Localization & Treatment Procedures in Radiation Therapy

LOCALIZATION & TREATMENT PROCEDURES IN RADIATION THERAPY

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RSTH:4230 RADIATION THERAPY CAPSTONE SPRING COHORT 2023

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INTRODUCTION

Welcome to "Localization and Treatment Procedures in Radiation Therapy," a comprehensive Open Educational Resource (OER) that walks you through the fundamental steps of radiation therapy treatment. This book thoroughly explores the treatment localization, planning, and delivery process for various sites, including the Brain, Head & Neck, Breast, Thorax, Abdomen, and Pelvis. The content was designed considering the American Registry of Radiologic Technologists (ARRT) content specifications and clinical competency requirements.

What sets this book apart is its dynamic nature and ability to evolve quickly, much like the field. We have integrated multimedia and interactive content into each chapter, exclusively available online. If you use an online or PDF version of this book, hyperlinks will guide you to multimedia and interactive components. Additionally, glossary terms are conveniently bolded, allowing you to access their definitions with a simple click or by referring to the glossary at the end of the book.

We also extend an invitation to faculty and teaching staff; we encourage you to personalize this OER book according to the specific needs of your program. We invite you to share your customized version with others in the field. We request feedback and resources to add and share with the community. Together, we can exchange knowledge and contribute to the growth and development of the radiation therapy community. We hope this book is an invaluable resource for radiation therapy students and their careers.

*Note – this resource is constantly adapting; additional content, resources, tools and citations will be added to improve its effectiveness. If you have edits, resources, tools, or feedback to share, please direct them to: jared-stiles@uiowa.edu.

ACKNOWLEDGEMENTS

Thanks & Gratitude

I want to express my gratitude to everyone who contributed to developing and completing this Open Educational Resource (OER). Their invaluable support, insightful suggestions, and dedicated efforts played a significant role in shaping this project.

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A special thank you to the workgroup members Emily Heithoff, Carol Scherbak, Kristi Tonning, Maria Thompson, & Nora Uricchio whose experience, guidance, and expertise were valuable in the creation of this resource. I am honored to have had the opportunity to collaborate with such remarkable individuals.

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Members of the Radiation Therapy Education Community: A special thank you goes out to the numerous individuals who graciously shared their educational videos and photos with the online community. Your contributions have enriched the learning experience for students, providing visual aids and real-world examples that enhance their understanding and engagement. Your generosity in sharing your resources has immensely increased the value and effectiveness of the OER.

I would also like to thank all the survey respondents who participated in the feedback process. Your input and perspectives have been valuable in shaping the content and structure of this textbook. Your willingness to share your thoughts, experiences, and resources made the content more comprehensive.

I also want to express my appreciation to my colleagues, friends, and family members who have supported me throughout this project, providing encouragement and understanding – thank you.

Finally, I extend my heartfelt gratitude to the educators who will use this resource. Your commitment to the profession and your student's education is a constant source of inspiration. We are mentors to the next generation of radiation therapists to provide safe, accurate, and compassionate care to members of our communities. To the present and upcoming students, you are the future of healthcare, and your vast knowledge and expertise will undoubtedly and profoundly impact countless lives.

Thank you all.
Jared L. Stiles MSL RT(R)(T)

PART I

CENTRAL NERVOUS SYSTEM

1.

OVERVIEW: CENTRAL NERVOUS SYSTEM

Learning Objectives

- Describe the anatomy, structures, and landmarks of the CNS
- Describe malignancies of the CNS
- Describe the simulation process
- Identify commonly used positioning & immobilization devices used for CNS treatments
- Define scan parameters and reference isocenter location for CNS simulations
- Discuss special considerations in CNS patient positioning
- Define treatment borders and how they relate to tumor spread
- Describe tumor volumes and margins of CNS tumors
- Discuss the various treatment procedures of CNS malignancies
- Perform tasks associated with the simulation and treatment of CNS malignancies

Key Terms

- **Avoidance Sectors**
- **Blood-brain barrier (BBB)**
- **Debulking**
- **Edema**
- **External Auditory Meatus (EAM**)

- **Fluoroscopy**
- **Forward-planning**
- **Gamma knife**
- **Hyperfractionation**
- **Hypofractionation**
- **Intracranial pressure**
- **Inverse-planning**
- **Necrosis**
- **Prophylactic**
- **Simulation**
- **Static**
- **Tentorium**

Overview: Central Nervous System

The Central Nervous System (CNS) is comprised of the brain and spinal cord. It is separated from vasculature by the **blood-brain barrier (BBB)**. The CNS receives nutrients that would typically be carried by blood, through the cerebrospinal fluid (CSF). Tumors of the CNS can be categorized as benign or malignant; malignant tumors represent <1% of malignancies in the US. Histologically benign tumors are sometimes treated as malignant due to their location. Nearly 85% of primary CNS tumors will involve the brain, the remainder are found in the spinal cord. In adults, most primary brain tumors are located **supratentorial** in the cerebrum.

In adults, the most common primary malignant tumors of the CNS are classified as high-grade (anaplastic) astrocytoma's and glioblastomas (38%). Meningiomas account for 27%; these tumors originate from the 3-layered membrane that protects the CNS. Approximately 90% of these tumors are classified as low-grade or benign. The most common brain tumors are "secondary" or metastatic; 20% to 40% of cancer patients develop brain metastasis in the course of their disease. Metastatic lesions most commonly occur in the cerebral hemispheres, with a single metastasis occurring 40-45% of the time. The most common primary site of disease responsible for brain metastasis is the lung, which occurs in 30-60% of patients; breast cancer and melanoma are also common primary sites. Brain metastases are uncommon in pediatric patients[1].

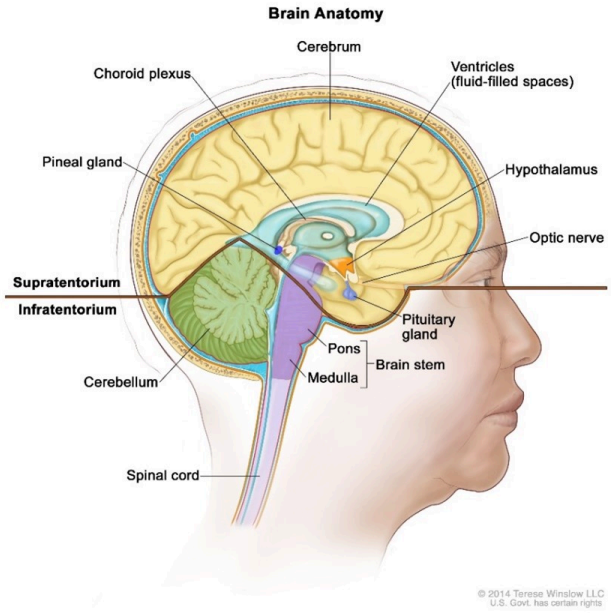


Figure 2. Demonstrates the most pertinent anatomy of the cranial cavity separated by the tentorium.

Primary CNS tumors are the second most common cancer in children, behind leukemia. These tumors are commonly located **infratentorial** in the posterior fossa. The most common pediatric brain tumor is a low-grade astrocytoma or pilocytic astrocytoma. Radiation is often avoided in children under the age of 3 due to long-term IQ detriments and developmental changes.

The most important prognostic factors include tumor histology (grade); the size and location, age, and Performance Status (PS) are also significant considerations. No universal staging system is currently in use for CNS tumors, this lack of standardized staging has resulted in confusion. The American Joint Committee on Cancer (AJCC) uses a 3-grade system based on the grade, tumor, metastasis (GTM) classification. The World Health Organization (WHO) has a similar 4-grade system. Lower grade tumors tend to be classified as benign; grade has the greatest prognostic significance.

Learn more HERE.

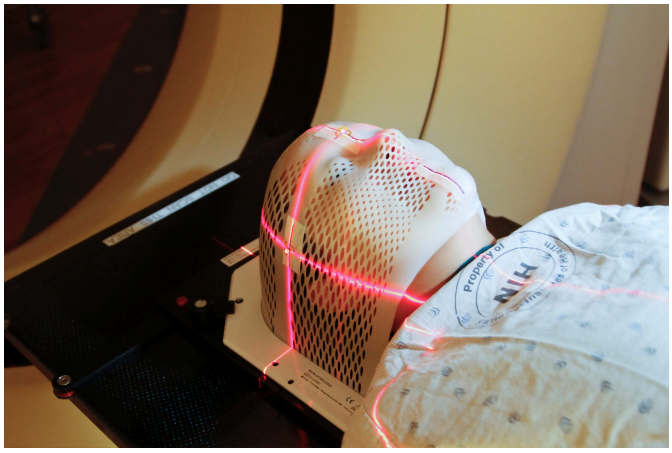
1. "Adult Central Nervous System Tumors Treatment (PDQ®)–Health Professional Version." National Cancer Institute, 14 Oct. 2022, www.cancer.gov/types/brain/hp/adult-brain-treatment-pdq.

Grade	Features of Grade
Grade I	Well differentiated, grow slow, classified as benign
Grade II	Moderately differentiated, grow slow but may spread to nearby tissues or recur
Grade III	Poorly differentiated, grow quickly and spread to nearby tissues – Anaplastic Astrocytoma
Grade IV	Undifferentiated, grow and spread very quickly via CSF, necrotic – Glioblastoma Multiform

Patient Simulation: CNS

Simulation (sim) is preformed after the patient's consultation and consent process are completed with the physician. The physician issues a sim order that specifies the patient's treatment site, use of contrast media, immobilization, and scan parameters; these are subject to department protocol and physician preference, but standards exist across the field. Immobilization is especially important in the head and neck area of the body due to the numerous tissue types with varying radiosensitivities. Radiation therapists should always review the order for accuracy and assess the patient's ability to achieve the requested position relative to the beam angles required for the treatment. A radiation therapist may need to test several positions and immobilization devices. Achievement of these goals will lead to less patient movement, improved treatment accuracy, and decreased setup time.

Patients are commonly simulated utilizing CT. Patients with brain tumors are typically positioned in the supine position, headfirst, with a thermoplastic mask, knee bolster, feet-banded, and hands clasped or holding a ring. Positioning aides, like the banded feet and ring, help make the patient more comfortable and serve as a reminder to hold still. Thermoplastic masks greatly reduce the errors in the reproducibility of a brain setup; these can be made using a hot water bath or oven. The head rest used should be a comfortable height and keep the patients head in a neutral position – as if they were standing looking straight ahead, matching the curvature of their neck. Markers or "fiducials" are placed laterally on each side of the mask just superior to the ear and midline anteriorly, superior to the orbits.



Reference isocenter placement of an anterior and right and left lateral fiducial placement for primary brain and whole brain CT simulation

The radiation therapist is responsible for thoroughly documenting the patients position and set-up instructions with lateral and anterior photographs. Photos should include all immobilization devices and positioning aides. Include closeup images of any fiducials or reference marks, bolus, or complexities in the patient setup.

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Special Simulation Considerations: CNS

Patients that are claustrophobic may require premedication, open face masks, and/or the eyes cut out of their mask to allow them to see. Proper coaching, pre-sim education, playing the patients music of choice, or providing them updates throughout the treatment could help keep them calm. Some patients with tumors of the brain may require a safety strap across their arms and chest due to the increased potential of a seizure. If mask-shrinking or facial swelling due to steroid use is a concern, a shim can be placed under the patient's headrest during mask formation – it must be removed after the mask cools, before the CT. It is important to allow the mask to cool to vendor specifications before removing.

Treatment Volume Localization: CNS

Primary brain tumors commonly spread through local invasion along pre-existing pathways defined by white matter tracts. Most gliomas tend to spread invasively because they do not form a natural capsule. Tumors expand through local invasion; more aggressive gliomas have cells break away into the circulating cerebrospinal fluid (CSF), allowing the tumor to spread to other parts of the CNS. Primary brain tumors do not metastasize through a lymphatic drainage system and rarely metastasize outside of the CNS.

Tumors of the brain are typically treated with lower energy beams (<6X) to avoid under dosage in the lateral aspects of the brain. Higher energies, have an increased skin-sparing effect (an increased dmax) and are a disadvantage. The treatment margin greatly depends on pathology, the treatment technique selected, and the Organs At Risk (OAR). Even palliative whole brain doses (30 Gy) can result in significant short-term memory deficits and decrease in a patient's quality of life. Studies have shown that limiting the dose to the hippocampus will greatly improve patient's side effects and lower the chances of negative neurocognitive declines[2].

2. Pokhrel, D., Sood, S., McClinton, C., Shen, X., Lominska, C., Saleh, H., Badkul, R., Jiang, H., Mitchell, M., & Wang, F. (2016). Treatment planning strategy for whole-brain radiotherapy with hippocampal sparing and simultaneous integrated boost for multiple brain metastases using intensity-modulated arc therapy. Medical Dosimetry, 41(4), 315–322. https://doi.org/10.1016/j.meddos.2016.08.001.

Organs at Risk (OARs)	**TD 5/5 (Whole Organ)**	**Outcome Associated**
Lens of Eye	10 Gy	Cataracts
Optic Chiasm	50 Gy	Blindness
Brain Tissue	47 Gy	Necrosis/infarction
Lacrimal Gland	26 Gy	Dry Eye
Optic Nerve	50 Gy	Blindness
Brain Stem	50 Gy	Necrosis/infarction
Spinal Cord	47 Gy (20 cm)	Myelitis/Necrosis
Parotid	32 Gy	Xerostomia
Ear	30 Gy 55 Gy	Acute Serous Otitis Chronic Serous Otitis

Treatment Techniques: CNS

Treatment doses and fraction schemes can vary greatly and depend on the tumor grade, the number of lesions, size and location of the lesion(s), the intent of the treatment (curative vs. palliative), and the patient's performance status and age. More details are provided in sections: Whole Brain & Primary Brain Tumors, Craniospinal Irradiation (CSI), & Stereotactic Radiosurgery (SRS).

Emerging Technologies & Treatments: CNS

Advances in technology are happening more rapidly than ever before. Today, there are several treatment technologies and devices available that have increased the accuracy and reduced treatment time for CNS malignancies. A few treatment advancements include:

- 6 degrees of freedom tables – Corrections for patient tilt and rotation (Vendor examples: Protura & Hexapod)
- Infrared motion/surface monitoring systems (Vendor examples: AlignRT & Real-time HD Motion Management with Gamma ICON)

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Media Attributions

2.

WHOLE BRAIN & PRIMARY BRAIN TUMORS

Patient Simulation: Whole Brain & Primary Brain Tumors

The simulation procedure commonly used for fractionated primary brain tumors includes a CT simulation and/or MR imaging with contrast. The patient's position and immobilization was provided in the Patient Simulation: CNS section. Scan parameters will extend from vertex to mid-neck (or as specified by physician). Metastatic disease or whole brain patients typically only require a CT sim without contrast. A MRI with contrast for each scan and will provide more insight into tumor vasculature, help differentiate edema from tumor, and enhance soft tissue contrast improving the identification and localization of critical structures. Frequently, CT scans of the brain use intravenous, iodinated, non-ionic, contrast. Therapists should ensure the patient has not received contrast in the last 24 hours, has good kidney function through the verification of lab values (GFR, BUN, Creatinine), and has had nothing to eat or drink (npo) for the last 4 hours. MR scans commonly use gadolinium "gad" contrast.

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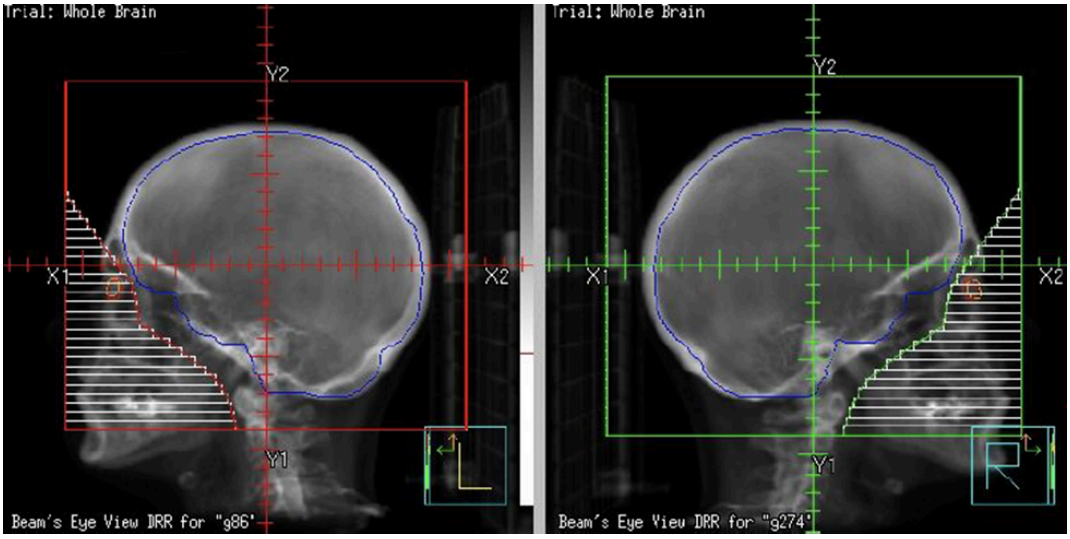
Treatment Volume Localization: Whole Brain (WBRT)

WBRT will encompass all microscopic disease within the cranial contents. The beam arrangement is a two-field technique using opposed laterals. Treatment field size is approximately 22cm x 17cm.

Treatment borders:

- Posterior, Superior, & Anterior: 1-2cm flash/field falloff (verify with field light)
- Inferior: Superior orbital ridge to 1-2cm below the mastoid tip (verify eye block)



Left (g86) and Right (g274) lateral whole brain DRRs

Treatment Techniques: Whole Brain (WBRT)

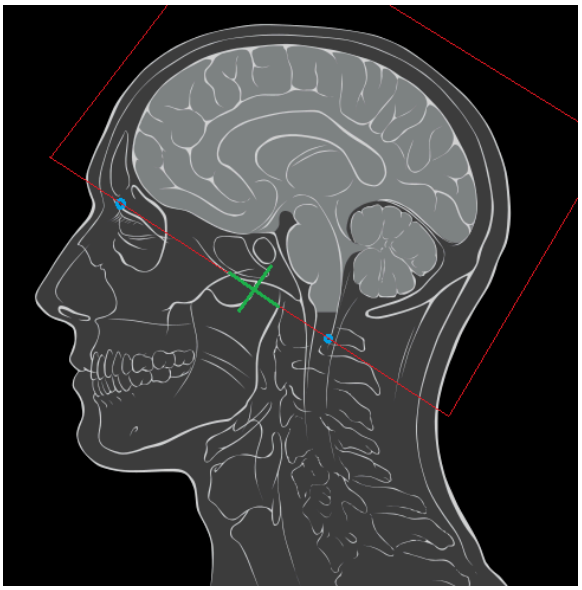
Radiation therapy for brain metastasis is typically a palliative treatment. Treatment can be given **prophylactically** for Small Cell Lung Cancers to a dose as low as 20-25 Gy. A slightly lower dose will reduce deficits associated with whole brain radiation therapy and allow for retreatment if metastasis occur later. Standard approach WBRT uses 3000-3750 cGy in 10-15 fx (250 to 300 cGy per fraction). The most common fractionation scheme is 30 Gy in 10 fractions. Other common fraction schemes include:

- 12 Gy: 6 Gy for 2 fractions given on consecutive days
- 20 Gy: 4 Gy/fx for 5 fractions daily

To avoid beam divergence into the opposite eye:

Option 1: Angle each beam posteriorly a few degrees until the beam divergence matches the opposing sides outer canthus. The appropriate angle can be verified in the treatment planning system. Notice, the beams match anteriorly just posterior to the lenses of the eyes. Clinically, this divergence can be matched utilizing two metallic BBs, placed at each eye's outer canthus, and rotating the gantry using **fluoroscopy** until they are superimposed.

The red beam represents gantry 274 degrees (Right lateral), the blue represents gantry 86 degrees (Left lateral). The anterior beams a parallel to the lens of the orbits.



Depiction of a half-beam block to eliminate beam divergence anteriorly. The blue circles represent the superior orbital ridge and mastoid tip. The green "+" represents the isocenter.

Option 2: Take advantage of the non-divergence of the central axis of the beam using a half-beam block. Rotate the collimator to match the inferior border (superior orbital ridge and mastoid tip). The isocenter will fall near the **EAM**. Ensure adequate light field falloff in anterior, superior, and posterior directions.

Emerging Technologies and Treatments: Whole Brain (WBRT):

Hippocampal WBRT is a growing treatment that is focused on sparring the right and left lobes of the hippocampus with the intent of avoiding radiation induced side effects. Like WBRT the entire cranial contents

are contoured, Hippocampal WBRT treatment utilizes the Linac's IMRT functions to limit dose to the hippocampus[1]. **Avoidance sectors** can help reduce dose to critical structures, like the lenses of the eyes.

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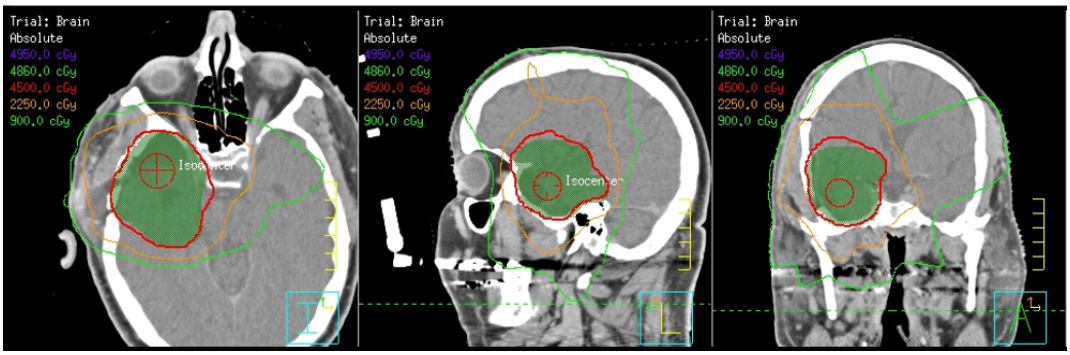
Treatment Volume Localization: Primary Brain Tumors

Treatment volumes for fractionated radiotherapy to primary brain tumors can vary by provider and institutional protocols. Historically, contours included the gross tumor volume (GTV) and surrounding edema (determined by pre-operative scans) with a 2-3 cm margin. With advances in technology, treatment margins are much tighter. Today, treatment volumes include the GTV, subclinical disease, and edema, comprising the CTV – clinical tumor volume and a 5mm expansion to the PTV – prescribed tumor volume.



A patient with a GBM of the right frontal lobe. The PTV is demonstrated by the red outline and is prescribed to receive a dose of 45 Gy with a boost to follow.

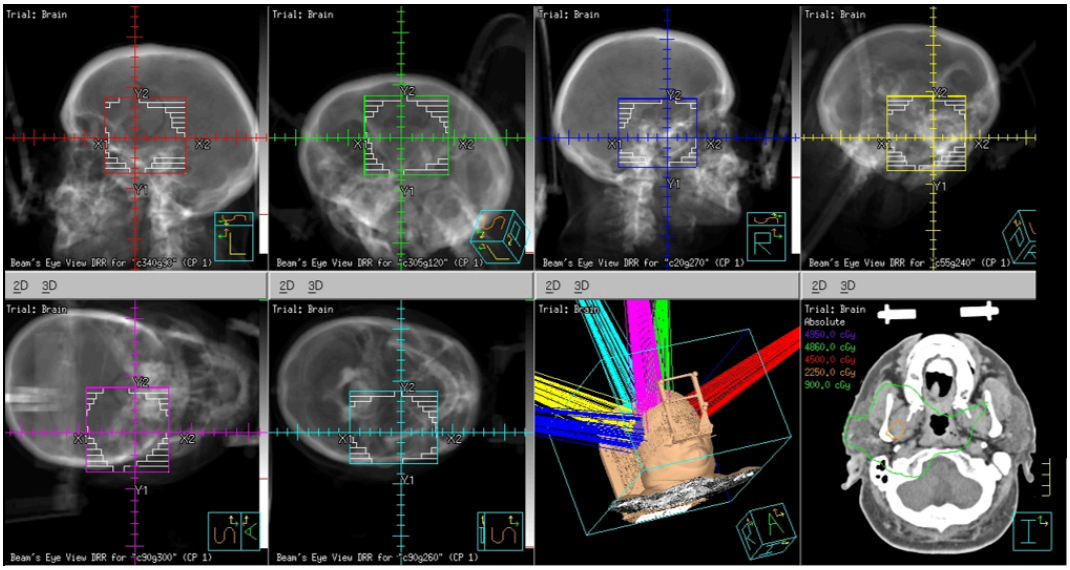
Treatment Techniques: Primary Brain Tumors

Historically, primary brain tumors were treated with a 2 or 3-field technique; two parallel opposed lateral beams and perhaps a third (anterior, posterior, or vertex) beam. Wedges were common to compensate for the

1. Pokhrel, D., Sood, S., McClinton, C., Shen, X., Lominska, C., Saleh, H., Badkul, R., Jiang, H., Mitchell, M., & Wang, F. (2016). Treatment planning strategy for whole-brain radiotherapy with hippocampal sparing and simultaneous integrated boost for multiple brain metastases using intensity-modulated arc therapy. Medical Dosimetry, 41(4), 315–322. https://doi.org/10.1016/j.meddos.2016.08.001.

round shape of the head to reduce hot spots and improve dose uniformity. Beam weighting can also achieve help achieve an acceptable dose distribution.

Modern photon treatments incorporate the use of 3D conformal planning using **forward-planning**. IMRT and VMAT plans using dynamic MLC's and treatment arcs can be accomplished with **inverse-planning**. Each type of treatment will have approximately 5 different beams and couch positions. Therapists must take extra caution in the movement of equipment to avoid any potential collisions. Dynamic treatment plans (Rapidarc/VMAT) are more conformal and allow for increased normal tissues sparing and potentially dose escalation.



The same GBM patient as the previous image with a 6-beam treatment plan at couch positions: 340, 305, 20, 55, and 90 degrees. The DRRs are color coordinated with their respective beams. Patient is being treated with an SRT biteblock system.

Low-grade tumors are primarily treated with surgery, but if radiation is needed (due to positive margins or remaining tumor), the dose is to approximately 45-54 Gy at 1.8-2.0 Gy/fx. High-grade tumors are treated to approximately 50 Gy with a 10 Gy boost at 1.8-2.0 Gy/fx. **Hypo-fractionation** has been found to have similar efficacy; this could shape treatments of the future. **Hyper-fractionation** and dose escalation have not demonstrated a significant survival benefit.

Emerging Technologies & Treatments: Primary Brain Tumors

- Proton therapy can significantly reduce the dose to normal tissues and is especially advantageous for pediatric patients and CSI treatments.
- MR Linac systems can provide enhanced imaging to detect changes daily and utilize Adaptive Radiation Therapy, generating a new plan and treatment daily based on the image resulting in greater normal tissue sparing and increased target dose.
- Gamma Tiles – Surgically targeted Radiation therapy for patients with operational brain tumors.

Inserted by a surgeon at tumor site immediately after removal. Delivers radiation to the targeted area and minimizes side effects.

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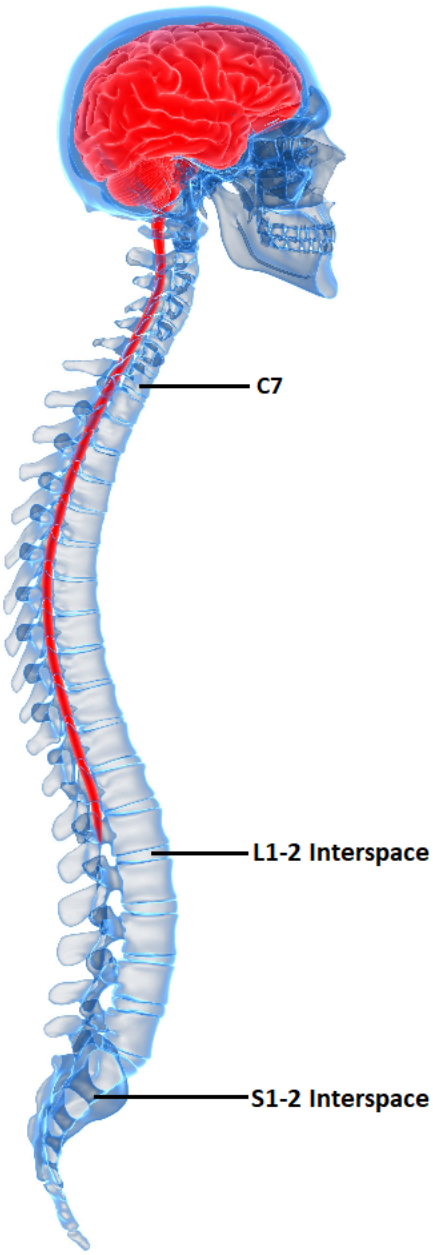
3.

CRANIOSPINAL IRRADIATION (CSI)

Patient Simulation: Craniospinal Irradiation (CSI)



Central Nervous System identifies the brain and spinal cord (red), the termination of the spinal cord termed the cauda equina at L1, and the S1-2 interspace where the CSF circulation ends

Medulloblastomas are a type of pediatric primary brain tumor accounting for approximately 20% of primary pediatric brain tumors. These tumors originate from primitive neuroepithelial tissues (PNET) and are classified as high-grade gliomas. They tend to spread via the cerebrospinal fluid (CSF) necessitating craniospinal irradiation. Oligodendrogliomas and Ependymomas can also spread through the CSF which may necessitate CSI.

Historically, patients were simulated and treated in the prone position to visualize the spine and gap between spinal fields (if more than one). For conventional simulation, the spine field is simulated first to obtain the collimator angle for the brain fields relative to the length of the spine field. Due to advances in imaging and treatment technology, most patients today are positioned supine. The supine position is more comfortable and reproducible; it also allows for access to the patient's airway if anesthesia is required.

Ensure the patient is positioned straight with their arms are at their side. Use a thermoplastic head and shoulder mask for head, neck, and upper spine alignment. A vacloc can be used under the lower extremities for pelvis and low spine alignment. If the patient is a small child, a body vacloc could be used abutting the headrest and a brain mask. Custom headrests can also improve comfort and reproducibility. Localization marks should be placed on the lateral and anterior aspects of the brain field with straightening marks down the abdomen for reproducibility of the spine position and lateral leveling marks for rotation. The simulation scan should extend from the patient's vertex through the sacrum.

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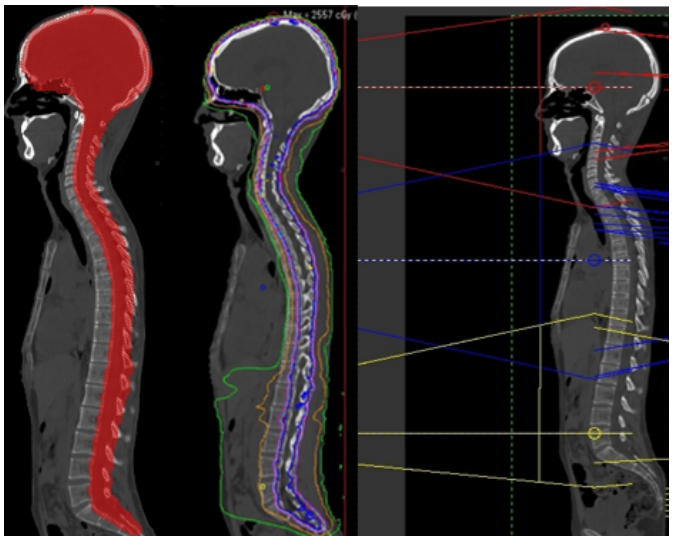
Treatment Volume Localization: CSI

Craniospinal Irradiation (CSI) treats all parts of the cranial and spinal cavities where CSF flows, terminating at the second sacral vertebrae. The cranial field boarders are the same as the whole brain fields apart from the inferior border extending from mastoid tip to approximately C5-7 to include the cervical spinal cord with a 2 cm margin. Treating the cervical portion of the spine with the lateral brain fields is advantageous to block the structures anterior to the spine that would otherwise receive exit dose from the posterior spine field. Additionally, a lower superior boarder of the posterior spine field will reduce divergence towards the patients mandible. The spine field will use an abutting or feathering technique and will extend to approximately S2. A feathering technique uses the MLCs to blend the dose at field junctions to avoid overdosing the spinal cord. Similarly, IMRT treatment techniques can blend the dose between fields. See Figure above.



The red wash represents the PTV (left). The blue isodose line receives 100% of the prescribed dose (middle). The right image demonstrates a 3-field/ isocenter plan (red/blue/yellow); the dose is modulated/feathered using the mlcs in the overlapped areas.

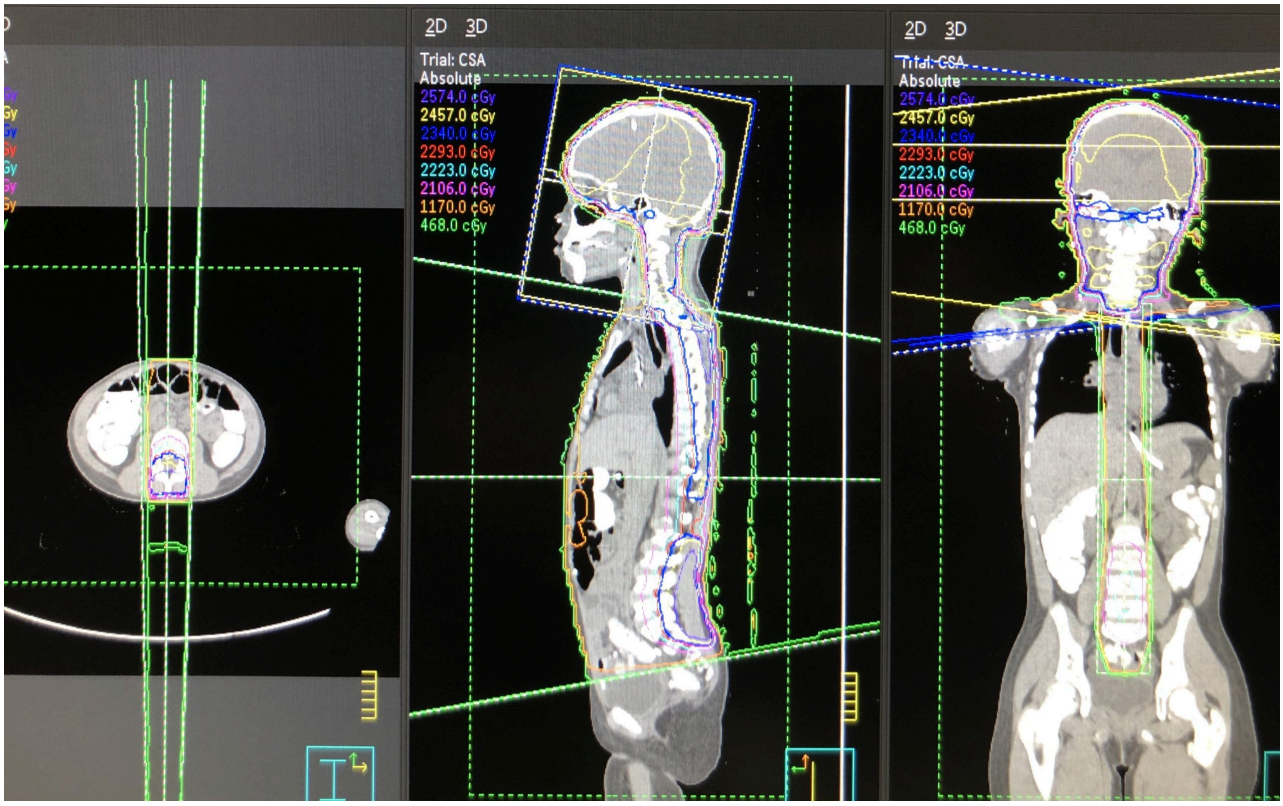
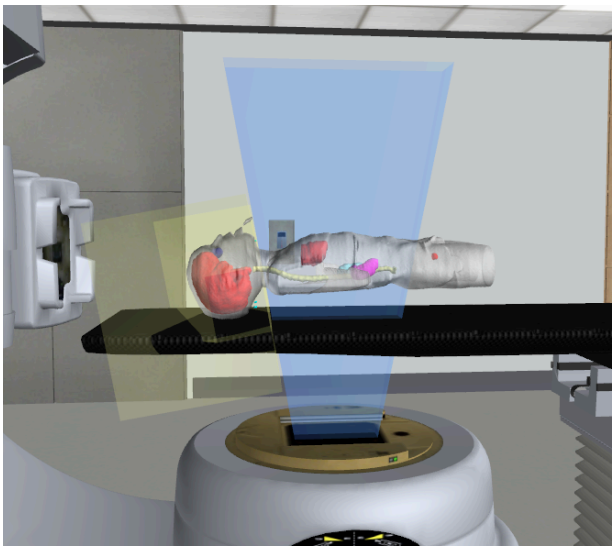


Figure depicts a 3D plan with an extended distance PA field and lateral whole brain fields. The beams were feathered at the junction, therefore a couch kick for the lateral brain fields was not necessary.

Historically, treatment consisted of lateral brain fields and posterior spine field(s). Careful planning and consideration must be given to match lines between the inferior aspect of the cranial field and superior aspect of the spinal field. The spinal field can be delivered at an extended distance to accommodate the entire spine length in one field or delivered in two fields utilizing a gap calculation or feathering to prevent overdosing the spinal cord at the field match.

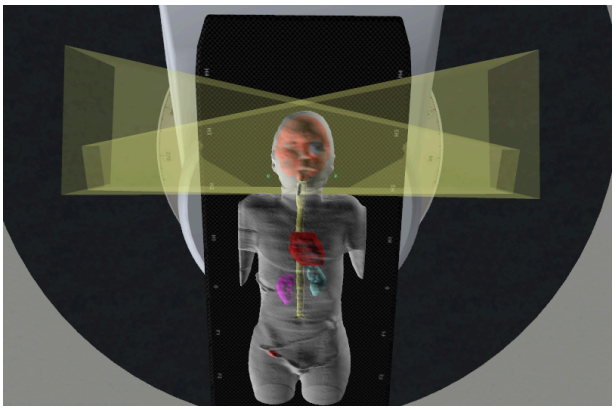
Sagittal isodose line distribution for a photon CSI. The spinal field gap is noticed at L1-2 with a cold spot over the spine and a hot spot in the abdomen demonstrating the importance of a shift in match location 3 times.

If the plan necessitates more than one spine field, and fields are **static**, the field gap must be calculated. The gap measures the separation of the two fields on the patient's skin's surface; this ensures field overlap occurs at a depth anterior to the spinal cord. All matching measurements, including the cervical spine field, are easiest with the patient in the prone position with this treatment technique. The lateral brain fields need superior flash that extends beyond the vertex by several cm to support the shifting of fields and match lines by .5-1 cm approximately 2-3 times during treatment.



The collimator rotation for the lateral brain fields matches the beam divergence of the PA spine field in the superior direction.

Field matching: Couch and collimator rotations are needed for 3D plans to prevent beam overlap and the potential devastating effects of a spinal cord overdose. The inferior border of the lateral cranial fields will overlap with superior border of the posterior spine field; the two divergences need to be accounted for. The cephalad aspect of the spine field diverges towards the cranial field, to account for this divergence, match the collimator rotation of the cranial field to the divergence of the spine field.



The foot of the couch must be rotated towards the gantry for each brain field to match the superior border of the spine field. A couch kick is NOT necessary if the brain field uses a half-beam block.

The second divergence involves the inferior aspect of the cranial fields diverging into the spinal field, rotate the foot of the couch toward the gantry until the inferior border of the cranial field is parallel or matched the superior aspect of the spinal field. The couch angle depends on the length of the lateral brain fields, approximately 5 degrees. When foot of couch rotates toward collimator, treatment distance in inferior half of brain field decreases, increasing dose. The superior portion of the field, the distance increases and dose decreases. The couch rotation can also lead to the most inferior aspect of the opposite temporal fossa to be missed.

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Treatment Techniques: CSI

Cranial and spinal field treatment doses are approximately 36 Gy in 1.8 Gy fractions. CSI treatment is followed by a boost of 10-20 Gy to posterior fossa/tumor bed (entire cerebellum, pons, medulla, extending from tentorium to foramen magnum).

Emerging Technologies & Treatments: CSI

- TomoTherapy offers possibility of irradiating large target volumes continuously and homogeneously without gapes and junctions. This ensures irradiation of entire neuroaxis in one session, short treatment times, and a full 360-degree treatment. Elective dose reduction to OARs and direct image verification of patient position via CT.
- Protons improve normal tissue sparing while also providing more homogenous target coverage than photons. Lower risk of secondary cancer and non-cancer adverse effects.
- IMRT/VMAT delivery techniques continue to make advancements in field-matching techniques.

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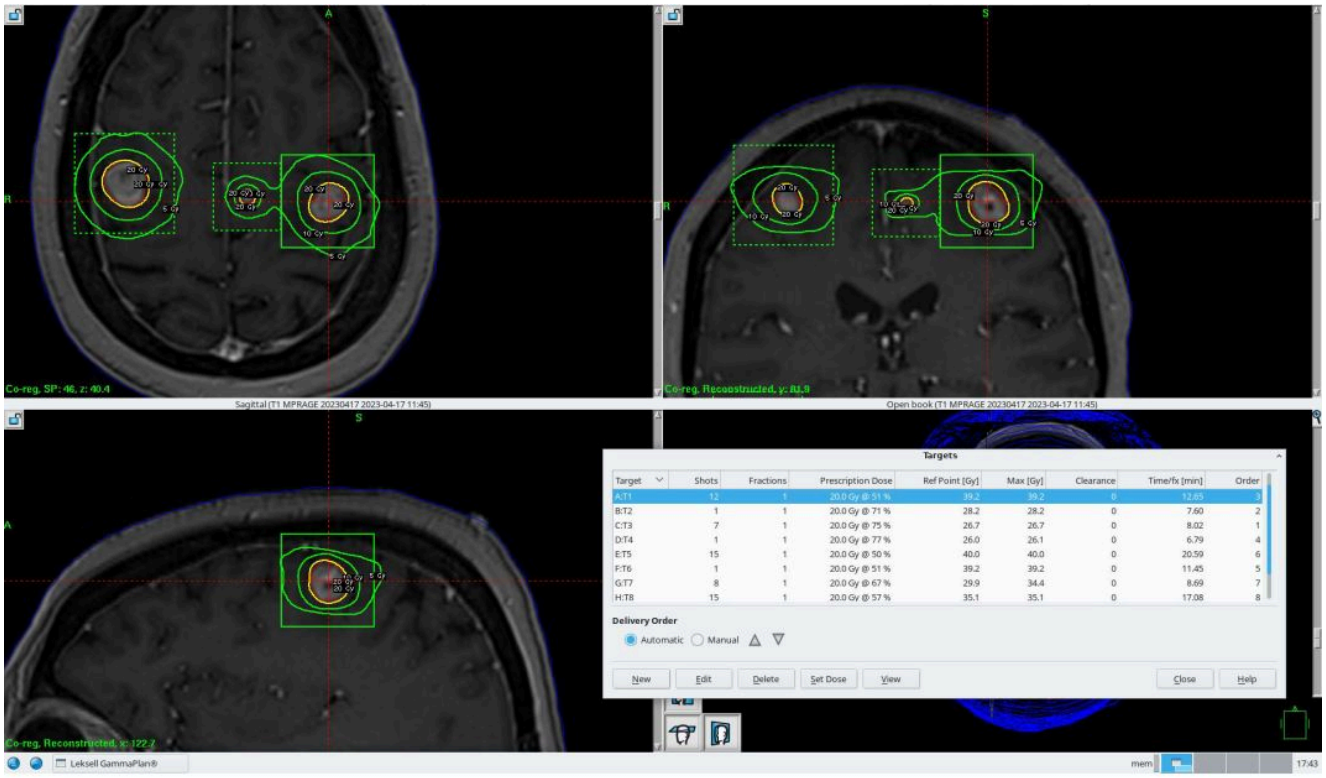
4.

STEREOTACTIC RADIOSURGERY (SRS)

Patient Simulation: Stereotactic RadioSurgery (SRS)

Stereotactic treatments have a precision of less than 1mm and are a single fraction. CT scan parameters should be set at 1mm slice thickness to not miss any small lesions. Patient immobilization is paramount for accuracy; there are a variety of treatment and immobilization techniques available. Patient selection for each will depend on the technology available, patient preference and ability, the number, shape, and size of the lesion(s), and the anticipated treatment time.



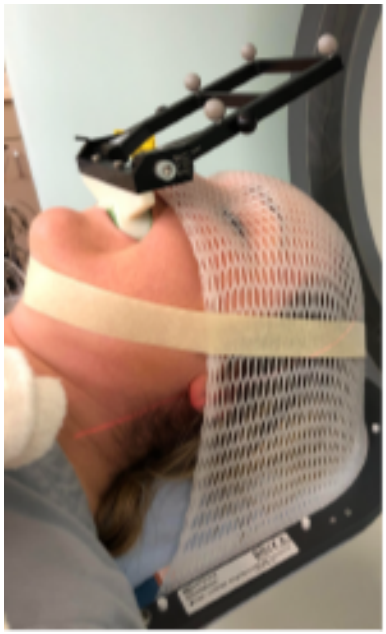
The image demonstrates a Gamma treatment plan for a patient with multiple brain metastasis and isocenters, each was prescribed 20 Gy.

Treatment options include frame and frameless fixation systems:

- Frame: The patient's frame is placed by a neurosurgeon or physician using 4 anchors into the skull. The CT sim, treatment plan, and treatment delivery are completed before the frame is removed all in the same day. The frame is used for immobilization and as a reference point for the treatment planning system. The frame-based system is most commonly used for patients who may have difficulty holding still, accuracy concerns, or pediatric patients under anesthesia.

Frameless fixation systems include:

- A thermoplastic mask and bite block of the upper teeth attached to a frameless array. An infra-red localization camera system (radiocam localization) displays coordinates localizing the isocenter with an accuracy of .5mm. The beam can be interrupted if a patient moves out of tolerance and adjusted. These treatments can be single fraction (SRS) or fractionated (SRT).
- A frame that is secured to the head by an impression of the upper teeth, an occipital tray with an impression of the occiput, and a strap that forcibly holds the dental and occipital impressions against the head.
- A thermoplastic facial mask with or without an infrared fiducial placed on the nose as a motion-monitoring system (Gamma ICON).



SRT biteblock using radiocam localization

Treatment Volume Localization: SRS Treatments

Historically, patients are treated with SRS if they have <5 metastasis and is reserved for tumors <3cm in diameter. More current practices consider treating a patient with up to twelve metastases – the limiting factor may not be the number of metastasis or isocenters, but the overall treatment time and the patient's ability.

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Treatment Techniques: SRS Treatments

SRS treatments are 1 fraction and 17-20 Gy. The total dose is limited by the size and location of the lesion. The graph below indicates some general recommendations.

Lesion Size	Dose / Treatment
<2 cm	20 Gy / 1 fx
2-3 cm	18 Gy / 1 fx
>3 cm	Surgery or 25 Gy / 5 fx or fractionated

Emerging Technologies & Treatments: SRS Treatments

Stereotactic treatments can be delivered using either gamma knife or a modified linear accelerator. Common technologies include:

- Gamma knife has a large lead "helmet" sphere that holds 192 Cobalt-60 sources. Radiation from these sources converges at the isocenter. With the shape of the isodose distribution being altered by selectively blocking some of the sources or by using multiple isocenters. Gamma Knife SRS Video
- Linac-based SRS utilizes MLCs or cone attachments to collimate the radiation to the treatment volume. The treatment takes advantage of gantry and couch rotations to create an isodose distribution that conforms to the target. Beams are delivered via arcs and multiple couch positions – typically 5 per isocenter. The treatment time, per isocenter, is about 15 minutes. Linac-based SRS
- Cyberknife is a unique non-isocenter treatment technology that use orthogonal kV images and a robotic vertical-mounted linear accelerator. It is cable of preforming SRS and SBRT treatments.

