the time of treatment for all MROQC lung cancer patients entered between January 2014 and September 2015. Here, we see that very few techniques to limit motion (such as breath-hold and gating) are used in practice for these conventionally fractionated patients. Gating consists of tracking the tumor motion and only treating while the patient is in a given window. An extreme form of gating would be breath-hold, where patients are only treated in a breath-held state (typically inhale for lung cancer patients to maximize the lung volume). Abdominal compression utilizes an abdominal plate or other device to dampen breathing motion.

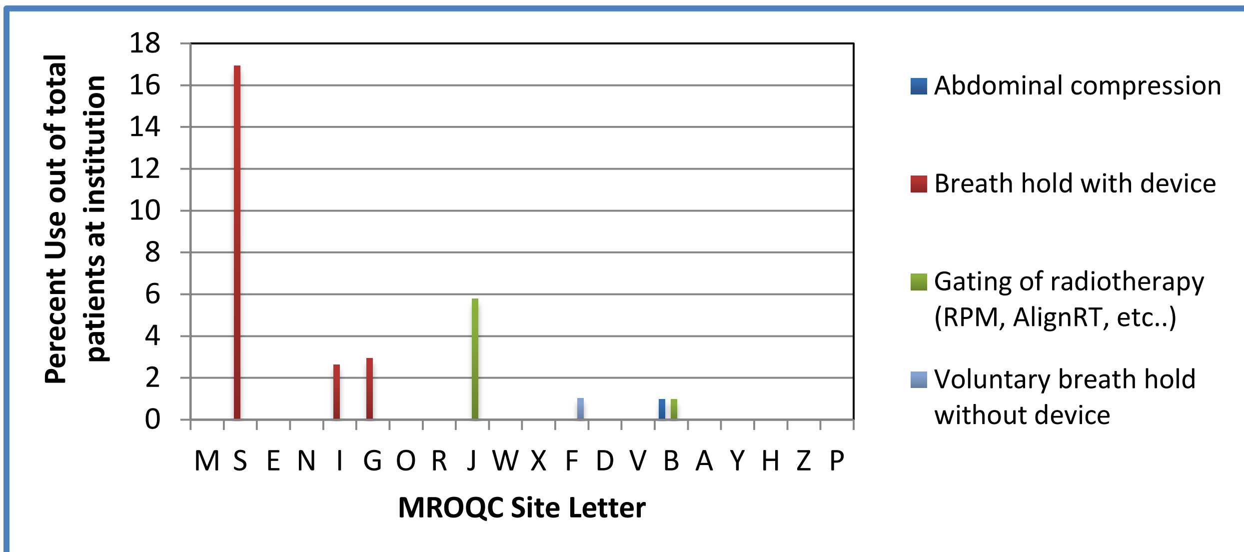


Figure 9. Motion control techniques used for treatment delivery across all MROQC sites for patients completed from January 2014 to September 2015.

"Good Practices" Observations and Suggestions

In addition to the above survey, members of the motion assessment working group also participated in 6 site visits to MROQC institutions that volunteered to open their departments to a review of their motion assessment and management strategies for lung cancer patients. These visits were extremely valuable and collaborative and allowed the group to observe many good practices as they related to motion assessment and motion management for conventionally fractionated lung cancer patients. Below is a summary of the "good practices" observed and suggested by the lung motion assessment working group in MROQC. The goal of these observations and suggestions is to aid MROQC institutions in improving the quality, safety, and efficiency of motion assessment practices in their departments. Since there are many high quality practices represented by a variety of different techniques and equipment, we have purposely stayed away from recommending "best practices" and instead tried to highlight practices that we think are positive in light of safe, quality, and efficient motion assessment and management for lung cancer radiation therapy. The good practices are organized into four categories: General, Simulation, Contouring/Image Fusion, and Image Guidance.

General

General good practices for motion assessment and management that were observed and are suggested for consideration to MROQC institutions are:

- **Training of the entire team** – Motion assessment, management, and treatment delivery of lung plans on varying motion managed datasets touches a large multidisciplinary group including therapists, dosimetrists, physicians, and physicists. End-to-end training that highlights the procedures from simulation to treatment for lung cancer patients is suggested to empower those making decisions during simulation and at the treatment unit, as well as minimize the risk for errors such as planning on the wrong dataset, using the wrong dataset for image guidance, or performing image guidance improperly, depending on the reference image being used for set-up.
- **Commissioning of entire process** – Commissioning of the processes and equipment used for motion assessment serves as a good indication of a high quality program. Commissioning ensures that the motion assessment strategies and equipment are working as intended and that there is standardization and consistency. End-to-end testing of the entire process as well as individual equipment and processes is suggested.