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PART II

HEAD & NECK

5.

OVERVIEW: HEAD & NECK

Learning Objectives

- Describe the anatomy, structures, and landmarks of the head & neck
- Describe malignancies of the head & neck
- Describe the simulation process
- Identify commonly used positioning and immobilization devices used for head & neck treatments
- Discuss special considerations in head & neck patient positioning
- Define scan parameters and reference isocenter location for head & neck simulations
- Define the treatment borders and how they relate to tumor spread
- Describe tumor volumes and margins of head & neck tumors
- Discuss the various treatment procedures of head & neck malignancies
- Perform tasks associated with the simulation and treatment of head & neck malignancies

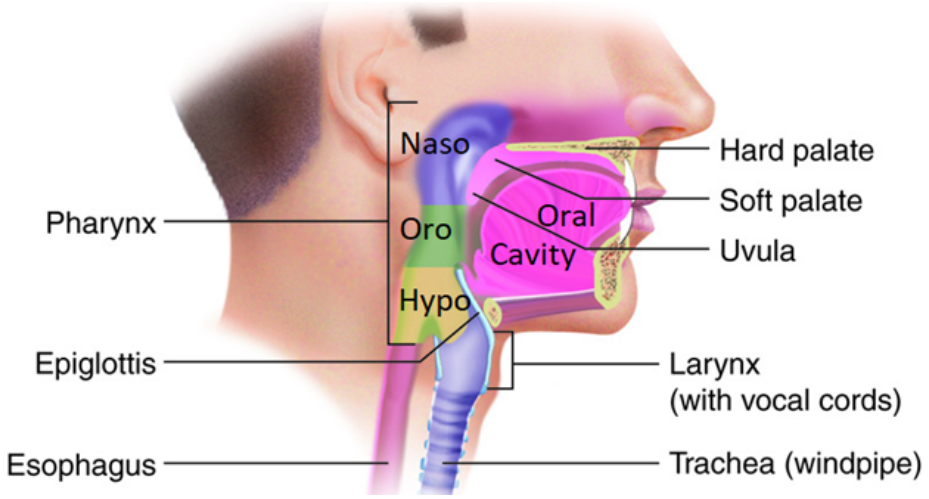
Key Terms

- **Adjuvant**
- **Bilateral**
- **Clinical presentation**
- **Contralateral**
- **Conventional**

- **Cosmesis**
- **Doubling time**
- **En face**
- **Hemiglossectomy**
- Hypofractionation
- **Ipsilateral**
- **Neck dissection**
- **Neoadjuvant**
- **Percutaneous Gastrostomy Tube "PEG tube"**
- **Reassortment**
- **Regional lymph nodes**
- **Tongue Depressor**
- **Xerostomia**
- **Yoke field**

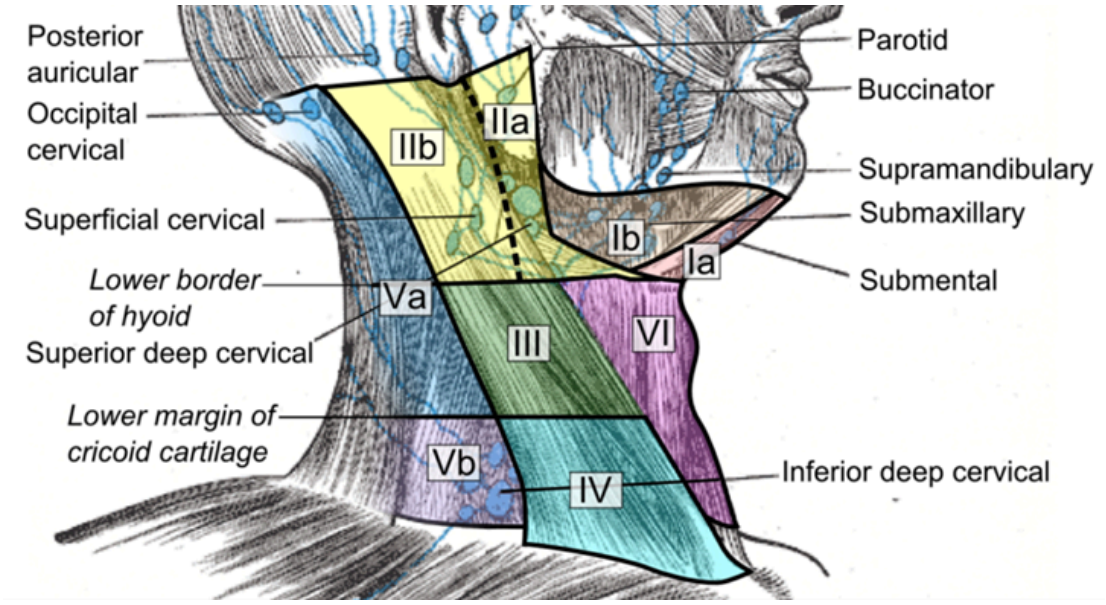
Overview: Head & Neck

Cancer treatment of the head and neck (H&N) is challenging because of the number of critical structures and proximity of different tissues with varying radiosensitivity. Tumors in the head and neck region are additionally challenging because this area is difficult to access with surgery. Thus, radiation therapy is indicated in most head and neck cancers. The head and neck are comprised of many anatomical sites, including the paranasal sinuses, nasopharynx, oral cavity, oropharynx, larynx, hypopharynx, and parotid glands. The prognosis generally decreases as the affected area progresses backward from the lips to the hypopharynx, excluding the larynx. The lungs are the most common site of distant metastasis. The most significant incidence of head and neck cancers is in the oral cavity and oropharynx. Incidence rates for the oral cavity and oropharynx are more than twice as high in men than in women.



Anatomical divisions and major structures of the head and neck.

Most head and neck cancers are squamous cell carcinoma, which arises from the epithelial cells of the upper aerodigestive tract. Adenocarcinomas comprise 7% of head and neck cancers, most of which are found in the salivary glands. There are numerous other less common histological subtypes within the head and neck. These cancers grow fast, most with a **doubling-time** of three to five days; therefore, it's vital to avoid significant breaks in treatment.

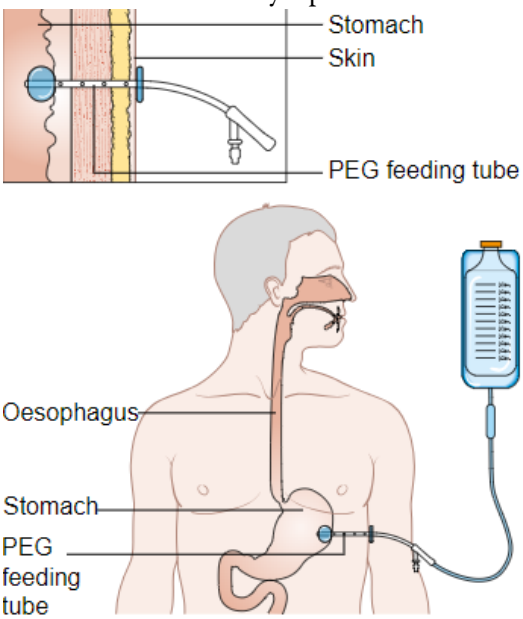


Cervical lymph nodes and levels. Note the location of the sternocleidomastoid muscle under IIb, III, and IV.

Nearly one-third of the body's lymph nodes are in the head and neck. Drainage usually occurs **ipsilaterally**, but some structures, such as the tonsils, the base of tongue, and the posterior pharyngeal wall, have **bilateral** drainage. True vocal cord (TVC), paranasal sinuses, and the middle ear have little to no lymphatic drainage.

Treatment of the lymph nodes in primary head and neck cancers depends on many factors, including cell type and differentiation, size of the primary tumor, lymphatic vascular space invasion of cancer, the extent of primary disease, the site of primary disease, and the clinical or present nodal status of the patient. The jugulodigastric lymph node or sub-digastric node is located below the mastoid tip near the angle of the mandible; it receives almost all the lymphatic drainage from the head and neck area. Therefore, this node is commonly involved in the treatment fields. Another important lymph node is the Node of Rouviere or the retropharyngeal lymph nodes. These nodes cannot be surgically removed, which leads to a high risk of distant metastasis; therefore, they should be included in the treatment fields.

Learn more about lymph node levels of the neck.



Many head and neck patients already have nutritional deficiencies. These deficiencies can be amplified due to side effects related to RT treatment. It is common for patients to have a **percutaneous endoscopic gastrostomy (PEG)** tube placement before or during treatment due to side effects that make eating painful and difficult. Because of these side effects, it is common for patients to lose weight, possibly requiring a new treatment simulation, mask, and treatment plan. General risk factors for head and neck cancer include tobacco and alcohol use, ultraviolet light exposure, viral infections, and environmental exposures. Tobacco and alcohol are two of the most significant risk factors. When used jointly, tobacco and alcohol have a synergistic effect, amplifying the impact each will have on developing diseases. Epstein-Barr virus (EBV), herpes simplex virus 1 (HSV-1), and human papillomavirus (HPV) have also been linked to head and neck carcinogenesis and have an improved prognosis using targeted therapies.

Clinical presentation is dependent on anatomical location. Symptoms by site may include:

Nasopharynx:

- Neck mass is the number one presenting symptom
- Epistaxis or bleeding form the nose

- Nasal obstruction
- Unilateral decreased hearing and otitis media due to eustachian tube compression
- Pain
- Headache due to clival or skull bone invasion
- Hearing changes
- Trismus if the pterygoid or masticator space is involved
- Cranial nerve deficits when there is skull base and cavernous sinus invasion

Oral Cavity:

- Leukoplakia or erythroplakia
- Non-healing sores or ulcers
- Halitosis
- Pain
- Dysphagia

Oropharynx:

- Neck mass is the number one presenting symptom
- Sore throat
- Dysphagia and/or odynophagia
- Otalgia or ear pain when the cranial nerve IX (glossopharyngeal nerve) is involved
- Hot Potato voice and hoarseness are associated with later stage, bulky base of tongue, or larynx involvement. It is noted this is not associated with HPV positive diseases

Larynx/Hypopharynx:

- Glottic cancers present with hoarseness as number symptom
- Supraglottic/hypopharyngeal cancers typically present with sore throat
- Dysphagia/odynophagia
- Cough
- Hemoptysis
- Neck mass

AJCC (TNM) Staging is predominately used for cancers of the head and neck area. Staging systems vary by disease location. More information about head and neck cancers can be found online.

Tumor Grading [1]

Grade	Features of Grade
Grade I	Well differentiated
Grade II	Moderately differentiated
Grade III	Poorly Differentiated

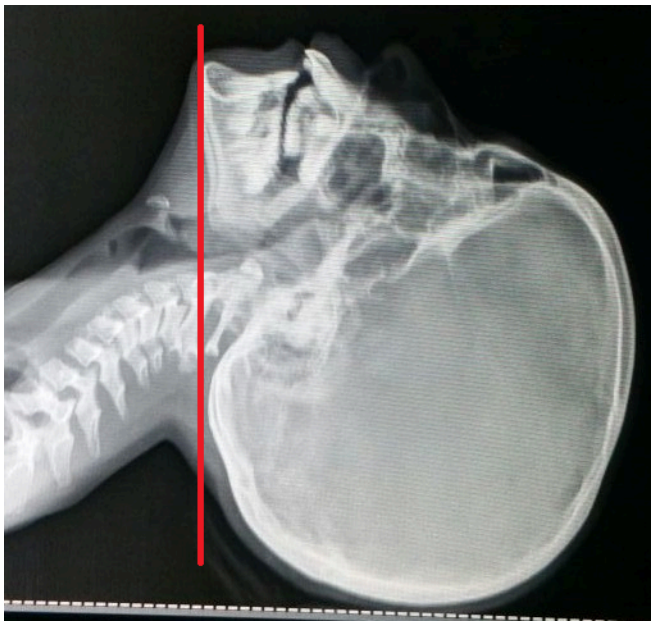
Patient Simulation: H&N

The simulation process is an essential part of a patient's treatment plan. The simulation is performed after the patient has met with the doctor and consented to treatment. The physician completes an image request for simulation specifying treatment setup and intended delivery. The request should include the patient's specific treatment site, contrast orders (if indicated), type of immobilization devices, scan parameters, and any special instructions regarding setup. Standards and similarities exist across the profession, but differences could occur due to physician preference, patient ability, equipment availability, and department protocol.

Attention to detail is crucial during the simulation process. A radiation therapist must review the physician's order and accurately follow scan parameters and department protocol. Pre-simulation education is vital in preparing the patient for treatment. The patient will need a dental appointment before the simulation appointment to address dental caries and tooth extractions. If tooth extractions are indicated, it is recommended that radiation begins after a 2–3-week healing time, beginning treatments earlier can compromise wound healing. When scheduling the simulation, therapists should confirm that a dental appointment has been scheduled. Patients may also need to be informed if shaving is required before mask formation.

When the patient arrives, it is important to consider the beam angles required for treatment before constructing the immobilization device. Then, help the patient lie supine and straighten them on the table; use external landmarks such as the glabellum, SSN (suprasternal notch T2/3), and xiphoid (T9/10). Typically, patients are headfirst, with a thermoplastic head and shoulder mask, knee bolster, feet banded, and hands clasped together or holding a ring. However, every patient and clinic protocol is different. Some patients may present with unique challenges when it comes to positioning. Before fabricating an immobilization device, ensure that the patient is comfortable and in a reproducible position.

Thermoplastic masks play a significant role in reducing setup errors of head and neck treatments. A headrest is used to hyper-extend the patient's chin so that the mandibular line to the mastoid tip is perpendicular to the table; this opens the cervical lymphatics and reduces the mandible dose. Before forming the thermoplastic mask, shoulder retraction may be indicated to help exclude the shoulders from interfering with the treatment path. Lastly, apply radiopaque markers (bb's) at the lasers reference isocenter laterally on each side of the mask and anteriorly before the topogram. For inferiorly located treatments, an alignment mark at the inferior aspect of the mask and on the patient's skin can help ensure the patient is straight. Localization marks should be near the center of the field and in a stable location, not near the edge of the shoulders. Most clinics mark the mask using a sharpie on tape to indicate the triangulation points.



A headrest that extends the chin perpendicular to the treatment table with the inferior aspect of the skull will open up the cervical lymph nodes and remove the mandible from the treatment beam.

Thorough documentation is essential for treatments of the head and neck due to the mobility of the structures and the numerous adjacent tissues with varying radiosensitivities. Photos, setup notes, and immobilization devices should be entered into the patient's chart.

Special Simulation Considerations: H&N

Special considerations must be accounted for based on each patient's unique needs and circumstances. For example, some people are claustrophobic and may need premedication before their simulation/treatment. Cutting the eyes out of the thermoplastic mask, using an open-faced mask, and playing music could all help calm a patient needing extra support. Patients with a previous medical history of limb weakness may need a strap to hold their arms. Additionally, patients with spinal conditions such as kyphosis or scoliosis may need a custom headrest to make them more comfortable. Radiation therapists can provide referrals for additional

support services such as social work, cancer support groups, and music therapy. They should communicate the patient's needs with the entire radiation oncology team.

Head and neck patients must remove any jewelry, hearing aids, or dentures before their simulation/treatment to ensure reproducibility and proper treatment delivery. A patient's tumor location may also require a **tongue depressor** or bite plate placed in the patient's mouth while the thermoplastic mask is formed. The purpose of the bite plate is to separate the tongue from the hard palate; this helps to exclude part of the tongue and oral mucosa, which is highly radiosensitive, from the treatment beams. This type of accessory plays a role in treating nasopharyngeal and oropharyngeal treatments. Additionally, patients with metal fillings could experience an increased mucosal reaction due to scatter; fluoride trays can help reduce the scatter. These trays should be worn for simulation and treatment and should have been made at the patient's dental appointment.

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Treatment Volume Localization: H&N

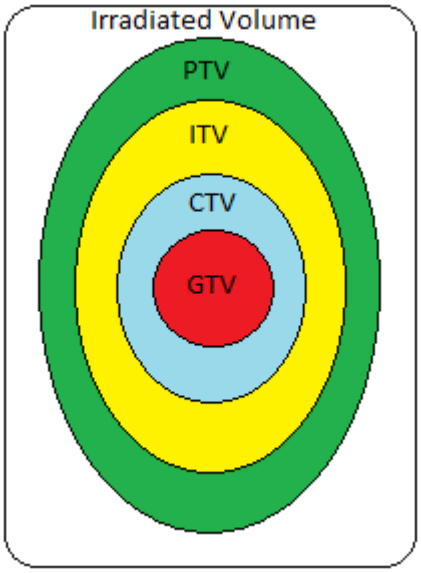
Head and neck tumors are typically treated with lower energy (6X) beams. Higher energies have greater penetration which can miss superficial structures like the submental, sub digastric, and cervical lymph nodes. Higher energies are also a disadvantage due to the separation, radiosensitivity, and surrounding organs at risk.

Due to the many critical structures within the head and neck, a cone beam CT is performed before treatment delivery to ensure all necessary structures are included in the target volume. Different institutions and physicians may have unique preferences on what anatomical structures to align patient images; this should be documented in the patient's chart.

TD 5/5 Doses & Endpoints

Organ	**Whole Organ Dose**	**Endpoint**
Parotid	32 Gy	**Xerostomia**
Spinal Cord	45 Gy	Myelitis/Necrosis
Tempo-mandibular Joint	60 Gy	Limitation of Joint Function
Larynx Cartilage	70 Gy	Cartilage
Larynx Vocal Cord	45 Gy	Edema
Thyroid	45 Gy	Thyroiditis
Lens	10 Gy	Cataracts
Lacrimal Gland	26 Gy	Dry Eye
Optic Chiasm	50 Gy	Blindness
Optic Nerve	50 Gy	Blindness
Brain (Temporal Lobe)	47 Gy	Necrosis/Infarction
Brainstem	50 Gy	Necrosis/Infarction
Ear	55 Gy	Chronic Serous Otitis

The general treatment margins for head and neck cancers includes a 5 mm PTV expansion of the gross disease (GTV), which will receive the highest dose. The elective treatment areas, the lymph nodes at risk for microscopic disease, perineural pathways, and the anatomical compartment have a 3 mm expansion. The expansion may change depending on the surrounding adjacent structures. These margins are much tighter than what was used with **conventional** treatment. With recent advancements in treatment localization and modern imaging techniques combined with proper immobilization, providers can have confidence in the reproducibility and consistency of these increasingly shrinking margins.



Planning target volumes

Volume Definitions

Gross Tumor Volume (GTV)	The gross demonstrable extent and location of disease that can be seen or felt.
Clinical Target Volume (CTV)	Includes the GTV plus a margin to account for microscopic disease that cannot be seen or felt. The area outside the CTV is presumed to have no cancer cells.
Planning Target Volume (PTV)	Includes the CTV plus a margin to account for possible geometric uncertainties, such as patient set-up.
Treatment Volume (TV)	Volume covered by the prescription isodose line. Volume is determined by delivery technique.
Irradiated Volume	Volume that receives a significant dose, usually defined as 50% of prescription dose. Volume is determined by delivery technique.
Organ at Risk Volume (OAR)	Volume encompassing a normal tissue whose radiation sensitivity may significantly influence treatment planning. Example: lens of eye, salivary glands, spinal cord, etc.

Squamous cell carcinoma of the head and neck are treated to approximately 70 Gy. The general curative dose-fractionation for head and neck cancers is 45-50 Gy to elective treatment regions and 60-70 Gy to the gross disease in 30-35 fractions, with a daily fractionation of 1.8-2 Gy.

Other fractionation schemes used in head and neck treatments include:

- Twice daily (bid): Hyper fractionated treatments deliver a smaller dose per fraction for the same number of treatment days and weeks as conventional fractionation. There is a 6-hour minimum between treatments for the **reassortment**, repair, repopulation of normal cells, and reoxygenation of the tissues.

- Quad shot: Hypo fractionated treatment used in patients with head and neck carcinoma. Palliative radiation therapy is delivered bid. on two consecutive days (4 fractions) to 14-14.8 Gy. Patients can receive up to three cycles at 4-week intervals.

Treatment Techniques: H&N

The disease site, function, and **cosmesis** strongly influence surgical options for head and neck cancers. Surgical resection may be challenging because of the surrounding critical structures. For example, most nasopharyngeal diagnoses, surgery is not possible due to anatomic constraints but is reserved as a salvage option. A radical nasopharyngectomy and a **neck dissection** may be indicated for residual or recurrent disease. Surgery can be performed as the initial or primary treatment for small lesions or after **neoadjuvant** chemotherapy or radiation.

Adjuvant chemotherapy is used with radiation as a radiosensitizer, which enhances the lethal effects of radiation therapy. This may be the case for advanced-stage tumors that are unresectable, post-operative, and for patients with positive surgical margins or extranodal extension. Chemotherapy can lead to a significant improvement in survival and locoregional control compared to giving radiation alone. Cisplatin is a common chemotherapy agent used for head and neck malignancies.

Intensity Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) have become the standard radiation therapy treatment technique for head and neck cancer. These treatment techniques can achieve a more conformal plan to complex target volumes. IMRT and VMAT are the preferred treatment modalities because the local extent of the disease is better encompassed while sparing healthy tissues and organs at risk.

Conventional treatments are used to treat midline lesions and bilateral neck node involvement cases with opposed lateral fields, which does not allow the sparing of the adjacent mucosa. For one-sided lesions, anterior and posterior oblique wedged fields were implemented with a lateral field to improve dose homogeneity.

Electrons are a treatment option for superficial structures like the lip, parotid, or lymph nodes. If electrons

are used, it is crucial to ensure the cone is placed en face to the involved area. Ensure that the treatment beam is perpendicular to the patient's surface and the electron block is parallel to the skin surface to achieve a proper dose distribution.

Brachytherapy is typically utilized for recurrence or as a boost after chemoradiation. Brachytherapy can be used through an intraoral cone or interstitial implant for small cancers, not close to the bone and accessible for implantation. Although brachytherapy is rarely performed, it offers the advantage of sparing normal tissues.

Side effect dose onset and management.

Side Effect	Dose	Treatment
Decreased saliva Loss of salivary function	20 Gy 40-45 Gy	Olive oil, ice chips, sugar free gum, etc.
Skin reactions: Faint erythema Erythema Dry desquamation Moist desquamation	16 Gy 20-30 Gy 30-40 Gy 40-60 Gy	Assess skin integrity, apply recommended moisturizing lotions free from alcohols or perfumes, avoid drastic temperatures, wear loose cotton clothing, avoid razor shaving, aerate skin folds, if dry and/or moist desquamation occurs may need prescription creams or other interventions
Tumoritis	20 Gy	Redness of the tumor; helps define tumor extent
Mucositis/ stomatitis	30 Gy	Soft bland, and moderate temperature diet
Dysphagia, pharyngitis, odynophagia, esophagitis	20-30 Gy	Saline gargle; soft bland, and moderate temperature diet
Taste alterations	10 Gy	Seasoning, sugar, marinating, chew thoroughly
Trismus	60 Gy	Exercise muscles, change diet, surgery
Dental caries	50-60 Gy	Extract diseased teeth
Fatigue	10 Gy	Rest and fluids

Emerging Technologies & Treatments: Head & Neck

Advances in technology are happening more rapidly than ever before. Today, several treatment technologies and devices have increased the accuracy and reduced treatment time for head and neck malignancies. A few treatment advancements include:

- 6 degrees of freedom tables – Correct for patient tilt and rotation issues (Vendor examples: Protura & Hexapod)
- Infrared motion/surface monitoring systems (Vendor examples: AlignRT)
- Proton beam radiation therapy is another treatment modality that can be used to treat the head and neck. Protons only travel a certain distance, so the tissues behind the cancer are exposed to very little radiation. Even the tissues in front of the tumor see less radiation than the tumor itself. Therefore, protons deliver radiation to cancer while minimizing damage to nearby healthy tissues.
- Targeted therapy uses drugs to target specific genes and proteins that enable cancerous cells to survive and grow. The downside to this emerging technology is that not all hospitals and clinics offer targeted therapy to patients because it is a growing treatment technique still being researched and studied. Target therapies continue to be investigated for their use in treating head and neck cancers.
- Immunotherapy is another emerging technology that is also called biologic therapy. Immunotherapy works by increasing the body's defense mechanisms to fight cancer. The role of immunotherapy in metastatic head and neck squamous cell carcinoma is evolving.
- Photodynamic therapy uses a photosensitive substance, which is a substance that is sensitive to light, to allow for tumor localization. This photosensitive substance is injected into the patient's bloodstream, and the cancerous cells that are present then harbor it and hold onto the substance longer than the healthy cells. Lasers are then directed at the tumor, which activates the substance to destroy the cancerous cells.
- Neutron therapy (Boron Neutron Capture Therapy – BNCT) is a technique that is being used for unresectable salivary gland cancers and other difficult to treat cancers. Studies show that treatments with neutrons, instead of conventional x-rays or electrons, can increase the local control rate and reduce the risk of late toxicity.

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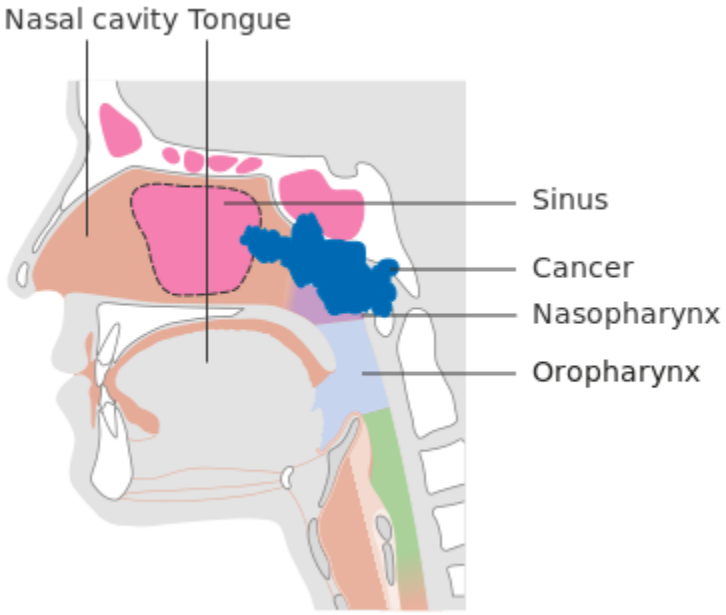
6.

NASOPHARYNX

Overview: Nasopharynx

The nasopharynx is a mucosa-lined box-like chamber that is 2 cm wide by 4 cm long. It is posterior to the nasal cavity and bordered inferiorly by the soft palate and oropharynx. Surgical resection in this area is impossible due to the base of the skull. The nasopharynx is a challenging area to examine, making it difficult to detect these cancers early. Tumors of the nasopharynx commonly arise in the roof or lateral wall behind the eustachian tube or orifice and spread via mucosa or submucosa to invade the nasal cavity or the oropharynx. Nasopharyngeal cancer is rare in the United States, but it does occur more frequently in other parts of the world, especially in Southeast Asia.



Cancer of the nasopharynx that has invaded the ethmoid sinus (dotted line) and the sphenoid sinus and bone superiorly.

Patient Simulation Overview: Nasopharynx

The simulation process is consistent with the typical head and neck simulation in treating nasopharynx tumors. Please refer to the "Patient Simulation: H&N" section.

Special Simulation Considerations: Nasopharynx

For patients who are at a higher risk for weight loss, a prophylactic percutaneous gastrostomy tube (PEG) may need to be placed before the patient's radiation therapy treatments. If possible, one parotid gland should be spared to preserve salivary function. Additionally, bite plates may be beneficial for moving the patient's tongue down and out of the radiation treatment field.

Treatment Volume Localization: Nasopharynx

Treatment of the nasopharynx is challenging. These cancers typically spreads via direct extension into the soft palate, the nasal cavity, and through the base of the skull. Radiation Therapy is delivered to the primary tumor and local and **regional lymph nodes** of the neck – even those not directly involved. Regarding lymphatic drainage, the nasopharynx has a rich lymphatic supply, with 80-90% of nasopharyngeal tumors presenting with positive cervical lymph node involvement. Half of these patients will have bilateral lymph node involvement. Therefore, the supraclavicular and the lower cervical lymph nodes are commonly treated due to the high probability of spread.

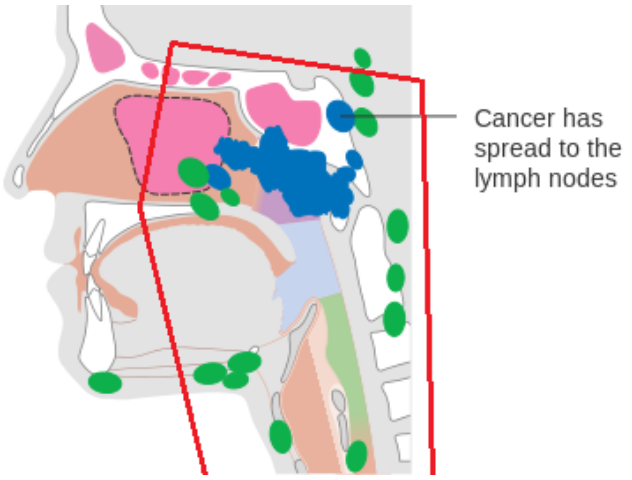
Common lymph nodes include:

- Retropharyngeal Lymph Nodes: Located anterior to C1 and C2, and they contain the Node of Rouviere.
- Deep Cervical Lymph Nodes: These nodes lie behind the sternocleidomastoid muscle at the junction of the spinal accessory and jugular nodes.
- Jugulodigastric Lymph Nodes

Learn more about lymph nodes of the head and neck.

Treatment Borders for T1, T2 & T3 Nasopharyngeal Tumors:

- Anterior: Posterior 2 cm of the nasal cavity, posterior 1/3rd of the maxillary sinus, the posterior ethmoid sinuses, and the posterior ¼ of the orbit.
- Posterior: Behind the spinous processes, including the posterior pharyngeal wall, the deep cervical, the posterior cervical, and the retropharyngeal lymph nodes.
- Superior: The entire sphenoid sinus, the cavernous sinus, and the base of the skull with at least a 0.5 cm margin.
- Inferior: To include include supraclavicular lymph nodes.



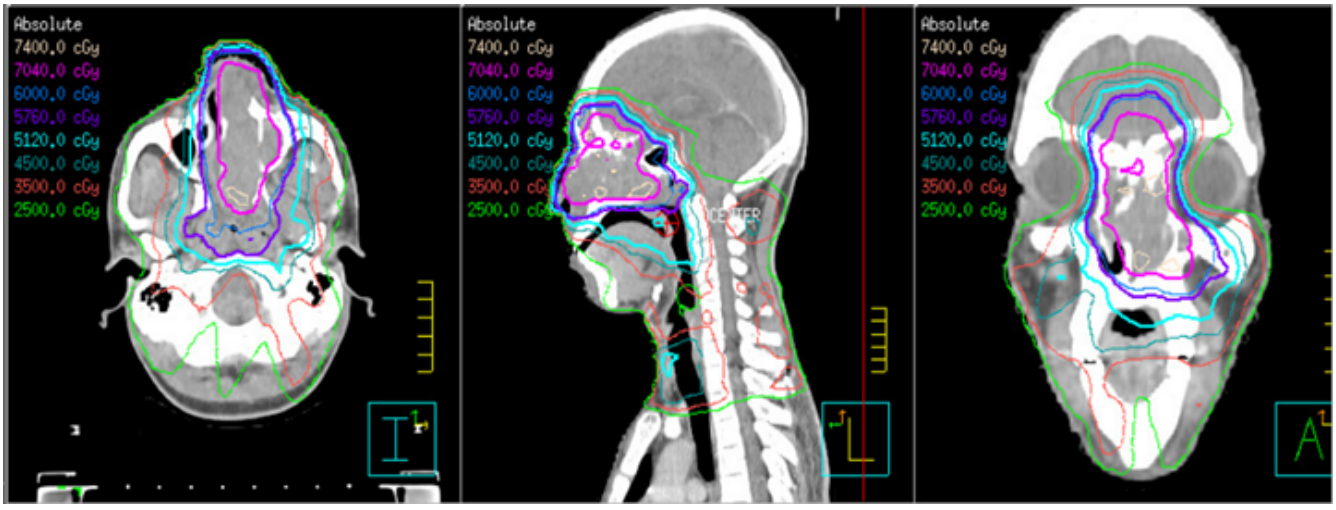
The red lines demonstrate the general field borders for treatments of the nasopharynx. The green circles represent lymph nodes.

For T4 tumors, treatment margins should include the pituitary gland and encompass all intracranial extension.

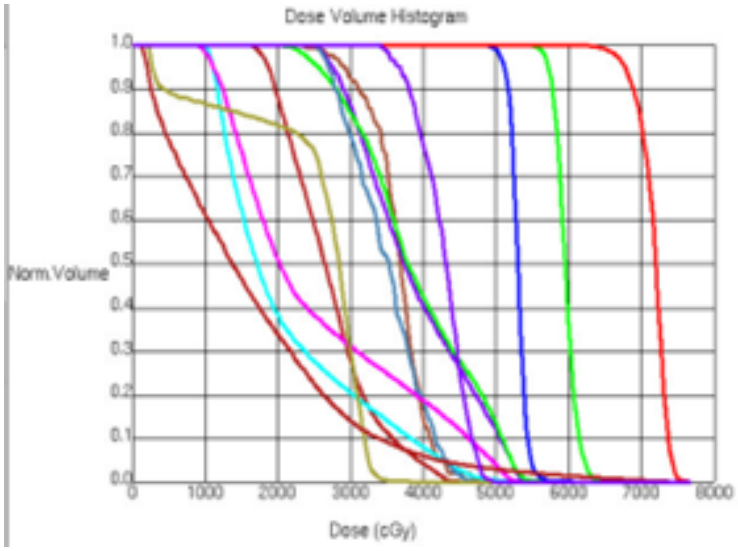
Treatments today still follow these general borders but are more conformal to targeted tissues, sparing normal tissues, and reducing toxicity. Please refer to the "Treatment Volume Location: H&N" section.

Treatment Techniques: Nasopharynx

Historically, the nasopharynx was treated with opposed laterals and/or anterior oblique wedged fields that are equally weighted. Once the spinal cord reaches the tolerance dose of 45 Gy, an off-cord boost of 15 Gy is delivered; these fields must include the Node of Rouviere because it is a common route of spread. The lower neck and bilateral supraclavicular nodes are treated to 50 Gy in 5 weeks with an anterior **yoke field**.



IMRT isodose distribution for a cancer of the nasopharynx.



DVH for a cancer of the nasopharynx.

ROI Statistics

Line Type	ROI	Trial	Min.	Max.	Mean
	PTV57.6	Dmpo 2	5080.5	6776.9	5953.6
	PTV70.4	Dmpo 2	5236.4	7651.0	7155.3
	RT Optic Nerve	Dmpo 2	2508.6	4695.2	3486.0
	RT Parotid	Dmpo 2	765.4	5315.7	2509.5
	Spinal Cord	Dmpo 2	215.8	3814.0	1830.7
	brain	Dmpo 2	110.7	7364.5	1385.7
	optic chiasm	Dmpo 2	3389.5	4965.7	4262.6

DVH structures for a cancer of the nasopharynx.

IMRT and VMAT treatments are most often used to treat nasopharyngeal cancers because of the higher dose we can give to the tumor while reducing side effects. Modern treatment techniques are reflected in the "Treatment Techniques: H&N" section.

Common dose-fractionation schemes:

- 70 Gy in 35 fractions over 7 weeks to PTV70 with concomitant Cisplatin.
- **Hypofractionation**: 74.4 Gy in 120 cGy BID fractions is common.

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7.

ORAL CAVITY

Overview: Oral Cavity

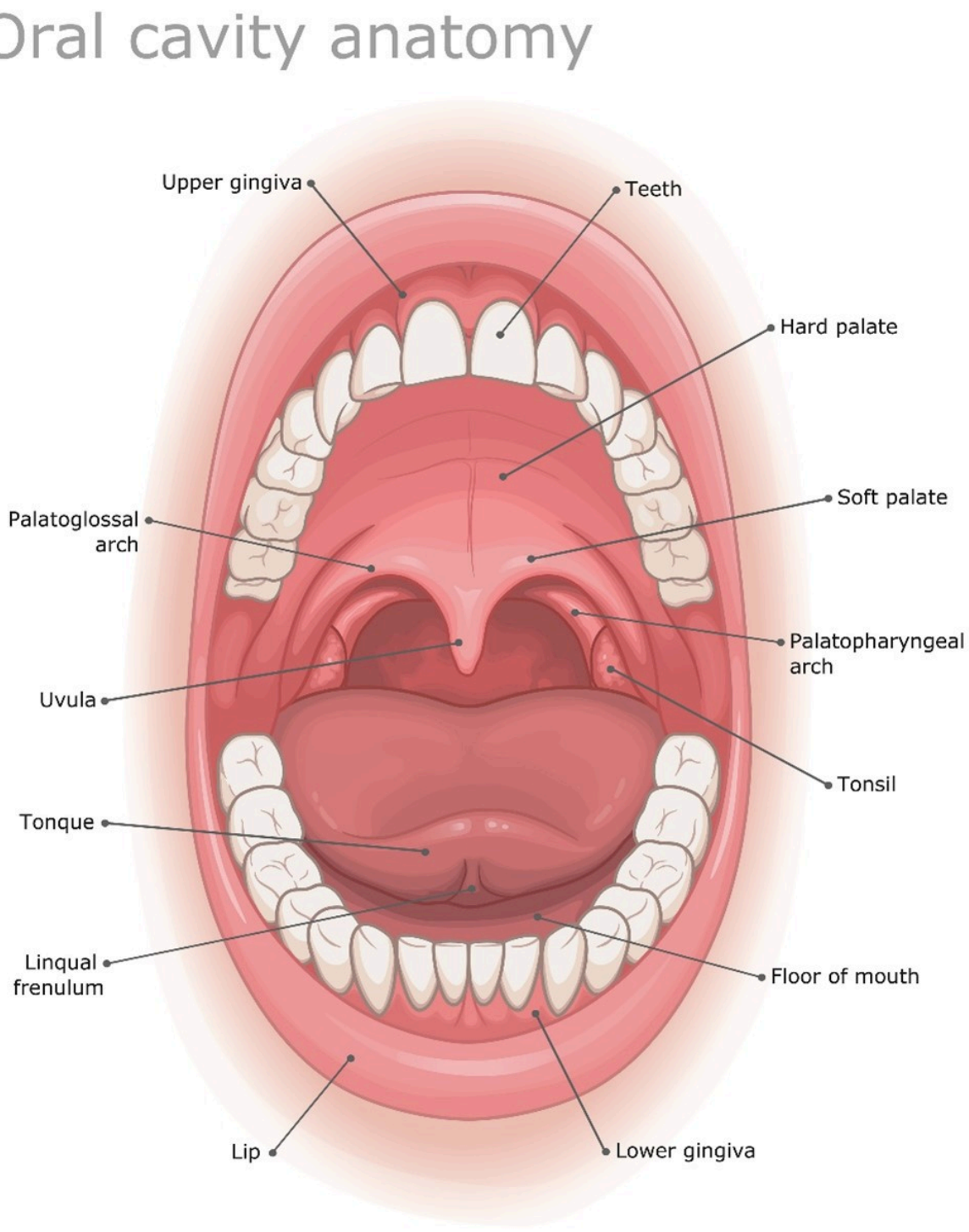
The oral cavity consists of the lip, floor of mouth, anterior two-thirds of the tongue, buccal mucosa, hard palate, and retromolar trigone; it extends from the lips to the posterior aspect of the hard palate. The circumvallate papillae separate the anterior two-thirds of the tongue, in the oral cavity, from the posterior third of the tongue, which in the oropharynx. The tongue is the most common tissue in the oral cavity to develop malignancy (~25%); the most common spread site is to the cervical lymph nodes. Other routes of lymphatic spread include the buccinator, jugulodigastric, submandibular, and submental nodes. Although lymphatic and hematogenous spread is rare.

Sun exposure carries the most significant risk for the development of carcinomas of the lip. Squamous cell carcinomas of the lip most commonly arise from the lower lip and spread by direct invasion. The upper lip drains into the submandibular and preauricular nodes. The lower lip and anterior mouth drain to the submental nodes. However, the oral cavity has the lowest incidence, except for glottic cancer, of nodal metastasis in the head and neck region. Lymph node involvement increases with large lesions, poorly differentiated tumors, spread to the wet mucosal surfaces, invasion of the dermis, or recurrent disease. Lip cancers are treated like skin cancers, most commonly with surgery. Radiation therapy is used to obtain better cosmesis; surgery may create a significant scar or affect the function and quality of life. Lip lesions are typically treated with superficial x-rays or electrons. The treatment field should include the primary lesion with a 2 cm margin. A teeth shield made of lead and wrapped with a bolus or wax material will absorb backscatter and reduce complications to the teeth and gums. The external beam dose in the treatment of lip cancer is 60-70 Gy at 2 Gy per fraction.

Most oral cavity tumors are candidates for surgical resection as a treatment option. Floor-of-mouth cancers are treated with surgery and radiation therapy. About 30% of these cancers have positive submaxillary and sub digastric nodes. If the lesion is confined to the mouth's floor, the tongue's tip is elevated out of the field with a bite plate. However, if the lesion has grown into the tongue, the tongue is flattened with a bite plate and included in the treatment. Typical doses are 50 Gy with a 10-20 Gy boost.

The oral tongue commonly drains to the submandibular and anterior cervical chain nodes. Surgery is preferred for small tumors, including a local excision or **hemiglossectomy**. Radiation therapy can be used in conjunction with surgery or alone. The treatment decision for oral cavity cancers strongly considers the

function of speech and swallowing. The floor of the mouth and oral tongue lesions are usually midline tumors; therefore, bilateral lymph node chains are at risk for disease.



Anatomy of the oral cavity.

The buccal mucosa is the mucous membrane that lines the inner surface of the cheeks and lips. These tissues are very radiosensitive; therefore, taking adequate care of the area throughout treatment is essential. The initial radiation therapy dose is 55-60 Gy in 6 weeks, followed by a boost of 20 Gy to spare the mandible.

Hard palate carcinomas are rare and originate in the minor salivary glands, primarily adenocarcinomas. They tend to spread to the bone and invade the maxillary antrum. Surgical resection is the most common treatment, with postoperative radiation therapy to 65-70 Gy for high-risk patients. A history of poor-fitting dentures or trauma is common.

The retromolar trigone comprises the tissues of the mandible's anterior ramus. The triangular subsite extends from behind the mandible's last molar superiorly to the maxilla's last molar. Carcinomas in this area are rare. Lymphatic spread occurs in the submaxillary and sub-digastric nodes. Lesions in this area have a high tendency for metastases to the neck; therefore, prophylactic neck treatment is critical. Treatment includes surgical resection and/or radiation therapy to a total dose of 66-74 Gy.

Patient Simulation & Special Considerations: Oral Cavity

The simulation process is consistent with the typical head and neck in treating oral cavity lesions. Please refer to the "Patient Simulation: H&N" section. Additional considerations for oral cavity treatments may indicate using a biteplate or tongue depressor. A bite plate can help keep the mouth open during treatment and make it easier to include or exclude oral mucosa from the treatment field. For example, when irradiating the hard palate, the tongue should be below the tongue depressor to push it inferiorly out of the radiation field. Or when treating the floor of the mouth, the oral tongue can be excluded by moving it above the bite plate. Patients with metal fillings may also benefit from fluoride trays worn during treatment to reduce scatter and irritation to oral tissues.

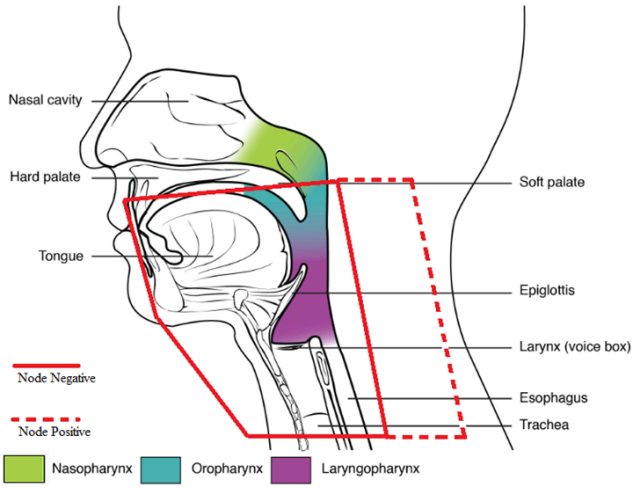
One or more interactive elements has been excluded from this version of the text. You can view them online here: https://pressbooks.uiowa.edu/radiationtherapy/?p=304#oembed-1

Treatment Volume Localization: Oral Cavity

The conventional 2D field borders for the floor of mouth and oral tongue lesions include:

- **Superior:** 1.5 cm above the tongue
- **Inferior:** thyroid notch
- **Anterior:** in front of the mandible (exclude the lower lip if possible)
- **Posterior:**
  - Node negative: behind the vertebral bodies
  - Node positive: behind spinous processes

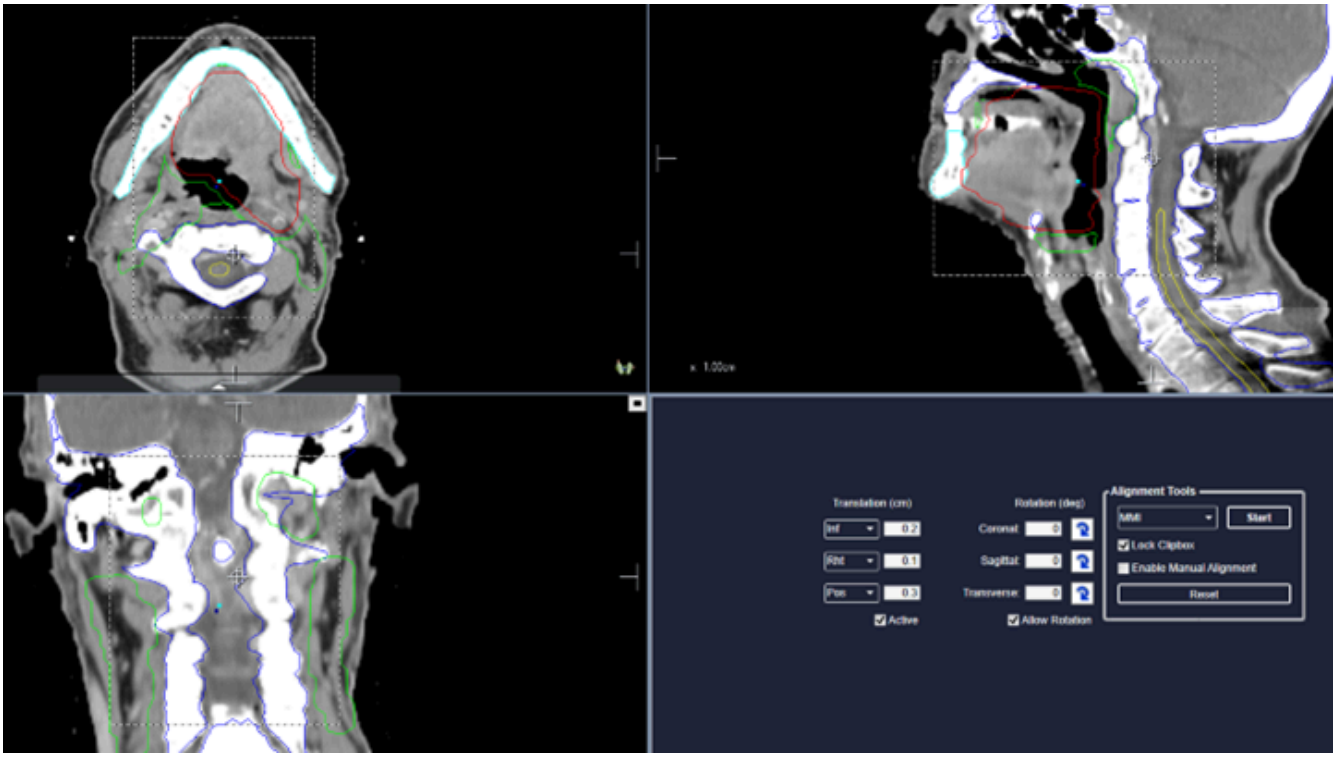
Treatments today still follow these general borders but are more conformal to targeted tissues, sparing normal tissues and reducing toxicity. Please refer to the "Treatment Volume Location: H&N" section.



The general field borders for treatments of the oral tongue. Note: a tongue depressor would move the tongue inferior to reduce dose the the hard palate. The dotted line represents the field extension for node positive disease.

Treatment Techniques: Oral Cavity

The dosing may vary depending on the specific site within the oral cavity. Typically, the involved or at-risk lymph nodes are treated to 45-50 Gy, followed by a boost to the gross disease. As a primary treatment for oral cavity cancer, radiation is generally administered daily over 6-7 weeks, to a total dose of 60-70 Gy. Modern treatment techniques are reflected in the "Treatment Techniques: H&N" section.



CBCT image for a malignancy of the oral tongue and tonsil (red contour) treated to 70 Gy. The green contours represent the lymph nodes which had a PTV of 56 Gy.

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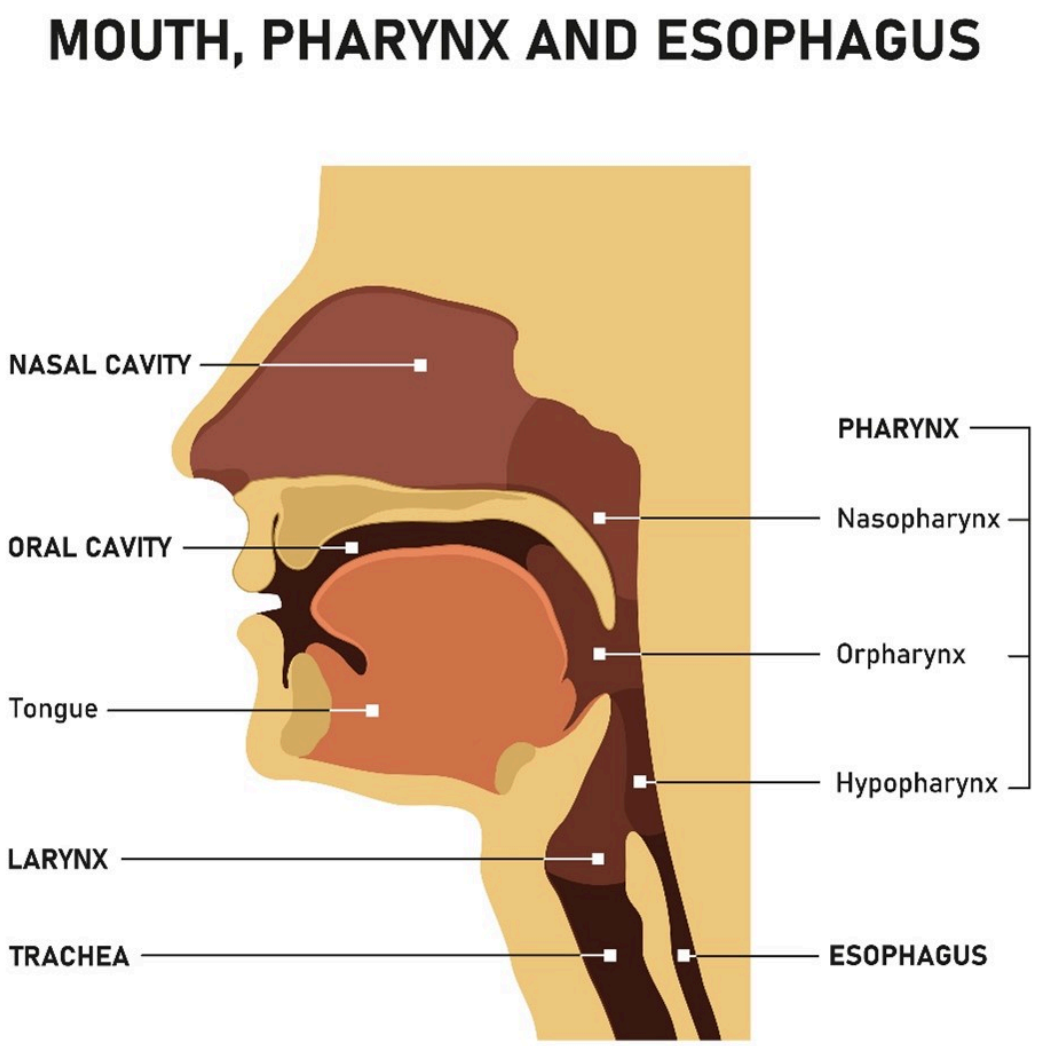
8.

OROPHARYNX

Overview: Oropharynx

Oropharynx tumors are close to the oral cavity but lie more posteriorly. The general rule of thumb is that head and neck cancers have a poorer prognosis as the affected site moves posterior from the lips and inferiorly. Oropharyngeal cancers typically arise as squamous cell carcinomas (95%). Lymphoma and lymphoepithelial tumors are rare but can occur. Tonsils are the most common primary site of disease within this group. Common symptoms at clinical presentation are sore throat and painful swallowing. Tumors in this region have a profound effect on aerodigestive function.



Anatomical divisions and major structures of the head and neck.

The anatomical position of the oropharynx makes surgical intervention more difficult; most tumors are inoperable. The primary treatment option is radiation therapy. Radiation therapy is the treatment of choice for early-stage oropharyngeal tumors. Large extensive tumors are commonly treated with combined surgery and postoperative radiation. Radiation therapy alone is often used for inoperable patients and palliation.

Patient Simulation: Oropharynx

The simulation process is consistent with the typical head and neck in treating oropharynx lesions. Please refer to the "Patient Simulation: H&N" section. An additional consideration is the potential necessity of tongue

immobilization. Depending on the anatomic location of the disease, it may be beneficial to depress the tongue into the floor of the mouth – this will reduce variability in tissue location and help spare normal tissues. The base of tongue cancer could be an example where the tongue would be immobilized to the floor of the mouth. The opposite technique may also be helpful – if treatment is of the lateral pharyngeal wall, the tongue may be immobilized away from the floor of the mouth.

Oral positioning video from "Simulation: Oral Cavity."

Treatment Volume Localization: Oropharynx

Treatment borders for the oropharynx include:

- **Anterior:** 2 cm anterior to the tumor
- **Posterior:** behind the spinous process to include the posterior cervical lymph node chain
- **Superior:** entire jugular chain and above C1
- **Inferior:** thyroid notch, or to include the supraclavicular region

Treatments today still follow these general borders but are more conformal to targeted tissues, sparing normal tissues and reducing toxicity. The treatment planning is consistent with the typical head and neck protocol in treating oropharynx cancers. Please refer to the "Treatment Volume Location: H&N" section.

Historical treatments included a separate anterior lower neck field, "yoke field," to treat the supraclavicular and lower jugular lymph nodes. Treatment of these nodes is crucial due to bilateral lymph node involvement. The yoke field abuts opposed laterals. The field match is most easily achieved using a half-beam block and a single isocenter, but a two-isocenter technique can be used with a couch-kick and collimator rotation for beam matching.

Different sites within the oropharynx have unique lymph node drainage pathways to consider in treatment planning.

Oropharynx Site	Lymph Node Drainage Pathway
Tonsil	Jugulodigastric & submaxillary nodes
Base of Tongue	Jugulodigastric, low cervical, & retropharyngeal nodes
Lateral Pharyngeal Wall	Retropharyngeal, pharyngeal, & jugulodigastric nodes
Soft Palate & Uvula	Jugulodigastric, submaxillary, & spinal accessory nodes

Treatment Techniques: Oropharynx

Curative dose-fractionation schemes can vary depending on the intent of treatment. 70 Gy in 35 fractions would be a typical regiment for early-stage conventional treatment. A hypo-fractionated course may also be considered for patients who cannot complete as many treatments as the conventional dose.

Hypo-fractionated dose examples of the oropharynx include:

- 55 Gy in 20 fractions at 2.75 Gy per fraction
- 44 Gy in 22 daily fractions at 2 Gy per fraction

Palliative dose examples include:

- 30 Gy in 5 fractions of 6 Gy twice weekly for two and a half weeks or
- 20 Gy in 5 daily fractions of 4 Gy.

Most recently, VMAT treatments allow multiple arcs to simultaneously treat the cervical nodes and the primary tumor using margins reflected in "Treatment Techniques: H&N" section. However, it is beneficial to understand conventional treatment techniques and borders.

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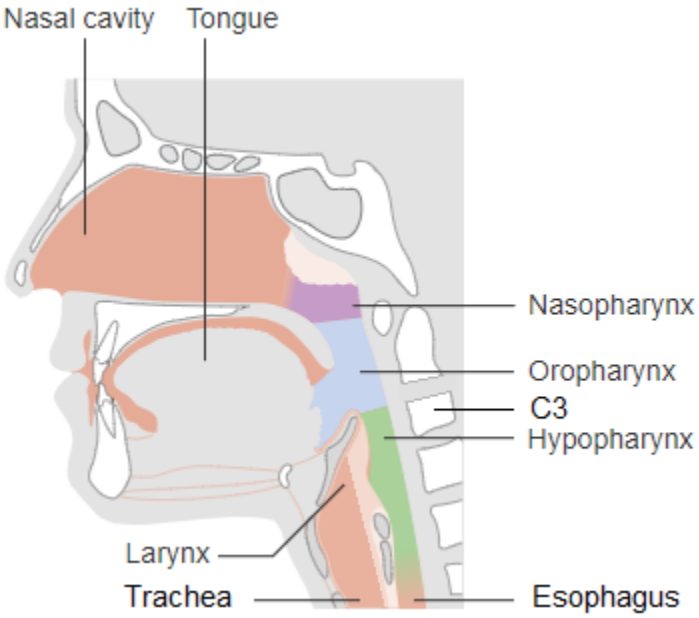
9.

HYPOPHARYNX

Overview: Hypopharynx

The hypopharynx, also known as the laryngopharynx, extends from the hyoid bone to the esophagus. The epiglottis is the superior border, at the level of C3. The hypopharynx is posterior to the larynx and is comprised of the "3 P's" – the pyriform sinuses, posterior cricoid, and lower posterior pharyngeal walls. The pyriform sinuses are the most common location for cancer within the hypopharynx. It commonly spreads to lymph nodes and invades nerves and muscles nearby. Regarding lymphatics, the hypopharynx drains to the mid-cervical nodes, superior deep, middle, and low jugular nodes, and retropharyngeal node (Node of Rouviere). Due to the rich lymphatic supply of the area, approximately half of all patients will be diagnosed with positive lymph nodes.



Divisions of they pharynx demonstrating the superior aspect of the hypopharynx at C3.

Patient Simulation: Hypopharynx

The simulation process is consistent with the typical head and neck in treating hypopharynx lesions. Please refer to the "Patient Simulation: H&N" section.

Treatment Volume Localization: Hypopharynx

Traditional treatment borders for the hypopharynx are:

- **Superior:** inferior aspect of the mandible and mastoid process to the base of the skull
- **Anterior:** in front of thyroid cartilage with a margin around tumor extension
- **Posterior:** behind spinous processes with a margin on all nodal disease
- **Inferior:** below the cricoid cartilage, to encompass the entire extent of the tumor with a 1.5-2cm margin or to include the lower jugular and supraclavicular area.

Treatments today still follow these general borders but are more conformal to targeted tissues, sparing normal tissues and reducing toxicity. Please refer to the "Treatment Volume Location: H&N" section.

Treatment Techniques: Hypopharynx

Historically, opposed lateral fields treat to 45 Gy, and beam size is reduced off the spinal cord to deliver 65 Gy to the primary tumor volume. Preoperatively, 45-50 Gy is given, followed by a laryngopharyngectomy. Postoperatively, 50 Gy is delivered in 6 weeks via lateral fields. An additional 10-20 Gy may be delivered to the stoma if the surgical margins are not clear of disease. Modern treatment techniques are consistent with the typical head and neck protocol in treating the hypopharynx and are reflected in the "Treatment Techniques: H&N" section.

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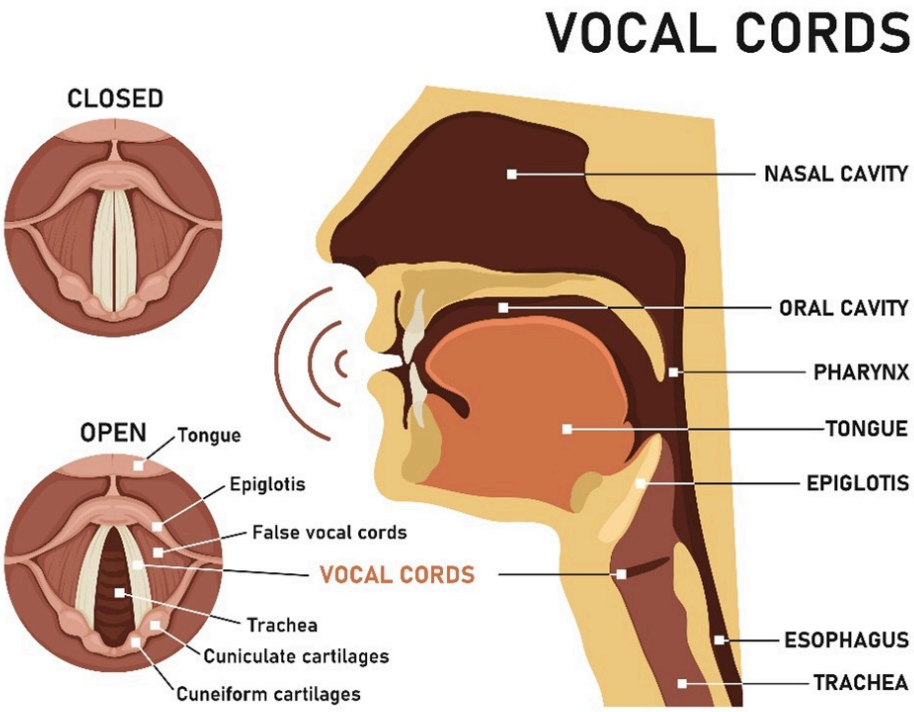
10.

LARYNX

Overview: Larynx "Glottis"

The larynx is comprised of the glottis, supraglottis, and subglottis, with the largest of these three regions being the supraglottis. Approximately 65% of cancers occur in the glottis, 34% in the supraglottis, and 1% in the subglottis. Treatments vary depending on the stage and origin of the malignancy.



Anatomy of the larynx and and vocal cords. Note: anatomically, the false vocal cords are located superiorly to the true vocal cords.

The larynx extends from the epiglottis to the cricoid cartilage at the level of C3 to C6. The supraglottis region includes the epiglottis, false vocal cords, ventricles, aryepiglottic folds, and arytenoids. The glottis region consists of the true vocal cords and the anterior and posterior commissures, and the subglottis region is located 1 cm below the true vocal cords. Cancer of the larynx is strongly associated with cigarette smoking and HPV;

most tumors are squamous cell carcinoma (SCC). HPV+ patients have an improved prognosis through the use of targeted therapies.

Simulation Overview & Special Considerations: Larynx

In treating the larynx, the simulation process is consistent with the typical head and neck simulation. Please refer to the "Patient Simulation: H&N" section.

Considerations when simulating patient with cancer of the larynx include using a headrest that extends their chin. The patient's shoulders should be low to keep them out of the lateral radiation treatment beams. A thermoplastic head and shoulder mask should be made while the patient relaxes their shoulders down or reaches towards their toes until the mask has cooled. Straps can also be used around the patient's wrists with their knees bent, having the patient straighten their legs on the strap, depressing their shoulders. It is important to document the length and position of the straps for reproducibility.

Shoulder retraction, a Civco device demo.

Treatment Volume Localization: Larynx

Supraglottic tumors spread to the jugulodigastric lymph nodes, the superior deep lymph nodes, and the mid-jugular lymph nodes. Treatment borders for the supraglottis and T3/T4 positive lymph node glottic cancers depend on the extent of spread. T3/T4 lesions, the treatment fields should encompass the lower jugular lymph nodes and the supraclavicular lymph nodes. Advanced glottic and supraglottic cancers will follow standard IMRT treatment margins; please refer to the "Treatment Volume Location: H&N" section.

Cancers of the true vocal cords, frequently called glottic cancers, spread through local invasion to the subglottic and supraglottic regions. However, most glottic cancers are detected early, and invasion is rare. Laryngeal tumors can spread lymphatically to Rouviere's lymph nodes through local extension or direct invasion. Metastasis rarely occurs unless the tumor spreads outside the true vocal cords; metastasis to the lung is the most common.

For treatment fields, the treatment portal for T1 lesions of the glottis is limited to the vocal cords. Lymphatics spread is rare; therefore, they are not included in the treatment ports. Early-stage (T1 & T2) glottic cancer is treated with parallel-opposed lateral fields and wedges.

The treatment borders include:

- **Anterior:** 1.5-2 cm beyond the thyroid cartilage (flash over skin)
- **Posterior:** Anterior margin of the vertebral bodies
- **Superior:** Top of the thyroid cartilage
- **Inferior:** Below the cricoid cartilage

Advanced T2 lesions are planned to have a 2-3 cm margin around the tumor and the jugulodigastric and mid-jugular lymph nodes are encompassed in the portals.

Advanced T2 Tumors of the glottis Treatment Borders:

- **Anterior:** 1.5-2 cm beyond the thyroid cartilage
- **Posterior:** Mid-vertebral bodies
- **Superior:** Supraglottic extension and 2-3 cm margin
- **Inferior:** Infraglottic extension and 2-3 cm margin

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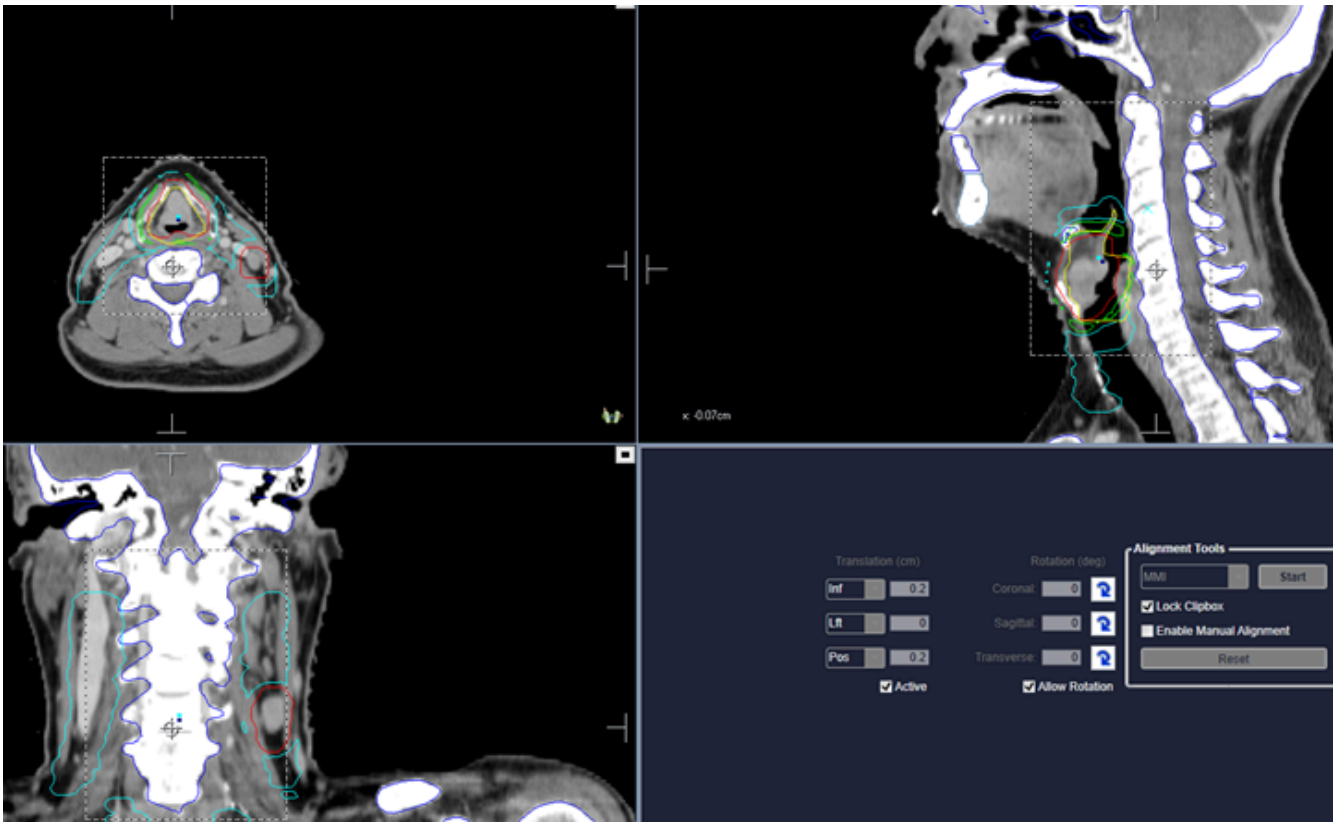
Treatment Techniques: Larynx

External Beam Radiation Therapy (EBRT) is the preferred treatment technique for early-stage glottic cancer as it helps to preserve voice quality and produce favorable cure rates; it is best when treating early-stage supraglottic lesions with minimal local extension. Broad-shouldered patients may need couch kicks to avoid treating the shoulders. A 15–30-degree wedge is commonly used to achieve a more uniform dose distribution across sloping skin surfaces of the anterior neck.

Advanced lesions of the glottic larynx are typically treated with a total laryngectomy and radical neck dissection, and postoperative radiation can be prescribed "salvage therapy" if needed. Patients with advanced disease and protocol patients can undergo concurrent radiation therapy and chemotherapy, whereas patients with fixed vocal cords should only receive radiation therapy. For patients with inoperable disease, radiation therapy can be prescribed for palliation.

Location / Stage of Disease	Beam Orientation & Dose	Sites included
Early-Stage Glottis (T1 & T2)	Opposed laterals; 4-6 MV; 60-66 Gy	Larynx
T3 & T4 Glottis	IMRT/VMAT; 4-6 MV; 70 Gy	Primary tumor and regional lymphatics
Glottic w. extension to Supraglottis or Subglottis	IMRT/VMAT; 4-6 MV; 74 Gy	Primary tumor and regional lymphatics

Regional lymphatics include the supraclavicular and lower jugular lymph nodes. All treatments curative treatments have a goal of minimal functional impairment. Modern IMRT margins are reflected in the "Treatment Techniques: H&N" section for advanced cancers of the larynx and supraglottis.



CBCT of a supraglotic malignancy treated with VMAT to 70 Gy in 35 fx.

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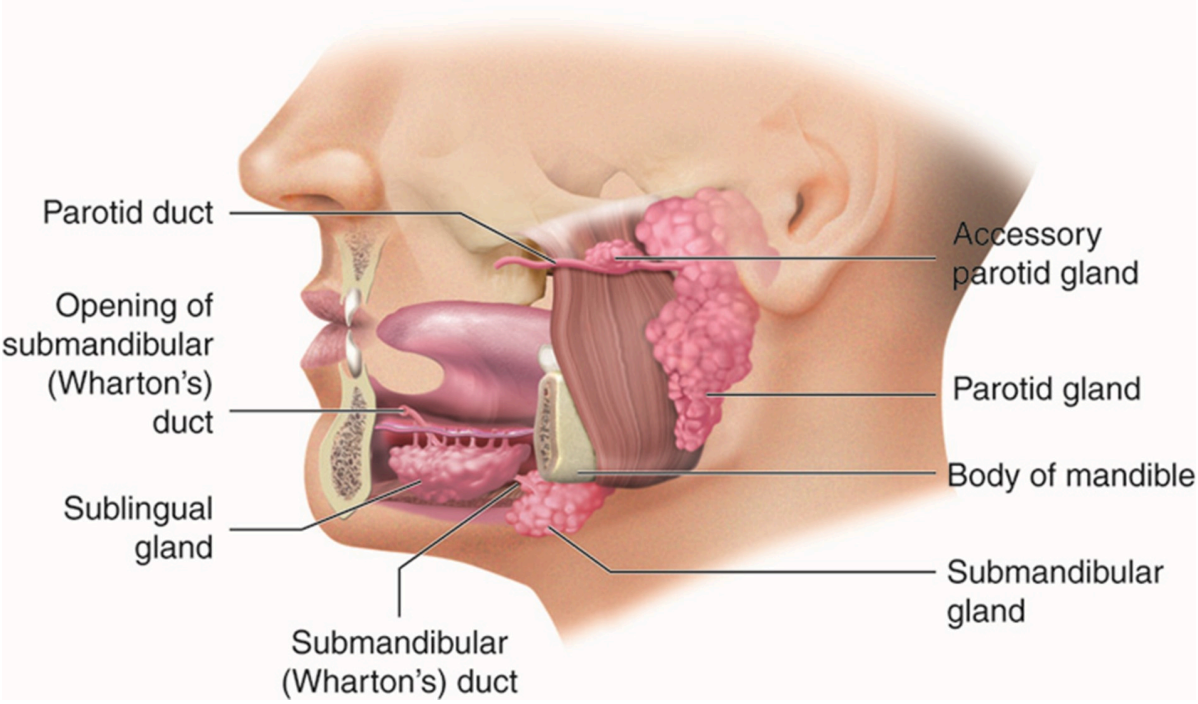
11.

SALIVARY GLANDS

Overview: Salivary Glands

The salivary glands consist of two major groups, the major and minor salivary glands. The major glands are the Parotid, Submandibular, and Sublingual glands. The word parotid means around the ear. The parotid gland is shaped by the structures that surround it. Superiorly the border lies below the zygomatic arch and below the external auditory meatus (EAM). Posteriorly it extends to the tip of the mastoid. Anteriorly the gland extends to the orifice of the parotid duct. Inferiorly the gland extends to the upper border of the posterior belly of the digastric muscle. Radiographically this lies between the mandible and the hyoid. The minor salivary glands are the labial and buccal glands, the gloss palatine, palatine, and lingual glands. These glands are commonly named after structures that they are adjacent to. You can visualize all the glands in the following diagrams.



Salivary glands of the head and neck.

The American cancer society states that there will be roughly 2500 new cases of malignant salivary cancer each year, representing approximately 7% of all head and neck cancers. The primary histology of these glandular

structures is adenocarcinoma. Most cancers are located in the largest salivary glands, the parotids. Malignant disease is most significant in the parotid glands because of the high incidence of tumors, even though two-thirds of tumors will be benign. The minor salivary glands will have a higher rate of malignant disease; roughly 75% will be malignant. The histologic breakdown of adenocarcinomas will commonly be adenoid cystic and mucoepidermoid disease. Of the pathologies, Mucoepidermoid disease is more common, and adenoid cystic carcinomas will generally have worse outcomes, therefore, the treatment should be more aggressive.

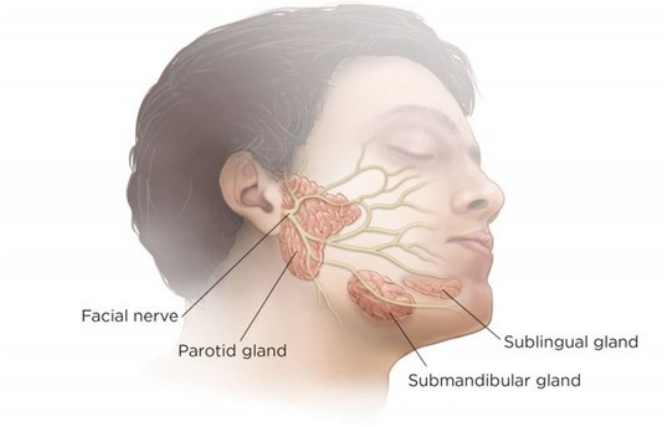
Patient Simulation & Special Considerations: Salivary Glands

Simulation for salivary gland cancers will be similar to other head and neck cancers. Please refer to the "Patient Simulation: H&N" section.

When treating salivary gland malignancies, it is important to include the postoperative scar, which must be considered while making the thermoplastic mask. Triangulation localization marks are generally placed on the chin anteriorly and inferior to the EAM on both sides. When obtaining the topogram, the therapist will set the scan borders from the vertex to the hyoid bone. If cervical nodes are involved, the inferior board may be extended below the clavicles to the carina.

Treatment Volume Localization: Salivary Glands

There are multiple special considerations when planning radiation treatments for salivary gland cancer. It is crucial to understand how salivary cancers spread. The superficial lymph nodes of the parotid receive drainage from the subcutaneous tissue of the face, auricle, middle ear, and external auditory canal. Due to this drainage, the parotid is commonly involved with metastatic diseases and primary parotid tumors. Most malignant tumors spread through local invasion, ipsilateral neck lymph node spread, and perineural invasion. One-quarter of parotid tumors present with lymph node metastases, and another quarter have facial nerve palsy from the invasion of cranial nerve seven. The primary route of lymph node spread will continue to the first echelon of drainage, the ipsilateral jugulodigastric lymph node.



Facial nerve location relative to the salivary glands.

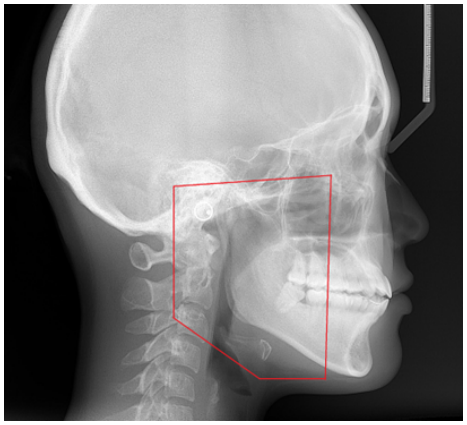
Cranial nerve involvement is likely for patients with bulky disease in the major salivary glands. The facial nerve (VII) has extensive bifurcation through the parotid, submandibular and sublingual glands. An increase in pressure on this nerve can lead to Bell's Palsy; this leaves the facial muscles in a state of paralysis. This condition is accompanied by pain and discomfort on the involved side of the face. Other symptoms include slurred speech, difficulty opening and closing the eyelid, and dysphagia.

The salivary glands are very radiosensitive and are commonly spared, so it is important to avoid the **contralateral** gland when treating parotid gland disease. These glands are vital in producing saliva, aiding mastication, and preventing tooth decay. It is crucial to ensure that the dose falloff from treating the involved gland is rapid enough to avoid xerostomia in the contralateral side.

Historically, conformal treatment techniques use two or three ipsilateral photon beams to provide a homogenous dose distribution to the CTV without exceeding the tolerance of the adjacent critical structures. The three-field technique uses a lateral beam and anterior and posterior oblique fields with wedges. A single mixed photon and electron beam may also be used as the primary treatment technique. If this is done, the field should include the entire incision and the parotid bed with a margin. The dose should be prescribed beyond the deepest lobe of the parotid gland, approximately 4 cm.

- **Superior:** zygomatic arch
- **Inferior:** top of thyroid cartilage
- **Posterior:** behind the mastoid process
- **Anterior:** anterior to the border of the masseter muscle

Treatments today still follow these general borders but are more conformal to targeted tissues, sparing normal tissues and reducing toxicity. Please refer to the "Treatment Volume Location: H&N" section.



General treatment borders for a parotid gland.

Treatment Techniques: Salivary Glands

Treatment doses for salivary glands are highly dependent on the stage of the disease. Surgery to remove either a section of or the entire parotid gland is likely the treatment of choice for stage 1 and 2 diseases. Radiation

therapy may be recommended for positive margins or residual disease. If there are clear margins, the optimal dose will be approximately 60 Gy following standard fractionation. If there is evidence of residual disease, the total dose is increased by approximately 10 Gy to a total dose range of 70-75 Gy.

Advanced-stage diseases, stages 3 and 4, will result in a much more challenging surgical resection due to the vast amount of cervical lymph nodes involved. Surgery is possible but is generally not recommended. At this stage, with the progression of the disease, it is more likely that systemic chemotherapy will be combined with radiation to a dose of 70-75 Gy. Because salivary gland tumors are so rare, these patients are good candidates for further clinical trials to investigate disease treatment. Treatment margins for IMRT are reflected in the "Treatment Techniques: H&N" section.

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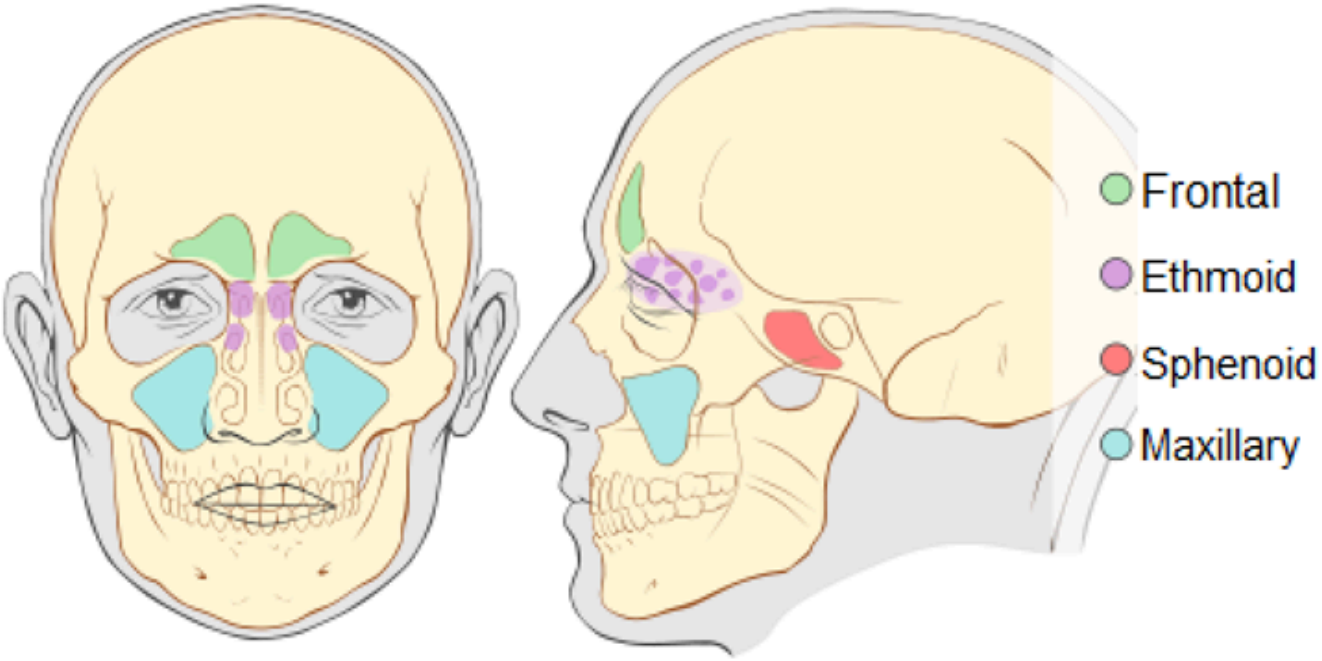
12.

SINUSES

Overview: Sinuses

The maxillary sinus is the largest sinus and the most frequently involved site of malignancy. 80% of maxillary sinus tumors are squamous cell carcinoma, and about 15% are adenocarcinomas. Primary tumors of the frontal sinuses or sphenoid sinuses are exceedingly rare; they comprise about 5% of head and neck cancers in the United States.



Cranial sinuses.

Simulation Overview & Special Considerations: Sinuses

In treating sinus cancers, the simulation process is consistent with the typical head and neck simulation. Please refer to the "Patient Simulation: H&N" section. Depending upon the disease location, patients may benefit from the use of a bite plate or tongue depressor to reduce dose to the oral tongue.

Treatment Volume Localization: Sinuses

Historically, maxillary antrum tumors were treated with conformal anterior and lateral wedged fields. A contralateral field is sometimes necessary to improve the uniformity of the dose distribution. The lateral field must enter posterior to the eye on the involved side and be angled posteriorly away from the contralateral eye. IMRT provides a more conformal dose distribution to the unusual PTVs in sino-nasal cancer, which are used today. Treatment borders depend upon tumor location and extent of the disease, but general borders for the all sinuses include:

Anterior field borders:

- **Superior:** 2 cm above the cribriform plate – It is important to have the patient look straight ahead to avoid over-dosage to the retina.
- **Inferior:** lateral commissure of the lip (this will provide a margin on the lower border of the maxillary sinus) to include the alveolar ridge.
- **Medial:** 1.5-2cm across the midline to include the ethmoid sinus and the medial aspect of the contralateral orbit.
- **Lateral:** to include the entire maxillary sinus tumor extent with an adequate margin (if the infratemporal fossa is involved, fall off is needed laterally).

Lateral field borders:

- **Anterior:** behind the contralateral bony canthus (the lateral portals can be angled 5 degrees posteriorly to shield the contralateral lens)
- **Superior:** 2 cm above the cribriform plate and follow the floor of the skull with a margin on the clivus.
- **Posterior:** includes the pterygopalatine fossa and the nasopharynx with a margin on the posterior extent of the tumor. In patients with nasal cavity/nasopharynx involvement, include the retropharyngeal nodes.
- **Inferior:** lateral commissure of the lip.

Treatments today still follow these general borders but are more conformal to targeted tissues, sparing normal tissues, and reducing toxicity. Please refer to the "Treatment Volume Location: H&N" section.

Treatment Techniques: Sinuses

Many different treatment techniques can be used for the paranasal sinuses. Initially, surgical resection is recommended if possible. Patients who present with invasion through the posterior wall of the maxillary sinus

(invasion of the nasopharynx or base of the skull) are generally inoperable and must be treated with radiation therapy alone. Modern treatment techniques are reflected in the "Treatment Techniques: H&N" section.

The dose-fractionation schemes for sinus cancers include:

- 60 Gy in 30 daily fractions given for 6 weeks OR
- 70 Gy in 35 daily fractions, if possible, where there is residual disease

Palliative dose-fractionation schemes:

- 36 Gy in 6 fractions of 6 Gy, treating once weekly

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PART III
THORAX

13.

OVERVIEW: THORAX

Learning Objectives

- Describe the anatomy, structures, and landmarks of the thorax
- Describe malignancies of the thorax
- Describe the simulation process
- Identify commonly used positioning & immobilization devices used for thorax treatments
- Define scan parameters and reference isocenter location for thorax simulations
- Discuss special considerations in thorax patient positioning
- Define treatment borders and how they relate to tumor spread
- Describe the lymphatic drainage and lymph node chains of the thorax
- Describe tumor volumes and margins of thorax tumors
- Discuss the various treatment procedures for thorax malignancies
- Perform tasks associated with the simulation and treatment of thorax malignancies

Key Terms

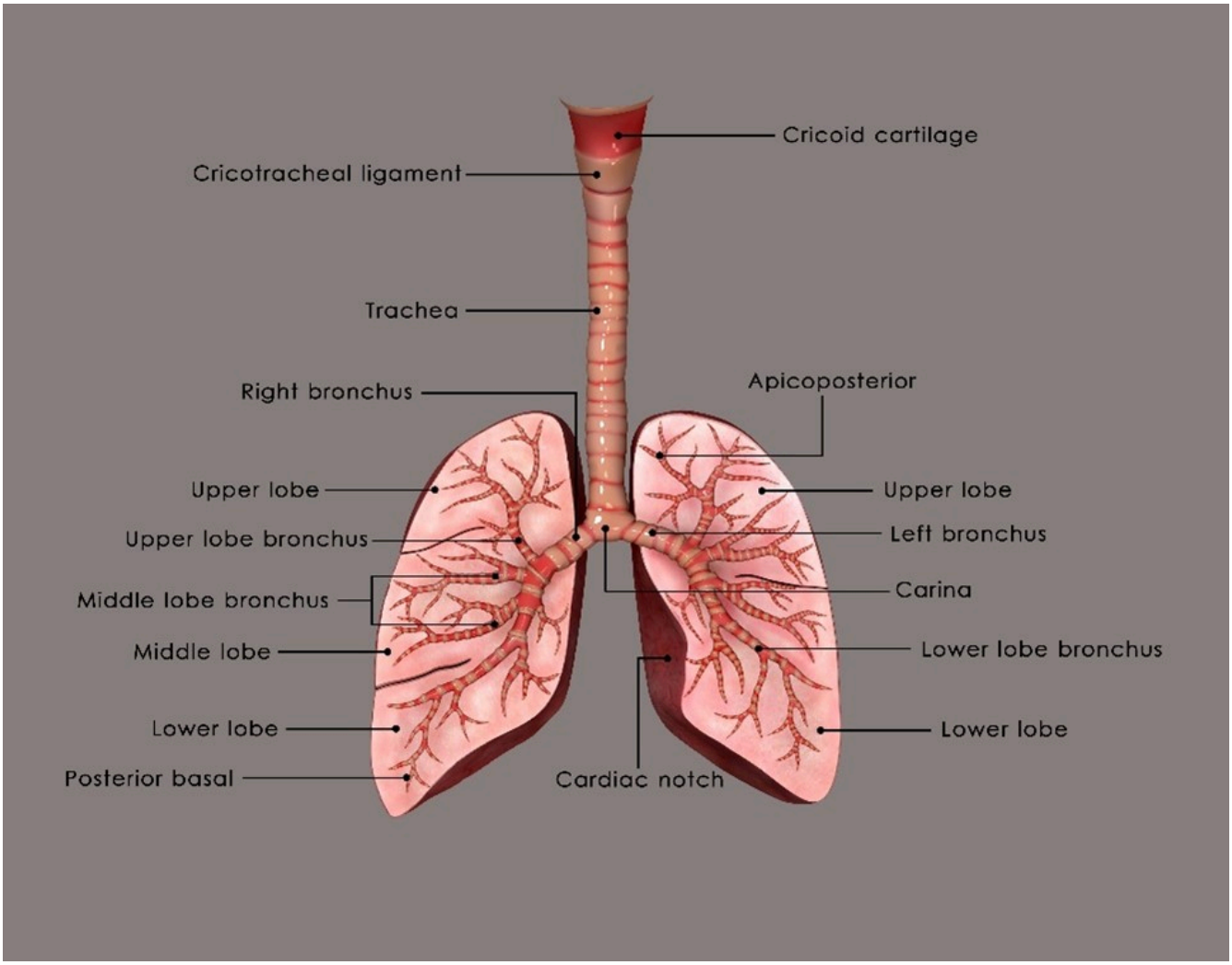
- **Akimbo**
- **Adventitia**
- **Bellows Belt**
- **Breathing Ratio**
- **Dyspnea**

- **Hemoptysis**
- **Hila**
- **Horner's Syndrome**
- **Mediastinum**
- **Mesothelioma**
- **Metaplasia**
- **Non-Small Cell Lung Cancer (NSCLC)**
- **Oligometastatic Disease**
- **Orthopnea**
- **Pancoast Tumor**
- **Pneumonitis**
- **Prophylactic Cranial Irradiation (PCI)**
- **Respiratory Gating**
- **Skip Metastasis**
- **Small Cell Lung Cancer (SCLC)**
- **Superior Vena Cava Syndrome (SVCS)**
- **Stereotactic Body Radiation Therapy (SBRT)**
- **Topogram**
- **Virtual Isocenter**

Overview: Thorax

The thorax contains the heart, major blood vessels, and lungs; the ribs, breastbone, and spine support and protect the organs. The esophagus is also included in this unit, although it is considered part of the digestive system. The right lung is divided into three lobes, an upper, middle, and lower. The left lung is divided into two lobes, an upper and lower. The apex, or top of the lung, is located a few centimeters above the clavicle, and the base, or bottom of the lung, sits at the diaphragm. When an individual inhales, the diaphragm moves inferiorly, allowing the lungs to fill with air. When an individual exhales, the diaphragm moves superiorly, pushing air out. The heart is located left of midline within the **mediastinum**.

The trachea (windpipe) extends from the larynx to the bronchi; it carries air to and from the lungs during respiration. At the inferior portion of the trachea, the bronchi bifurcate, or divide, into primary bronchi; this location is called the carina. The carina is around the fifth or sixth thoracic vertebra, but can be anywhere from T4-T7, depending on the patient's anatomy and body habitus. The carina serves as an important landmark in radiation therapy that can be seen in 2D and 3D imaging.



Structures of the respiratory system. The right lung has 3 lobes, the left 2 and the heart.

The lungs are separated midline by the mediastinum, composed of the heart, thymus, trachea, great vessels, esophagus, and lymph nodes. The mediastinum can be divided into the superior and inferior compartments. The **hila** of the lungs contain blood vessels, bronchi, and lymphatics. The superior vena cava (SVC) is also important in radiation therapy; it is a vital venous channel for the return of blood to the heart from the upper thorax, head, neck, and upper extremities. The SVC is surrounded by structures in the anterior mediastinum and numerous lymph nodes.

Lung and bronchus cancer is the second most common cancer diagnosed in men and women and is the leading cause of cancer death in the United States. The leading etiologic factor is smoking, while radon exposure is the leading environmental risk factor, second overall. The average age of diagnosis of lung cancer is 65 years of age.

Lung cancers can arise anywhere in the lungs. One example is a **Pancoast tumor**, which is a tumor that

occurs at the apex or the superior aspect of the lung. This cancer was named after Henry Pancoast in 1932 and is also called a superior pulmonary sulcus tumor. Pancoast tumors are rare (they only account for 3-5% of lung cancers) and may present with unique symptoms because of their location that may involve one-sided shoulder pain or **Horner's syndrome**. Horner's syndrome includes the same side drooping of the eyelid (ipsilateral ptosis), lack of facial sweating (anhydrosis), and pupil constriction (miosis).