- **Consistency between providers** – Given the potential complexities around treatment planning and image guidance in different motion management situations, there is likely a higher than standard risk of an error happening. A good practice that can help to combat this risk is to have a written policy regarding a standardized and consistent workflow per certain body site as well as consistency between providers who treat the same body site. For example, imagine the situation where the first case of the day uses the average CT for dose calculations and alignment of a free-breathing patient while the second case uses a free-breathing CT scan (which could be at any breathing state) for dose calculation and alignment. If strict IGRT guidelines are not given, the therapists may align both cases to soft tissue, which could cause the latter case to be off systematically by an amount on the order of the breathing magnitude.
- **Quality and Effective Documentation** – Documentation, either paper or electronic, of the motion assessment commissioning, workflow, procedure, and patient-specific quality assurance or assessment appeared to contribute to a smooth motion assessment procedure at many of the sites visited. This appeared to be especially important in the context of training programs or simulation areas where staff may rotate in and out. Having documentation of the workflow to follow for a motion assessment simulation was a positive factor in promoting confidence in the program. In addition, documentation of patient specific motion assessment procedures appeared to aid in reducing questions and confusion during the planning process and aid in decision-making. For example, noting that the patient's breathing trace was irregular during simulation may result in the physician or dosimetrist suggesting a slightly larger PTV margin for a given patient. Institutional policy to aid in standardization of procedures as well as troubleshooting workflow is highly recommended.
- **Continuous quality improvement** – Finally, a good practice that is noted in many areas of radiation oncology, is continuous quality improvement. A multi-disciplinary review of the process, procedures, and equipment in place for motion assessment and management of lung cancer patients on a periodic scale may be very successful in improving efficiency. For example, during a periodic training session for therapists at one institution, it was noted that avoidance sectors (arc segments where the beam is off) in volumetric modulated arc therapy (VMAT)were causing unnecessary breath holds and delays for lung cancer patients treated at breath hold. This led to improved planning procedures with partial arcs used instead of avoidance sectors for breath hold VMAT patients.

Simulation

Good practices for motion assessment and management begin at the time of simulation or even perhaps before with team training, commissioning, and preparation of documentation, as noted above. Some of the good practices observed and discussed by the motion assessment working group were:

- **Consideration of online motion assessment or direct motion management** – There was wide variation noted in the type of motion assessment and management being performed, including several sites employing offline motion assessment with 4DCT only. While the latter is motion conscious, it does not allow for excessive motion to be managed, risking the use of a potentially large internal target volume being necessary. It may be desirable, if resources permit, to allow for an online motion assessment procedure at the time to simulation to identify patients that may benefit from motion management techniques such as abdominal compression, breath hold, or gating. If an online motion assessment procedure is not possible, sites may wish to consider the use of motion dampening devices for the initial simulation, such as an abdominal compression plate, or an upper body plastic wrap. Both techniques have been shown to reduce breathing amplitude and may reduce the amount of normal tissue required to be treated when using the ITV approach. It is important to note that any device employed in simulation should be consistently used during treatment delivery as well. In addition, these techniques may also be beneficial for sites employing gating to dampen the motion and improve the duty cycle.
- **Evaluation of binning technique for 4DCT** – The majority of MROQC institutions utilized 4DCT for motion assessment and management by employing the ITV approach for treatment planning. As part of the commissioning progress for 4DCT, it is suggested that institutions evaluate phase versus amplitude based binning on their equipment or reach out to those that have done the same evaluation with the same hardware. It was observed that some systems show a benefit in automation with amplitude binning with little to no effect on scan quality and noise – especially for regular breathing traces. However, it should also be noted that the choice between amplitude and phase based binning may be best implemented on a case-by-case basis, depending on the breathing trace. For example, amplitude binning has been shown to be favorable with non-periodic motion while low amplitude, or shallow breathing patterns may be best served by phase binning[5].
- **Automation and efficiency for 4DCT reconstruction –** It was observed that different types of software and hardware were equally capable of providing the basic requirements for a motion assessment and in most cases, a 4DCT scan. However, one area in which the performance of

systems varied was in the reconstruction automation and time. For example, some systems were able to reconstruct and display 10 phases from a 4DCT scan in a completely automated fashion within 2-3 minutes while other systems required 2-3 minutes of processing prior to reconstruction followed by reconstruction times over 30 minutes. Members of the group also reported on systems that performed reconstruction off-site. It was observed that lengthy reconstruction times hindered the ability to perform or at the least, the efficiency of, an online motion assessment procedure. It is likely that more institutions would perform online motion assessment for conventionally fractionated lung cancer patients, if the process were more efficient. As such, the group observed the ability to automate and quickly reconstruct and display a 4DCT in less than 5 minutes, as a very positive aspect of a motion assessment program. For institutions limited by resources to upgrade to faster reconstruction systems, it was also observed that reconstruction of fewer than 10 phases (4-6, for example) could provide similar results for contouring and planning using the ITV approach. In addition, for those doing online motion assessment, it is also possible to reconstruct the predicted inhale and exhale phases first and perform a preliminary motion assessment to determine the need for motion management. The latter does pose a risk of missing some motion or artifacts present in the 4DCT.