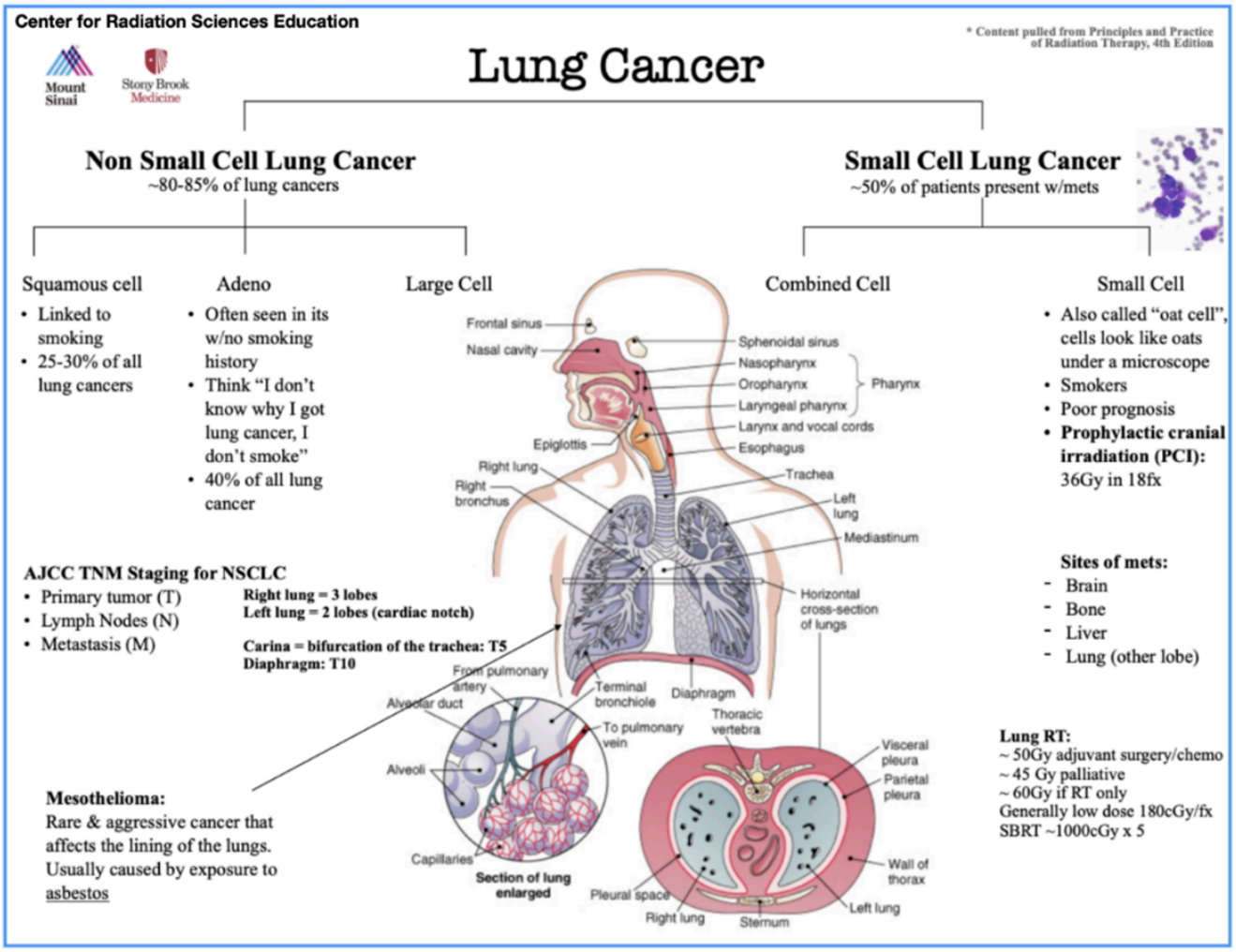
Lung cancer is treated with curative or palliative intent and is divided into two main categories: ***Non-small cell lung cancer (NSCLC)*** and ***Small cell lung cancer (SCLC)***.

NSCLC accounts for roughly 80-85% of all lung cancers; it includes the histology's of squamous cell carcinomas, adenocarcinomas, and large cell tumors. Squamous cell carcinomas are more common in patients with a long smoking history. Tobacco damages cilia enabling chemical carcinogens to irritate the lung's tissues and cause damage. In contrast, adenocarcinoma is the most common lung cancer in patients with no smoking history. These tumors tend to arise in the outer parts of the lung. Large cell tumors are the least common and tend to grow and spread quickly. NSCLC is treated with surgery when the tumor is localized and in its early stages. Higher dose radiation (>60 Gy) and concurrent chemotherapy should be offered for optimal control in more advanced stages or when the tumor is inoperable.

SCLC, also called "oat cell," is a rapidly spreading pathology with a high probability of metastasis at diagnosis (50%). Due to its rapid spread, multiagent chemotherapy and radiation therapy offer the best chance for a complete response. Most SCLCs are located in the central or hilar regions of the lungs. **Prophylactic cranial irradiation (PCI)** is often recommended as a preventative measure for brain metastases. More information on prophylactic radiation therapy can be found in the CNS section.

Mesothelioma is a rare and aggressive cancer that affects the lining of the lungs. The mesothelial cells secrete a serous fluid to lubricate between the chest wall and the lungs. Cancers here are often associated with asbestos exposure.

Surgery, if a treatment option, provides the best chance to cure lung cancers. Radiation and chemotherapy are commonly used due to the advanced stage at diagnosis and aggressiveness of these malignancies. Cisplatin is the chemotherapy of choice when treating lung cancers.



Lung cancer overview.

Patient Simulation: Thorax

Positioning for simulation of the thorax.

Patients with cancers of the thorax are positioned supine with arms above their head in a wing board, arm board, or vacloc, and a knee bolster. The patient is uncovered above the waist, removing any jewelry. They are centered and straightened on the table, and reference isocenter marks are placed anteriorly and laterally on stable points, not too close to the armpit or skin folds. Reproducible and precise immobilization is essential in treating lung lesions.

Often, intravenous (IV) contrast is requested for scans of the thorax. Radiation therapists should follow departmental contrast protocols concerning patient education and pre-contrast assessment. Patients will initially follow the machine's breathing instructions for the **topogram**; this allows the therapist to choose the proper scanning parameters. Generally, scans of the thorax extend from the mid-neck to the inferior costal margin or the third lumbar vertebra.

Special Simulation Considerations: Thorax

Simulations of the thorax can present with numerous challenges. The most common consideration for cancers of the thorax is tumor motion caused by respiration. Several treatment technologies and devices are available to reduce tumor motion; patient selection for each is important. Some devices utilize abdominal compression that restricts the depth of inspiration for the patient. Other techniques coach the patient how to breathe and include a breath-hold technique, active breathing control (described in the breast unit), and **respiratory gating** using a 4D CT.

Department protocols will vary based on the devices and technology available, but commonly 4D scans are taken to evaluate target motion. A 4D scan uses "time" as the fourth dimension; they capture multiple images of the patient's anatomy at different phases of the breathing cycle, creating a dataset representing the range of motion. Patients with tumor motion greater than 5 mm will benefit from motion management treatment, like gating or compression. Both techniques will spare normal tissues by reducing the treatment field size.

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During the simulation, patients are educated to establish their eligibility for compression or gating. If a 4D scan is an option, breathing instructions are explained to the patient. It is important to note the patient's nominal breaths per minute and **breathing ratio**. These measurements determine the patient's breathing pattern during the simulation. Respirations are monitored throughout the scan via a belt or tracking device.

Departmental protocols will vary. The University of Iowa acquires an expiration breath-hold scan with contrast for their primary dataset and a 4D scan. The 4D scan is performed using the patient's established breaths per minute and breathing ratio. After the scan, a physicist or dosimetrist evaluates the CT slices for any artifact. Another option is to obtain a max inspiration and an expiration scan to determine the total amount of motion possible. A free-breathing scan is used for patients that are not good candidates for compression or gating. These scans help determine target volumes and assess tumor motion for treatment planning.

Through analysis of the 4D CT dataset, the radiation oncology team can identify the specific phases of the breathing cycle when the tumor is most stable and accurately target those phases for gated treatment. Most treatments deliver the radiation at the bottom of the patient's breathing cycle (exhalation). For example, when the beam is on, the gating window may be set at 40% expiration to 40% inspiration. Gated treatments require a system that tracks the patient's breathing cycle while connected to the treatment delivery system. These treatments take longer because the beam stops when the tumor is outside the treatment volume, relying on the patient to breathe consistently. Established workflows should exist in each facility.

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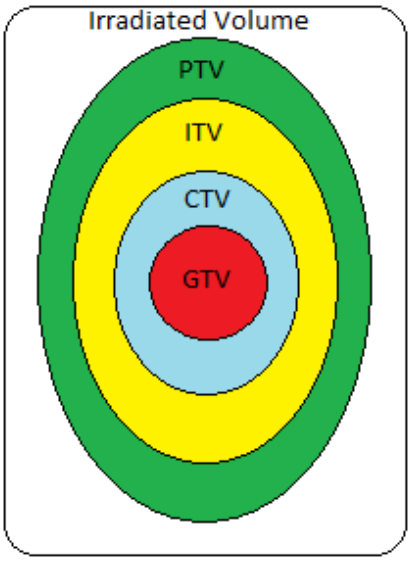
Other challenges for treatments of the thorax are patient position and physical ability. For example, if a patient cannot raise their arms above their head, planning beams to safely reach their tumor may be difficult. Therapists should inform the physician and dosimetry; the best arm position may be **akimbo**. The akimbo position will move the arms away from the thorax, reducing the chance they will receive dose and open up the thorax to more beam angle options. Patients with COPD or large thorax tumors may have difficulty breathing laying flat; elevating the patient's head with an incline board or vacloc may be necessary.

Treatment Volume Localization: Thorax

Treatment design for thorax malignancies is based on the primary tumor's size, location, proximity to critical structures, and lymphatic drainage. Commonly affected nodes include the hilar and mediastinal nodes, but lymphatic drainage depends on the tumor's location. Patients that are not candidates for respiratory monitoring with a free-breathing CT simulation, will have about a 2 cm expansion from the Internal Target Volume (ITV). The ITV encompasses the CTV with a margin for motion. Patients that are 4D candidates, the PTV is an expansion of 5-8 mm from the ITV.



Planning target volumes.

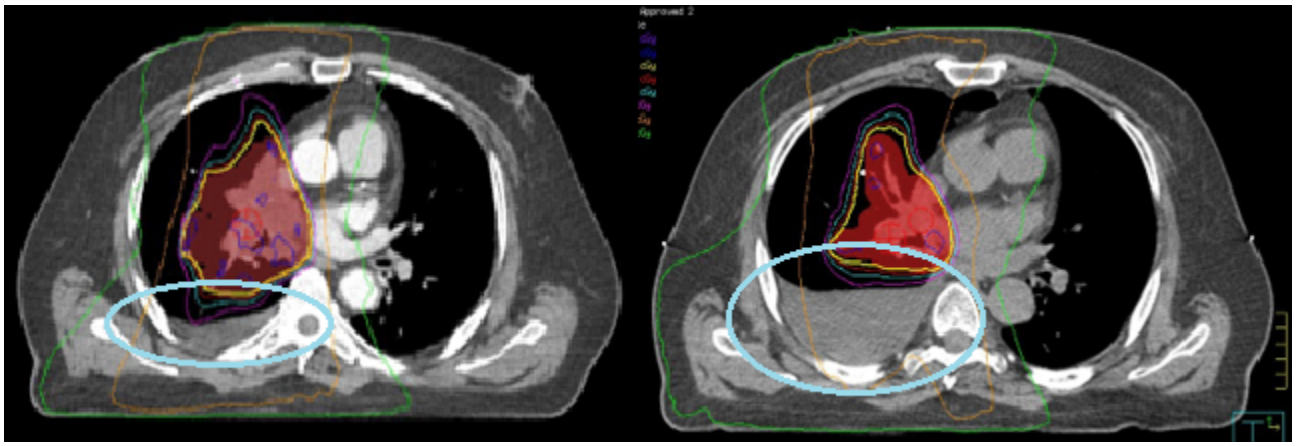
Whole organ TD 5/5 for common OARs (Organs at Risk) for thorax radiotherapy

OAR	**TD 5/5 (Whole Organ)**	**Outcome Associated**
Spinal Cord	45 or 47 Gy	Myelitis/Necrosis
Lung	18 Gy	**Pneumonitis**
Heart	40 Gy	Pericarditis
Esophagus	55 Gy	Stricture/Perforation
Brachial Plexus	55-60 Gy	Nerve Damage

Treatment Techniques Overview: Lung

During the verification simulation appointment, first, position the patient to their 3-point reference (CT) isocenter. Indicated shifts from dosimetry are then applied to move the patient to the planned treatment isocenter. Depending on department preference, new set-up marks may be placed on the patient to indicate the planned isocenter and to eliminate daily shifts. Otherwise, shifts from the reference 3-point marks are applied daily. New marks should only replace existing marks when they can be placed on stable surface anatomy. SSD's should be documented and table parameters recorded. Patients with lateral isocenters (>8 cm off midline) may require a lateral off-set to reduce clearance issues. For example, if a patient has a right lateral lung lesion greater than 8 cm off midline, placing the patient closer to the left edge allows the right side of the body to be closer to

the center of the treatment table. A **virtual isocenter** may be needed for conebeam (CBCT) clearance if daily imaging is indicated. For safety, always verify gantry clearance before exiting the room.

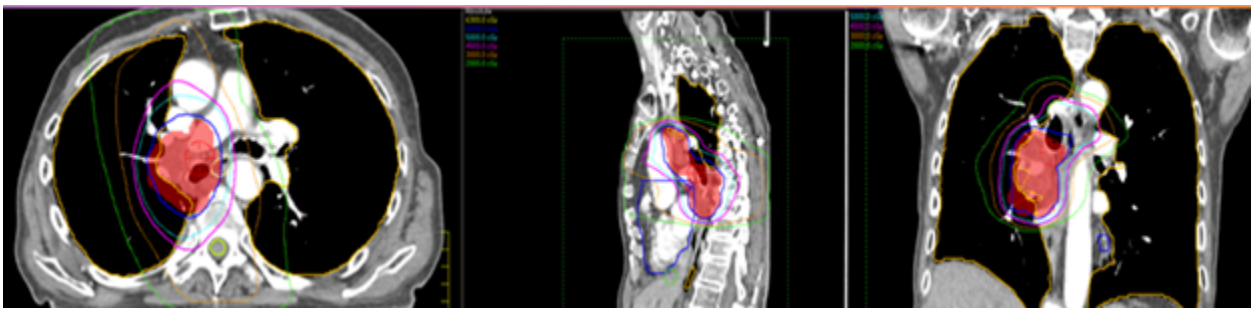


The left image demonstrates the initial CT sim isodose distribution of a right lung tumor. The right image demonstrates fluid changes (blue circles) which shifted the tumor necessitating a second simulation and new plan. The discrepancy was noticed by a therapist on daily imaging.

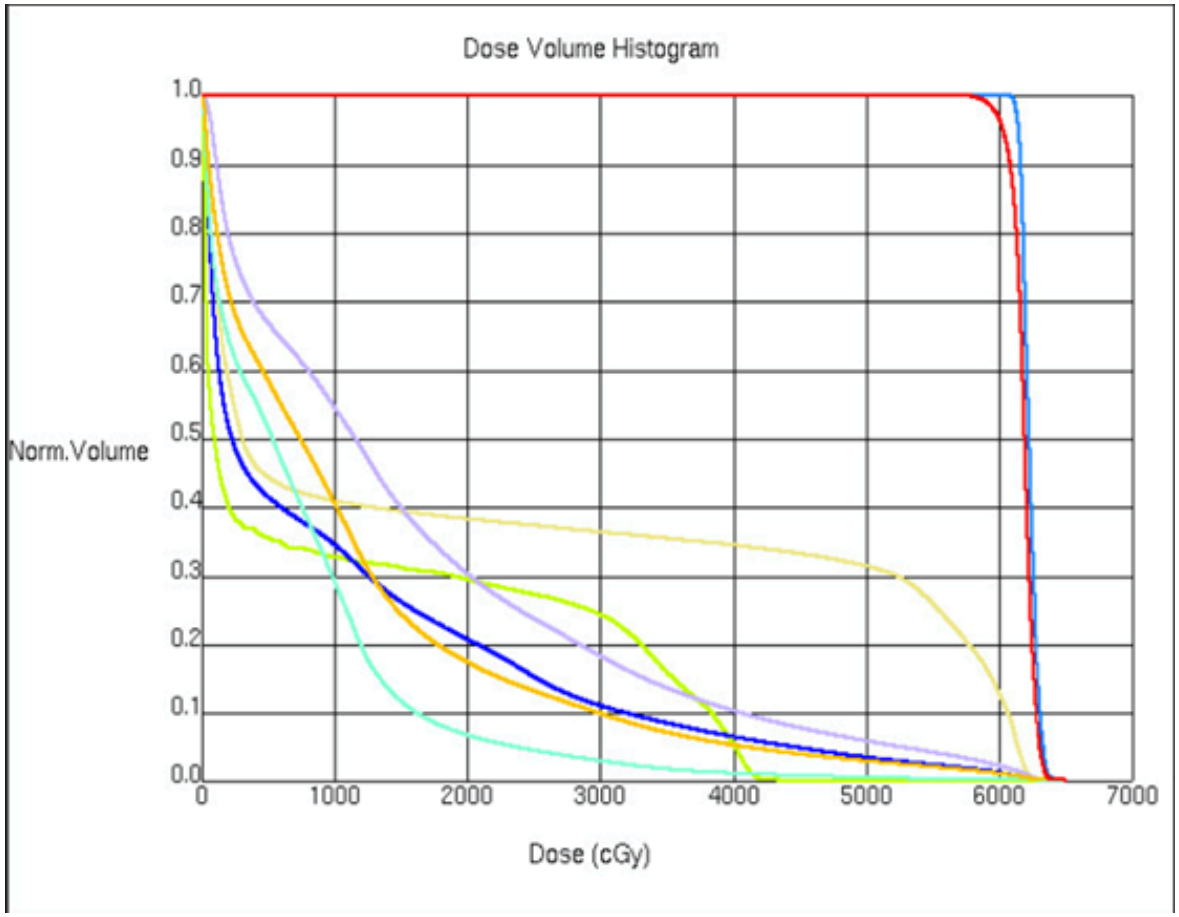
Most treatments today utilize some form of daily Image Guided Radiation Therapy (IGRT). If the tumor is well defined, align to the planning target volume (PTV) and check bone and carina for verification. The PTV includes margins for uncertainties in beam alignment, tumor motion, and patient positioning. The thoracic spine is the most stable boney anatomy for alignment, especially for posteriorly located lesions. Ensure the spinal cord contour is within the vertebral foramen and verify the carina. For mediastinal tumors, align the carina first and then check the spine.

- **Palliation (AP/PA):** beam arrangement was historically used for lung treatments but is now commonly reserved for palliation. The initial AP/PA fields were treated to a dose of 45 Gy. If doses above 45 Gy are required, the beam arrangement is modified to obliques termed an "off-cord boost" to avoid overdosing the spinal cord and subsequent transverse myelitis.
- **3D Conformal Radiation Therapy (3DCRT):** The size of the PTV and its location to structures dictate the beam arrangement. A three-field conformal plan is used for early-stage disease (Stages 1 & 2). The three fields are an anterior oblique, a posterior oblique, and a lateral. Wedges are used on the oblique beams to compensate for the curvature of the chest wall. Multi-leaf collimator (MLC) shielding conforms each beam shape to the PTV. More beam angles are added with increasing disease stage to improve the overall dose to the tumor and reduce the dose to the normal lung volume and surrounding tissues.
- **Volumetric Modulated Arc Therapy (VMAT)/IMRT:** Most treatments of the thorax use daily conebeam CT (CBCT) imaging and IMRT or VMAT treatment. These highly conformal plans reduce

the dose to normal tissues and maximize the dose to the PTV. Plans are designed by setting dose limits and parameters in the planning system and the computer optimizes a treatment plan to the specifications.



IMRT isodose distribution of the right hilar region.



DVH for a VMAT plan of the hilar region of the right lung.

Line Type	ROI	Trial or Record	Min.	Max.	Mean	Std. Dev.	% Outside Grid	% > Max	Generalized EUD
	SpinalCord	R Lung Me	--	4336.5	841.7	1432.6	25.84 %	0.00 %	0
	Heart	R Lung Me	22.0	6341.3	1042.7	1446.2	0.00 %	0.00 %	0
	Esophagus	R Lung Me	20.6	6335.1	2218.3	2612.2	0.00 %	0.00 %	0
	Lung_L	R Lung Me	13.9	6287.5	737.8	828.1	0.00 %	0.00 %	0
	Lung_R	R Lung Me	18.6	6495.9	1605.3	1583.8	0.00 %	0.00 %	0
	Lungs	R Lung Me	13.9	6495.9	1129.1	1301.6	0.00 %	0.00 %	0
	ITV KP	R Lung Me	5955.6	6495.9	6227.5	58.6	0.00 %	0.00 %	0
	PTV6000 KP	R Lung Me	5504.5	6495.9	6181.0	86.7	0.00 %	0.00 %	0

IMRT DVH key of the right hilar region.

Common Prescriptions for Lung Cancer ***Total dose is dependent on the histology of the tumor. Energies used are 6 and 10 MV .***

Pre-op	45-50 Gy in 1.8-2 Gy/fx*
Post-op	50-54 Gy in 1.8-2 Gy/fx*
Definitive/Curative	Treat nodes to 45 Gy then boost ipsilateral lymph nodes to 60-70 Gy*
Palliative	20 Gy in 5 fx or 30 Gy in 10 fxs
Hyper fractionation (Limited stage SCLC)	1.5 Gy BID to 45 Gy over three weeks
Stereotactic Body Radiation Therapy (SBRT)	25 Gy in 5 fx with a minimum of 40 hours between fractions OR 50 Gy in 5 fx with a minimum of 40 hours between fractions*
Emergent – Superior Vena Cava Syndrome/SVCS	Initial fx doses of 3-4 Gy/fx for approximately 2-4 days until improvement in symptoms THEN fractions of 1.8-2.0 Gy/fx to a total dose of 45-60 Gy*

Emerging Technologies & Treatments: Thorax

Surface monitoring systems assist during patient setup and monitor the patient's position throughout treatment. Surface monitoring systems can track surface motion and position with <1 mm accuracy. These systems use a 3D model of the patient acquired during their CT simulation. A red light projects onto the patient's skin surface and records their surface position. The systems monitor the pitch, yaw, and roll of the patient. Pitch is the back elevation, yaw is the hip adjustment, and roll is the patient's rotation.

During treatment setup, surface monitoring systems assist in reproducing the patient's position. After daily imaging and completing table adjustments, a new image capture is taken for treatment. The image is used as a baseline to monitor patient movement during treatment – this is required daily. Some clinics utilize surface monitoring systems that automatically interrupt the radiation beam if the patient moves out of tolerance.

Motion monitoring systems like respiratory gating (previously described) and live imaging continue to make advances.

Proton Therapy: Motion improvement techniques for pencil beam scanned proton therapy should be evaluated and selected based on organ motion. Organ movements to be assessed for proton therapy include those of the target and all organs in the potential proton beam path. For example, treating the lower esophagus using posterior fields where the diaphragm moves severely impacts the delivered beam range relative to the treatment target.

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14.

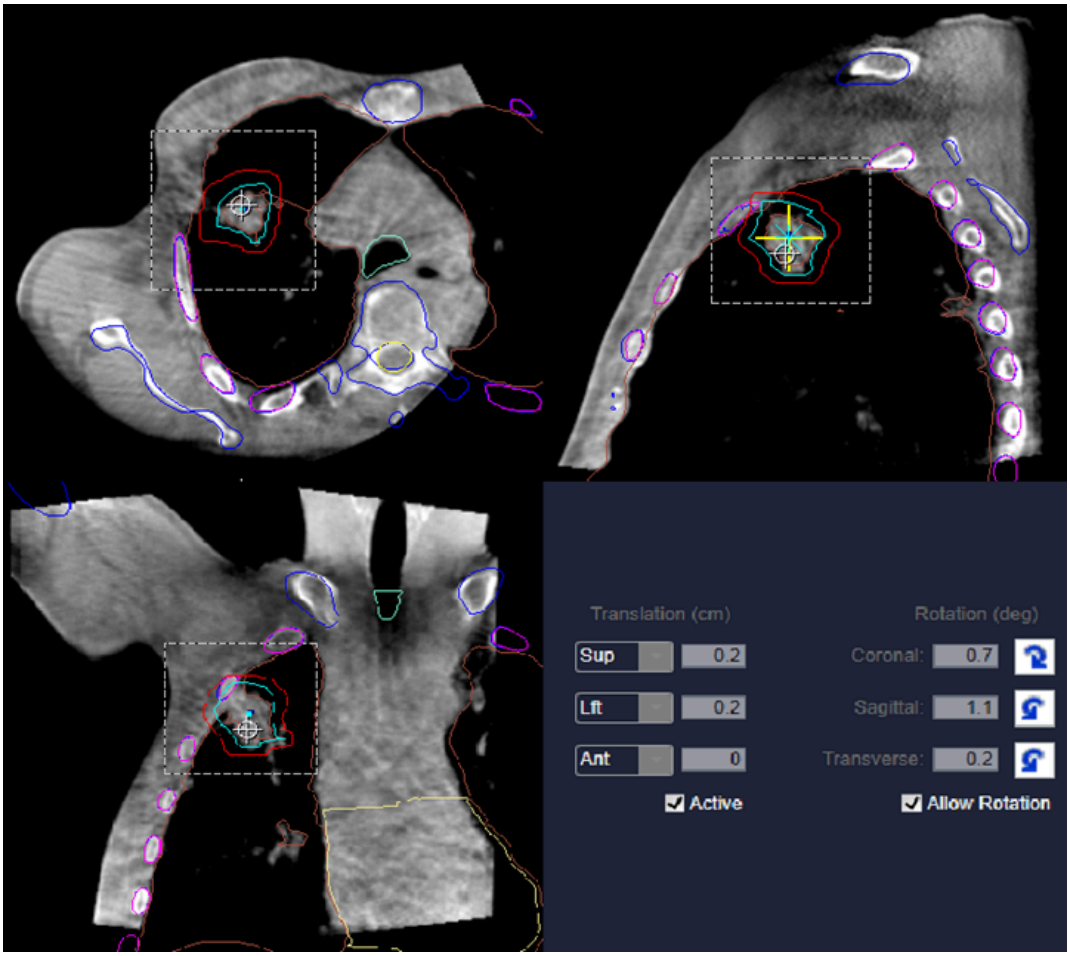
STEREOTACTIC BODY RADIATION THERAPY (SBRT)

Patient Simulation & Special Considerations: SBRT

To ensure the effectiveness of SBRT, it is crucial to immobilize the patient well and reproduce the setup precisely for each fraction. The dose per fraction is higher than conventional radiation therapy; this is possible because of the precise targeting and immobilization techniques used to minimize the radiation exposure to surrounding healthy tissues and organs. Patient positioning and treatment devices are used to reduce patient motion and increase treatment accuracy. The simulation process is consistent with the thorax simulation, but often, scans are 4D and use surface guidance because of the tight treatment margins. Please refer to the "Patient Simulation: Thorax" section.

Treatment Volume Localization: SBRT

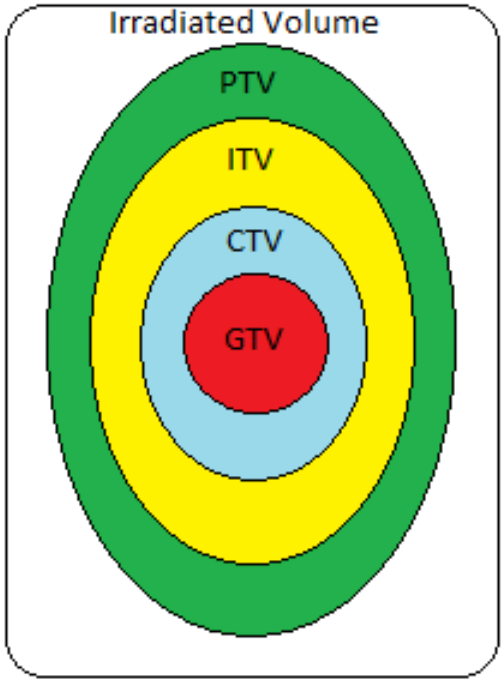
SBRT is an advanced and precise technique for treating small and well-defined tumors. Treatments include tumors throughout the body, but common sites include the lungs and liver. It is commonly used for lung cancers in treating early-stage, non-small cell lung cancer. The treatment plan is designed in consideration of the tumor's size, location, motion, and proximity to critical structures. Treatments deliver a concentrated and accurate dose of radiation to the tumor. Compared to traditional radiation therapy, SBRT offers the advantages of improved tumor control rates and reduced side effects. It achieves this by delivering high radiation doses in a small number of fractions, five or fewer.



Right upper lobe SBRT CBCT image.

The American Association of Physicists in Medicine (AAPM) Task Group 101 provides comprehensive guidelines on the use of SBRT for lung cancer. According to these guidelines, the maximum gross tumor volume (GTV) size for lung cancer treated with SBRT is typically limited to 5 cm. These guidelines evolve over time as new research and advancements in technology emerge. It is always recommended to consult with a radiation oncologist who can provide the most up-to-date and personalized information based on the specific clinical situation.

When designing the treatment volume for lung cancer, the physician identifies the visible extent of the disease, known as the gross tumor volume (GTV). A margin of 5-10mm is added to define the clinical target volume (CTV), which accounts for microscopic disease that may not be visible. Additionally, an internal target volume (ITV) is included to compensate for the internal movements of the CTV during treatment. Finally, the planning target volume (PTV) is determined by adding a margin to account for patient setup errors, encompassing both the CTV and internal margin. A common clinical practice is to avoid treating through the contralateral lung.



Planning target volumes.

Treatment Techniques: SBRT

SBRT treatments often use 4D motion-monitoring systems to reduce uncertainties using IGRT as previously described. The specific protocol may vary between facilities, but image alignment and prescription verification from the oncologist and physicist is often required before administration due to the high dose per fraction. Treatments involve using multiple arcs or beams to precisely target the tumor, delivering a dose of 25-50 Gy in ≤5 fractions using standard energies of 6 and 10 MV. SBRT lung treatments should avoid critical structures and consists of various lateral, anterior, and posterior oblique beams.

The most common treatment technology used for SBRT treatments is a linac-based VMAT with CT or MRI image guidance. The flattening filter is often removed because of the small field size and to achieve a high-dose-rate – 1400 MU/minute; this reduces the length of treatment.

SBRT	SRS	Standard Fractionation
Extracranial Treatments (outside the cranial cavity)	Intracranial Treatments (in the cranial cavity/brain)	Anywhere in the body
Tumor Size <5 cm	Tumor Size <3 cm	Any size treatment field, whole body to conformal
Hypofractionated (≤5)	Single Fraction	Fractionated (~25 – 35)
High Doses, 6 – 30 Gy/fx; delivered 2-3 fx/wk (>40 hrs between fx)	High Doses (~18 – 90 Gy)	1.8 – 2.0 Gy/fx; delivered M-F over 5-7 weeks

Current research is comparing the use of a single isocenter versus multiple isocenters for SBRT treatments. In one study, a single isocenter approach for multiple lung metastases showed reduced treatment time and improved patient comfort, with a slight increase in lung dose as the trade-off. The authors suggest that this technique may be suitable for patients experiencing severe pain or with **oligometastatic disease**; it can also be highly beneficial for patients with multiple target volumes.

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Other treatment technologies include the Accuray CyberKnife.

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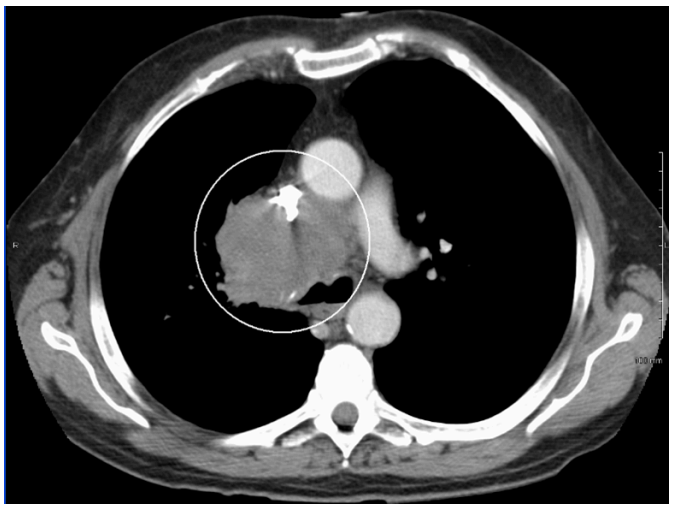
15.

SUPERIOR VENA CAVA SYNDROME (SVCS)

Patient simulation & Special Considerations: SVCS

Superior Vena Cava Syndrome is considered a medical emergency; patients must start treatment immediately and receive 2-3 daily fractions. Patients with a SVC obstruction often present with shortness of breath and **dyspnea**, facial swelling, distension of the veins of the neck and thorax, chest pain, cough, **dysphagia**, and cyanosis of the upper body. These side effects result from a tumor compressing the thin-walled superior vena cava in the upper chest.



Superior Vena Cava Syndrome CT image. The circle includes the tumor volume (gray) and the narrowing of the superior vena cava contrast enhanced (bright white).

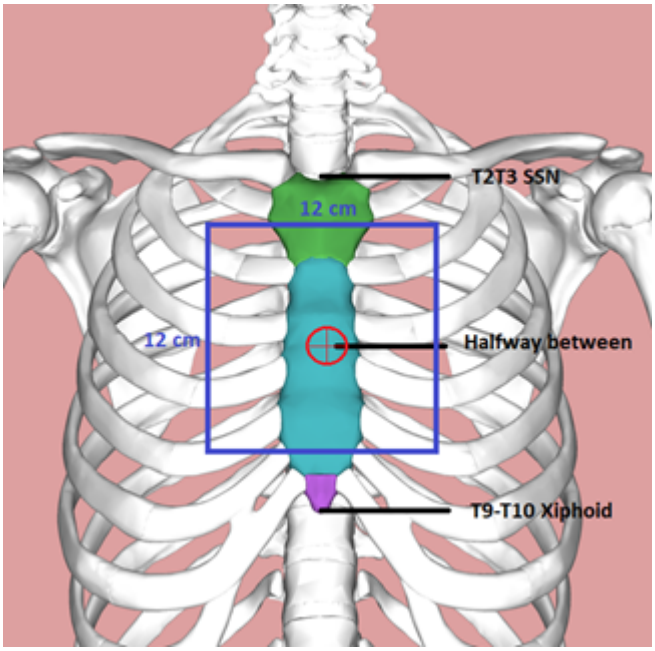
Positioning patients with SVCS is complex because of the respiratory compromise and subsequent **orthopnea**. Most patients with this condition will require elevation of their upper body using an incline board or custom vacloc or cushion to elevate their head and upper chest. The patient is positioned as close to supine as possible for clinical setups. Some patients may benefit from their doctor prescribing oxygen during their treatment; their oxygen saturation should be monitored throughout simulation and treatment.

SVCS patient positioned on an incline to help with breathing.

Treatment Volume Localization: SVCS

Clinical setups for SVCS start with a 12×12 cm field size. First, palpate the suprasternal notch at the T2-T3 vertebral level and the xiphoid process at the T9-T10 vertebral level and center halfway between. Place the isocenter mid-sternum over the hilum/carina. To find the treatment depth, measure the patient's thickness at isocenter and divide it by 2; set the SSD. For example. If the patient's thickness is 20 cm / 2 = 10 cm. The anterior SSD is 90 cm.

The treatment field should include the primary tumor and a 2-3 cm margin. Mediastinal, hilar, and supraclavicular areas are also included. The doctor approves the treatment portal images for every field before treatment. Therapists should document the patients setup with photos and the table and field parameters. A monitor unit calculation should utilize a second check by a physicist or physician.



Isocenter location and field setup for SVCS.

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Treatment Techniques: SVCS

External beam radiation therapy is the treatment of choice for SVCS. The initial 2-3 treatments consist of AP/PA beams with doses of 3-4 Gy/fx given daily until symptoms have improved or a computer-based plan is generated. After the initial treatments, smaller fractions of 1.8-2.0 Gy are delivered daily. The total dose delivered, and future treatment techniques depend on the histology of the tumor. For example, if the SVC is related to a lymphoma, treatment fields may remain the same. If the pathology is lung cancer, an IMRT or VMAT plan may be implemented.

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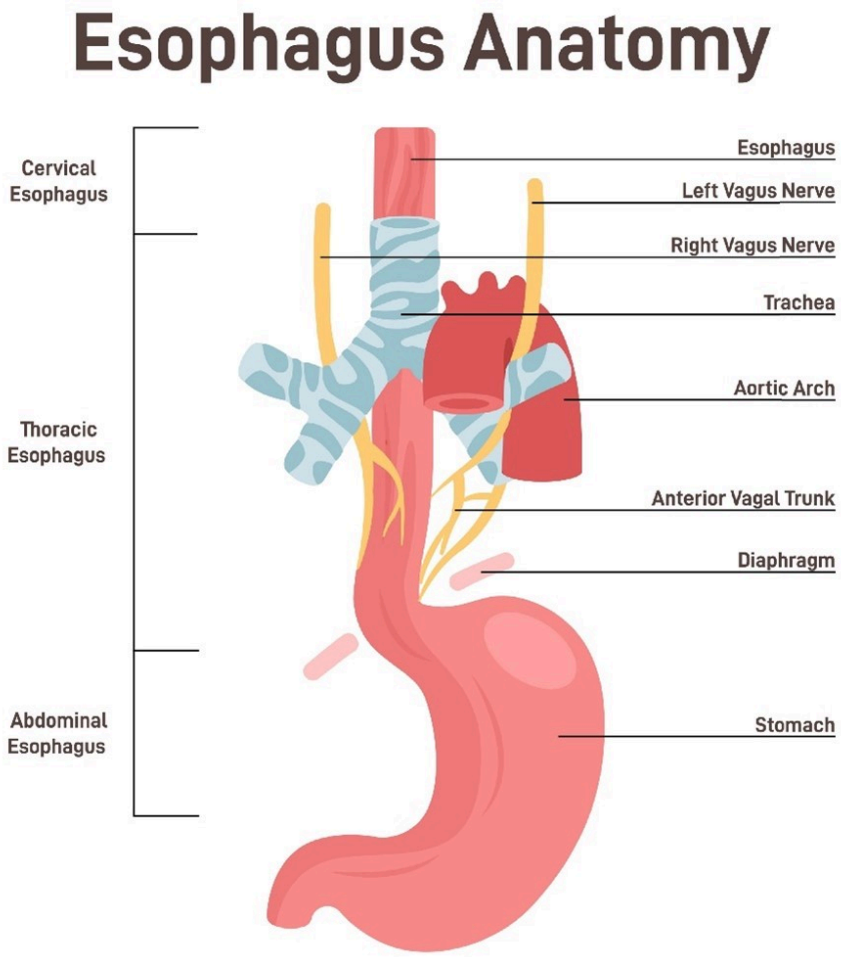
16.

ESOPHAGUS

Overview: Esophagus

The esophagus is a muscular tube anterior to the spine and posterior to the trachea that connects the cricoid cartilage of the pharynx to the stomach at the gastroesophageal (GE) junction. It is divided into three sections: cervical, middle, and lower. Esophageal cancer is a rare form of cancer, accounting for only 1% of all new cancer cases in the US. About 4 out of 5 people diagnosed with esophageal cancer are male, and the average age at diagnosis is 67.



The three divisions of the esophagus: Cervical, Thoracic, and Abdominal.

Several factors contribute to the development of esophageal cancer. These include smoking, excessive alcohol consumption, gastroesophageal reflux disease (GERD), and Barrett's Esophagus. Two common types of esophageal cancer are squamous cell carcinomas and adenocarcinomas.

- Squamous cell carcinoma is often associated with tobacco and alcohol abuse and typically occurs in the upper two-thirds of the esophagus.
- Adenocarcinomas of the esophagus tend to present in the lower one-third of the esophagus, where the distal esophagus meets the proximal stomach at the GE junction. These cancers are primarily linked to GERD and Barrett's esophagus. The squamous cells typical of the distal esophagus transform (**metaplasia**) into columnar epithelial cells, which are better able to tolerate the acidic conditions known as Barrett's Esophagus. The change in tissue type is responsible for the cancers being classified as adenocarcinomas.

Unlike many other organs, the esophagus lacks a serosal layer and instead has **adventitia**, a fibrous connective tissue. The adventitia has a rich lymphatic supply, which contributes to the early spread of these cancers and a poor prognosis.

Patient Simulation & Special Considerations: Esophagus

When simulating a patient for an esophagus treatment, a supine position is used, and it is essential to consider which portion of the esophagus has cancer.

- For the upper esophagus, use a head and shoulder mask and a headrest that extends up the mandible to reduce its dose.
- For the lower two-thirds of the esophagus, the arms are above the patient's head in an arm board or vacloc. The doctor may request patients not eat 2-4 hours before simulation and daily treatment to aid in reproducibility. Educate the patient on the importance of this and ask them daily before treatment.

Straightening the patient's body from SSN to xiphoid and umbilicus is vital, especially when treating the distal esophagus. Localization marks are placed anteriorly along the patient's midline and lateral marks on each side. Scan parameters extend from around the EAM (external auditory meatus) to about the second lumbar vertebra.

Treatment Volume Localization: Esophagus

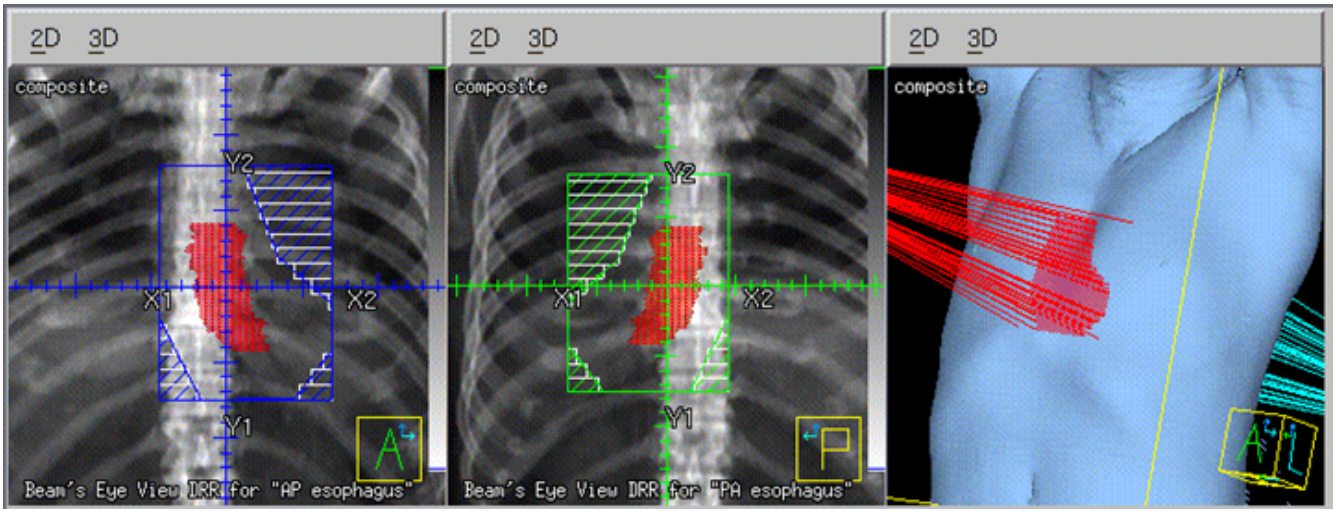
Esophageal cancers tend to spread via the lymph. **Skip metastasis** are a particular pattern of lymph node spread involving the distant lymph nodes from the tumor site but not the peritumoral lymph nodes. As such, longitudinal treatment boarders are generous; the PTV is typically 5 cm superior/inferior beyond the treatment volume. Anterior straightening marks are important to account for the long treatment fields. The lateral margins are generally 2-2.5 cm beyond demonstratable disease. Motion management 4D techniques previously described may be beneficial for tumors of the distal esophagus that move with the diaphragm.

Treatments of the esophagus are often given definitively or preoperatively and in combination with chemotherapy. In patients receiving concurrent chemo, slightly lower doses are sometimes used to prevent toxicities. Patients with positive surgical margins or regional nodal involvement can receive treatment postoperatively. Palliative treatment is beneficial in relieving symptoms of obstruction and dysphagia.

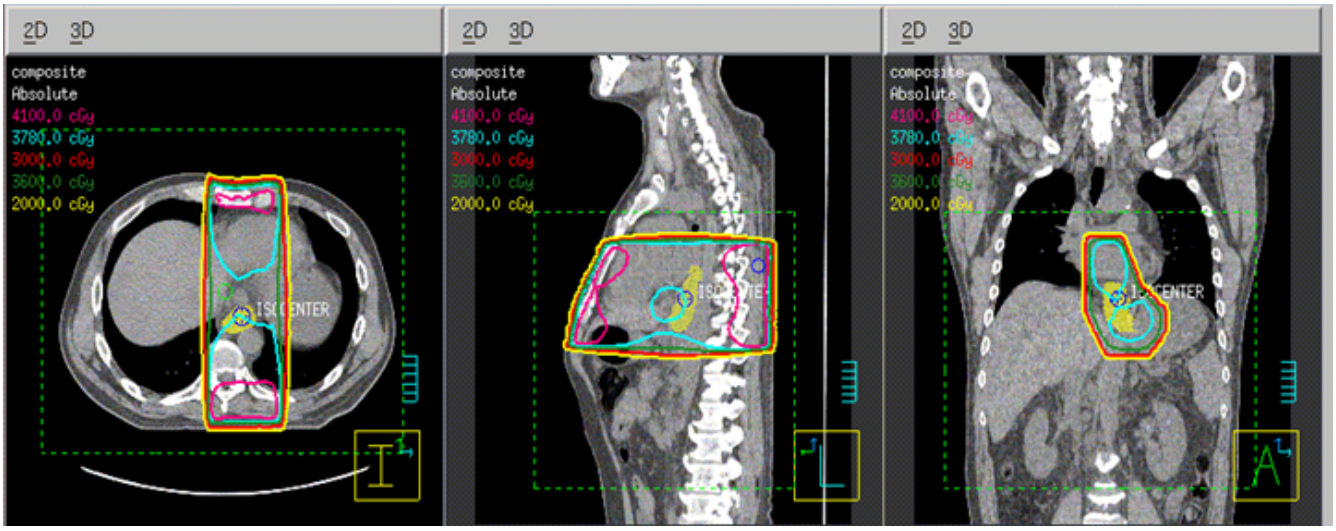
Organs at Risk (OARs)	TD 5/5 (Whole Organ)	Outcome Associated
Spinal Cord	45 or 47 Gy	Myelitis/Necrosis
Lung	18 Gy	Pneumonitis
Heart	40 Gy	Pericarditis
Esophagus	55 Gy	Stricture/perforation
Brachial plexus	60 Gy	Nerve damage
Liver	30 Gy	Clinical hepatitis
Kidney	23 Gy	Nephritis/Loss of function

Treatment Techniques: Esophagus

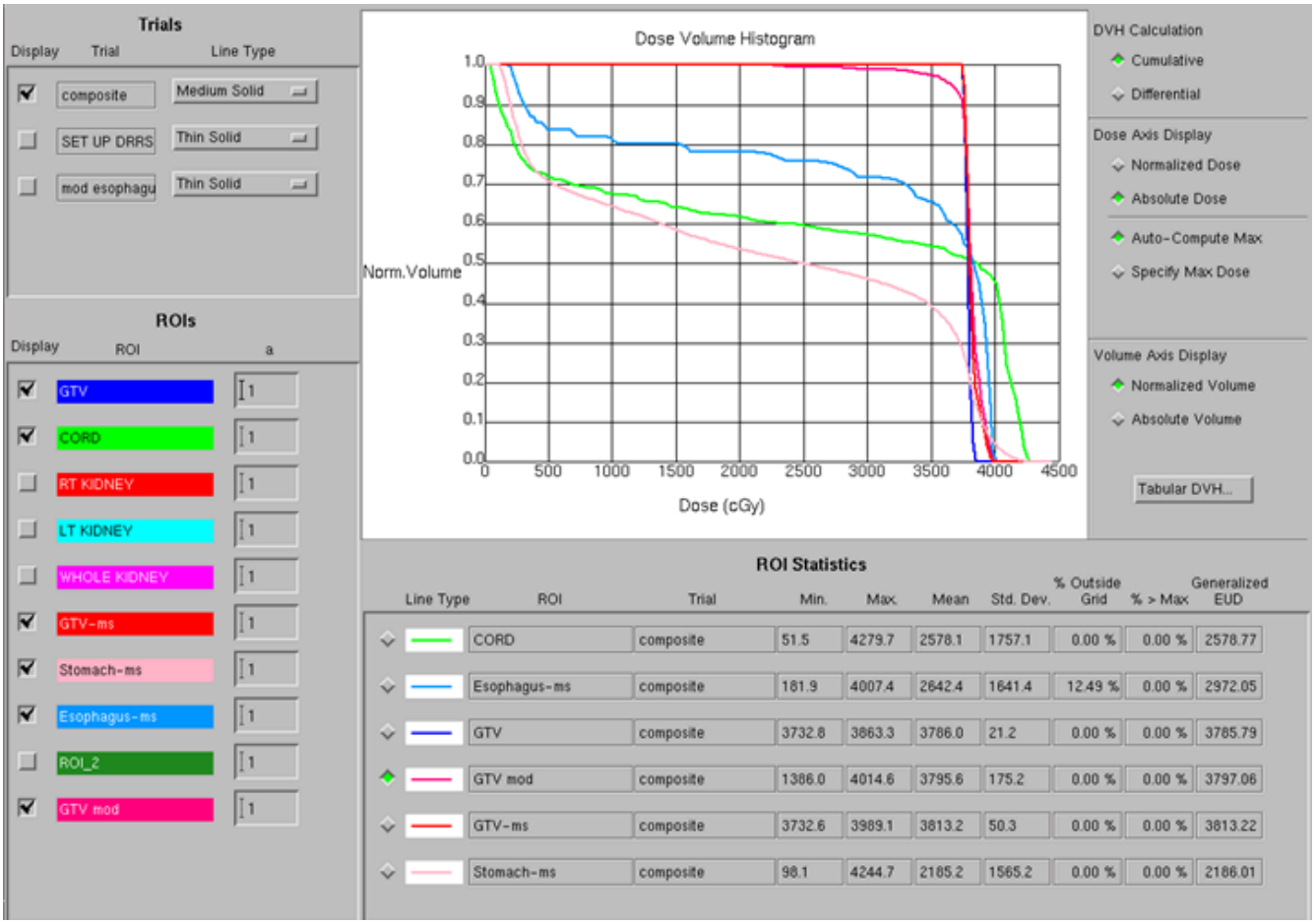
Treatment techniques include 3D conformal radiation therapy (3DCRT) using multiple beam angles, or IMRT. When comparing the two, IMRT can often reduce the dose to critical structures while delivering the prescribed dose to the primary tumor and areas at risk. Higher energy beams (10 MV) minimize the dose delivered to the lung volume. Treating the supraclavicular lymph nodes is considered for the upper two-thirds of the esophagus to 45 Gy.



Palliative AP/PA Beam's Eye View (BEV) plan of the esophagus treated to 40 Gy.



Isodose distribution for a palliative AP/PA plan of the esophagus.

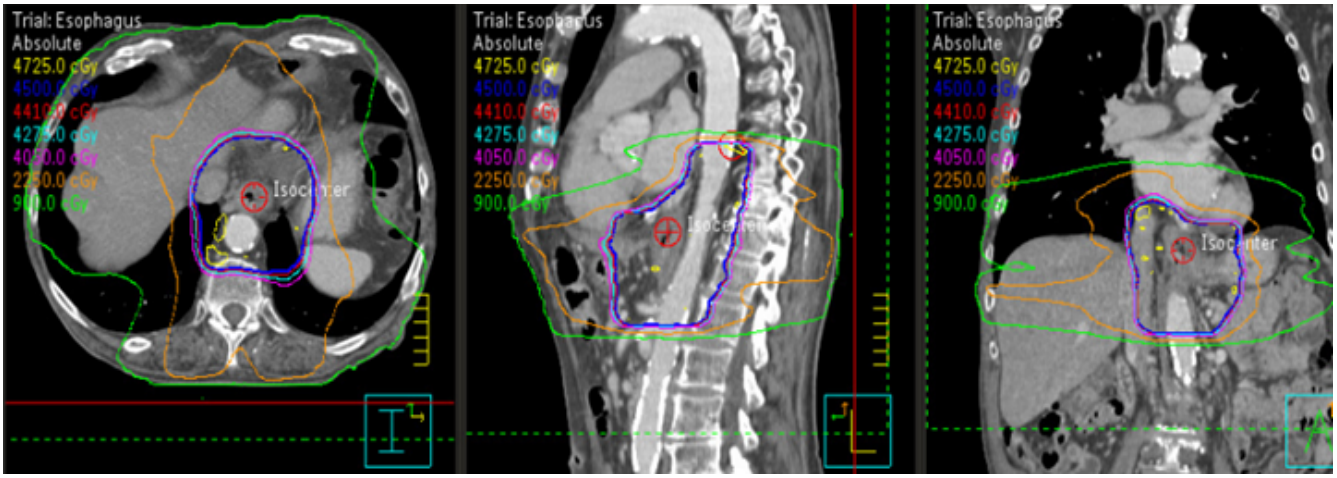


Palliative AP/PA DVH of the esophagus.

- **Image Guided Radiation Therapy (IGRT):** Image guidance uses daily imaging in the localization and treatment of cancer. Imaging modalities include CT, MR, and kV & MV images. In general, when aligning images, align to the planning target volume (PTV) and verify the position of the spine and carina.
- **3D-CRT (Computerized Radiotherapy):** Uses multi-leaf collimators (MLC) to conform each beam shape to the PTV. The size of the PTV and its proximity to critical structures dictate the beam arrangement/angles. With increasing disease stage, more beam angles are added to improve the overall dose to the tumor and reduce the cumulative dose to the lung volume and other OARs. Treatments of the upper one-third of the esophagus are more complicated due to the curvature of the spine and the angle of the esophagus. Anterior oblique wedged fields should be carefully planned to exclude the spinal cord and wedges may be necessary for dose uniformity. For the lower two-thirds of the esophagus, AP/PA treatments to the spine tolerance of 45 Gy are delivered. A boost is often delivered with a cord-sparing technique and custom beam shaping to minimize the dose to normal lung tissue.
    - **Three-field:** Anterior and two posterior oblique fields (with wedges) can reduce the spinal cord dose

- **Four-field:** Two anterior and two posterior oblique fields minimize the dose to the spinal cord
- **Multiple-field:** 5-7+ conformal beams target the PTV

- **Volumetric Modulated Arc Therapy (VMAT)/Intensity Modulated Radiation Therapy (IMRT):** VMAT/IMRT plans significantly reduce the dose to normal tissues and increase dose conformity to the PTV. An arc technique is best for complex treatments of the upper esophagus. These treatments often utilize dynamic treatment techniques. It is essential to be aware that as the beam moves around the patient, the target's and spinal cord's shape and position change in the Beam's Eye View.



Isodose distribution for a VMAT plan of the esophagus.

Common Prescriptions for Esophageal Cancer

Note: These doses exceed the spinal cord tolerance; therefore, the treatment technique should be IMRT/VMAT. If using a 3-field technique, an off-cord boost after 45 Gy is necessary.

Definitive Chemoradiation	50-50.4 Gy in 25-28 daily fractions with cisplatin-5FU*	45-50.4 Gy in 25-28 daily fractions if radiation is given preoperatively*
Curative Radiation Alone	55 Gy in 20 daily fractions of 2.75 Gy given in 4 weeks*	60-65 Gy using IMRT/VMAT or off-cord bst after 45 Gy
Palliative Radiation	30 Gy in 10 fractions (3 Gy/fx)	20 Gy in 5 fractions (4 Gy/fx)

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PART IV
BREAST

17.

OVERVIEW: BREAST

Learning Objectives

- Describe the anatomy, structures, and landmarks of the breast tissue
- Describe malignancies of the breast
- Describe the simulation process
- Identify commonly used positioning and immobilization devices used for breast treatments
- Define scan parameters and reference isocenter location for breast simulations
- Discuss special considerations in breast patient positioning
- Define the treatment borders and how they relate to tumor spread
- Describe tumor volumes and margins of breast tumors
- Discuss the various treatment procedures for breast malignancies
- Perform tasks associated with the simulation and treatment of breast malignancies

Key Terms

- **Brachytherapy**
- **Breast-Conserving Therapy**
- **BRCA 1 & 2**
- **Chest wall**
- **Deep Inspiration Breath Hold (DIBH)**
- **Fluoroscopy**

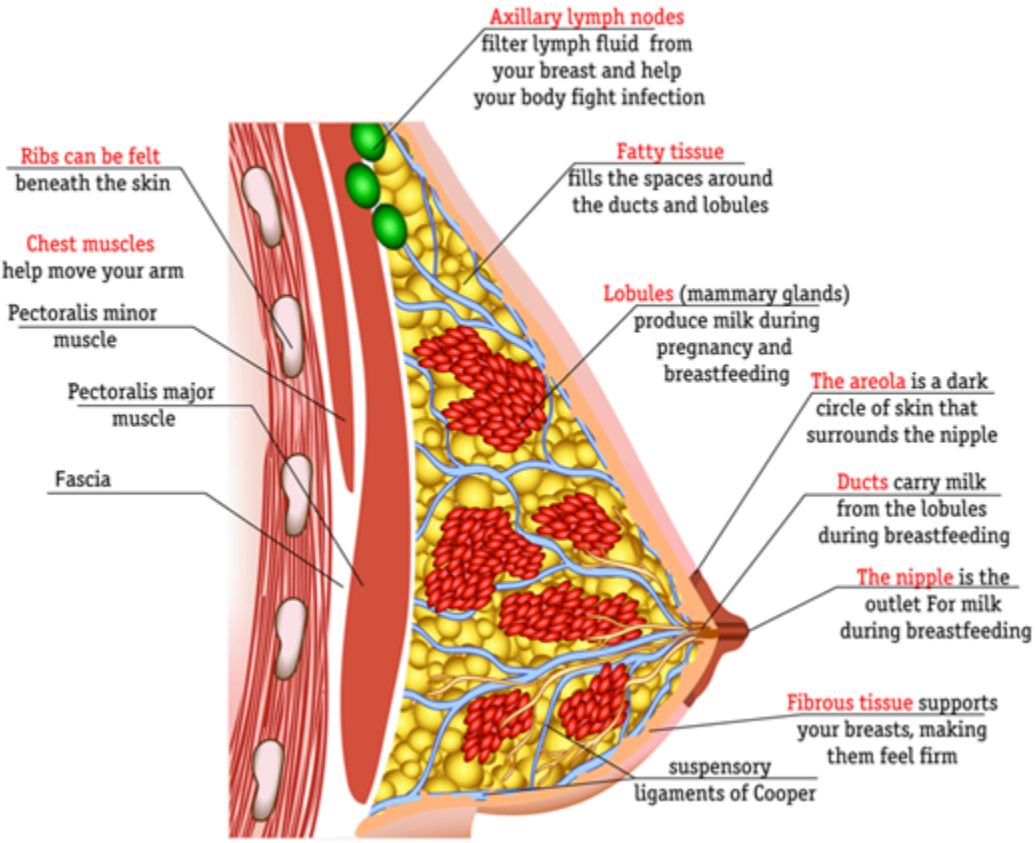
- **Hypofractionation**
- **Inflammatory Breast Cancer**
- **Ductal Carcinoma In Situ**
- **Intra-operative Radiation Therapy (IORT)**
- **Invasive Ductal Carcinoma (IDC)**
- **Lumpectomy**
- **Lymphovascular Invasion**
- **Mammographically Occult Breast Cancer**
- **Mastectomy**
- **Mepitel Film**
- **Partial Breast Irradiation (PBI)**
- **Posterior Axillary Boost (PAB)**
- **Stairstep technique**
- **Supraclavicular fossa**
- **Surface-Guided Radiation Therapy (SGRT)**
- **Tangential Fields (tangents)**
- **Triple-Negative Breast Cancer**

Overview: Breast

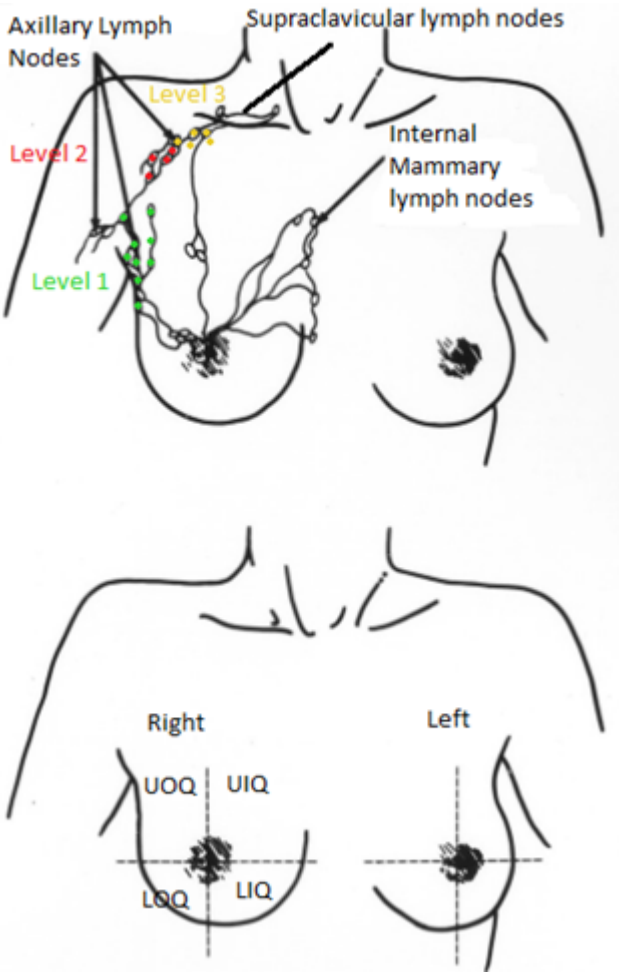
Breast cancer is the most common cancer diagnosed in women in the US; one out of eight women is projected to develop breast cancer in their lifetime. The average age of diagnosis is 62, and major risk factors include a familial history of breast cancer and **BRCA 1 & 2 gene mutations**. Approximately 1% of breast cancer diagnosis occur in men.

Breast tissues are located between the second and sixth ribs in the sagittal plane, extending from the suprasternal notch to the xiphoid process. Breast tissue extends from the axilla along the inferolateral edge of the pectoralis major muscle forming the tail of Spence. Two-thirds of breast tissue is found in the deep pectoral fascia that overlies the pectoralis major muscle while the other third rests on the fascia covering the serratus anterior muscle. The breast parenchyma consists of 15 to 20 glandular lobules embedded in adipose and fibrous connective tissue. Each lobe is drained by a duct that opens at the nipple.

MEDICAL STRUCTURE OF THE FEMALE BREAST



The breast's lymphatic drainage occurs through three main routes – the axillary lymph nodes, the internal mammary, and the supraclavicular lymph nodes. Most lymphatic drainage occurs via the axillary lymph nodes; this chain is divided into levels I, II, & III. Level I nodes are located lateral of the pectoralis minor muscle and are the most superficial. Level II nodes are located under the pectoralis minor muscle. The level III nodes are found superior and medial to the pectoralis minor muscle and are the most challenging to treat due to their depth. The internal mammary lymph nodes are in the parasternal and intercostal spaces and run alongside the corresponding artery and vein; they are found in the first, second, and third intercostal spaces. The supraclavicular lymph nodes are in the **supraclavicular fossa**,which provides drainage for internal mammary and axillary lymph node chains. Centrally located tumors may have direct drainage to these nodes requiring inclusion in the treatment.



Top Image demonstrates the lymph nodes of the breast; the bottom image demonstrates the quadrants of the breast.

Breast cancer is classified by its histology and location. The breast is divided into four quadrants; upper outer, upper inner, lower outer, and lower inner. The upper outer quadrant is the most common site of breast cancer. Most breast cancers originate in the milk ducts and lobules. Ductal carcinoma originates in the lactiferous ducts, while lobular carcinoma originates in the breast lobules.

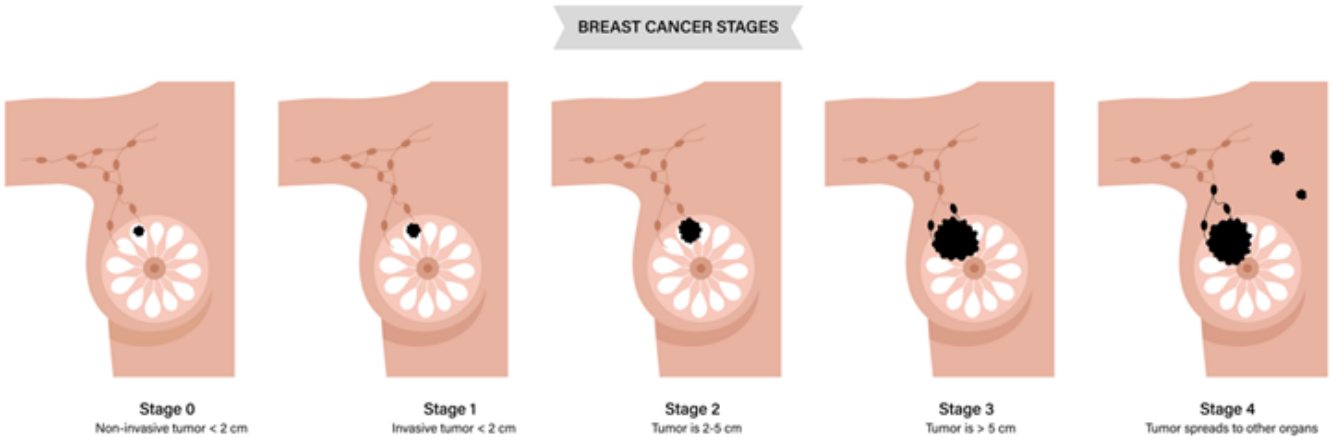
The American Joint Committee on Cancer (AJCC) classifies breast cancers as in situ or invasive.

- **Ductal carcinoma in situ (DCIS)** is confined to a preexisting duct system of the breast without penetration of the basement membrane and invasion of surrounding tissues on microscopic examination; it represents 21% of all breast cancers. DCIS is a precancerous condition but is treated like cancer.
- **Invasive ductal carcinoma (IDC)** is the most common invasive cancer of the breast, accounting for 70 to 80% of invasive lesions. This type of breast cancer is also subdivided into grades based on its histology, with well-differentiated tumors assigned a lower grade and poorly differentiated tumors receiving a higher grade.
- **Lobular carcinoma in situ (LCIS)** is found in the lobules and is like DCIS because it has not

demonstrated its ability to penetrate the basement membrane and spread; however, LCIS rarely turns into invasive cancer and typically uses a "watch-and-wait" treatment approach.

- **Invasive lobular carcinoma** is the second most common type of invasive breast cancer, accounting for 5 to 10% of all invasive lesions.
- **Inflammatory breast cancer** is an aggressive histology that is more likely to spread before diagnosis. The rapidly proliferating cancer blocks lymph vessels, causing skin edema and pitting, resulting in a peau d'orange (orange peel) appearance. Inflammatory breast cancer is rare, accounting for 1-5% of all breast cancers in the U.S. Patients are classified as Stage III or Stage IV if mets are present.

Breast radiation therapy is done with curative treatment; patients are often diagnosed before the cancer spreads to other parts of the body. Surgery is typically performed as the initial treatment. A mastectomy is the surgical removal of all breast tissue; a lumpectomy is a removal of the tumor plus a margin of breast tissue and is sometimes referred to as **breast-conserving therapy**. Breast cancer commonly spreads through lymph nodes to the bones, lungs, and liver. Patients that present with metastatic disease may receive palliative radiation to metastasis, but not their breast.



Cell receptor status is an important prognostic factor in breast cancer. Estrogen (ER), Progesterone (PR), and human epidermal growth factor type 2 (HER-2 neu) are proteins of the surface of breast cancer cells that, if present, can promote cancer growth. Targeting these receptors can slow down or prevent cancer growth. For example, estrogen receptor-positive (ER+) tumors exhibit a 5 to 10% lower risk of recurrence than patients with receptor-negative (ER-) cancer. Triple-negative cancers (ER-, PR-, HER2-) lack expression of all receptors and often behave more aggressively than other breast cancers. Targeting these molecular pathways and combining them with other modalities, like surgery and radiation, improves treatment outcomes.

Weak Risk Factors	Moderate Risk Factors	Strong Risk Factors
Family history post menopausal Late menopause / early menarche Nulliparity Obesity Alcohol Consumption Hormone Replacement Therapy High socioeconomic status	Older Age Family history of pre menopausal Personal history of benign conditions Dense breast tissue (>50%)	Family history in 3+ relatives or bilateral breast cancer in a premenopausal relative Evidence of BRCA1/2 mutation Personal history of LCI or benign conditions Dense breast tissue (>75%)

Patient Simulation: Breast

The simulation procedure commonly used for fractionated breast treatments includes a CT simulation without contrast. Patients will disrobe above the waist and remove jewelry such as necklaces and earrings. Patients are typically positioned supine with their arms above their head in an immobilization device (I.e., armboard, vacloc, breast board), with a knee bolster under their knees. Therapists should instruct patients to extend their chin upward and turn their head away from the treatment side to reduce the dose to the anterior neck, esophagus, and mandible.

Physicians may prefer to define the treatment field borders and breast tissues using a radiopaque wire during simulation. Mastectomy, lumpectomy, and surgical drain scars may not be visible on the CT and are also wired for localization. Departmental protocols will vary, but these markers help delineate areas on the scan that are useful in the treatment planning process.

The therapist should place a reference isocenter mark on the patient's lateral skin surface, in a stable location – not too close to the arm or on movable tissue. The anterior reference isocenter should fall around the nipple-line in a stable location. BBs are placed at all 3 reference marks for visualization and triangulation in the planning system.

The general scan parameters will extend from the mastoid tip superiorly to include the entire lung volume inferiorly (or as specified by the physician). The scan is taken with the patient breathing normally.

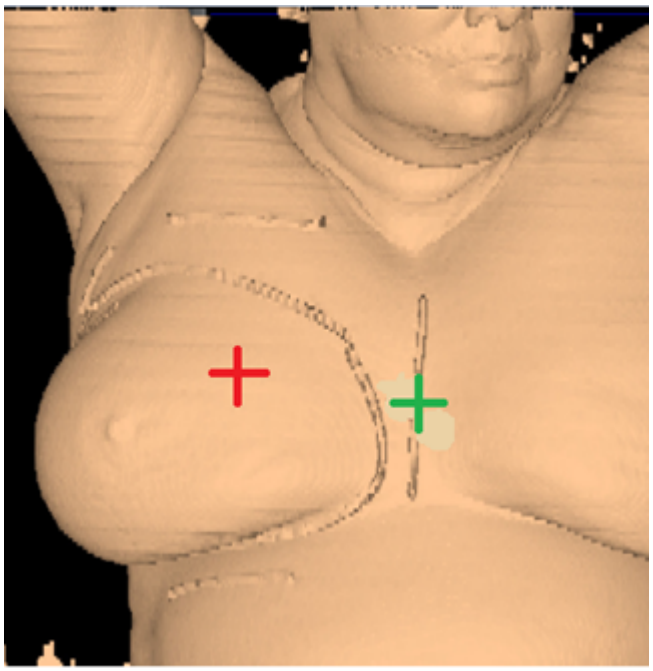


Image demonstrates the patient's position, wired anatomy and treatment field borders. The green mark represents the CT reference iso center and the red mark represents the treatment isocenter.

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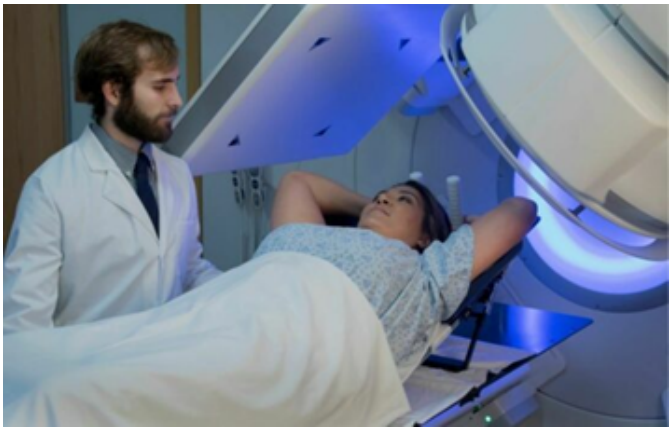
Special Simulation Considerations: Breast

Breast simulations require many special considerations based on the patient's body habits, tumor location, and the organs at risk. Details should be included in the physician's simulation order, but often recommendations and modifications need to be made by the therapists. One example is when treating both breasts, the patient's head should be neutral with their chin extended. Each patient is unique and may benefit from some additional considerations.

Patients may have difficulty raising their arm due to surgery, reconstruction, and lymph node dissection. The angle of the arm on the affected side depends on the patient's ability to raise their arm without discomfort, their ability to position the arm in a way that reduces skin folds in the supraclavicular area, and the size of the

immobilization device and its ability to move through the CT bore. A custom vacloc or cushion molded into the arm board may be required to support their modified treatment position as comfortably as possible.

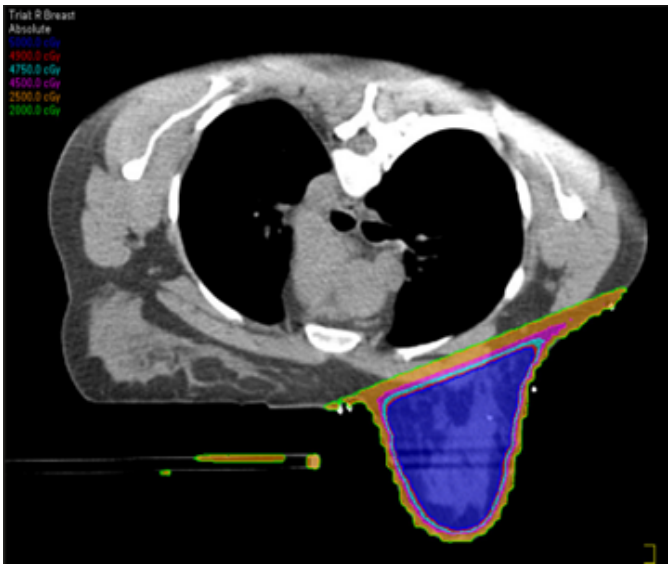


Patient positioned on an incline board for a breast treatment.

Patients with larger breasts are often positioned on an incline to prevent the breast tissue from being displaced in the infraclavicular area. The incline forces the breast tissue to fall inferiorly, helping to include the entire breast while avoiding dose exposure to the upper arm. Arm extension consistency is important, especially if the Level II, III, and supraclavicular lymph nodes are treated. An index mark documenting the arms extension will help in reproducibility. A bottom-stop will prevent the patient from sliding down during positioning which would affect the couch vertical during treatment.

Prone positioning using a breast board is an option for women with large, pendulous, breasts. Advantages to prone positioning include reducing lung tissue in the treatment fields, the gravitational displacement of the breasts away from the body, separation of the contralateral breast from the treatment field, and reduced skin folds and skin reactions.

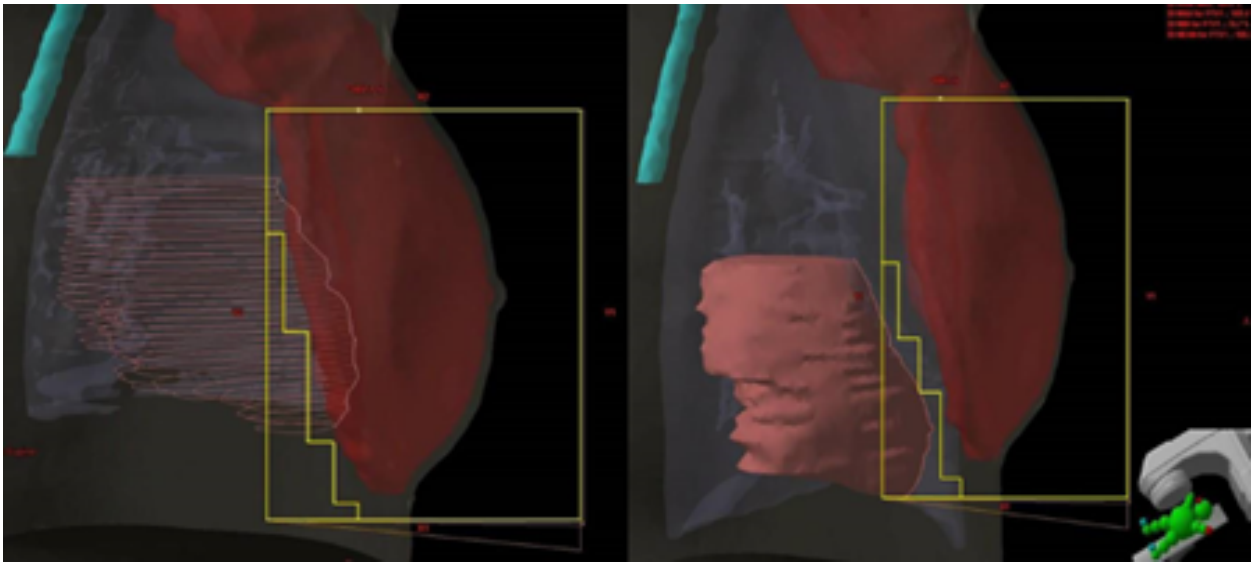
Patient positioned for a prone breast treatment.



Prone breast treatment plan.

The drawbacks of treating patients in a prone position are it is often uncomfortable and challenging for patients to get into the treatment position – patient selection is important based on their size and ability. The prone position can be difficult for the radiation therapist to reproduce; indexing the patient longitudinally on the board is vital. Additionally, field matching is a challenge because of the limited visualization of the medial border and, therefore, would not be used for a 4-field technique. Sometimes there are clearance issues due to the patient and the device's vertical height. The heart falls anteriorly towards the treatment field, potentially allowing it to receive a dose.

Breast tissue movement caused by respiration is one of the most differentiating factors from other simulations. **Surface-Guided Radiation Therapy (SGRT)** using the deep inspiration breath hold (DIBH) or active breathing coordinator (ABC) technique is commonly employed for left-sided breast cancers to move the breast tissue away from the heart. Special circumstances and physician or patient preference may desire to use it for right-sided treatments too.



DIBH breast tangent field simulated on Vert demonstrates the reduced heart dose during deep inspiration (right image) opposed to regular breathing (left image).

During the simulation process, the patient is evaluated to establish if they are a candidate for the DIBH technique. Patients must be able to hold their breath for the scan's length – around twenty seconds. A free-

breathing scan is also obtained for comparison. Patients breathe normally during the free-breathing scan but are instructed to take a breath and hold it during the inspiration scan. The dosimetrist, medical physicist, and physician will evaluate the scans and the distance of the heart and lungs from the treatment volume to determine the best treatment, DIBH or free-breathing.

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Treatment Volume Localization: Breast

The treatment volume, number of fields, and fractionation scheme used will vary. Fields are dependent upon the location of the primary tumor in the breast, the extent of disease, and the amount of lymph node spread. Radiation therapy of the breast typically utilizes lower energy beams, 6-10 MV depending on the depth and amount of breast tissue present. The organs at risk in the treatment of breast cancer are included in the table below.

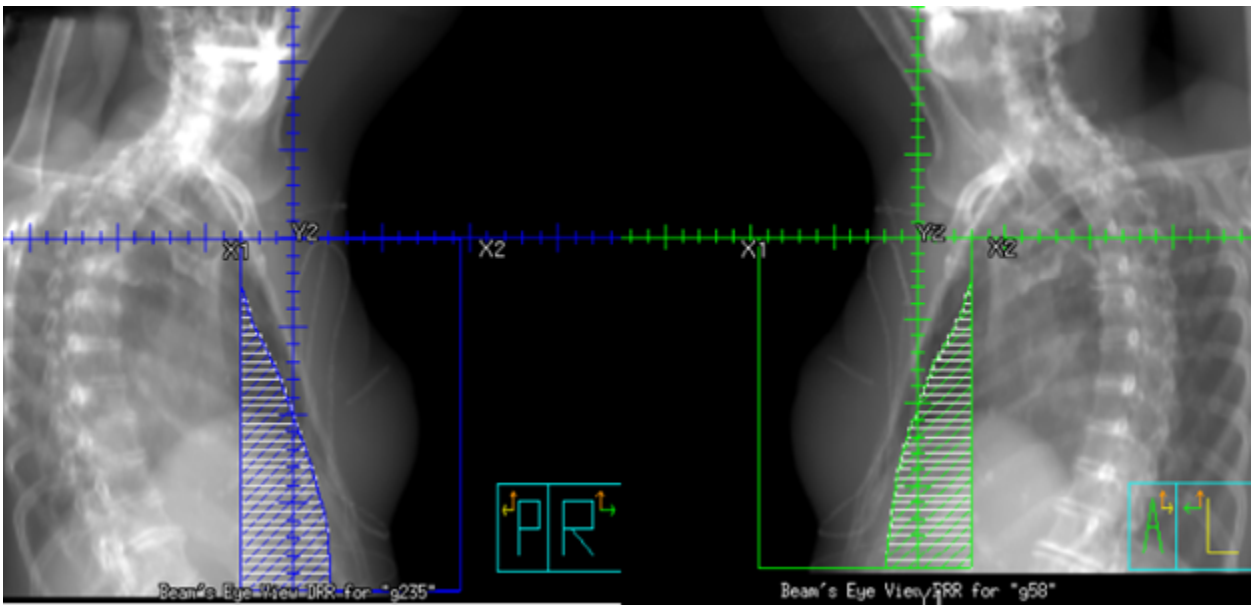
Whole Organ TD 5/5 for common OARs (Organs at Risk) for breast radiotherapy

OAR (Organ at Risk)	TD 5/5 (Whole Organ)	Outcome Associated
Lung	18 Gy	Pneumonitis
Spinal Cord	45 Gy or 47 Gy	Transverse Myelitis
Heart	40 Gy	Pericarditis
Esophagus	55 Gy	Stricture
Brachial Plexus	55-60 Gy	Clinically apparent nerve damage
Skin	55 Gy	Fibrosis

Skin care: Patient's will experience acute effects beginning around 20 Gy with erythema, then dry desquamation around 30 Gy, and moist desquamation at 40+ Gy. Using moisturizing lotions, like Aquaphor, early in the treatment process can reduce side effects and improve comfort. Mepitel Film is used for breast patients to prevent uncomfortable, painful skin reactions from radiation treatments. The dressing-like material prevents tissues from rubbing and sticking together. It does not interact with the beam and can be worn during treatment.

Treatment Fields:

Tangential fields (tangents) are used for early-stage disease and consist of medial and lateral oblique beams. This technique is commonly used to treat the whole breast/**chest wall** and the Level I axillary lymph nodes while sparing the heart and lungs. The isocenter is centered over the affected breast or chest wall and close to the posterior field border to reduce the beams divergence into the lung. Beams are rotated slightly past 180 degrees to match the beams posterior divergence. Matching the fields is easily accomplished in the treatment planning system or under **fluoroscopy** using radiopaque wires and the medial and lateral borders clinically.



Tangential fields for a right 4 field breast treatment using a half beam block. Note the position of the isocenter at the superior field border.

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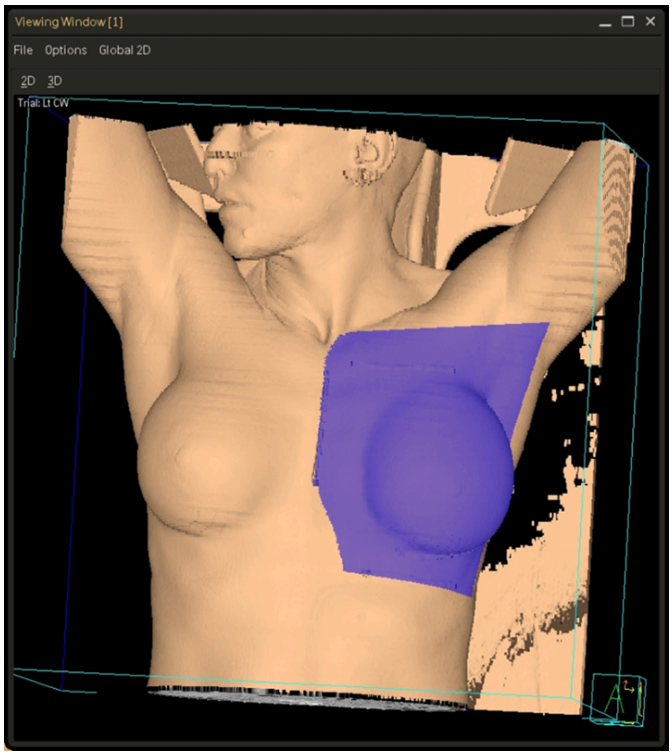
If treating the chest wall, bolus can be used to bring the dose more superficially to the skin surface. Bolus is a tissue-equivalent density material typically comprised of Paraffin wax, Vaseline gauze, wet gauze or towels, water bags, and other commercially available products. Patients with tissue expanders do not have breast tissue and require bolus for treatment; this presents a unique challenge to form the bolus, free of airgaps, to the patient's skin surface. Wet towels or a brass chainmail bolus will more easily conform to the patient's surface. It is important to note, bolus is only used for the tangential fields.

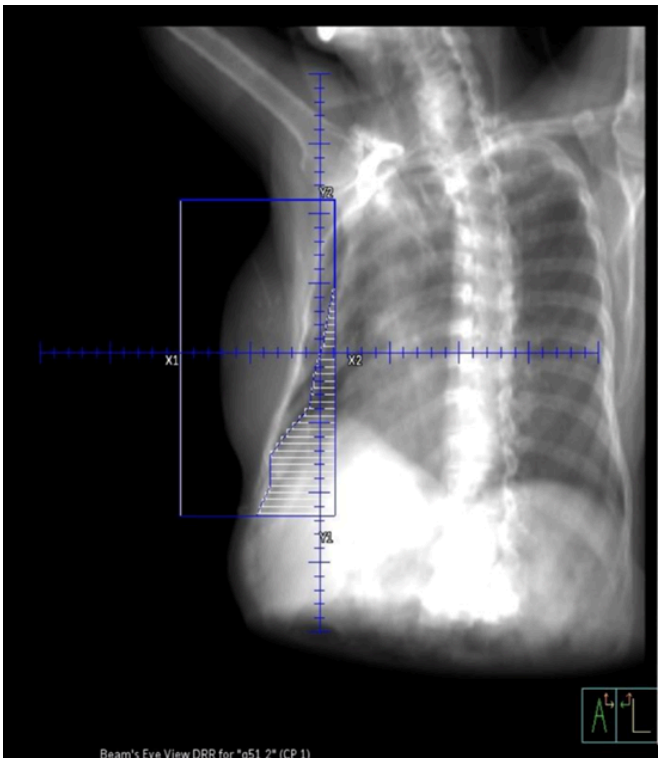
Superflab bolus or .5 cm, 1 cm, and 2 cm thickness.

Tangential Treatment borders:

- Medial: Midline (Sternum)
- Lateral: Mid-axillary line (2 cm beyond breast tissue)
- Superior: 1st costal space (or as superior as possible, may be limited by the ipsilateral arm)
- Inferior: 1-2 cm below inframammary fold
- Anterior: Field light fall-off ("flash") and SSD should be checked during the verification simulation on the linac.



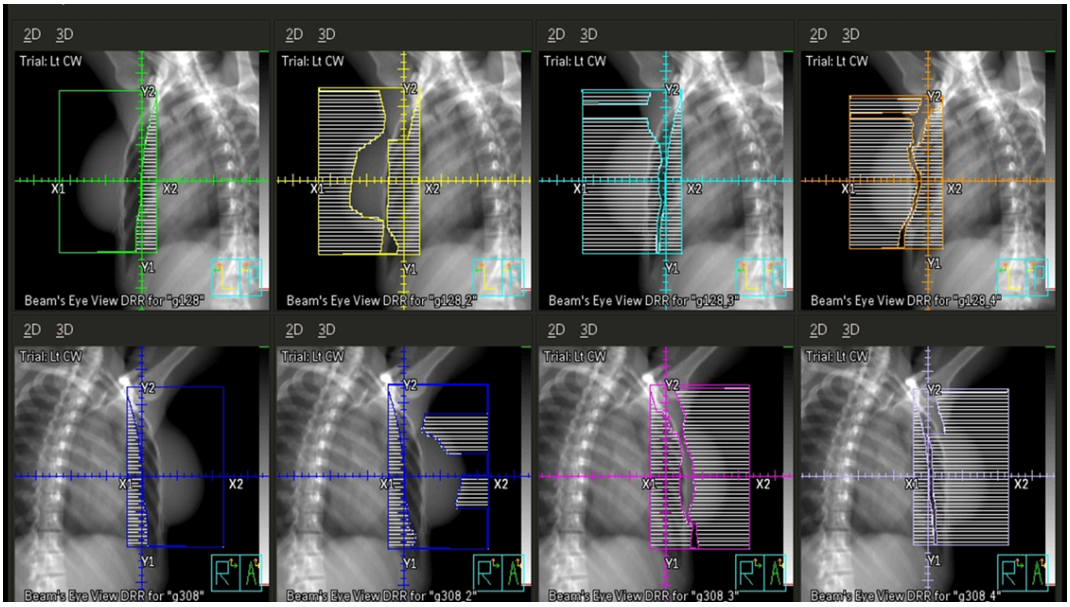
Surface rendering of a left tangent breast field. Note the patients head position, field borders, and beam divergence laterally.



Left medial tangent breast DRR of the previous patient. The image demonstrates 1-2 cm of field falloff anteriorly. Note the placement of the isocenter in the center of the field and its placement posteriorly to reduce divergence into the lung.

Flash is a visual representation of the area included in the treatment field, and based on breast treatment borders, there should be 1-2 cm of flash over the anterior and inferior surface of the breast. This margin accounts for the respiratory motion to ensure the inclusion of all breast tissue. Place a hand perpendicular to the central ray to check the light field and move it along the patient's tissue contour to ensure coverage. Source-to-skin distance (SSD) is then verified. The SSD should be within 1 cm of the planned SSD, and the couch vertical referenced from the simulation should also be within 1 cm.

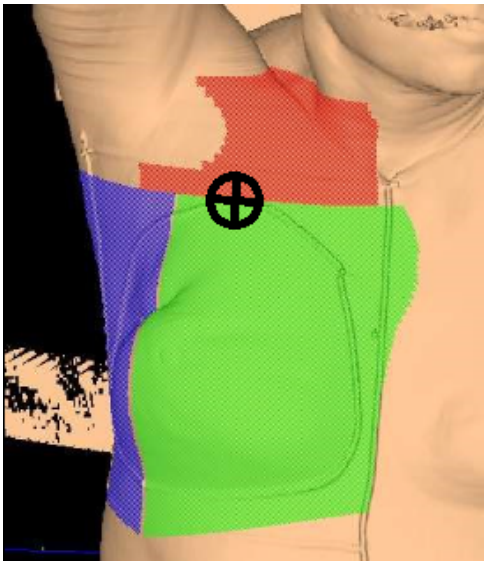
Due to the shape of the breasts and thorax, wedges are used to achieve dose homogeneity and reduce hot spots. The presence or absence of breast tissue determines wedge use. Generally, less breast tissue corresponds to a larger wedge angle required for treatment. For example, a patient who underwent a mastectomy without reconstruction may require a 45-degree wedge for uniform dose distribution. A patient who underwent a lumpectomy with significant breast tissue remaining may only require a 15-degree or no wedge. Some facilities use physical wedges placed in the head of the machine; others use computerized wedges found in the gantry head. Electronic compensation "ec" is another option to achieve dose homogeneity. The multi-leaf collimators (MLCs) are used in a step-and-shoot technique to achieve a uniform dose.



MLCs acting as a wedge using electronic compensation at g128 (4 ec-fields) and g308 (4 ec-fields). Notice how the field size decreases with each ec-field, which will mimic the isodose lines similar to a wedge.

Three & Four-field Techniques

In addition to tangent fields, a third and sometimes fourth field are added when there is nodal involvement. A supraclavicular (supraclav) field is treated for patients with 4+ positive axillary nodes or extracapsular extension; it includes the supraclavicular nodes and the level II & III axillary lymph nodes. Field matching is critical to prevent hot spots or cold spots in the treatment area.



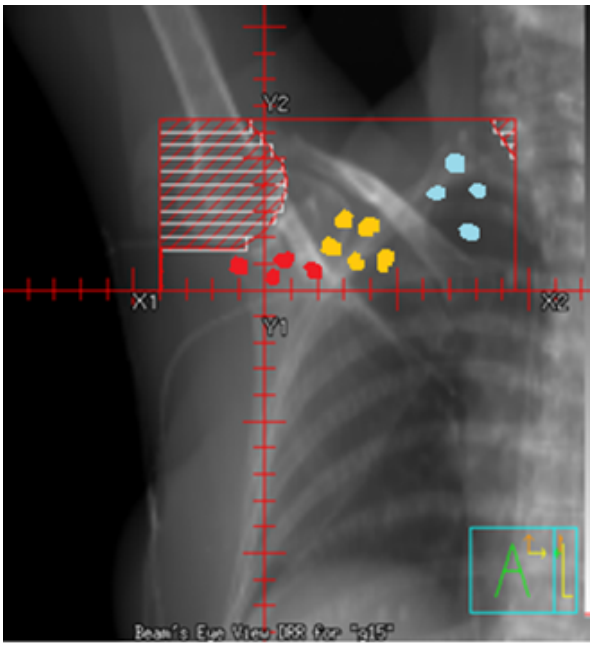
4-field breast skin rendering demonstrating treatment fields and isocenter location.

The easiest, most efficient, and safest way to accomplish a field match is using a single isocenter – a monoisocentric technique. This technique utilizes the non-divergent edge of a half-beam block, placing the isocenter at the field match at the level of the sternoclavicular (SC) joint. The lower half of the supraclavicular "supraclav" beam is blocked to avoid divergence into the tangent fields. The superior half of the beam is blocked on the tangential fields. The beam is angled 10-15 degrees mediolaterally (towards the unaffected side) to avoid lateral beam divergence into the spinal cord and esophagus.

For a two isocenter technique, it is important to use a couch kick on the tangential fields. The foot will rotate *away* from the collimator, so the divergence of cephalad field margins matches the inferior aspect of the supraclav field. This angle is decided using the equation: Tan = half field length/distance. Learn more HERE.

Supraclavicular Treatment borders:

- Medial: 1 cm across midline (or at midline)
- Lateral: From acromioclavicular (AC) joint, bisect humeral head to include coracoid process (Axillary lymph nodes are medial to the humeral head and coracoid process. If undissected axilla, include the entire lateral aspect of the humeral head to include the Level 1 axillary nodes)
- Superior: Approximately 5 cm above suprasternal notch (SSN) extending laterally across neck to the acromion process
- Inferior: 1st costal interspace or abutting the tangent field



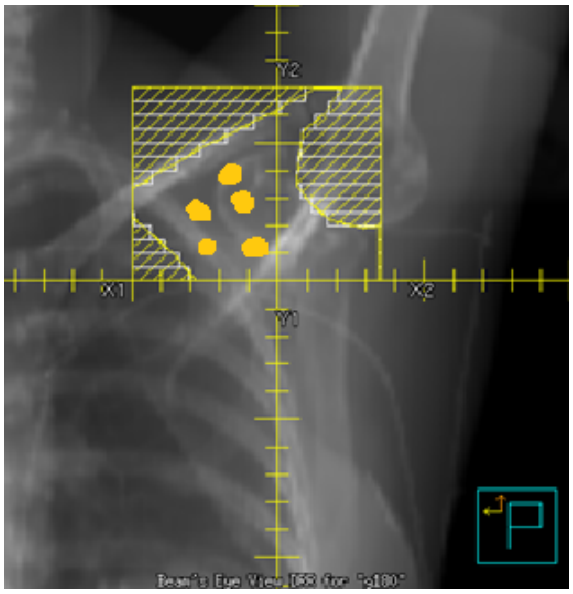
Supraclavicular field at g15 demonstrates the humeral head block, half-beam block (inferior half of field), and inferior isocenter. The supraclavicular nodes (blue) the level II (red) & III (Yellow) axillary lymph nodes are included in the field.