- **Consistent and complete physician orders** – At the majority of sites visited, physicians provided very clear and consistent documentation on how to perform a motion assessment or 4DCT-based simulation. This led to confidence during the simulation with no confusion about intent. One area where the orders were particularly helpful was the detail on scan parameters including extent of the scan and contrast instructions prior to scanning.
- **Standard troubleshooting procedure –** An area where little overlap from institution to institution was observed was in the procedure for troubleshooting in the event that a 4DCT was of poor quality or a patient was clearly unable to perform motion assessment or receive a 4DCT. Given that these decisions on a case-by-case basis usually required lengthy discussions with the team and lead to delays, it is recommended that institutions consider adopting a written policy that includes the standard troubleshooting procedure. Having consistency also helps reduce confusion for cases that may be exceptions to the usual workflow. Consistent procedures for troubleshooting that minimize required deviation from standard planning scans/procedure are suggested. For example, in cases of a poor breathing trace or 4DCT, the first option may be to evaluate the external surrogate being used to measure the breathing trace, such as a belt device or infrared marker. Another potential

option could be to minimally coach the patient to breathe consistently and then repeat the 4DCT. Then, the standard workflow can be used for planning and delivery. However, when this isn't possible, reducing time and imaging dose may also be strong factors in determining what to do. Options to provide the extent of tumor motion without a 4DCT include slow CT, inhale/exhale scan pairs, or fluoroscopy. Whatever is chosen, it is suggested that it be consistent whenever possible, with a documented alternate workflow for planning and image guidance.

- **Minimal use of free-breathing scans** – The use of free-breathing scans for treatment planning and IGRT for lung cancer patients treated using free-breathing has been common, especially before the widespread use of 4DCT. However, free-breathing scans capture an undetermined breathing phase and can cause inaccuracies of varying degrees (depending on motion) for dose calculations as well as image guidance. The suggestion of the motion assessment working group is to minimize the use of free-breathing scans for treatment planning when possible. When use of a free-breathing scan is needed due to workflow, troubleshooting, or other reasons, it is a good practice to employ strict image guidance instructions. For example, a CBCT based soft-tissue alignment to a moving tumor is not appropriate when the reference scan was taken at an undetermined breath hold.
- **Timely supervision and review of motion assessment scans** – It is suggested that the appropriate staff be present to review motion assessment scans and give recommendations on motion management, usability of scans for planning, and potential troubleshooting. Typically, the qualified staff for this task is the physician along with a physicist or perhaps another member of the motion assessment team that is well-versed in the decision making process, such as a dosimetrist or sim therapist. Prompt review is observed to have a positive impact on patient comfort and simulation workflow, especially when troubleshooting is required.
- **Procedure and patient-specific quality assurance** – As with other devices in the clinic, performing quality assurance at periodic intervals on the motion assessment equipment and software is part of a quality QA program. An end-to-end test on a phantom is an example of a QA procedure than can be done for 4DCT. In addition to machine and equipment QA, it was also observed that it is a good practice to perform patient-specific QA for 4DCT scans as well as reproducibility checks for patients simulated using a motion management technique. As an example, QA for a 4DCT may be as simple as reviewing the scan at the time of simulation for its suitability for planning by investigating the scan extent, artifacts, and noise level of the images. For patients being treated with a motion management technique, it is a good practice to ensure the technique is reproducible. An example of

QA in this setting would be performing multiple scout images at breath hold for a breath hold patient and ensuring the diaphragm or tumor (if visible) is within a predetermined motion tolerance.

- **Proper communication with dosimetry** – One of the themes noted during the site visits was excellent communication between simulation and dosimetry. Whether verbal or written, providing detailed information to the planning team about how the patient was simulated is a good practice. In some cases, the dosimetrist was highly involved in the motion assessment procedure itself and thus very aware of the simulation scans taken. This practice is likely to improve planning efficiency and quality, ensure the proper scans are used for treatment planning, and make sure that any important items regarding the simulation, such as the patient needing a larger margin due to breathing artifacts, are properly communicated. It may be a good practice to make sure important details are recorded in the patient record to make any planning hand-offs seamless. This is especially important when a nonstandard workflow is used.