Four-field breast treatments encompass the breast tissue/chest wall and the superiorly located lymph nodes that filter from the breast. Fields include tangents, a supraclavicular field, and a **posterior axillary boost (PAB)** field. The PAB field "boosts" the level III, deep axillary lymph nodes because they receive an insufficient dose from the supraclav field. This beam is usually of higher energy, 10 or 18 MV.

PAB Treatment borders:

- Superior: Bisect clavicle and humeral head
- Inferior: Field matches the superior border of the tangential field (same as supraclav field)
- Medial: Approximately 1 cm of the lung to include the axillary nodes close to the chest wall
- Lateral: Latissimus dorsi muscle

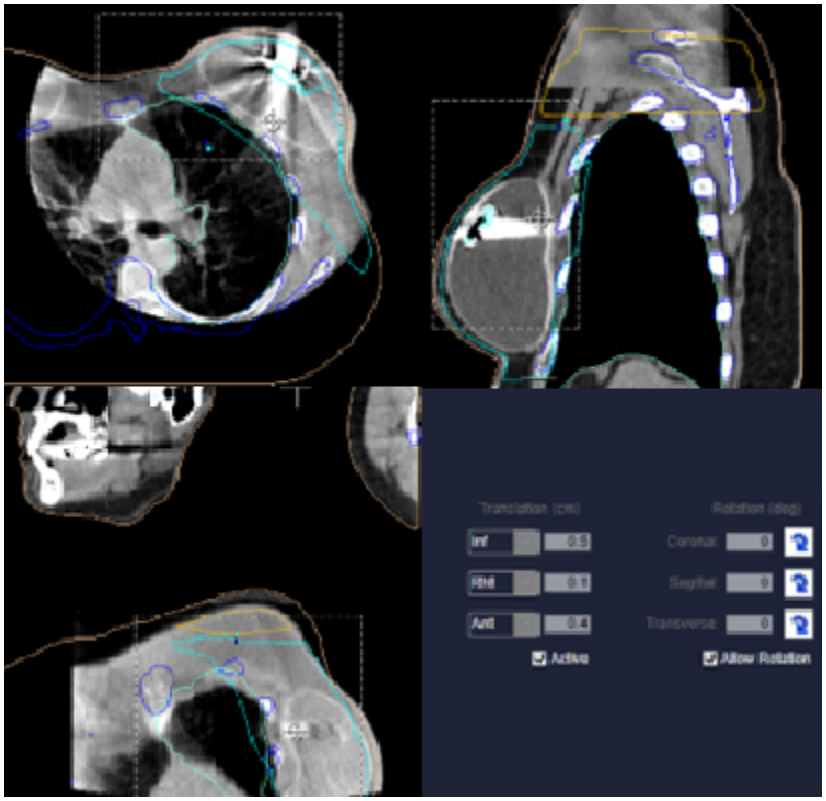
An additional **internal mammary field** is utilized to include the internal mammary lymph node chain. This field is achieved with a separate electron field. Today, to include these lymph nodes, most centers will extend the medial tangent border past midline (approximately 3cm) to the unaffected side. A radiation therapists should always verify the medial field border with the physician or dosimetrist if the field border is not standard and document it in the patient's chart.



PAB treatment field at g180 to boost the Level III deep axillary nodes. Note the isocenter location, humeral head block, and half beam block inferiorly.

Treatment Techniques: Breast

Alignment for breast treatments is typically done through imaging using an orthogonal pair, MV port films, or cone beam CT (CBCT). For VMAT treatments, it is best to align the patient using a CBCT, matching the patient's body contour, checking the sternum, and humeral head. Because VMAT is very conformal, it is critical to ensure that all the necessary anatomy is included in the imaging and treatment fields. Static fields are standard and not conformal. If using 2D imaging (kV or port films), verify the sternum on the lateral image, and ribs/chest wall on the anterior image. Verify the body, breast tissue, and body contour is reasonable with the tangent port – within falloff margin. If not imaging daily, before each treatment therapists should verify the treatment field falloff anteriorly, check the medial tangent SSD, and reference the couch vertical with the treatment simulation value – values should be within 1 cm.

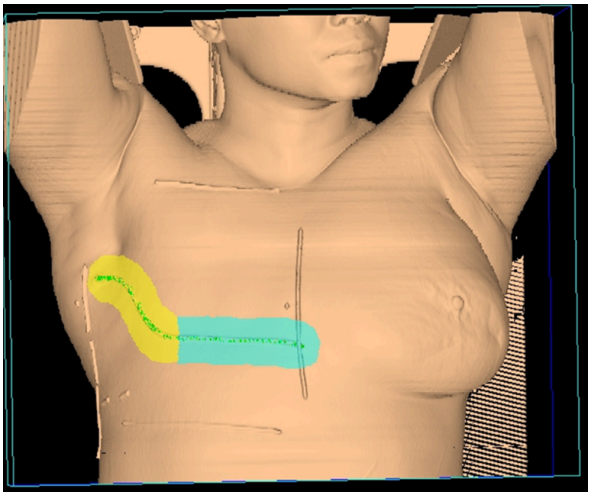


The standard dose fractionation schemes for conventional external beam breast radiation ther

Treatment technique	Standard dose fractionation
Tangents/Chest wall	46.8- 50.4 Gy at 1.8-2Gy/fx
Lymph Nodes: Supraclavicular/PAB	45-46.8 Gy at 1.8 Gy/fx
Tumor bed/scar	Boost above doses to ~60 Gy for patients with close margins, recurrent disease, or advan
Palliative	Bone mets: 8 Gy, 1 fx; 20 Gy, 4 fx; 30 Gy, 10 fx Fungating Primary: 36 Gy, 6 fx once or twice/week

In some cases, seromas arise during treatment. Seromas are fluid-filled sacs under the skin's surface that occur after surgery and during radiation treatment. They can be persistent and must be drained multiple times throughout the radiation course. It is essential to look for these on imaging or the skin, so checking SSD and light fields is essential. If a seroma is found, the patient will likely not be treated that day as they need to see a nurse and doctor to drain the fluid.

Treatment Techniques: Electron Boost



Following the delivery of the initial prescription, patients with close surgical margins, recurrent disease, or advanced primary tumors are "boosted" with an electron or photon treatment to the tumor bed/surgical scar. Boosts are typically set up clinically, though some departments use a dosimetry plan and shift from the primary treatment isocenter to the boost isocenter. Typically, the patient remains in their breast treatment position. The central ray is placed perpendicular (en face) at 100 SSD to the patient's surface over the treatment area.

The image demonstrates an abutting electron setup. Due to the size of the scar and the curvature of the patient's surface, two fields were required to be "en face."

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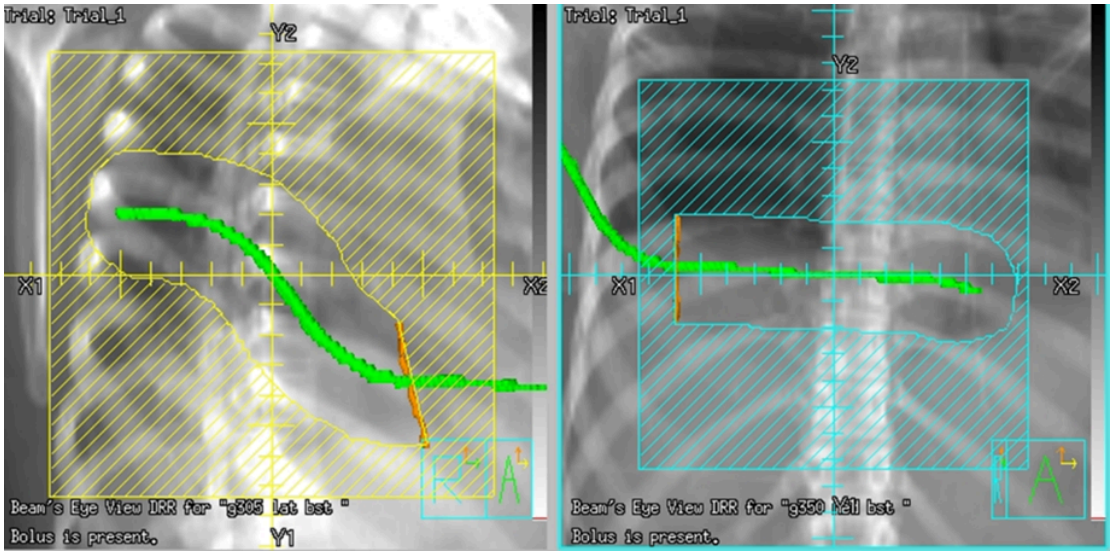
Electron fields cannot be imaged; the doctor will approve the patient's setup before treatment. It's important to document the treatment field(s) and setup with photos. An option to reproduce the an electron field is to create a template that can be used as a map for future treatments. Using a clear plastic template is beneficial because they do not require putting Tegaderm on a patient's sensitive skin. Marking the scar(s), moles, birthmarks, or other distinguishing marks on the template is helpful for the reproduction of the treatment field. Label the template with directional landmarks such as medial/lateral, superior/inferior, or anterior/posterior. Patients with a deeper tumor bed or larger breasts sometimes will have a photon boost instead.



En face electron blocks for the abutting electron. The beams are matched on the skin surface which will result in a hot spot below the surface.

Each electron boost patient will have a custom Cerrobend block held in place by an electron cone. The size of cone used is dependent on the block size. The distal edge of the cone, the side closest to the patient, measures 95 cm from the machine source; therefore, the distance from the block to the patient is 5 cm. Safely moving the patient to the appropriate treatment distance is challenging. A **stairstep technique** is required whenever the gantry is not at 90, 0, or 270 degrees.

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Beam energy will vary dependent upon treatment depth; typically, patients are prescribed to the 90% isodose line. The energy required for the 90% isodose line is easily calculated by taking 1/4 the energy. For example, a 12 MeV beam's 90% isodose line is at a depth of 3 cm; 12/4=3. Sometimes a bolus is required to achieve the desired depth. Department protocol or doctor preference may set the SSD to the bolus or skin surface. For example, if the dose prescribed is to the surface of a 1 cm bolus, the SSD on the skin would read 101 cm; when the bolus is added, the SSD will read 100 cm. The bolus should cover the entire treatment field and be free of air gaps. The physician will determine the prescription and use of bolus; standard boost fractionation schemes consist of a 5-fraction boost with 2 Gy per fraction to 10 Gy.

General "Rules of Thumb" for electrons.

• 1 MU = 1 cGy at the 100% isodose line (dmax) for standard jaw setting, large field size, & no obliquity • Surface dose increases with energy (70-80% at 6 MeV; 95% at 18 MeV)

Rp = (practical range)	Energy / 2cm
R80 (80% isodose line)	Energy / 2.8 cm (or divide by 3 to ensure coverage)
R90 (90% isodose line)	Energy / 3.2 cm (or divide by 4 to ensure coverage)

Emerging Technologies & Treatments

Breath hold Techniques are most commonly used for left-sided breast cancers.

Hypofractionated treatment schemes are becoming more prevalent. This fractionation style consists of 40 – 42.56 Gy in 15-16 fractions at 2.66 Gy/fx. The benefit of **hypofractionation** is a decrease in side effects and treatment course length. The tumor bed boost can be treated simultaneously with the primary treatment course. Eligible patients are early stage, low risk, disease.

Partial Breast Irradiation (PBI) is often used to treat early-stage breast cancer patients without nodal involvement; radiation is delivered to the lumpectomy cavity with a margin instead of the whole breast. Patients must meet specific criteria to be candidates for partial breast irradiation. These treatments reduce local recurrence rates and toxicity due to less tissue irradiated, which improves cosmetic outcomes. PBI can be treated via external beam (IMRT/VMAT), **intraoperative radiation therapy (IORT)**, or **brachytherapy** techniques.

- **IMRT/VMAT** treatment techniques are becoming the most common technique for partial breast irradiation. This treatment technique has improved cosmesis and provides excellent target coverage to the chest wall and regional lymph nodes with minimal dose to critical structures such as the heart and lungs. This technique also provides a better dose homogeneity. When aligning images, use the surgically placed localization clips in the lumpectomy cavity; if not present, use the body contour and check the sternum. These treatments use a conventional dose-fractionation scheme.
- **Intraoperative radiation therapy (IORT)** is a single fraction treatment using Intrabeam. Treatment is to the lumpectomy cavity using a 50 kV technique and 10-20 Gy completed *during* surgery. The tumor cavity has depth requirements to qualify as a candidate for treatment. The University of Iowa's, Dr. Sugg describes the IORT treatment procedure.
- **Brachytherapy** high-dose-rate (HDR) procedures commonly use Iridium-192 sources and is referred to as an Accelerated Partial Breast Irradiation (APBI). Treatment involves placing radioactive sources inside or near the tumor site and may be performed for partial breast irradiation. Interstitial brachytherapy

treatments are used to treat a quadrant, or less, of the breast. This delivery method requires surgical skill for implantation of a treatment catheter.

- Balloon brachytherapy (Mammosite) is another option that utilizes the placement of a fluid-filled balloon into the breast cavity. The balloon is inserted during the lumpectomy and filled with saline to distend the cavity for treatment. Patient selection requires at least 1 cm of tissue between the skin and the balloon surface. Patients typically receive 10 treatments BID (6 hours between treatments) to 34 Gy. A boost treatment of 10 Gy in 2 fractions over one to two treatment days is prescribed. SAVI is another type of applicator that does not have skin spacing restrictions, making more patients eligible.

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PART V
ABDOMEN

18.

OVERVIEW: ABDOMEN

Learning Objectives

- Describe the anatomy, structures, and landmarks of the abdomen
- Describe malignancies of the abdomen
- Describe the simulation process of the abdomen
- Identify commonly used positioning & immobilization devices used for abdominal treatments
- Define scan parameters and reference isocenter location for abdominal simulations
- Discuss special considerations in abdominal patient positioning
- Define the “traditional” treatment borders and how they relate to tumor spread
- Describe tumor volumes and margins for abdominal tumors
- Discuss the various treatment procedures of abdominal malignancies
- Perform tasks associated with the simulation and treatment of abdominal malignancies

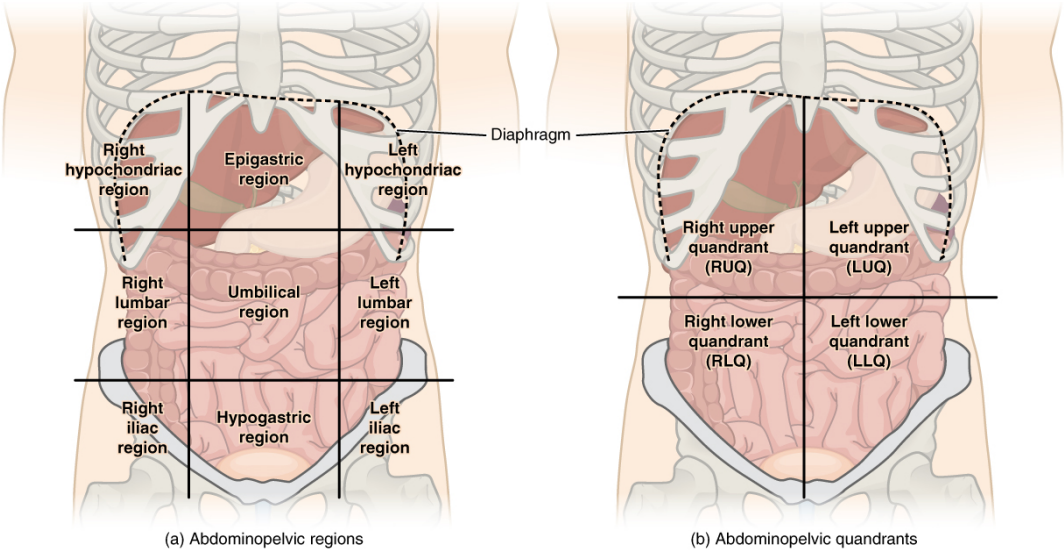
Key Terms

- **Anastomosis**
- **Adapt to Position**
- **Adapt to Shape**
- **Embolization**
- **Enteritis**
- **Intraperitoneal**

- **Magnetic Resonance-guided Radiation Therapy (MRgRT)**
- **MIBG Radiotherapy**
- **Nephrectomy**
- **Neuroblastoma**
- **NPO**
- **Palliative Whole Abdomen Irradiation**
- **Retroperitoneal**
- **TIGER-PaC**
- **Whipple Procedure**
- **Whole Abdomen Irradiation (WAI)**
- **Wilms Tumor**

Overview: Abdomen

The abdomen is commonly described anatomically in four quadrants; the Right Upper Quadrant, Left Upper Quadrant, Right Lower Quadrant, and Left Lower Quadrant. The major components of the abdomen abdomen include the pancreas, kidneys, liver, gallbladder, stomach, intestines, and colon. These tissues have a rich lymphatic drainage that converges at the cisterna chyli at the second lumbar vertebra before draining to the thoracic duct.



Abdominopelvic regions and quadrants.

Learn more abdominal anatomy by visiting this website.

Patient Simulation: Abdomen

Patients undergoing abdomen cancer treatment are first changed into a gown. Ensure the patient's waste bands, zippers, or buttons, are out of the field of view and not moving the patients tissues. Begin by positioning the patient supine with arms above their head in an indexed wing board or arm board. A vaclok or a knee bolster under the legs will improve comfort and help flatten the back to improve reproducibility. While these are the most commonly utilized immobilization devices, other options exists and are depending upon the patient's ability, equipment availability, and doctor preference.

The patient's upper half is uncovered, and their lower half should expose midthigh; protect the patient's modesty as much as possible. Three reference marks are placed at a stable position on the patient's skin; laterally on each side and anteriorly. Straightening marks are also placed superior and inferior to the anterior isocenter for straightening. Abdomen marks can be unstable depending on a patient's body size and habitus. Patients with a larger body habitus, especially in the abdominal area, will likely have a less reliable and reproducible anterior mark. The CT scan parameters generally range from above the diaphragm to below the iliac crest depending upon the treatment site.

It is common for the doctor to request IV and oral contrast when simulating a patient for abdominal treatment. Oral contrast should be given before the simulation, but IV contrast should be given after the tomogram image is completed. Contrast enhances blood, vessels, intestines, and specific organs to assist the doctor when designing the treatment plan.

Special Simulation Considerations: Abdomen

One of the most common considerations in treatments of the abdomen is tumor motion due to respiratory motion. Various methods exists to reduce tumor motion during treatment. These techniques include abdominal compression, active breathing control, deep-inspiration breath hold, and respiratory gating with tumor tracking. Motion management is often patient-specific, and the chosen technique is often the one that is best suited for the patient. These are techniques are further described in the Special Simulation Considerations: Thorax section.

This video describes the ANZAI Respiratory Gating System. It simulates the technology for a breast patient, however, the same technique is used for abdominal treatments following the same process. This link describes the ANZAI Respiratory Gating System; its general purpose, involved equipment, and clinical workflow.

In addition to respiratory motion, peristalsis and eating before treatment can cause motion or a shift in anatomical position of some anatomy. Some patients are instructed not to eat two to four hours before treatment or NPO, meaning nothing by mouth. Not eating before treatment can also help reduce nausea induced by the radiation. Always be sure to communicate these instructions to the patient before their simulation as well as each treatment.

Patients who cannot bring their arms above their head can be positioned with their arms high on their chest with hands clasped if treating the lower abdomen. If the treatment area is in the upper abdomen, the patient can clasp the opposite arms elbows wresting their forearms on their forehead. A headrest and vaclok under the patients head can help support the arms and improve reproducibility.

Treatment Volume Localization: Abdomen

Cancers of the abdomen have varying margins depending on the treatment intent – palliative or curative. Margins also depend on the treatment technique and surrounding anatomy. Treatment design is based on the location of the primary tumor, surrounding critical structures, and the lymphatic drainage of the primary site. Tumor motion is considered during treatment planning and will be used if determined beneficial. Due to the contents of the abdomen, conformal treatments are preferred to limit side effects and spare healthy tissue and unaffected organs. For this reason, VMAT is the treatment of choice for curative treatments of abdominal cancers.

Organs at Risk (OARs)	TD 5/5 (Whole Organ)	Outcome Associated
Kidney	23 Gy – One Kidney 18 Gy – Mean dose to both Kidneys	Renal Insufficiency
Liver	30 Gy	Hepatitis
Lung	18 Gy	Pneumonitis
Heart	40 Gy	Pericarditis
Stomach	55 Gy	Perforation/Stricture
Rectum	55 Gy	Diarrhea
Bladder	65 Gy	Cystitis/Stricture
Femoral Heads	52 Gy	Osteonecrosis
Small Bowel	40 Gy	Obstruction/Perforation
Large Bowel (Colon)	50 Gy	Obstruction/Perforation
Spinal Cord	45 or 47 Gy	Transverse Myelitis
Ovaries	2-3 Gy	Sterilization

Treatment Techniques: Abdomen

Due to the critical structures in the abdomen, nausea is a common side effect of radiation. The dose rate can affect the intensity of the nausea. Patients typically begin with a standard dose rate, with their symptoms monitored throughout treatment. If nausea occurs, anti-nausea medications an hour or two before treatment can reduce these affects. If nausea persists, the radiation oncologists can prescribe to lower the dose rate. Typically a dose rate lower than 300 MU/min ran reduce the patient's nausea. However, this does increase the time it takes to deliver the patient's treatment. Most treatments today use daily imaging before treatment – Image-Guided Radiation Therapy (IGRT). Depending on tumor location, the structures to align daily imaging to may vary. The spine is always a good starting reference. It is vital to double-check your longitudinal alignment with at least one other reference point, such as the carina, lung/diaphragm, 12th rib, kidneys, liver edge, or iliac crest. From here, patient alignment should focus on the PTV and the surrounding structures.

- **Palliation (AP/PA):** This beam arrangement is commonly reserved for pain relief and symptom reduction; doses are 20-30 Gy in 5-10 fractions.
- **3D Conformal:** Treatments utilizes multiple beam angles and fields to create a conformal dose distribution.
- **VMAT:** Curative abdominal treatments are often delivered via the VMAT technique due to the abundance of critical structures. VMAT can deliver radiation quickly from various angles while using

MLCs to shape the beam. A significant benefit of this technique is its ability to spare normal tissue and keep side effects to a minimum, which is especially important in the abdominal region.

- **SBRT:** Lesions < 5 cm are treated using SBRT on a Linac or MR-Linac. The energy is typically 10 MV using a flattening-free-filter (10 MV) beam. Most lesions of the abdomen treated with this technique are located in the liver. They are further described in the SBRT unit.

Emerging Technologies & Treatments: Abdomen

Surface monitoring systems assist during patient setup and monitor the patient's position throughout treatment. Surface monitoring systems can track surface motion and position with <1 mm accuracy. These systems use a 3D model of the patient acquired during their CT simulation. A red light projects onto the patient's skin surface and records their surface position. The systems monitor the pitch, yaw, and roll of the patient. Pitch is the back elevation, yaw is the hip adjustment, and roll is the patient's rotation. During treatment setup, surface monitoring systems assist in reproducing the patient's position. After daily imaging and completing table adjustments, a new image capture is taken for treatment. The image is used as a baseline to monitor patient movement during treatment – this is required daily. Some clinics utilize surface monitoring systems that automatically interrupt the radiation beam if the patient moves out of tolerance.

Motion monitoring systems like respiratory gating (previously described) and live imaging continue to make advances.

Proton Therapy: Motion improvement techniques for pencil beam scanned proton therapy should be evaluated and selected based on organ motion. Organ movements to be assessed for proton therapy include those of the target and all organs in the potential proton beam path. For example, treating the lower esophagus using posterior fields where the diaphragm moves severely impacts the delivered beam range relative to the treatment target.

Magnetic Resonance-guided Radiation Therapy (MRgRT): Due to abdominal organs' movability and placement, a popular emerging treatment option is to treat these patients with MRgRT. The radiation delivery via a magnetic resonance linear accelerator (MR-Linac) uses magnetic resonance imaging with radiation to treat cancer patients. A significant benefit of this treatment technique is the ability to provide motion management and real-time imaging during treatment to ensure the target remains in the treatment field and sparing healthy tissue. It also allows the treatment to "Adapt to Shape" or "Adapt to Position" before each fraction. This is ideal for these cancers because the stomach may be in a slightly different position each day.
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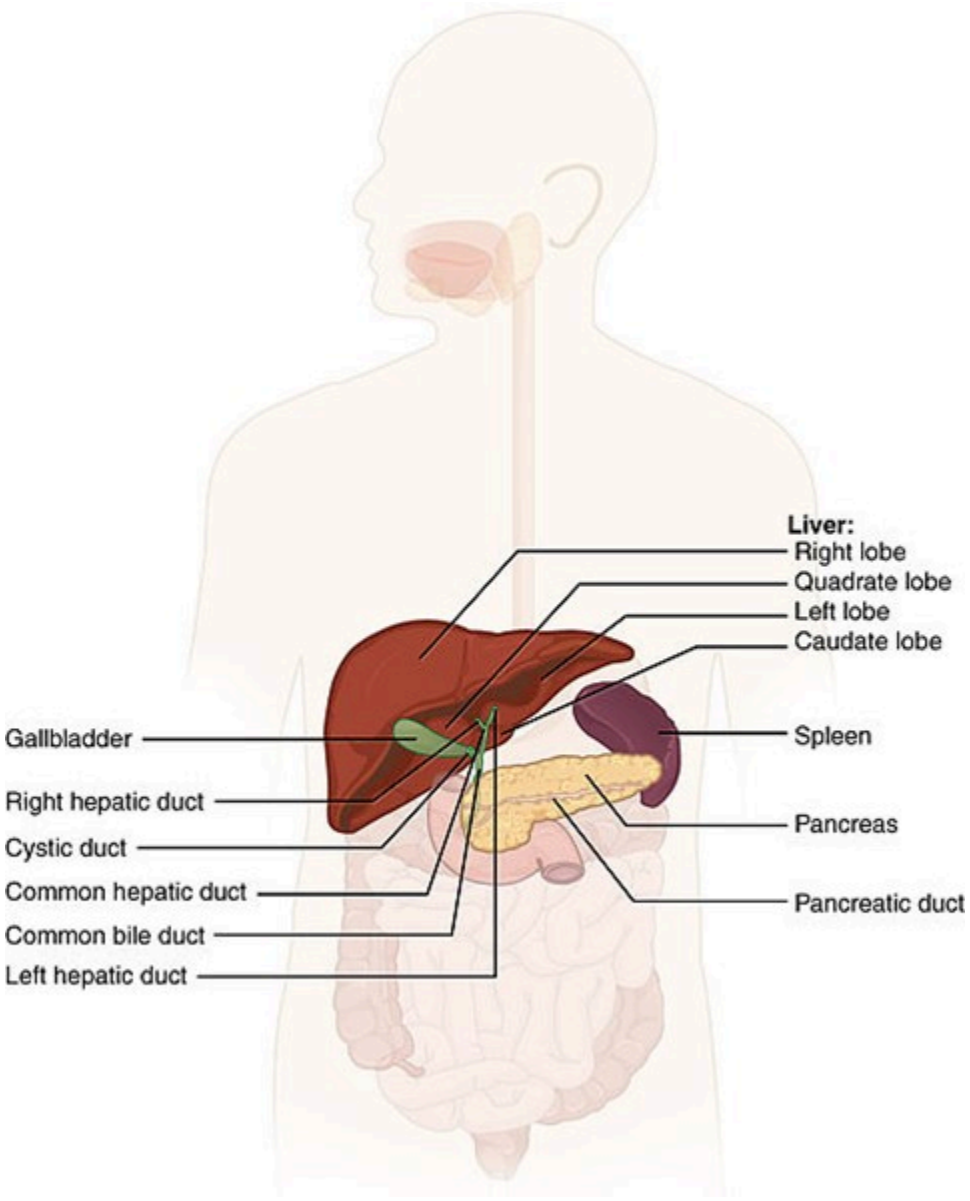
19.

PANCREAS

Overview: Pancreas

Located at the T12 to L2 vertebral bodies, the pancreas lies retroperitoneally in the upper portion of the abdomen. It is divided into the head, body, and tail. The pancreas is in direct contact with the duodenum, jejunum, stomach, major vessels (IVC), spleen, and kidney. The tail of the pancreas is the most superior portion, while the head is the most inferior portion located in the C-loop of the duodenum. The main lymph node groups of the pancreas include the superior and inferior pancreaticoduodenal, porta hepatis, suprapancreatic, and paraaortic nodes. Most patients have advanced local or metastatic disease at the time of diagnosis due to the abundance of regional lymphatics. Most pancreatic cancers are adenocarcinomas and carry a very poor prognosis.



Pancreas and surrounding anatomy.

Patient simulation & Special Considerations: Pancreas

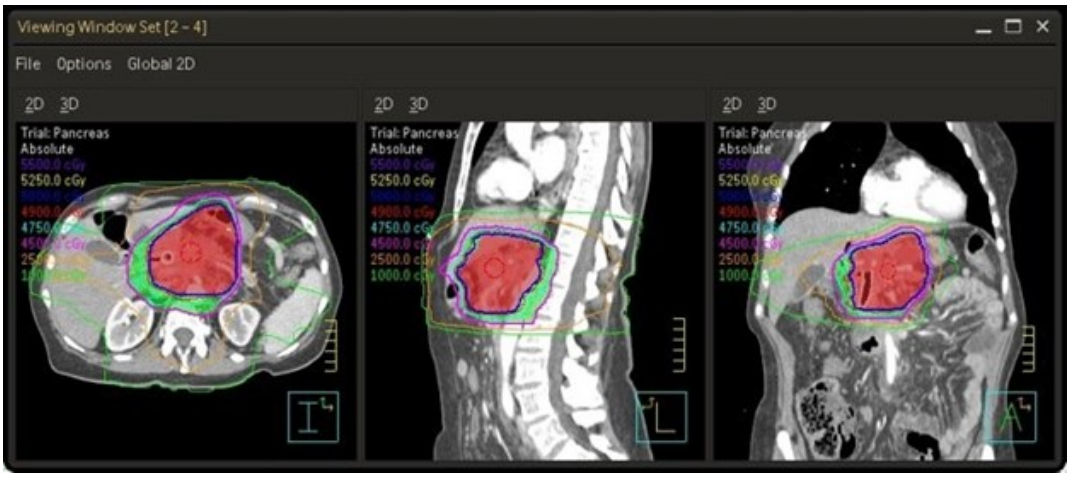
The simulation process is consistent with the typical abdomen in treating pancreatic cancer. Please refer to Patient Simulation: Abdomen section. The patients pancreas is highly moveable and can shift locations depending on the fullness or emptiness of surrounding structures. The physician may request patients may be NPO 2-3 hours before treatment.

Treatment Volume Localization: Pancreas

Lymph nodes associated with pancreatic cancer include the pancreaticoduodenal, porta hepatis, suprapancreatic, and celiac nodes. When treating the head of the pancreas, the nodal areas above and the entire duodenum must be treated. When the tumor is in the tail or body of the pancreas, the splenic hilar lymph nodes and paraaortic lymph nodes are at risk.

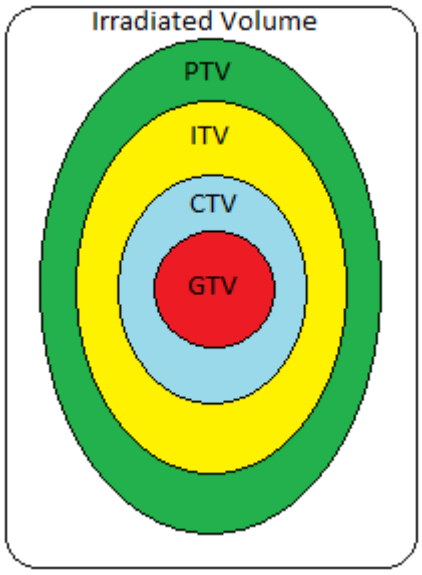
Historically, a 4-field box was used (opposed anterior and posterior fields and opposed lateral fields) to treat pancreatic cancer. The problem with this field arrangement is that the dose delivered to the spinal cord, right kidney, and liver section are higher. Wedges and beam weights are also necessary for treatment planning. Treatment borders for pancreatic irradiation are as follows:

- **Superior:** the mid or upper portion of T11
- **Inferior:** include the L3 vertebral body
- **Lateral:** at least 2/3rds of the right kidney needs to be excluded with a 2-3 cm margin around the tumor or tumor bed
    - It is not necessary to include the entire duodenal loop
    - The treatment field is extended to the left of the pancreas so that a 3 cm margin around the tumor is created to treat the splenic hilum
- **Posterior:** vertebral bodies should be split with a one to 2 cm margin beyond the tumor or tumor bed anteriorly



Treatment plan for a VMAT of the pancreas.

Treatments today still follow these general borders but are more conformal to targeted tissues, sparing normal tissues and reducing toxicity. Because of the difficulty in determining tumor margins, radiologists and radiation oncologists should consult closely to delineate from scans the GTV, including any enlarged regional lymph nodes of 1.5 cm or greater. The CTV should include the visible tumor and the surrounding edema. This area is of considerable uncertainty, and margins must be individually designed. PTV margins are anisotropic with 5-10 mm in the AP direction, 2-4 mm in the transverse plane, and 15- 30 mm craniocaudal for organ movement with respiration or abdominal motion and set-up variations. If breath hold techniques or gating is used (ITV), craniocaudal margins may be reduced.

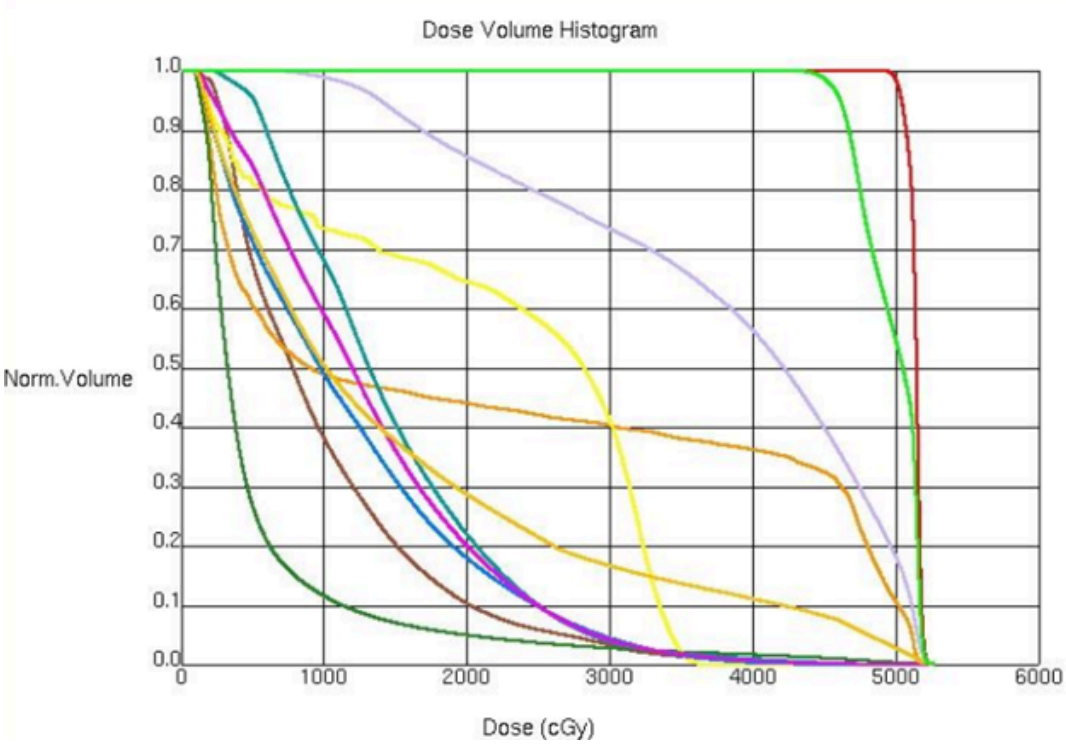


Planning target volumes.

Treatment Techniques: Pancreas

Traditional fractionation for pancreatic cancers is 200-220 cGy with 25-28 fractions. Resectable tumors are usually treated with 45 Gy to the tumor bed, surgical **anastomosis**, and regional lymph nodes. If critical structure tolerances are not exceeded, a boost to 50-65 Gy may be delivered. Nonresectable cases have a target dose of 50-60 Gy. The typical energy that provides adequate skin sparing on the lateral aspects of the patient while still evenly distributing the requested dose to the tumor is 10 MV photons. This energy may vary based on patient thickness.

Today, VMAT and MR-Linac are used to treat pancreatic cancer due to their ability to conform to the pancreas and spare surrounding healthy tissue. Common VMAT treatments for the pancreas will consist of two to three complete 360-degree arcs. Studies have shown that IMRT and VMAT treatment techniques further reduce the liver, kidneys, stomach, and small bowel dose compared to 3D conformal treatment. MRLinac SBRT pancreas fractionation consists of a total dose of 40 Gy delivered in 5 fractions with 8 Gy per fraction. This technique utilizes a treatment every other day, so there should be 40 hours minimum between treatments.



DVH for a VMAT of the pancreas.

Line Type	ROI	Trial or Record	Min.	Max.	Mean
	Large Bowel	Pancreas	91.0	4629.0	1004.5
	Duodenum	Pancreas	102.3	5204.1	2231.3
	Stomach	Pancreas	598.4	5255.1	3790.5
	Small bowel	Pancreas	87.9	5137.1	563.9
	Spinal Cord	Pancreas	145.2	3626.2	2199.6
	Kidney_R	Pancreas	222.0	4718.2	1453.6
	Kidney_L	Pancreas	117.8	4297.4	1175.3
	Kidneys Combir	Pancreas	117.8	4718.2	1322.0
	Liver	Pancreas	74.1	5244.3	1560.8
	PTV5000	Pancreas	4830.2	5268.0	5139.5
	PTV4500	Pancreas	3988.6	5268.0	4971.1

DVH structures for a VMAT of the pancreas.

Emerging Technologies & Treatments: Pancreas

A pancreaticoduodenectomy, also called the Whipple procedure, is a potentially curative surgical procedure consisting of the resection of the head of the pancreas, entire duodenum, distal stomach, gallbladder, and common bile duct. Reconstruction is done to maintain the continuity of the biliary GI system. The remaining pancreas, bile ducts, and stomach are anastomosed onto various sites of the jejunum. This highly invasive procedure requires lots of recovery time, making it one of the most challenging surgeries for patients but it does offer the best chance of cure. Newer surgical techniques allow this surgery to be complete laparoscopically.

The TIGER-PaC Clinical Trial uses RenovoRX's innovative therapy platform to evaluate RenovoGem. This clinical trial treats locally advanced pancreatic cancer through intra-arterial delivery of gemcitabine, a systemic chemotherapy agent often used to treat pancreatic cancer. Systemic chemotherapy associated with debilitating side effects may be ineffective in treating pancreatic cancer due to pancreatic tumors lacking blood vessels. The chemotherapy for the TIGER-PaC trial is delivered via an incision in the leg to give the chemotherapy to the targeted tissue across the vessel wall. The primary goal of this clinical trial is to improve overall survival and quality of life for patients with pancreatic cancer.

Proton Therapy: Can help reduce dose to surrounding organs at risk through a reduction in entrance and exit dose. However, organ motion may present a challenge for proton therapy.

Magnetic Resonance-guided Radiation Therapy (MRgRT): Due to abdominal organs' movability and placement, a popular emerging treatment option is to treat these patients with MRgRT. The radiation delivery via a magnetic resonance linear accelerator (MR-Linac) uses magnetic resonance imaging with radiation to treat cancer patients. A significant benefit of this treatment technique is the ability to provide motion management and real-time imaging during treatment to ensure the target remains in the treatment field and sparing healthy tissue. It also allows the treatment to "Adapt to Shape" or "Adapt to Position" before each fraction. This is ideal for these cancers because the pancreas may be in a slightly different position each day.

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20.

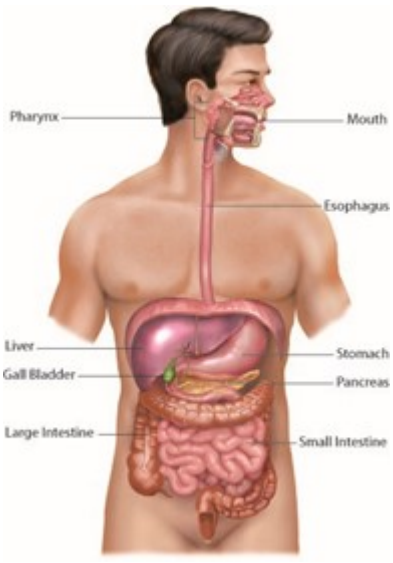
STOMACH, LIVER, & COLON

Overview: Stomach, liver, & Colon

The stomach is a reservoir for food and aids in digestion after food enters from the esophagus. Distally, it connects to the small intestine at the duodenum. Cancers of the stomach typically grow slowly and develop over many years. Most cancers are classified and adenocarcinomas.

The liver is the largest solid organ in the body, located in the upper right quadrant of the abdomen. The most common type of primary liver cancer is hepatocellular carcinoma. Most tumors of the liver are secondary or metastasis from other sites. The common cancers that spread to the liver are from the pancreas, colon, rectum, breast, and lung. The gallbladder is surrounded by the liver and aids in the digestion of fatty foods. Cancers here are rare and most are adenocarcinomas.

The colon (large bowel) consists of eight regions: the cecum, ascending colon, descending colon, splenic flexure, hepatic flexure, transverse colon, sigmoid, and rectum. The cecum, transverse colon, and sigmoid sections are located **intraperitoneally** and can be surgically removed unless the tumor is invading adjacent structures. The ascending colon, descending colon, hepatic flexures, and splenic flexures are located retroperitoneally or outside the peritoneum. Due to their location and lack of mesenteric support, cancers found in these portions of the colon commonly spread outside the bowel wall to adjacent soft tissues, like the kidney and pancreas. Lymphatic drainage along the colon is extremely rich and dependent upon the section of the colon. Most colon cancers are adenocarcinomas.



Major organs of the digestive system

Patient simulation & Special Considerations: Stomach, liver, & Colon

The simulation process is consistent with the typical abdomen in treating cancers of the stomach, liver, and colon. Please refer to the Patient Simulation: Abdomen section. The stomach and colon are highly moveable structures and can shift locations depending on their fullness or emptiness. The physician may request patients

may be NPO before simulation (also required if receiving contrast) and treatment. These structures may also benefit from motion management, like compression or 4D treatment, caused by respiration.

Stomach: When simulating a patient with stomach cancer, the doctor will want the patient to be NPO for up to 4 hours before treatment to keep the treatment volume smaller and consistent throughout treatment. It is essential to communicate these instructions with the patient.

Liver & Gallbladder: Some options for motion management include 4DCT, breath hold, gated breathing, fiducial tracking, abdominal compression, and MRgRT. Another vital aspect of simulation for liver treatment is that CT contrast is highly recommended. If a patient has any contraindications to IV contrast, fusing the image with an MRI for planning purposes is ideal.

Colon: Patient simulation for the abdominal colon will utilize a supine position with arms positioned high on the chest. One to two pillows should be situated under the patient's head, and a lower vaclok used to immobilize the patient's legs. The patient can also be simulated in a prone position, but this is usually reserved for malignancies of the distal (sigmoid) colon and rectum. Positioning the patient prone displaces the small bowel out of the pelvis. For more information about prone positioning, see the Special Simulation Considerations: Pelvis unit.

Treatment Volume Localization: Stomach, liver, & Colon

Stomach: Oral contrast at simulation will define the stomach. Regional lymph nodes at risk for disease include the pancreaticoduodenal, porta hepatis, supra-pancreatic, splenic hilar, and those of the greater and lesser curvature. The margins used in this structure's treatment are variable; ideally, the stomach is empty and the entire volume is treated. The proximity of the heart can create challenges in treatment field design.

Liver & Gallbladder: A significant dose-limiting factor when treating the liver is radiation-induced hepatitis. However, this can be overcome with complex treatment plans and stereotactic treatments. Motion management is highly recommended for these treatments due to the diaphragm's proximity. If this is not possible for the patient, then larger expansion volumes should be used to cover any uncertainties in the plan. When we are treating the gallbladder, we treat any involved nodes. This is often the common bile duct and hepatoduodenal ligament. The GTV is determined after the CT scan. The CTV should include the gallbladder fossa and adjacent liver and regional lymph nodes. Margins should be 20 mm craniocaudally and 8 mm anteroposterior, and 9 mm laterally to allow for breathing motion. Another option to compensate for breathing motion is gated treatment delivery.

Colon: The goal of treatment, whether preoperative or postoperative, is to include the primary tumor, or tumor bed, with a 4-5 cm margin. The primary nodal drainage pathways are typically included in the treatment fields.

Lymphatic Drainage for the Colon and Rectum

Parts of colon	Lymphatic Drainage
Right colon	Follows superior mesenteric vessels and includes the ileocolic and right colic nodes.
Left colon	Follows inferior mesenteric vessels and includes the regional nodes termed the mid-colic, inferior mesenteric, and left colic.
sigmoid	Drains into the inferior mesenteric system and includes nodes along the superior rectal, sigmoidal, and sigmoidal mesenteric vessels.
Upper rectum	Follows superior rectal vessels into the inferior mesenteric system.
Middle/ Lower rectum	Lymphatic drainage along the middle rectal vessels with the primary nodal group comprising of the internal iliac nodes. Other nodal groups at risk of rectal cancer are the perirectal, lateral sacral, and presacral nodes. Low rectal lesions that extend into the anal canal can drain into the inguinal nodes.

Refer to Treatment Volume Localization: Abdomen section for TD 5/5's.

Treatment Techniques: Stomach, liver, & Colon

Stomach: The role of radiation therapy in stomach cancers is typically used adjuvant to surgery and chemotherapy. The most common treatment options are 3D-CRT or IMRT. According to The World Journal of Gastroenterology's article, the radiation dose for these treatments would be 60 Gy in 1.5-2.0 Gy fractions for unresectable gastric cancer. Another trial at the Mayo Clinic treated unresectable gastric cancer with or without 5-FU chemo during the first three days of radiation and treated with 35-37.5 Gy in 4-5 weeks.

Liver & Gallbladder: For liver metastasis, 20-30 Gy in 13-29 fractions is delivered to the whole organ to relieve painful hepatomegaly. Another option is 20-25 Gy to in 2-3 weeks. For lesions <5 cm, SBRT is the treatment of choice, giving 45-54 Gy in 3-5 fractions. For more information about SBRT treatments, review the Treatment Volume Localization: SBRT section.

The treatment regimen for gallbladder lesions is chemoradiation. This tends to have more potent side effects but is more effective, especially for nodal involvement. The gallbladder was historically treated with a field arrangement like a pancreatic tumor or through AP/PA fields. The target includes the primary lesion, adjacent tissues, and any involved regional nodes. The dose fractionation for inoperable gallbladder disease is 54 Gy in 20 fractions with a 15 Gy IORT boost. Another fractionation option is 35-55 Gy EBRT and 15 Gy in 3 fractions using brachytherapy.

Colon: The treatment of choice for rectal cancer is the surgical removal of the primary tumor and primary nodal drainage. Neoadjuvant Radiation Therapy, decreases the viability of tumor cells that could spread at

the time of surgery, improving the ability to resect large tumors and reducing small bowel complications by radiating in a nonsurgical area. Adjuvant Radiation Therapy, has the advantage of better selection of patients for treatment based on the surgical and pathologic findings.

Dose Recommendations for Colon Cancer

Treatment	Dose
Conventional (Curative)	45-50 Gy @ 1.8 – 2 Gy/fx (with a possible boost to follow)
Preoperative	Hypo-fractionated: 25 Gy in 5 fx
Boost:	Preoperative: 5.4 Gy @ 1.8 Gy/fx (50.4 Gy total) Post-operative: 5.4 – 9 Gy @ 1.8 Gy/fx (50.4 – 61.2 Gy total)
Palliative Radiation	Palliative chemoradiotherapy may be used for maximal local control of inoperable rectal cancers where prolonged survival is possible. • Conventional: 45 Gy @ 1.8 Gy in 25 fx • Hypo-fractionated: 30-36 Gy in 5-6 fx, delivered once a week

Emerging Technologies & Treatments: Stomach, liver, & Colon

Treatment advances and technologies available for the stomach, liver, and colon are the same as those described in the Emerging Technologies & Treatments: Abdomen section.

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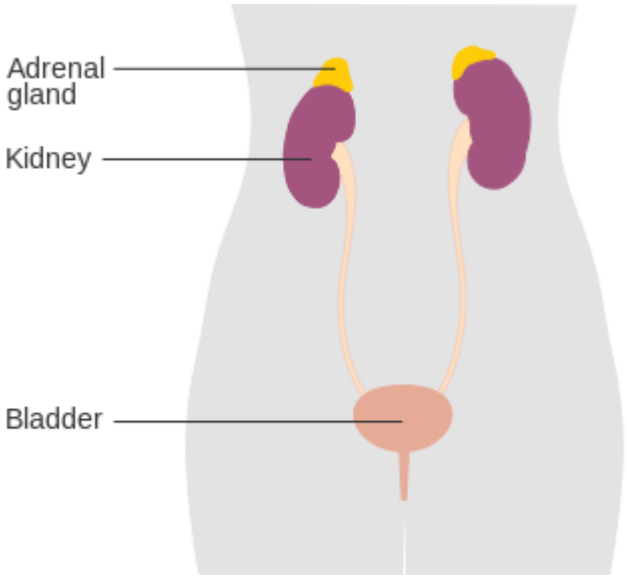
21.

KIDNEY, WILMS, & NEUROBLASTOMA

Overview: Kidney, Wilms, & Neuroblastoma

The kidneys are retroperitoneal structures located between the T12 and L3 vertebrae. The right kidney is commonly situated more inferior than the left due to the position of the liver. Renal lymphatics consist of the paraaortic and lumbar nodes. Primary tumors of the kidney in adults are commonly renal cell pathology. Wilms tumors, also known as nephroblastoma, are the most common type of pediatric kidney cancer. They are classified as either favorable histology or anaplastic histology.

The adrenal glands sit on top of each kidney. They produce hormones that regulate the body's immune system, blood pressure, metabolism, response to stress, and other essential functions. Adult malignancies of the adrenal glands are commonly metastatic. However, primary pediatric tumors of the adrenal glands are termed neuroblastoma. These tumors are the most common **extra-cranial** malignancy found in children and are the most common malignancy before age 1. They originate from early forms of sympathetic nerve cells termed Primitive Neuroectodermal Tissues (PNET), most often found in an embryo or fetus. PNET-associated tumors can occur anywhere in the body, but are most commonly found in the adrenals.



The location of the adrenal glands relative to the kidneys, ureters, and bladder.

Key Differences between Wilms Tumor and Neuroblastoma

Malignancy	Wilms Tumor	Neuroblastoma
Age	Older (3-4 years)	Less than 18 months
Systemic Symptoms	No	Yes
Calcifications	No	Yes
Location	Kidney	Adrenal gland
Crosses midline	Not typical	May cross
Fixed/immobile	May be displaced	Fixed/immobile

Patient Simulation & Special Considerations: Kidney, Wilms, & Neuroblastoma

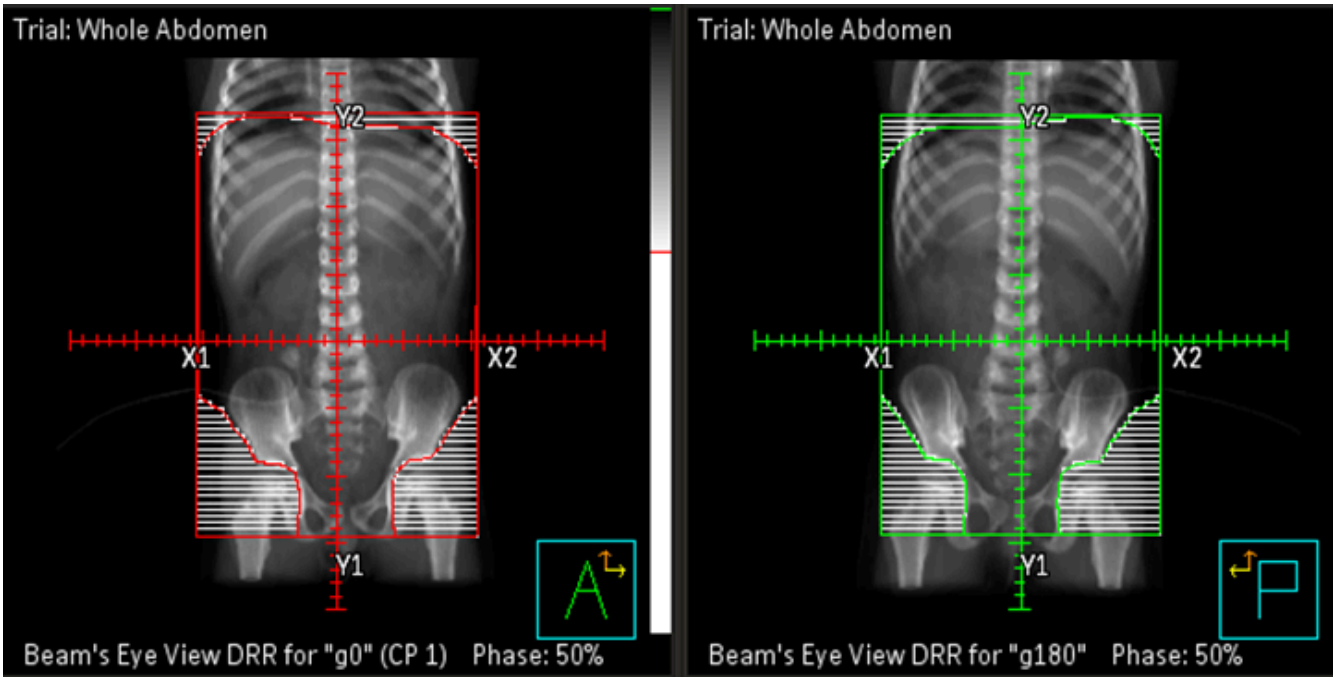
The simulation procedure for cancers of the kidneys and adrenal glands follow the general guidelines found in the Patient Simulation: Abdomen section. However, special consideration should be given to the use of intravenous contrast. Kidney function is reduced and these using iodinated contrast may be contraindicated – be sure to consult with the physician and review recent kidney function lab results. Additionally, the amount of contrast needed for pediatrics is based on the patient's weight if it's used, it's important to follow the institution's protocol. Pediatric patients may also need anesthesia to complete the simulation process and daily treatment – coordination of care is important. Treatment first thing in the morning is best for npo requirements.

Treatment Volume Localization: Kidney, Wilms, & Neuroblastoma

Surgery, if possible, and chemotherapy are the primary treatment options for cancers of the kidneys and adrenal glands. Radiation therapy is recommended for advanced and aggressive disease or for palliation to relieve symptoms such as pain, bleeding, or other problems caused by cancer spread. The Organs at Risk (OARs) to consider are the small bowel, liver, spinal cord, and unaffected kidney. The remaining kidney should receive no more than 1800 cGy for functional preservation purposes. It is important to spare as much of the liver as possible, especially if treating on the patient's right side. For specific TD 5/5's, refer to the Treatment Volume Localization: Abdomen section.

Kidney: Treatment fields consist of the post-operative renal bed and paraaortic lymph nodes. Traditionally, treatments included the entire length of the involved ureter. Modern treatment techniques apply a 3-5 mm margin to the PTV. Respiratory management can reduce these margins further.

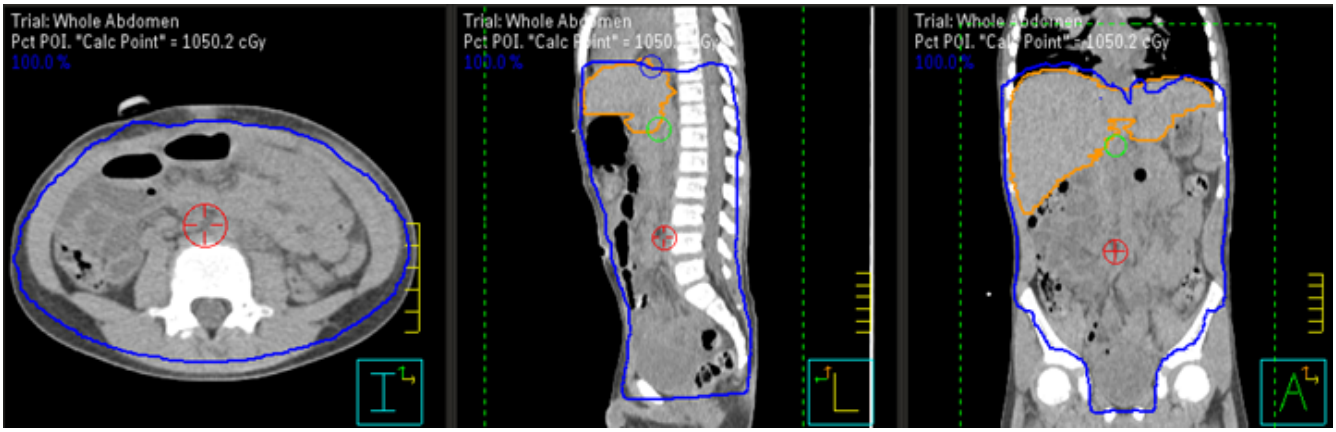
Wilms tumors and Neuroblastoma: Treatment margins are generally determined MRI or CT images and the operative report. Both tumors can grow very large before diagnosis requiring very large treatment fields. Additionally, the entire width of the vertebral bodies should be included to uniformly affect the epiphyseal growth plates on both sides of the spinal column and reduce the incidence of subsequent scoliosis. If the peritoneal cavity tests positive for disease or if the tumor ruptures during surgery, whole abdomen radiation therapy may be recommended.



Whole abdomen DRRs for Wilms tumor.

Preoperative Treatment Field Borders:

- **Lateral:** Encompass the abdominal wall (outside peritoneal line).
- **Medial:** Includes the entire width of the vertebral bodies with enough contralateral extension to include the paraaortic lymph nodes while excluding the opposite kidney.
- **Superior:** Includes the kidney tumor with a 1 cm margin – the field should extend to the dome of the diaphragm only if the tumor goes that high.
- **Inferior:** Kidney and entire preoperative tumor extent with a 1 cm margin.



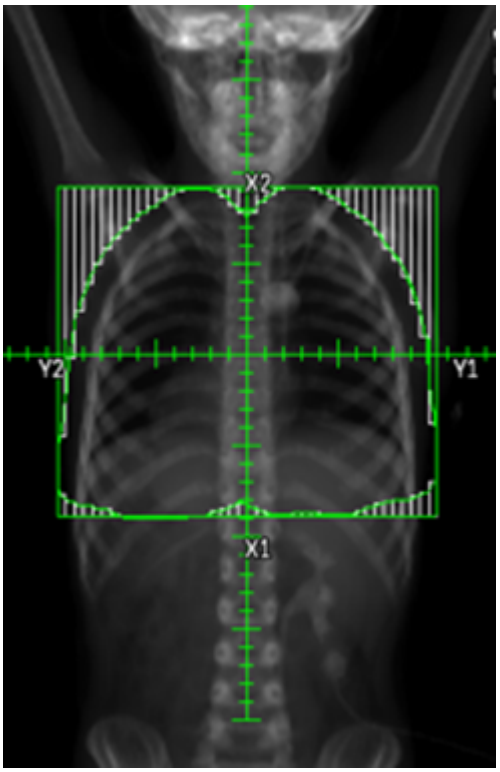
Whole abdomen treatment plan for Wilms tumor; 1050 cGy in 7 fractions. Patient received whole lung treatment one month later.

IMRT and VMAT treatment treatment options still follow these general borders but are more conformal to targeted tissues, sparing normal tissues, and reducing toxicity. The PTV typically has an expansion of 5 mm depending on the department protocol, equipment availability, and patient's disease. It is important to continue to consider the potential growth impairment. Treatment fields may require treatment volumes to extend across the midline to preserve symmetry, and care must be taken since some organs may be displaced following surgery. Generally, beam sizes are at least 6 cm.

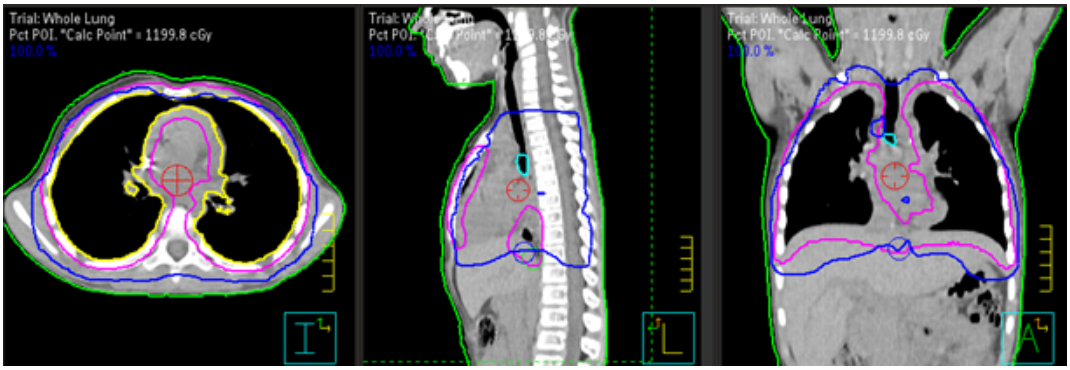
Treatment Techniques: Kidney, Wilms, & Neuroblastoma

Kidney: The treatment of choice for patients with localized renal cell carcinoma (RCC) T1 and T2 is a radical nephrectomy. This surgery completely removes the intact Gerota's fascia and its contents. Lymphadenectomy is usually performed as well. Preoperative radiation therapy can shrink the tumor and increase resectability. Postoperative radiation is commonly done to sterilize microscopic disease leftover after surgery. The kidneys are commonly treated with isocentric AP/PA fields. The treatment plans should include equal weighting, bias loading, and other wedge pair techniques.

Wilms: Removing the malignant kidney via nephrectomy is the first step in treatment. Regional lymph nodes are biopsied during surgery, and the contralateral kidney is examined for disease. Postoperative radiation therapy of the tumor bed is sometimes given depending on the stage and histologic subtype of the disease. Only when Wilms's tumor has metastasized to the lungs will whole lung irradiation be employed.



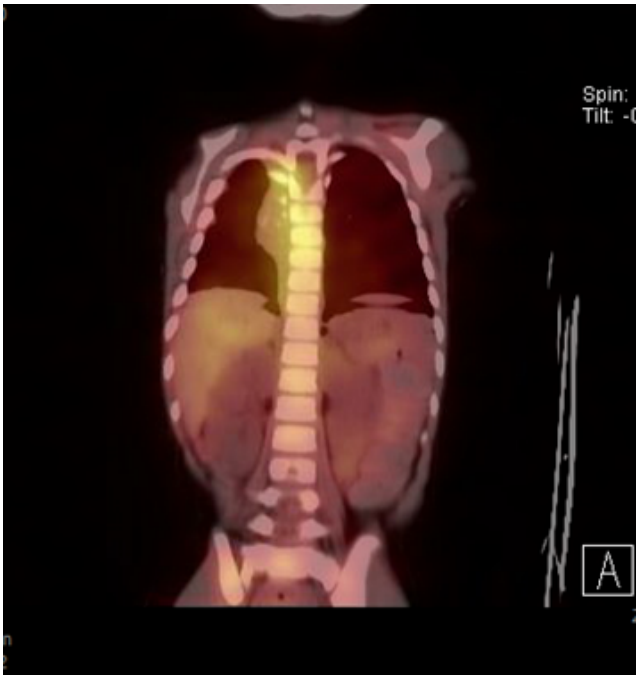
Whole lung DRR for Wilms tumor.



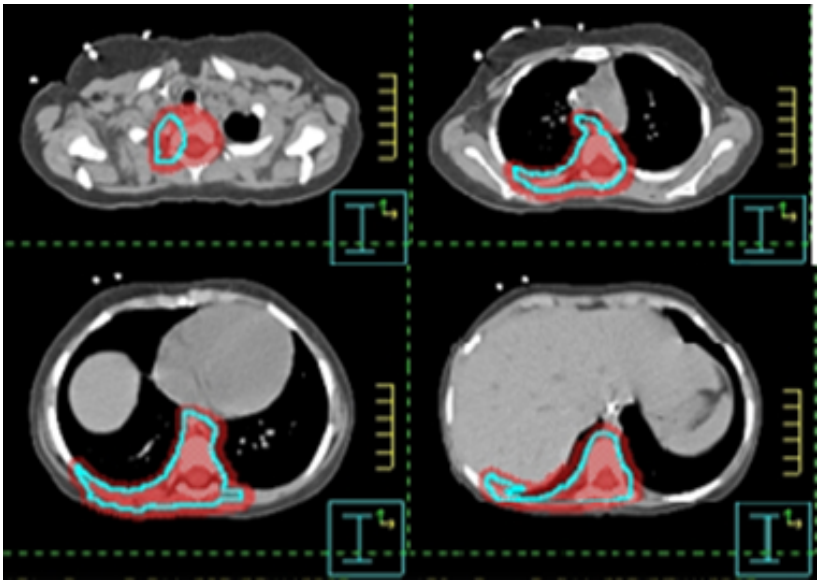
Whole lung treatment plan for Wilms tumor – 12 Gy in 8 fractions. Treatment was following a one month break from whole abdomen.

Neuroblastoma: Surgical excision is often the treatment of choice for children with abdominal primary, node-negative disease. Multimodality treatment include:

- Initial chemotherapy followed by surgery. For high-dose chemotherapy, a transplant to replace the bone marrow stem cells damaged by the chemo may need to be performed.
- Retinoid Therapy uses retinoids, which are chemicals related to vitamin A, that help some cancer cells mature into normal cells.
- MIBG Radiotherapy uses MIBG, a chemical similar to norepinephrine made by sympathetic nerve cells. A slightly radioactive form of MIBG is sometimes injected into the blood as part of an imaging test to look for neuroblastoma cells in the body. However, a more radioactive form of MIBG can also be used to treat some children with advanced neuroblastoma, often along with other treatments.
- Radiation Therapy – The dose for neuroblastoma varies depending on the tumor stage, size of fields, and age of the child. For patients with gross residual tumors remaining after surgery and patients with positive lymph nodes, postoperative radiation therapy of the tumor bed with wide margins is beneficial if chemo does not produce a complete response. External beam radiation therapy (EBRT) is used to shrink tumors, which makes them easier to remove. Radiation might be given to the primary tumor area and other areas of the body that might have active disease seen on the MIBG scan.



MIBG scan for neuroblastoma.



Treatment plan based off MIBG scan for neuroblastoma.

Summary of Dose Recommendations for Kidney & Adrenal Cancers

Treatment	Doses/Fractionation**
Kidney: Postoperative	• 45 to 55 Gy • The dose that can be safely given to the upper abdomen with an acceptable complication rate is 50.4 Gy at 1.8 Gy per fraction over 5 to 6 weeks. • A boost of 5.4 Gy in 3 fractions to a smaller volume may be added to bring the total tumor dose to 55.8 Gy.
Kidney: Right-sided tumor	• Field reduction is needed at 36 – 40 Gy to ensure no more than 30% of the liver parenchyma is irradiated to a higher dose.
Wilms	• Therapeutic doses range from 1080-3000 cGy depending on the child's age, stage, and disease histology. • Stage III favorable: 10.8 Gy in 6 fxs at 1.8 Gy/fx • Stage III intermediate: 14.4 Gy in 8 fxs at 1.8 Gy/fx • Stage II & III high risk: 25.2 Gy in 14 fxs at 1.8 Gy/fx ◦ A boost of 10.8 Gy in 6 fxs at 1.8 Gy/fx is given if node-positive or microscopic residual disease. • WAI ranges from 1050-1500 cGy at 150 cGy per fraction via anterior and posterior fields
Neuroblastoma	• Conventional dose: 21 Gy in 14 fractions at 1.5 Gy/fx ◦ May include a boost to the primary tumor bed of ~5-10 Gy • TBI in preparation for stem cell transplant in high-risk patients

Three-dimensional conformal radiation therapy (3D-CRT): With virtual simulation or 3D definition of the GTV, AP/PA beam arrangements with MLC shaping are often still appropriate to produce symmetrical irradiation of the vertebrae, avoid the contralateral kidney and minimize whole body doses.

IMRT/VMAT: Because of multiple constraints and the proximity of vital organs, inverse planning and the use of IMRT may be necessary to achieve an optimal plan for treatment. Delivers a higher dose to the tumor while sparing normal tissue.

Emerging Technologies & Treatments: Kidney, Wilms, & Neuroblastoma

Proton therapy: Ideal for pediatric patients because it offers fewer long-term side effects.

Other treatment advances and technologies available for cancers of the kidneys and adrenal glands are the same as those described in the Emerging Technologies & Treatments: Abdomen section.

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22.

WHOLE ABDOMEN IRRADIATION (WAI)

Overview: Whole Abdomen Irradiation (WAI)

Whole abdomen irradiation (WAI) is less common today but historically was used in treating cancers that have an increased likelihood to spread to the abdominal cavity referred to as "peritoneal seeding." Gynecological malignancies, primarily ovarian cancers, and some pediatric cancers like neuroblastoma and Wilm's tumors benefit from this treatment. Due to the large field size and volume of irradiated tissues, WAI causes acute nausea, fatigue, vomiting, diarrhea, loss of appetite, and myelosuppression. Late toxicities include enteritis, small bowel obstruction, late renal and hepatic injury, and fistula. Today alternative treatments produce similar outcomes with reduced side effects.

Patient simulation & Special Considerations: WAI

The patient setup for a whole abdomen follows the general guidelines described in the Patient Simulation: Abdomen section. If the patient is unable to bring their arms above their head, they can be placed akimbo along the patients side, making sure they're away from their body as far as possible. Some patients may benefit from using a strap to support their arms.

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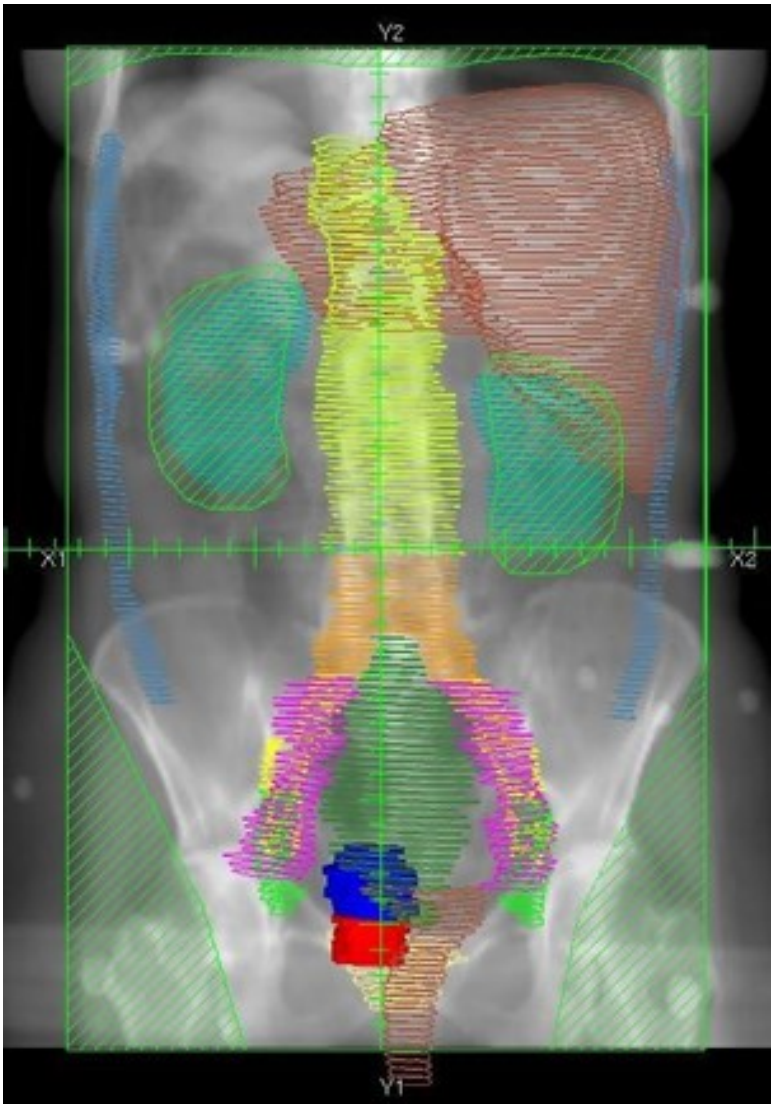
Treatment Volume Localization: WAI

The beam arrangement for WAI is AP/PA. Due to the kidneys' low tolerance dose, blocks are used during WAI to decrease the kidneys dose. Anatomically the kidneys are positioned more posteriorly in the body, therefore,

divergence will cause the posterior beam blocks to be larger than the anterior blocks. Three methods can be used to shield the kidneys:

1. Kidney blocks are added during treatment once their tolerance dose is met. This was generally considered the best option because it ensured that the kidneys received their target dose or as much dose as possible if the patient discontinues treatment before the entire prescription is delivered.
2. Blocks that allow partial beam transmission are used for the entire radiation course.
3. Kidneys are fully shielded for the AP or PA treatment field for the entirety of the treatment.



Whole abdomen treatment field. Note the field blocking of the kidneys.

Even with kidney blocks, a significant dose (10-15%) will still reach the kidneys due to internal scatter. Transmission of the beam, approximately 3%, is also possible through the blocks and leaves. The dose

transmitted through the blocks depends on the size of the irradiated area, beam energy, and block size. Liver blocks can also shield the right lobe of the liver after 25 Gy is delivered.

The borders for whole abdomen irradiation are:

- **Superior:** 1-2 cm above the dome of the diaphragm; the margin is best determined under fluoroscopy, with the patient breathing quietly due to the constant motion of the diaphragm.
- **Inferior:** Include the entire pelvic floor and to the bottom of the obturator foramen.
- **Lateral:** Include the peritoneal cavity

Sometimes, lateral fields are employed to treat the anterior abdomen and spare dose to the kidneys. Studies surrounding whole-abdominal irradiation show a wide variation in margin due to the definition of motion direction and measure of displacement. CTV and PTV margins varied from 3-20 mm for thoracic and abdominal targets.

Treatment Techniques: WAI

Gynecological treatments using whole abdominal irradiation deliver 1.25-1.5 Gy per fraction to a total dose of 30 Gy. The initial treatment may have a boost to the pelvis and the paraaortic lymph nodes. The boost to the pelvis is delivered with 1.8 Gy per fraction to a total dose of 45-50 Gy. A boost given to the paraaortic and pelvic lymph nodes is treated to a dose of around 42 Gy, depending on the presence of gross disease.

Standard energies for this treatment vary based on patient thickness. Most treatment plans utilize 6 MV photons, but 10 MV is used for thicker patients. This energy consideration is necessary due to the variation in dmax.

Whole-abdominal treatment fields need to minimize the amount of bone marrow, lung, and heart in the radiation field. AP/PA beam arrangements often deliver adequate doses to the whole abdomen but require large treatment fields. A critical organ tolerance dose is the kidneys. For an adult, the dose to the whole kidneys must be limited to 20 Gy; for a child, the dose must be below 15 Gy. The liver is another critical organ with a tolerance dose of 30 Gy. Liver blocks are also added after the delivery of about 25 Gy.

Emerging Technologies & Treatments: WAI

IMRT/VMAT: Technology advancements in treatment planning and delivery are making it possible to deliver treatments to large treatment fields like those required for WAI. If the field is too large for a single field, an important consideration is the “match” between fields where the doses are blended and the longitudinal shift. This treatment technique can help deliver a more uniform dose to the abdomen and reduce the dose to the kidneys.

TomoTherapy offers possibility of irradiating large target volumes continuously and homogeneously without gapes and junctions. This ensures irradiation of entire abdomen in one session, short treatment times, and a full 360-degree treatment. Elective dose reduction to OARs and direct image verification of patient position via CT.

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PART VI
PELVIS

23.

OVERVIEW: PELVIS

Learning Objectives

- Describe the anatomy, structures, and landmarks of the male and female pelvis
- Describe the malignancies of the pelvis
- Describe the simulation process
- Identify commonly used positioning & immobilization devices used for pelvis treatments
- Define scan parameters and reference isocenter location for pelvis simulations
- Discuss special considerations in cancers of the pelvis
- Define treatment borders and how they relate to tumor spread in the pelvis
- Describe tumor volumes and margins of cancers of the pelvis
- Discuss the various treatment procedures of pelvic malignancies
- Perform tasks associated with the simulation and treatment of pelvic malignancies

Key Terms

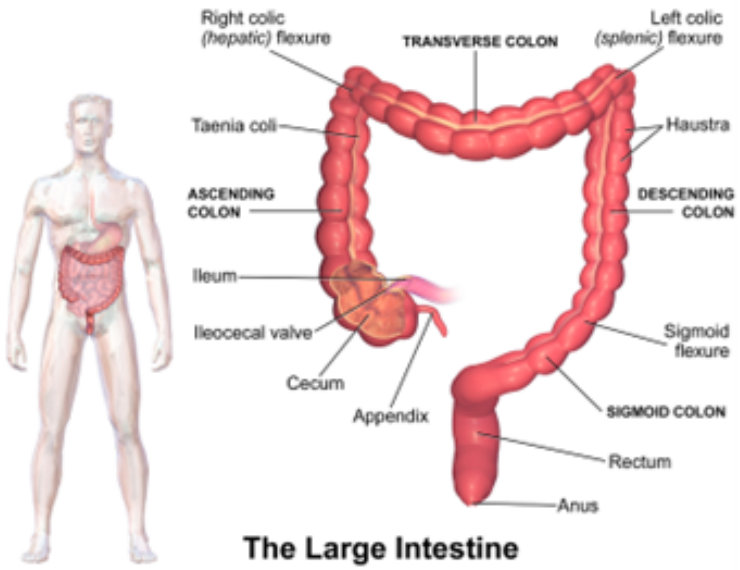
- **ADT (Androgen deprivation therapy)**
- **Anteroposterior (AP)**
- **Digital Rectal Exam**
- **FIGO (International Federation of Gynecology and Obstetrics)**
- **Gross hematuria**
- **Immobilization devices**

- **Nulliparity**
- **Opposed laterals**
- **Osteoblastic**
- **Prostate Specific Antigen (PSA)**
- **Tamoxifen**
- **Trigone**
- **Vaclok**

Overview: Pelvis

Cancers of the pelvis that affect both males and females include cancers of the lower gastrointestinal tract including the colon, rectum, and anus and those of the urinary system including the ureters, bladder, and urethra. Rectal cancer is commonly grouped with cancers of colon in terms of epidemiology and are often referred to as colorectal cancers. Colorectal cancers are the 3rd most common malignancy in the US with males having slightly higher incidence rates over females. A screening colonoscopy examines the colon and rectum for polyps or signs of cancer and is recommended for those of average risk beginning at age 45.

The colon begins with the cecum in the lower right of the pelvis where the small intestine's ileum terminates. From the cecum, the colon then ascends superiorly (ascending colon) to the hepatic flexure near the liver, then travels horizontally from right to left (transverse colon), turning close to the level of the spleen (splenic flexure), and then descends inferiorly down the left side (descending colon). It then makes an S-shaped curve called the sigmoid colon as it moves back into the pelvis and more midline. From there it proceeds inferiorly into the rectum, and eventually the anus as it exits the body.



Anatomy of the colon.

The dentate line separates the rectum and anus. The transition from glandular tissue of the rectum and squamous cell tissues of the anus occurs here. Most colon and rectal cancers are adenocarcinomas and anal cancers are typically squamous cell carcinomas. Anal cancer is twice as common in women than men. Rectal or anal bleeding or change in bowel habits are common presenting signs of colorectal or anal cancers.

Risk factors for colorectal cancer include high fat, low fiber diets, smoking, alcohol use, inflammatory bowel disease, and genetic predisposition. Common routes of spread include invasion of adjacent pelvis structures and lymphatic spread to the mesenteric, peri-rectal, internal iliac, and sacral lymph nodes. Risk factors for anal cancer include HPV, HIV, smoking, and anal intercourse. The common route of spread is drainage to the inguinal lymph nodes .Cancers of the urinary system are more common in males; most cancers occur from transitional (urothelial) epithelium cells. Bladder cancer is the most common urinary malignancy and is typically diagnosed in the 50–60 year-old population. Patients usually present with **gross hematuria** at the time of diagnosis.

Risk factors for bladder cancer include cigarette smoking, chronic bladder irritation, and exposure to aniline dyes. The triangular area between the three orifices (ureter and two urethra) is termed the **trigone**; this area is one of the most common sites for carcinoma. Common routes of spread for bladder cancer are through direct extension and the bladder wall. More specific information about male and female pelvic cancers is listed below.

A general overview and explanation for the common screening types of cancers of the pelvis can be found in the link below. Please see individual sections for specific cancer screening types.

Cancer Screening Guidelines | Detecting Cancer Early

Patient Simulation: Pelvis

An essential part of the patient's treatment plan is the simulation process. The simulation is performed after the patient has met with the doctor and consented to radiation therapy treatments. The physician completes an image request for simulation specifying positioning and treatment considerations. This should include the patient's specific treatment site, contrast orders for the CT simulation, positioning, type of immobilization devices, and scan parameters. Standards and similarities exist across the profession, but differences could occur due to physician preference, patient ability, equipment availability, and department protocol.

Attention to detail is crucial during the simulation process. Reviewing the physician's order and accurately following scan parameters is an essential role of a radiation therapist. Considering the beam angles required for treatment before constructing the immobilization device is vital. Begin by helping the patient lie on the table and straighten them using the overhead sagittal laser aligning to the patient's midline. Many pelvis patients are positioned supine. However, there are some cases where prone is a better option for the treatment plan and are discussed in "Special Simulation Considerations." Typically, patients are headfirst, with pillows under the head and an immobilization device called a **vaclok** under their legs. As always, before fabricating an immobilization device, ensure that the patient is in a reproducible position and is as comfortable as possible and able tolerate the position for the anticipated length of treatment.

Detailed documentation of the simulation procedure is necessary, as different therapists will likely perform the patient's verification setup and treatments. Include photos, setup notes, and immobilization devices in the patient's chart or record and verify system. This is especially important for pelvic cancers because there are often special instructions for the bladder fullness and rectal emptying. A full bladder scan and an empty bladder scan may be acquired to determine the internal target volume and account for variability that could occur during the treatment course. Intravenous contrast and oral contrast may be used for better delineation of the contrast-enhanced pelvic vessels and bowel contouring. The therapist should ask the patient each day if their bladder is full or empty as instructed before treatment and verify with imaging.

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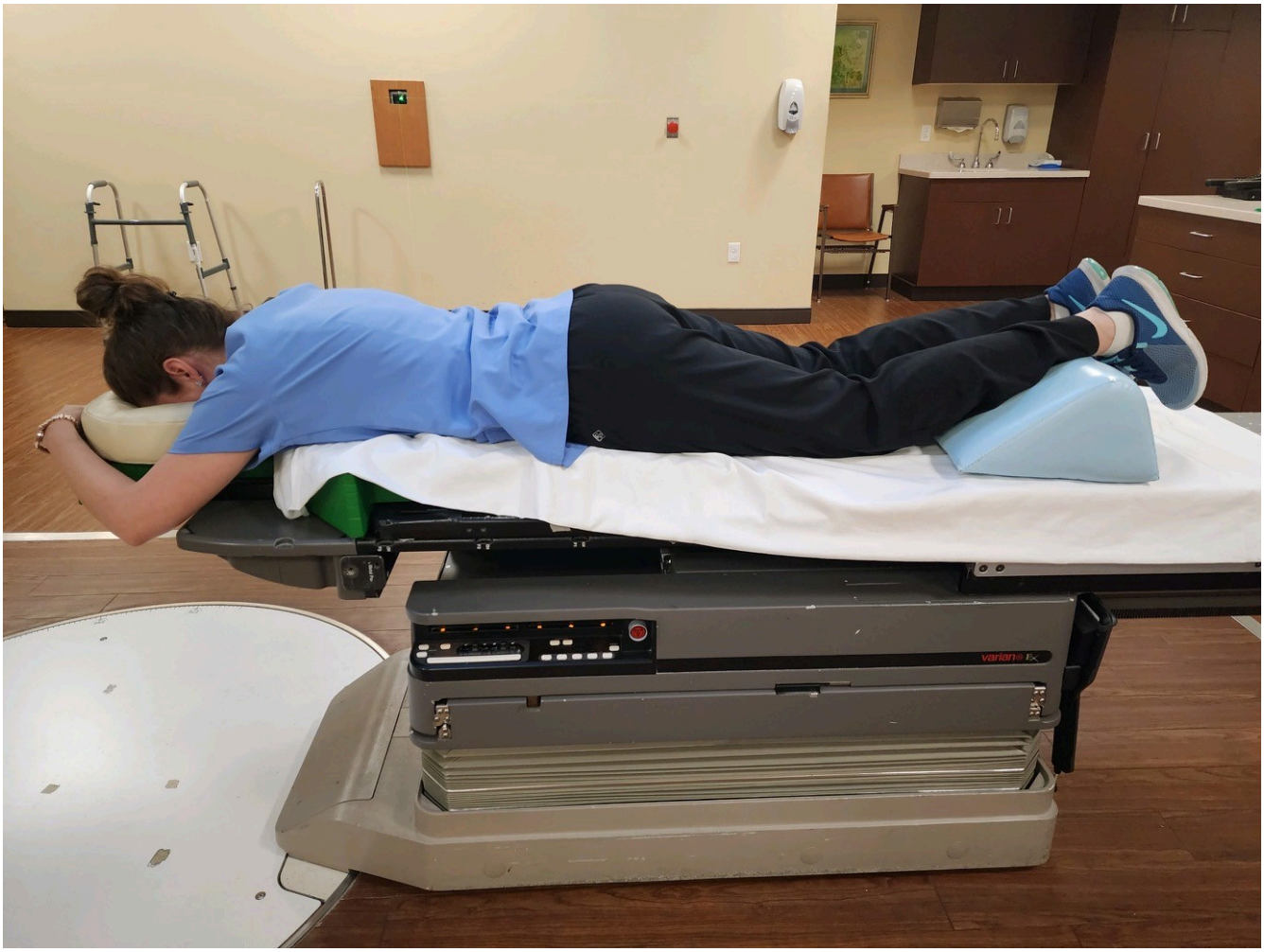
Special Simulation Considerations: Pelvis

Each patient's unique needs and disease circumstances may require changes to their simulation setup. For

example, educating patients on the importance of their position enhances their understanding and cooperation to hold still during treatment. When treating the pelvis, the patient is typically positioned supine or prone.

Supine Position: Patients are often positioned in a supine position when treating the pelvis as it is a more stable and tolerable position. Another benefit of this position is the ability to visualize the inguinal nodal areas commonly included in the treatment volume. Positioning and immobilization devices include pillows under the head, a low extremity to reproduce the hips and pelvic position, and/or a knee bolster. For patients requiring the inclusion of inguinal nodes in the treatment fields, positioning their legs in a frog-leg or spread-out knee position helps with better visualization of the inguinal nodes and reduces skin folds that could lead to more severe skin reactions during the course of treatment. The arms are typically placed high on the patient's chest or above the head if treating para-aortic nodes to keep them out of the treatment field.

Prone Position: The prone position is another treatment setup commonly used for treating the pelvis. The main advantage of prone positioning is that the small bowel falls forward and out of the pelvis, reducing its dose; it also allows the glutes to fall apart, resulting in less skin-on-skin contact, helping reduce scatter and skin reactions. A belly-board or custom made prone vaclok device with an anterior void allows allows the radiosensitive small bowel to fall forward out of the pelvis. The patient is indexed longitudinally on the belly-board using the ruler found on the right and left lateral sides of the board. It is important that the pubic symphysis sits at the inferior ridge of the belly board to displace as much small bowel as possible. Almost all patients benefit from the prone position, regardless of size, when the goal is to displace the small bowel anteriorly. Patients with a strong abdominal muscle tone may not benefit as much from this position as other patients.



Physicians often instruct pelvic patients to have a comfortably full bladder for simulation and throughout treatment to enhance reproducibility internally and reduce dose to surrounding structures. A comfortably full bladder will push the small bowel superior out of the treatment fields. However, when treating the bladder, patients are coached to have an empty bladder to reduce the size of the treatment field. During simulation, it is also critical to monitor the fullness of the rectum. An empty rectum will prevent the bowel from pushing on adjacent structures into the treatment field. Depending on the doctor's preference, external radiopaque markers may be placed on the anal or vaginal verge to visualize and ensure adequate tumor coverage.

Contrast may be administered during simulation to enhance critical structures in the treatment area. Male urethral contrast may be inserted and held in place by a penile clamp. Intravenous contrast may be used to better visualize the bladder, lymph nodes, and vessels. Oral contrast may also be necessary to visualize the small bowel.

Treatment Volume Localization: Pelvis

Tumors of the pelvis are typically treated with higher energy beams (10MV to 18MV) due to tumor depth and

subsequent beam attenuation. IMRT and VMAT techniques are currently not possible with 18 MV beams, treatments at this energy use static fields.

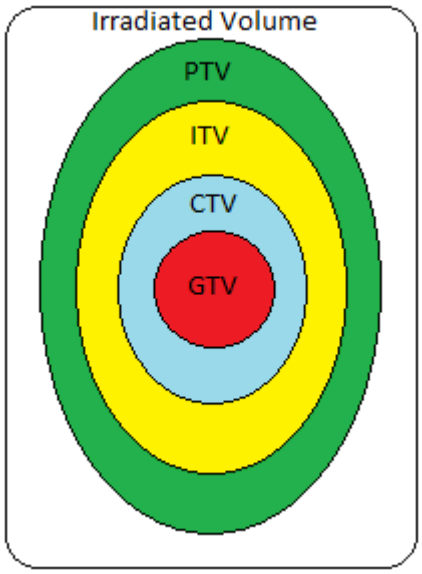
Organ at Risk (OARs)	**TD 5/5 Whole Organ**	**Outcome Associated**
Bladder	65 Gy	Bladder contracture/Volume loss
Rectum	60 Gy	Proctitis/Necrosis/Fistula
Small Bowel	45 Gy	Obstruction/Perforation/Fistula
Large Bowel	50 Gy	Obstruction/Perforation/Ulceration/Fistula
Femoral heads	52 Gy	Necrosis
Spinal Cord	45 Gy	Myelitis/Necrosis

Treatment Margins:

At the University of Iowa Hospitals, treatment margins are organized by grouping all gynecological sites together and isolating the prostate separately. The treatment techniques used are specific for each group. For instance, limiting the rectal dose when treating the prostate is of great concern, whereas considering the clinical spread of the disease is more critical for gynecological cancers.

The standard practice for treating the prostate margins is to encompasses the prostate and seminal vesicles with a 6 mm expansion in all directions except posteriorly. Posteriorly the expansion is limited to 4 mm due to the rectum's proximity. These margins are for standard fractionation on a linear accelerator. Treatment units with ATS (adapt-to-shape) capabilities allow for tighter margins of 5 mm in all directions with a 3 mm posterior margin.

Regarding gynecological margins, the rule of thumb is an expansion from the involved nodes. GTVs and CTVs will not expand into bone due to the much lower likelihood of the disease spreading to the bone than involved tissues. There will commonly be a 7 mm margin around the GTVs of solid tumors with a 5 mm expansion to create the CTV to PTV margins. The increased PTV considers the inherent inconsistencies with daily setup reproducibility.



Planning target volumes.

Gross Tumor Volume (GTV)	The gross demonstrable extent and location of disease that can be seen or felt
Clinical Target Volume (CTV)	Includes the GTV plus a margin to account for microscopic disease that cannot be seen or felt • The area outside the CTV is presumed to have no cancer cells
Internal Target Volume (ITV)	Includes the CTV plus a margin to account for internal motion of the target • Note: There will be no ITV if there is no tumor motion
Planning Target Volume (PTV)	Includes the CTV and ITV plus a margin to account for possible geometric uncertainties, such as patient set-up
Treatment Volume (TV)	Volume covered by the prescription isodose line • Volume is determined by delivery technique
Irradiated Volume	Volume that receives a significant dose, usually defined as 50% of prescription dose • Volume is determined by delivery technique
Organ at Risk Volume (OAR)	Volume encompassing a normal tissue whose radiation sensitivity may significantly influence treatment planning • Example: lens of eye, bladder, rectum, spinal cord, etc.

Traditional field borders of the pelvis remain consistent laterally with a 1-2 cm margin beyond the pelvis inlet to include the common iliac nodes. The next chapters include site-specific borders and describe the superior, inferior, anterior, and posterior treatment margins.

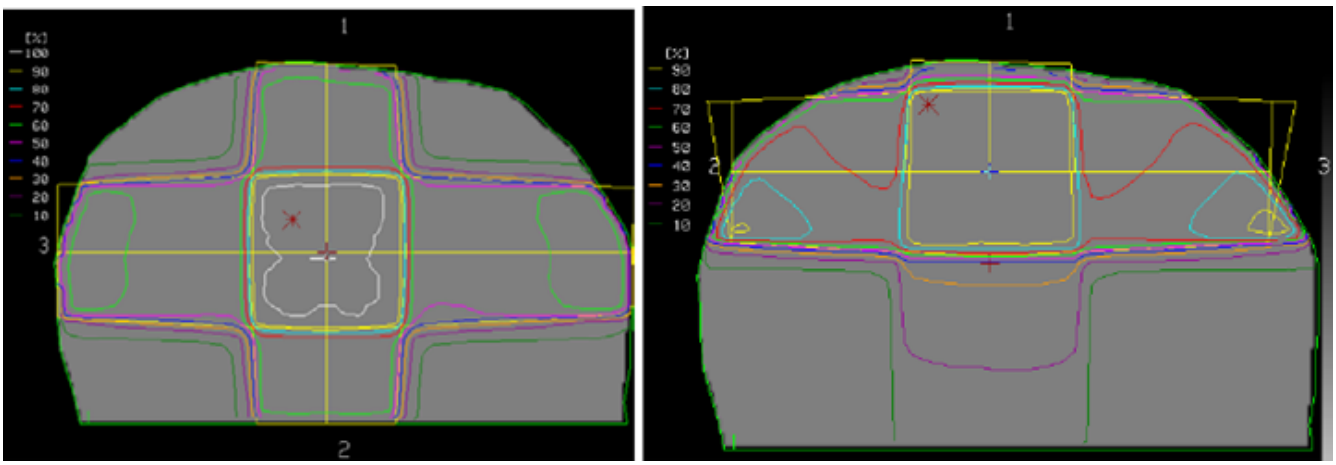
The general curative dose-fractionation for pelvic cancers is 45-50 Gy followed by a boost. The PTV includes the tumor volume and regional lymph nodes. A boost to the GTV and involved areas follows with a daily fractionation of 1.8 to 2 Gy. The total dose is dependent on the primary site and organs at risk; these are are described in future site-specific chapters.