Contouring/Image Fusion

- **Use of average 4DCT scan for planning free-breathing or gated patients** – In general, studies have shown that the average scan computed from all or some phases (in the case of gating) of the 4DCT is an appropriate scan to use for dose calculations as an alternative to accumulating dose on all phases of the scan[6-8]. It is a good practice to use this type of scan for planning and dose calculations when possible. There could be inaccuracies, especially in cases of large tumor motion, when a free-breathing or breath hold scan is employed for dose calculations since the densities may be captured at an extreme breathing phase.
- **Use of consistent "ITV" terminology –** The published ICRU definition of an ITV is a motion encompassed CTV. However, with 4DCT, many institutions use the term "ITV" to denote a motion encompassed GTV. A good practice to avoid confusion is to adopt the use of consistent terminology for target definition in lung cases. The MROQC motion assessment group supports the use of IGTV (to denote a motion envelope for a GTV) and ICTV (to denote a motion envelope for a CTV) instead of ITV to minimize confusion regarding drawn structures.
- **Perform QA on 4DCT based contours** – A good practice that was observed at several MROQC institutions was a high level of quality assurance on 4DCT contours. Examples of potential good practices include contour peer review by another physician prior to planning, physicist and dosimetrist review prior to planning and treatment approval of 4D contours while watching 4DCT

movie. QA on contours is especially important when the maximum intensity projection (MiP) is used for contouring, as it may underestimate the target volume near areas of unit density such as mediastinum and diaphragm. Therefore, review of the IGTV or ICTV on all phases of the 4DCT is suggested along with the use of caution when using a MiP image for contouring except in tumors completely surrounded by lung.

- **Motion management conscious image fusion** – Although not tied directly to motion assessment, it was noted that image fusion was common between PET images as well as contrast CT scans. If using a 4DCT for treatment planning (typically with dose calculation on the average dataset), image registration is required. As such, it was observed to be good practice to ensure the image registration procedure was appropriate based on the motion management state of the source scans. For example, if a patient is treated at breath hold, image registration to a free-breathing PET/CT may create errors in contouring if not done with care. In some cases, it may be the best practice to use the additional image only for reference if an appropriate image registration is not possible. As an example, imagine a free-breathing PET/CT where the CT is taken at voluntary exhale and the PET is ungated. If an average 4DCT scan is used for planning, then it wouldn't be appropriate to locally align the tumor on CT from PET/CT to the average scan. This would cause a systematic shift in the CT alignment and as such, the PET alignment. Instead, a bony alignment followed by adjustment when reviewing the PET vs. average scan may be more appropriate. In general, a free-breathing PET should align well with an average scan on 4DCT when using the same immobilization equipment, and a gated PET may prevent over-contouring in breath hold patients. Finally, it should be noted that deformable image registration (DIR) may not be appropriate for PET due to differences in breathing motion. Proper commissioning of DIR should be done according to the AAPM TG-132 report that will be published later this year.

Treatment/Image Guidance

The proper image guidance instructions play an important role in ensuring that lung cancer patients are aligned and treated correctly. Given the myriad of reference image options, the MRQOC motion assessment group has identified a few good practice observations and suggestions:

- **Minimize use of free-breathing scans as the IGRT reference image** – It was suggested earlier to minimize the use of free-breathing scans for planning and IGRT. That suggestion is reiterated here. Since free-breathing scans can be captured at any breathing phase, it is not appropriate to use any form of soft tissue alignment in areas where motion is expected. If free-breathing scans must be employed, strict image guidance instructions and procedures should be followed consistently. Typically bony alignment is the most appropriate option in that situation.

- **Quality IGRT review –** As in other body sites, IGRT should be reviewed by the physician and physics or dosimetry to ensure IGRT goals are being met. This is especially suggested when nonstandard workflows are used.
- **Therapist training on IGRT methods and implications** – Due to the potential for misalignment when different types of reference scans are used, it is a good practice to ensure that all therapists are well trained on the implications of IGRT in different scenarios (free-breathing vs. breath hold, etc.).
- **Clear guidance on IGRT goals** – In addition to therapist training on the current standards in place at each institution, clear guidance and if needed, patient specific IGRT instructions should be given to therapists to aid in alignment. Again, this is especially important in non-standard workflows and scans. One area where guidance is helpful is CBCT alignment and when the nodes and primary tumor are being treated with the same plan and isocenter.
- **Consistency between simulation and treatment** – Especially important in gated and breath hold treatments, consistency in device use, placement, and patient instructions are critical for treatment reproducibility.

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