Treatment Techniques: Pelvis

The treatment plan chosen for a patient is based on several different factors. These factors include the sites of possible regional involvement, the performance status of the patient (Karnofsky Performance Scale/KPS), and the extension of the primary disease.

Three-dimensional conformal treatment techniques commonly used in treating the pelvis are three and four-field beam arrangements.

- The three-field treatment includes a posteroanterior (PA) field and **opposed lateral** fields with wedges. The heel of the wedges is placed posteriorly, where the PA and lateral beams meet, to reduce hotspots in the posterior pelvis. The three-field technique is most seen for patients positioned prone when treating rectal cancer.
- A four-field treatment, "box" technique, the beam arrangement is AP/PA and opposed lateral fields. This method is used when anterior structures like the prostate or vagina are involved or at risk for disease. When treating a four-field pelvis, it is preferred to use higher energies to fully penetrate to the deep pelvis and reduce hotspots in the more superficial tissues of the pelvis. Sometimes beams are weighted more posterior or anteriorly depending on the structures involved. For example, if treating the rectum, the posterior beam may deliver a higher dose.



Intensity Modulated Radiation Therapy (IMRT)/Volumetric Modulated Arc Therapy (VMAT) have become the standard radiation therapy treatment technique for pelvic cancer, allowing for more sparing of the small bowel, colon, bladder, and femoral heads.

Brachytherapy is another treatment modality frequently used in treatments of the pelvis. The technique is a form of internal radiation therapy that uses sealed radiation sources. The sources are placed inside the patient's body beside or within the tumor. This treatment delivery technique spares the surrounding healthy tissues and improves survival outcomes. Brachytherapy is commonly prescribed for prostate, endometrial, cervical, and vaginal cancers.

Emerging Technologies & Treatments: Pelvis

Advances in technology are happening more rapidly than ever before. Today, several treatment technologies and devices have increased treatment accuracy and reduced treatment time for pelvis malignancies. A few treatment advancements include:

- 6 degrees of freedom tables – Corrections for patient tilt and rotation (Vendor examples: Protura & Hexapod).
- Infrared motion/surface monitoring systems (Vendor example: AlignRT)
- Proton beam radiation therapy is another treatment modality that can be used to treat the pelvis. Protons have unique physical properties and only travel a certain distance based on their energy. By adjusting the energy, the depth the dose is deposited is controlled which means treatments are delivered using only one or two lateral beams. The tissues before (entrance dose) and after (exit dose) the cancer receive minimal radiation, reducing side effects.
- ART – Adaptive Radiation Therapy is an advanced treatment technique that optimizes patients' treatment plans daily based on real-time imaging with MRI or CT scans. This technique ensures the radiation is delivered precisely to the tumor while minimizing damage to healthy tissues. By adapting the

treatment to the patient's changing anatomy and tumor characteristics, ART increases treatment accuracy and efficacy, potentially improving patient outcomes and reducing side effects. (Vendor examples: Varian Ethos, Elekta Unity, ViewRay, MRIdian)

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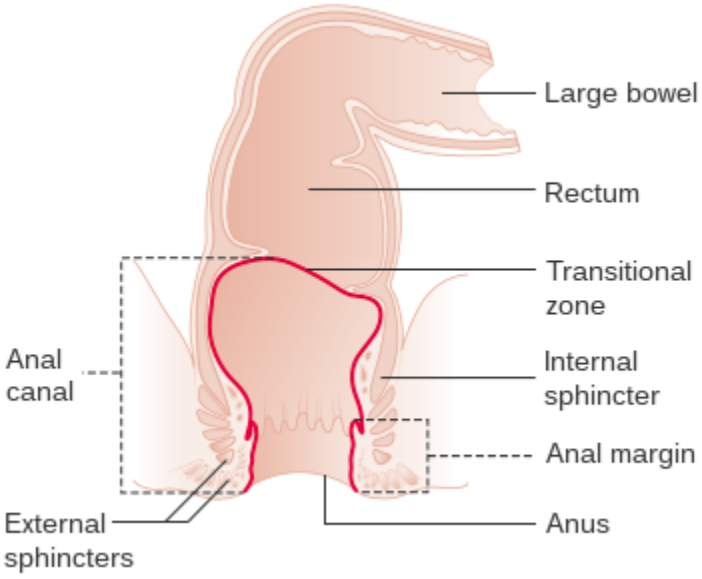
24.

RECTUM & ANUS

Overview: Rectum & Anus

The rectum is 12-15 cm in length and located between the sigmoid colon proximally and the anus distally. The rectum is divided into three sections: the upper, middle, and lower. The upper rectum tissues drain to the inferior mesenteric, sigmoidal, and sacral lymph nodes. The middle and lower rectum tissues drain to the internal iliac, external iliac, common iliac, presacral, obturator, and inguinal lymph nodes. The sigmoid colon meets the rectum at approximately the third sacral vertebra. The rectum follows the sacral curvature posteriorly. In females, it is attached anteriorly to the vagina; in males, it is bound to the trigone of the bladder, seminal vesicles, and prostate. Due to its location, rectal cancers can invade these adjacent structures.



Anatomy of the rectum and anus.

The anal canal extends about 3 cm from the anorectal ring superiorly to the anal verge inferiorly. Rectal and anal cancers commonly spread through direct extension to nearby structures. Transperitoneal implantation can occur during surgery for rectal cancers. Lymphatic and hematogenous spread occurs primarily to the liver.

Patient Simulation & Special Considerations: Rectum &

Anus

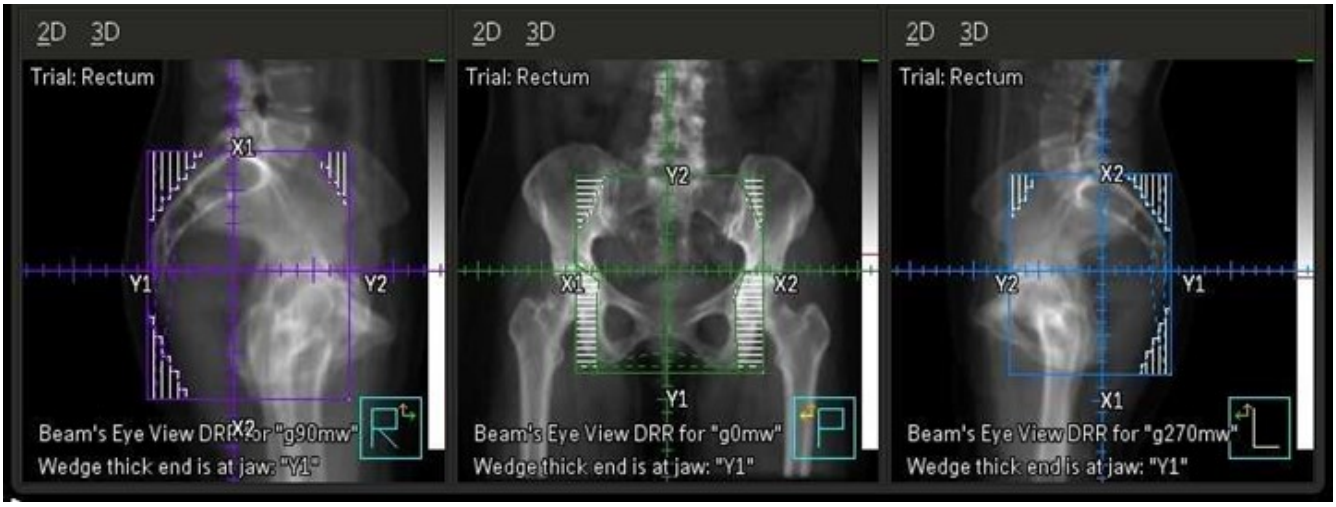
In treating the rectum and anus, the simulation process is consistent with the typical pelvis (anchor1), with the addition of a few considerations. Depending on the doctor's preference, an external radiopaque marker may be placed on the anal verge for visualization to ensure adequate coverage of the tumor. Due to the shallow location of the anus, bolus may be necessary to bring the dose more superficial. Prone positioning is easiest for placement of the bolus with minimal air gaps. Some patients may benefit from wet or Vaseline-coated gauze to fill gaps under the bolus – consult with the physician and dosimetrists.

Treatment Volume Localization: Rectum & Anus

When treating rectal patients, the most common 3D beam arrangement is a 3-field technique: PA field and opposed lateral fields with wedges.

Treatment borders for the rectum and anus are as follows:

- **Superior:** L5-S1 interspace
- **Inferior:** 5 cm below the tumor; below obturator foramina
- **Lateral:** 1-2 cm beyond the pelvic inlet
- **Anterior:** Anterior to or mid-acetabulum for a standard lateral field; anterior to the pubic symphysis to include the external iliac nodes (if needed)
- **Posterior:** Posterior to the sacrum



DRRs for a 3-field treatment plan for a cancer of the rectum. Note the wedge placement on the lateral beams posteriorly.

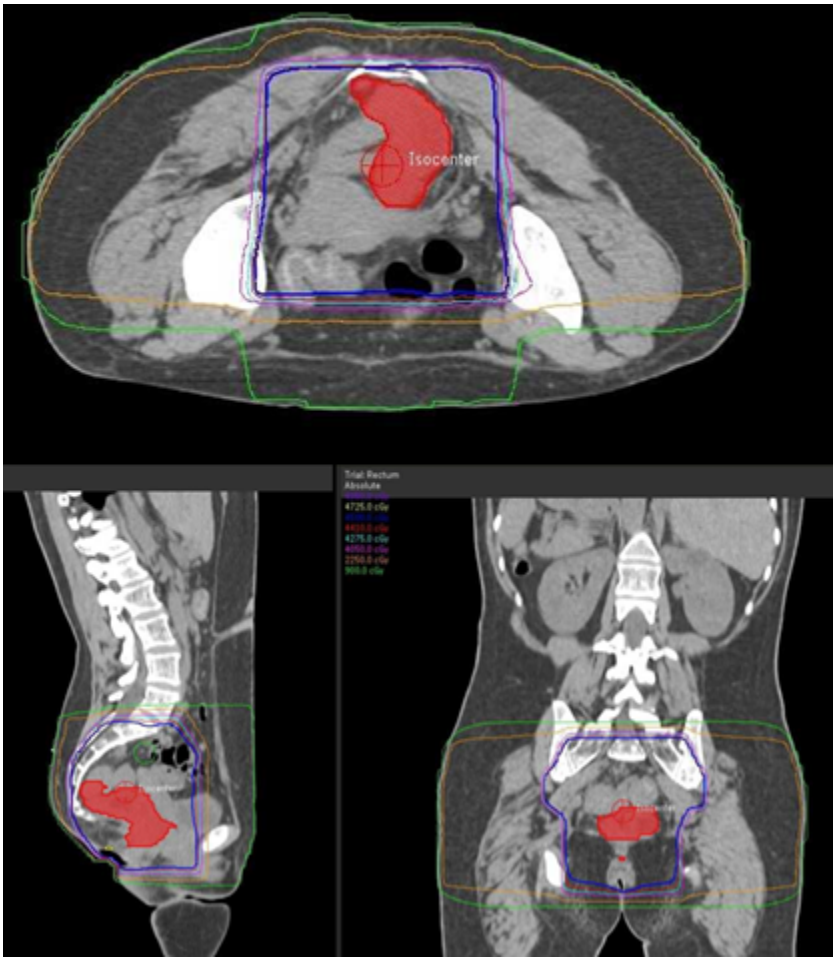
IMRT and VMAT treatments still follow these general borders but are more conformal to targeted tissues, sparing normal tissues, and reducing toxicity. Please refer to the "Treatment Volume Location: Pelvis" section.

Treatment Techniques: Rectum & Anus

Surgery is the treatment of choice for rectal cancer. Radiation therapy is used as an adjuvant treatment, either before or after surgery with chemotherapy. Preoperative radiation therapy reduces the risk of tumor seeding in surgery, shrinks the tumor, and treats the tumor when it has better oxygenation and is therefore more radiosensitive. Postoperative radiotherapy has the advantage of knowing the geographical extent of disease for treatment planning. Patients with residual postoperative disease are referred to radiotherapy.

The dose fractionation for rectal cancer includes:

- Standard Course: 45 Gy in 25 fractions of 1.8 Gy in 5 weeks with a boost of 5.4 Gy in 3 fractions
- Postoperative radiation therapy: 45 Gy in 25 fractions of 1.8 Gy in 5 weeks with a boost of 5.4-9 Gy in 3-5 fractions
- Short Course: 25 Gy in 5 fractions of 5 Gy in 1 week

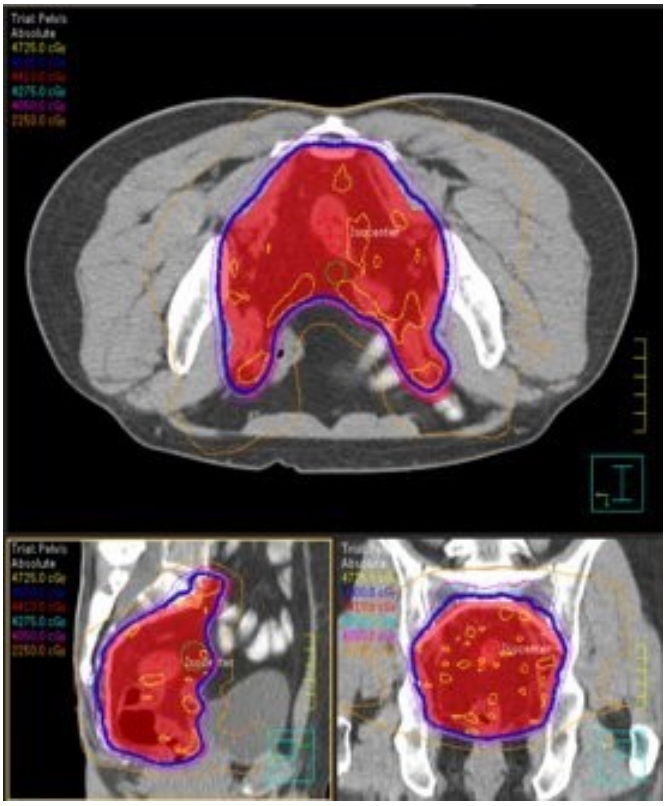


3-field treatment plan (PA & laterals) for a cancer of the rectum; the patient is positioned prone.

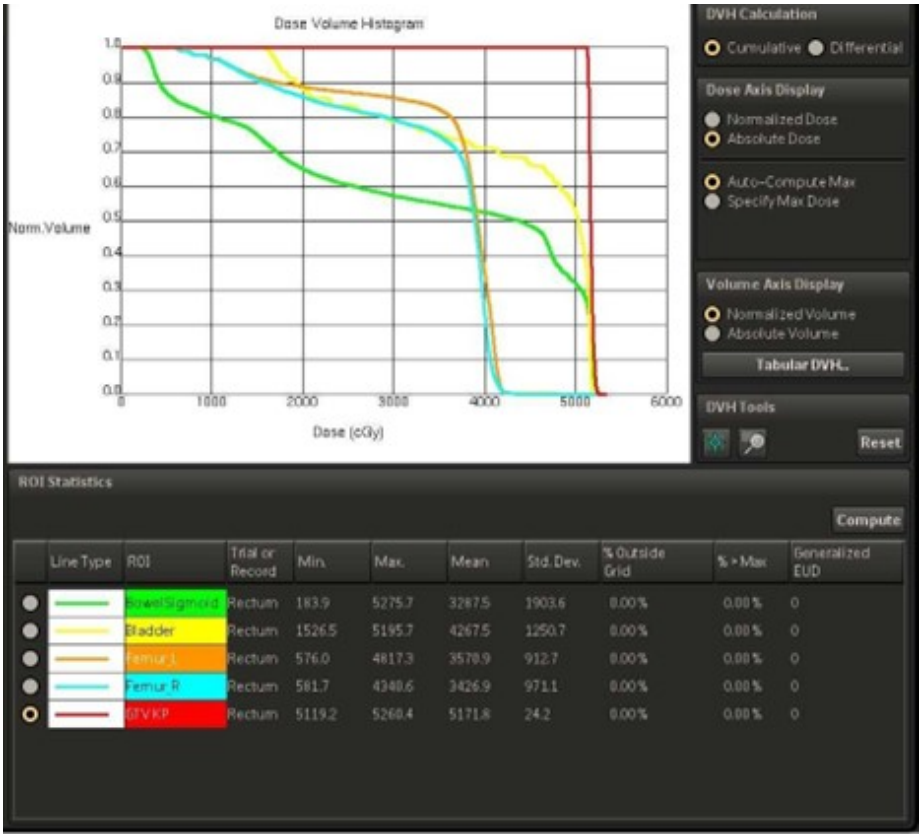
Adjuvant chemotherapy has the benefit of decreased disease recurrence and improved survival rate. Common chemotherapy drugs that may be given are 5-FU, Cisplatin, and Mitomycin C.

Anal cancer is usually treated by radiation therapy with or without chemotherapy. Radiation therapy consists of delivering 45 to 50 Gy to the entire pelvis, inguinal lymph nodes, and the perineum. A boost of 15 to 20 Gy is then given to the primary tumor. Interstitial implants may also be used.

Treatment techniques that can be used in rectal and anal cancer cases coincide with the techniques used in many other pelvic regions, such as three-field, four-field, IMRT/VMAT, and IORT.



IMRT plan for a cancer of the rectum and pelvic nodes.



DVH for a 3-field treatment plan for a cancer of the rectum.

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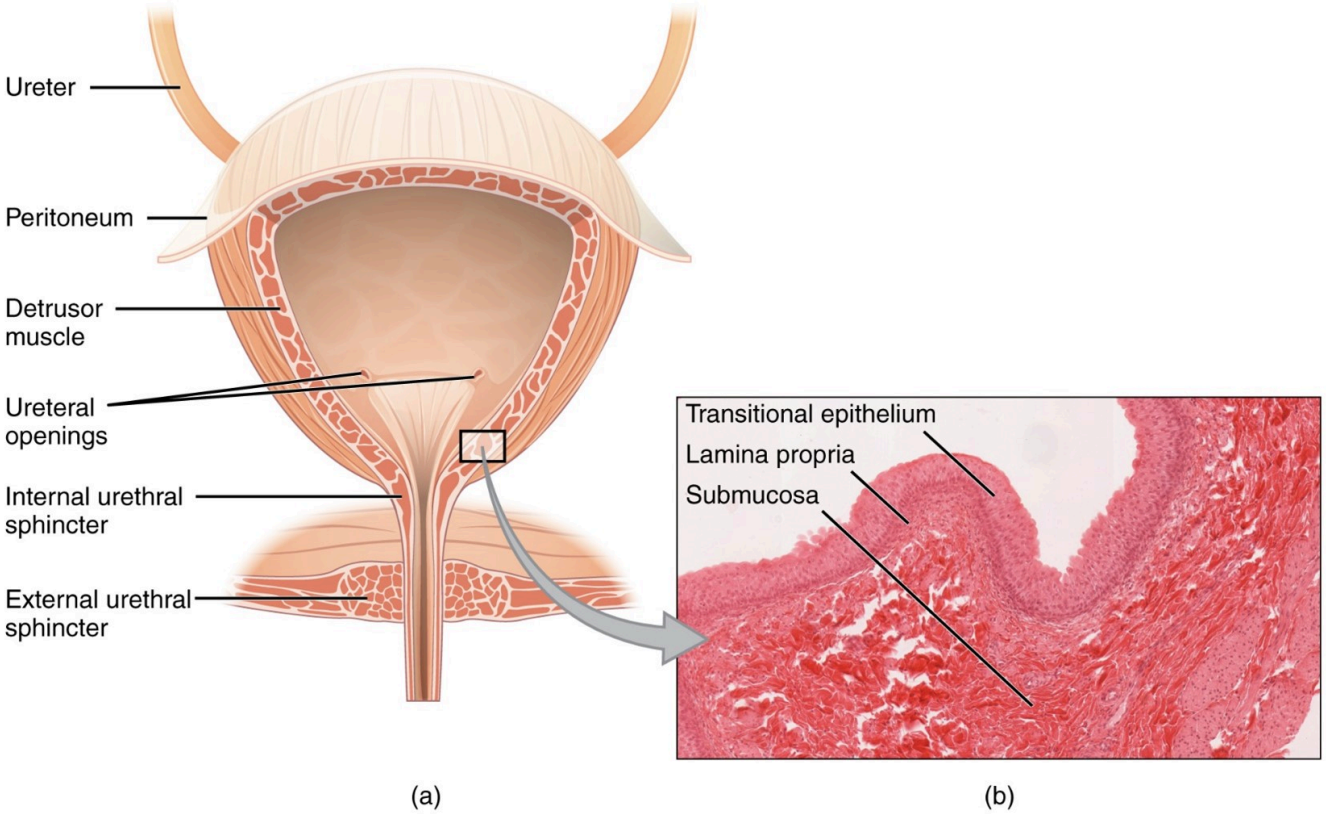
25.

BLADDER

Overview: Bladder

The bladder is located in the true pelvis when empty. The apex of the bladder is located inferiorly and points to the pubic symphysis. Most bladder cancers are found on the trigone in the posterior wall of the bladder (formed from three openings from the two ureters and the urethra). The most common presenting symptom of bladder cancer is gross or microscopic hematuria. Distant metastases include the lung, bone, or liver. Transitional (urothelial) cells are the most common histology, with squamous cell carcinoma, adenocarcinoma, and small cell carcinoma being less common. Important lymphatics to include in the field for bladder cancer are external iliac, common iliac, presacral, and paraaortic nodes.



Anatomy of the bladder. Note the trigone is the triangular floor of the bladder between the ureteral opening and the urethra.

Patient Simulation & Special Considerations: Bladder

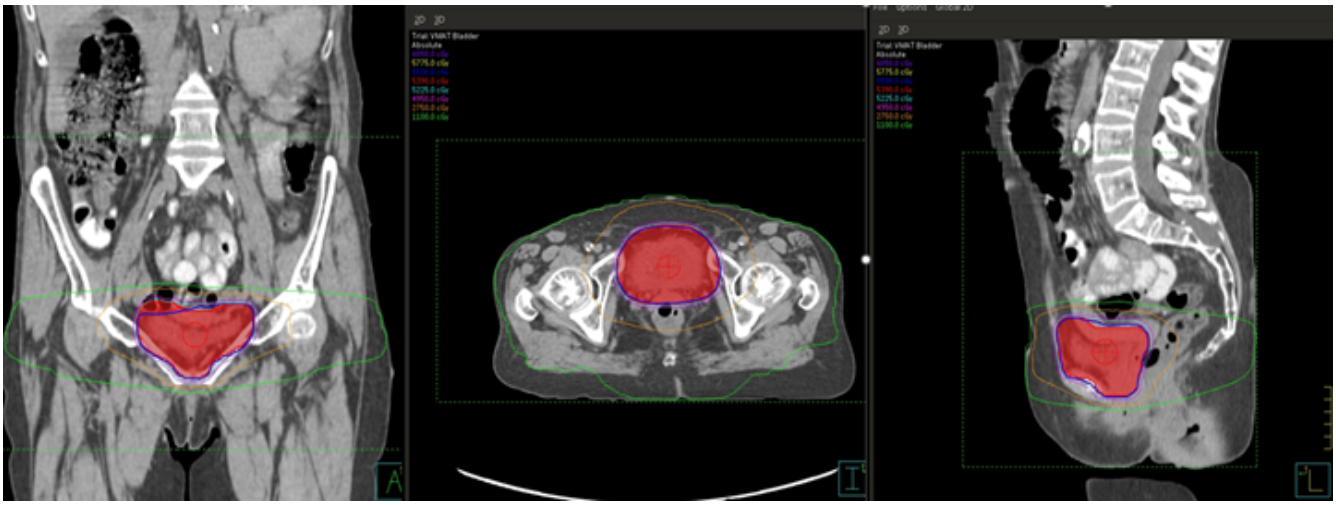
One critical difference for simulation of the bladder is ensuring the patient has an empty bladder when coming in for their simulation and treatment each day. For boost fields, a second simulation and treatment plan may require a full bladder; this helps target the affected tissues and reduces the dose to healthy tissues. The simulation process is otherwise consistent with the typical pelvis setup. Please refer to the "Patient Simulation: Pelvis" section.

Treatment Volume Localization: Bladder

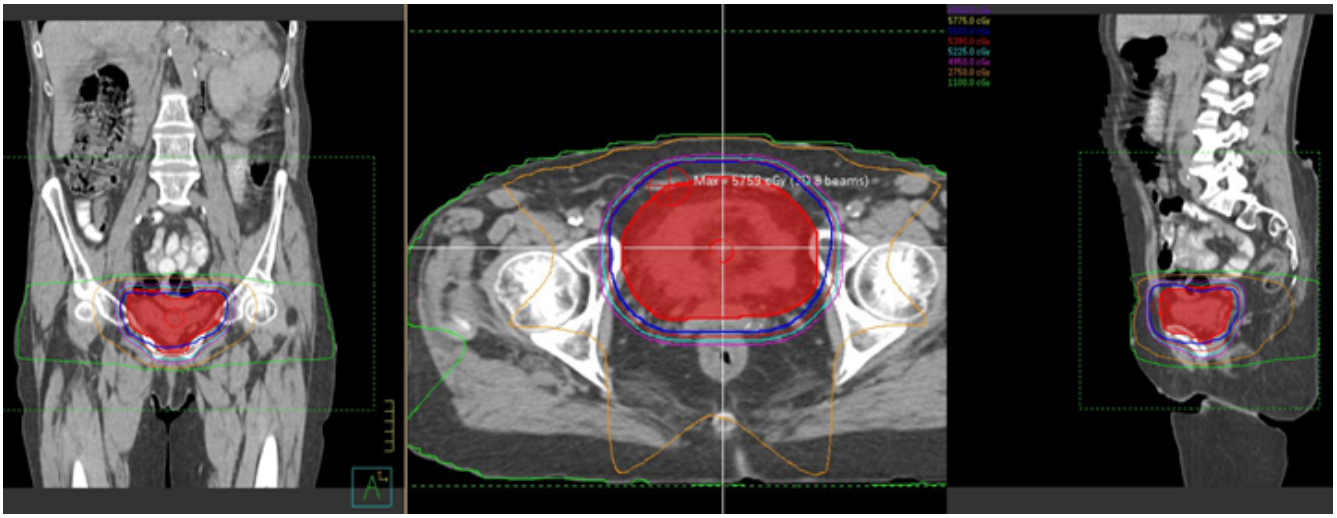
Traditional treatment borders for the bladder are:

- **Superior:** between S1 and S2
- **Inferior:** bottom of obturator foramen
- **Lateral:** one to two centimeters beyond the bony pelvic side walls (Field shaping is usually done around the femurs)
- **Anterior:** usually extends 1-2 cm beyond the bladder (approximately 1-2 cm anterior to the pubic symphysis)
- **Posterior:** usually extends 2-3 cm behind the bladder and tumor volume. Dose to surrounding normal tissue and to critical structures, such as the posterior rectal wall, small bowel, and anus should be limited.

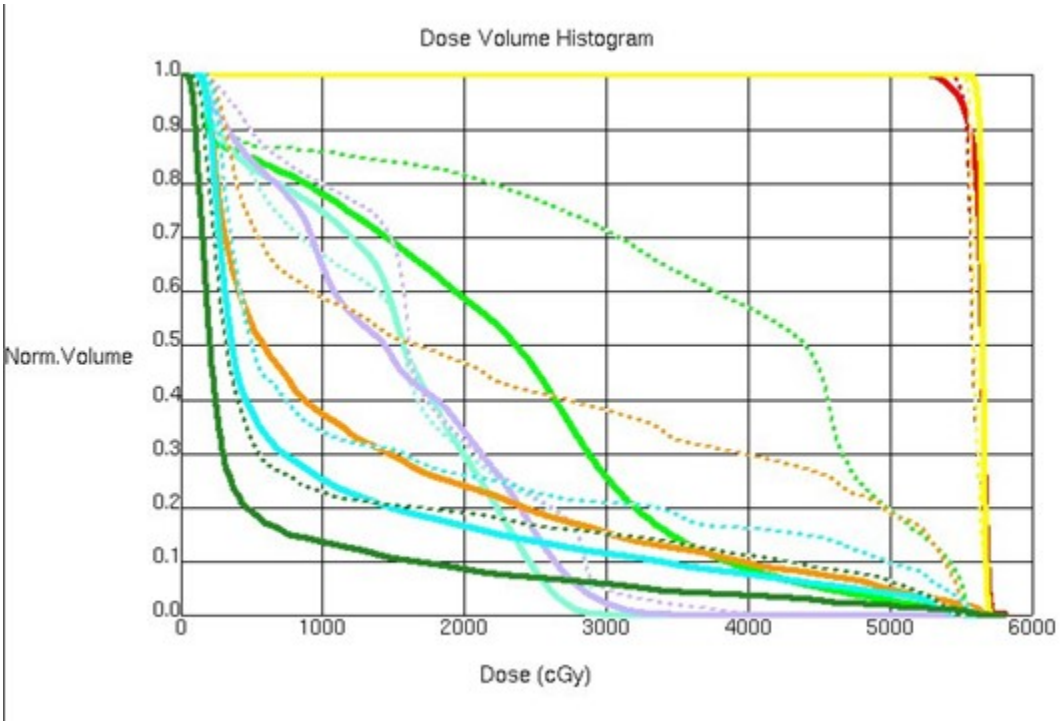
Treatments today still follow these general borders but are more conformal to targeted tissues, sparing normal tissues, and reducing toxicity. Please refer to the "Treatment Volume Localization: Pelvis" section (Anchor 2).



VMAT plan of the bladder.



8-field 3D-CRT plan of the bladder.



Treatment plan comparison; the dotted line is an 8-field 3D-CRT and the solid line is a VMAT plan.

Treatment Techniques: Bladder

The most common treatment for early-stage malignancies of the bladder is by surgical resection via cystoscopy – Transurethral Resection of Bladder Tumor (TURBT). More advanced cancers will benefit from a partial or complete cystectomy and radiation therapy. Doses for the bladder are approximately 55 Gy in 20 fractions over a 4-week period or 64 Gy in 32 fractions over a 6.5-week period. The beam arrangements are consistent with the typical four field arrangement for pelvis cancers. Please refer to the "Treatment Techniques: Pelvis" section.

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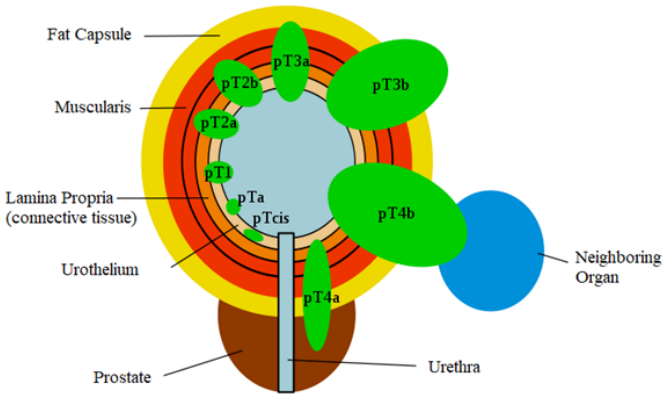

Bladder cancer stages based on depth of invasion of a male.

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26.

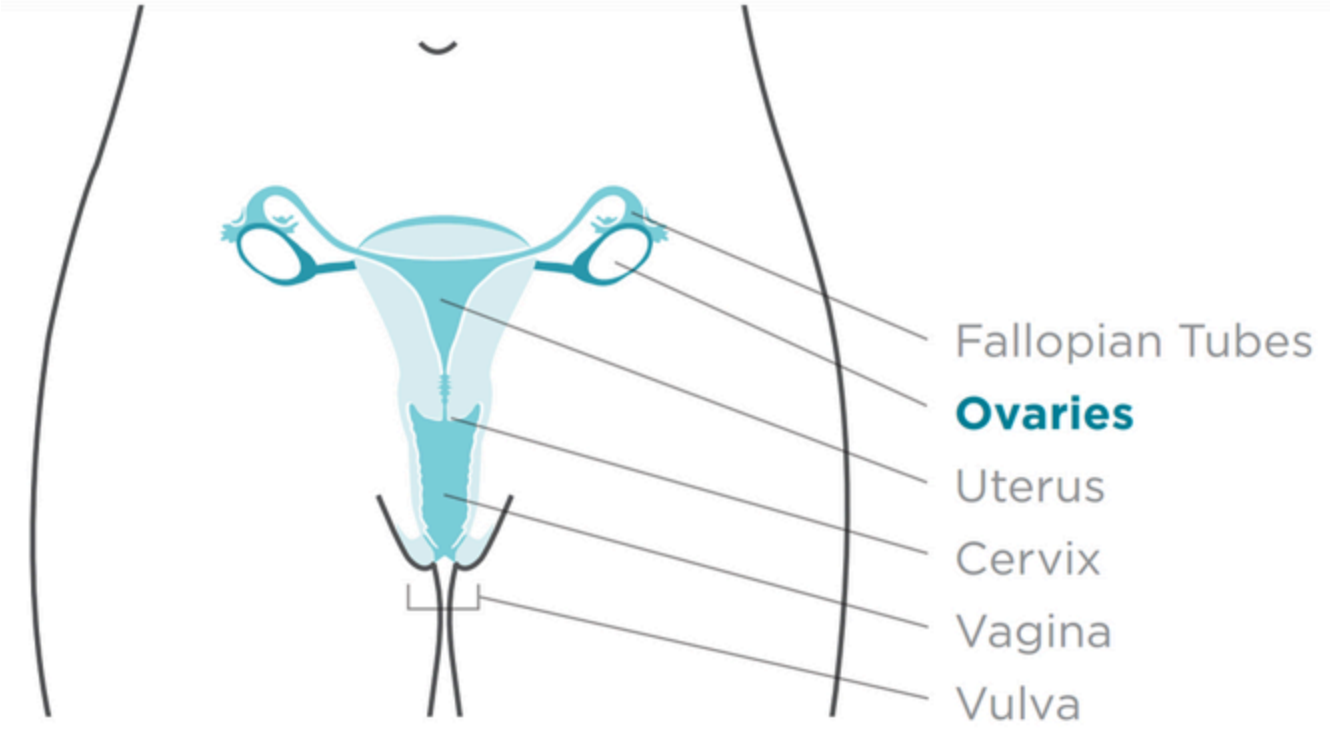
FEMALE PELVIS

Overview: Female Pelvis

The most to least common gynecological malignancies are endometrial, ovarian, cervical, vulvar, then vaginal. Many risk factors for endometrial cancers are associated with increased estrogen levels over a an extended period; this includes **nulliparity**, number of menstrual cycles, obesity, hormone therapy, and a history of **tamoxifen therapy** from a previous breast cancer. The most common histology for endometrial cancers is adenocarcinoma. At the cervix, the tissue type transitions to squamous cell, and the most common pathology for cancers of the cervix, vagina, and vulva are squamous cell carcinomas.

Ovarian cancer is the deadliest gynecological cancer. Risk factors for ovarian cancer include older age, increased exposure to estrogen, history of breast, colon, or endometrial cancers, and genetics (BRCA1 & 2). The most common histology for ovarian cancers is epithelial germ cell. Treatment of these malignancies are covered in the "Whole Abdomen" chapter.

The third most common malignancy in women is cervical cancer. Cervical cancer is correlated with lower socioeconomic status, early sexual activity, and HPV infection. Signs and symptoms commonly associated with gynecological lesions include bleeding, pelvic pain, mass, etc. The staging system used for gynecological malignancies is the FIGO (International Federation of Gynecology and Obstetrics) staging system.



Gynecological structures of the female Major anatomy of the female pelvis.

The most common patterns of spread for cancers of the female pelvis include direct extension, lymphatic spread, hematogenous spread, and distant spread. Intraperitoneal seeding can also deposit tumors along the recesses of the peritoneum; these metastases can manifest as soft tissue nodules or plaque masses. Lymphatic channels serve as routes of spread for pelvic disease as spread can occur along the ligaments and the mesentery. Common sites of distant metastatic disease include the lungs, the pelvic and para-aortic lymph nodes, and the peritoneum. Local recurrence is often a common concern.

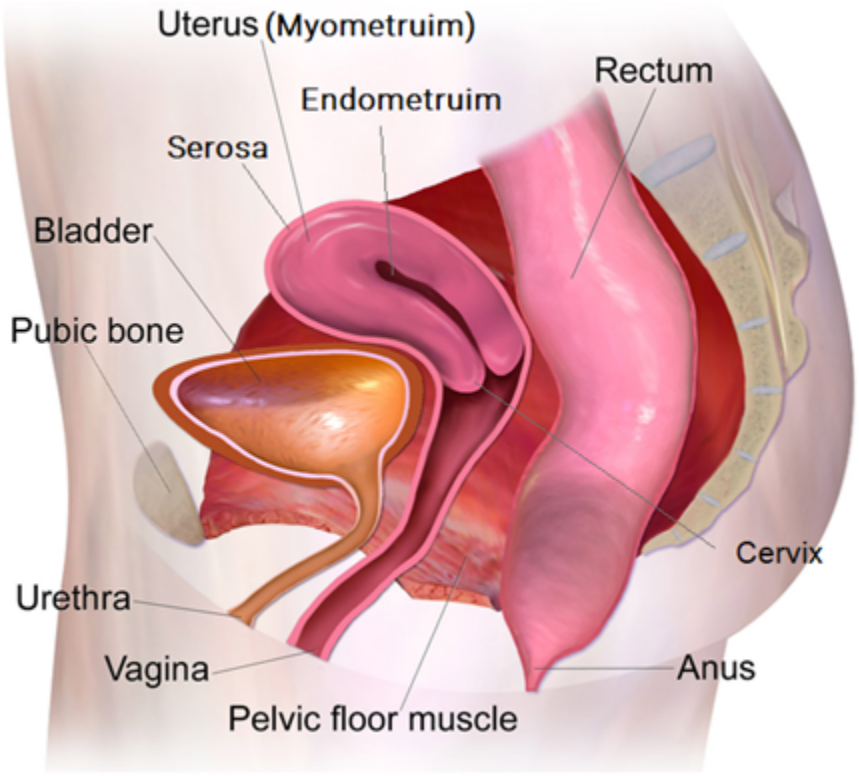
Whole Organ TD 5/5 for OARs (Organs at Risk) for Female Pelvis Radiotherapy

OAR (Organ at Risk)	TD 5/5 (Whole Organ)	Outcome Associated
Rectum	60 Gy	Proctitis, necrosis, fistula
Colon	45 Gy	Obstruction, ulceration, perforation/fistula
Bladder	65 Gy	Cystitis, ulcer, perforation/fistula
Femoral Heads	52 Gy	Necrosis
Small Bowel	40 Gy	Obstruction, ulceration, perforation/fistula
Ovaries	2 Gy	Sterility, early menopause
Vulva / Skin	55 Gy	Fibrosis
Uterus, Cervix, and Vagina can tolerate very high treatment doses (>140 Gy); Fibrosis, ulceration, and fistula may develop		

Overview: Endometrium & Cervix

The most common gynecologic malignancies treated with radiation therapy are cervical and endometrial cancers. The uterus is located in the true pelvis, posterior to the bladder and anterior to the rectum. The three portions of the uterus are the fundus, corpus, and cervix. The body of the uterus has three layers: endometrium, myometrium, and serosa.

Carcinoma of the endometrium is the most common malignant lesion that arises from the female genital tract. The most common histology for endometrial cancers is adenocarcinoma. The most common routes of spread are by direct extension into the cervix, vagina, bladder, and rectum, lymphatics, and transperitoneal spread. The lymphatics that are commonly involved are the external iliac, internal iliac, common iliac, and periaortic lymph nodes. Endometrial cancer uses the **FIGO** staging system to describe the extent of the disease. The following link provides a breakdown of the stages: Endometrial Cancer Stages.



Major anatomy of the female pelvis.

Cervical cancer is the third most common cancer in women worldwide. However, invasive cervix carcinoma has decreased significantly with the advent of screening; current recommendations of the American Cancer Society include a pap smear starting at 25 years old. Chronic HPV (human papillomavirus) is a significant

risk factor for cervical cancer; most cases are found in developing countries where preventative vaccinations are unavailable. PHV+ patients have an improved prognosis.

Squamous cell carcinoma is the most common pathologic type of cervical cancer. A rich lymphatic system encompasses the cervix and uterus. The three most frequently involved nodal groups are the obturator and internal and external iliac nodes. Cervical cancer uses the FIGO staging system to describe the extent of the disease. The following link provides a breakdown of the stages: Cervical Cancer Stages | How to Stage Cervical Cancer.

Patient Simulation & Special Considerations: Endometrium & Cervix

For advanced cervical cancers, the para-aortic lymph nodes may require treatment; if so, position the patient with their arms above their head and add straightening marks to the superior abdomen. Using a knee bolster can help the patient flatten their spine and improve comfort and reproducibility. Additionally, a radiopaque marker may be inserted onto the vaginal apex to help identify the area by CT scan. The simulation process is otherwise consistent with the typical pelvis in treating endometrial and cervical cancers. Please refer to the "Patient Simulation: Pelvis" section.

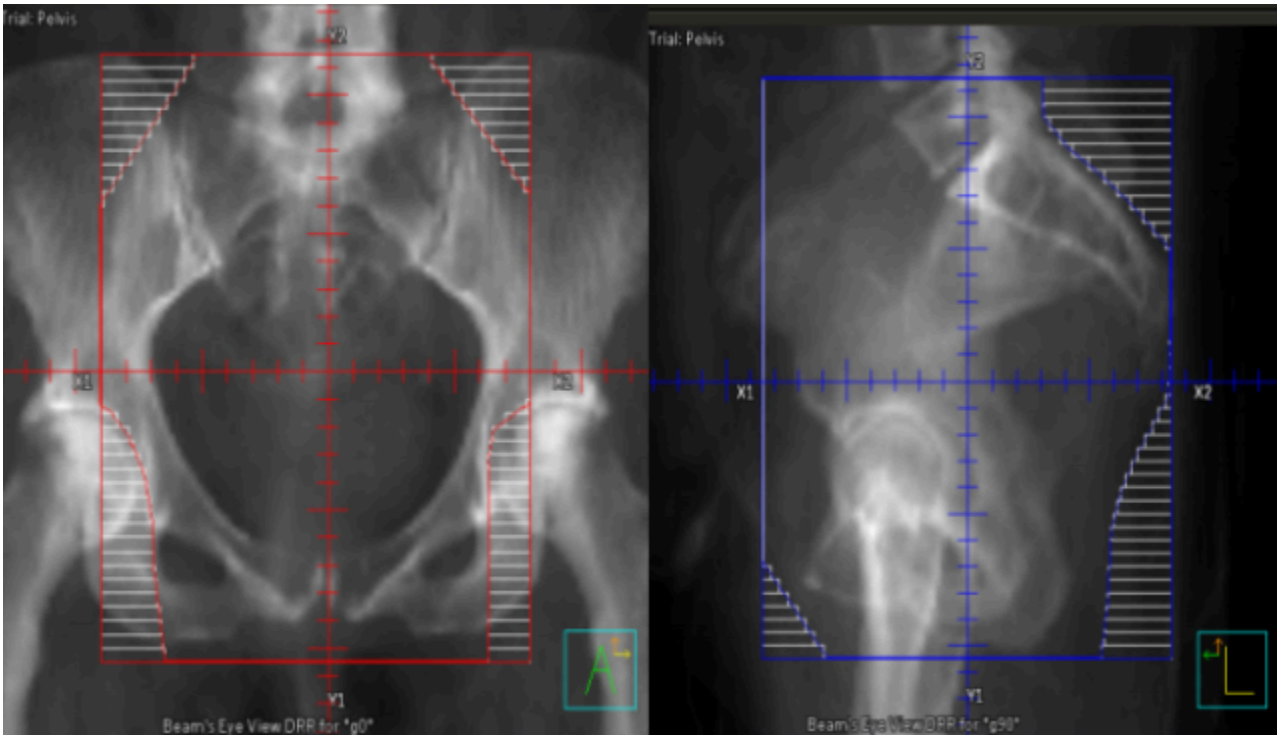
During simulation for brachytherapy, the patient will be in a supine position with the vaginal applicators in place. Image-guidance is provided with AP kV images, CT, and/or MRI to confirm the applicator is in the correct position or if any changes need to be made. These images should contain the entire brachytherapy applicators(s) and critical structures including the bladder and rectum.

Treatment Volume Localization: Endometrium & Cervix

Traditional treatment borders for the endometrium and cervix 4-field "box" are:

Endometrial cancer treatment fields:

- **Superior:** L5-S1 interspace to include the common iliac nodes
- **Inferior:** bottom of the obturator to include the common iliac nodes
- **Lateral:** a minimum of 1 cm lateral to the pelvic brim to encompass the external and internal iliac nodes.
- **Anterior:** encompass the symphysis pubis
- **Posterior:** split the sacrum

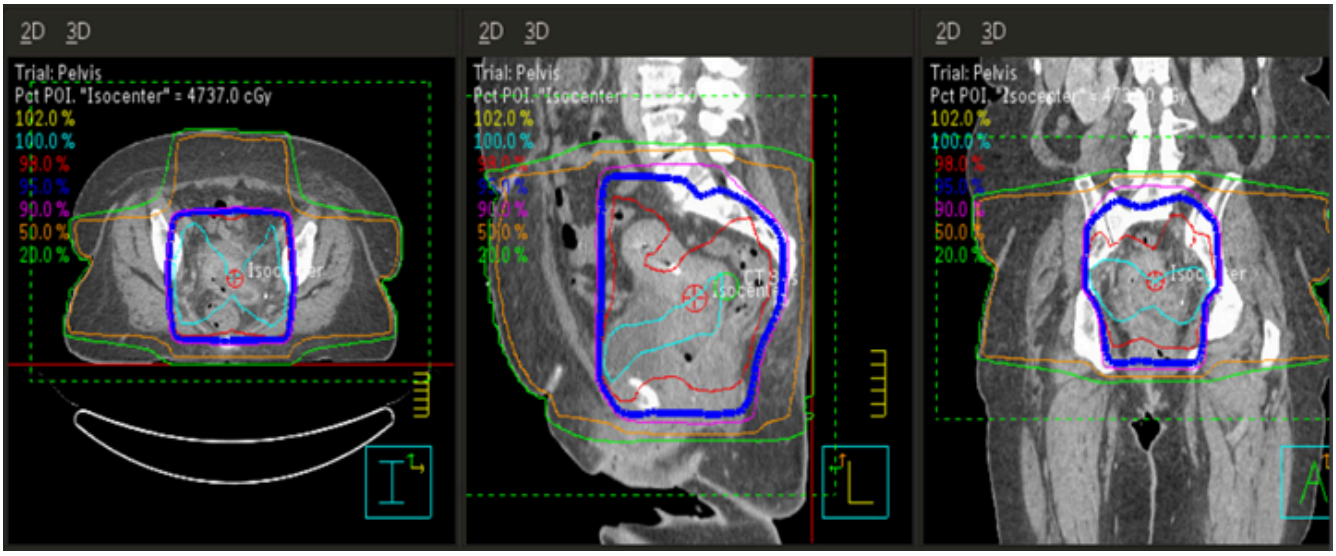


Left lateral beam and AP beam for a 4-field pelvis for cervical cancer with equal weighting; 180 cGy / fraction to 45 Gy using 18 MV.

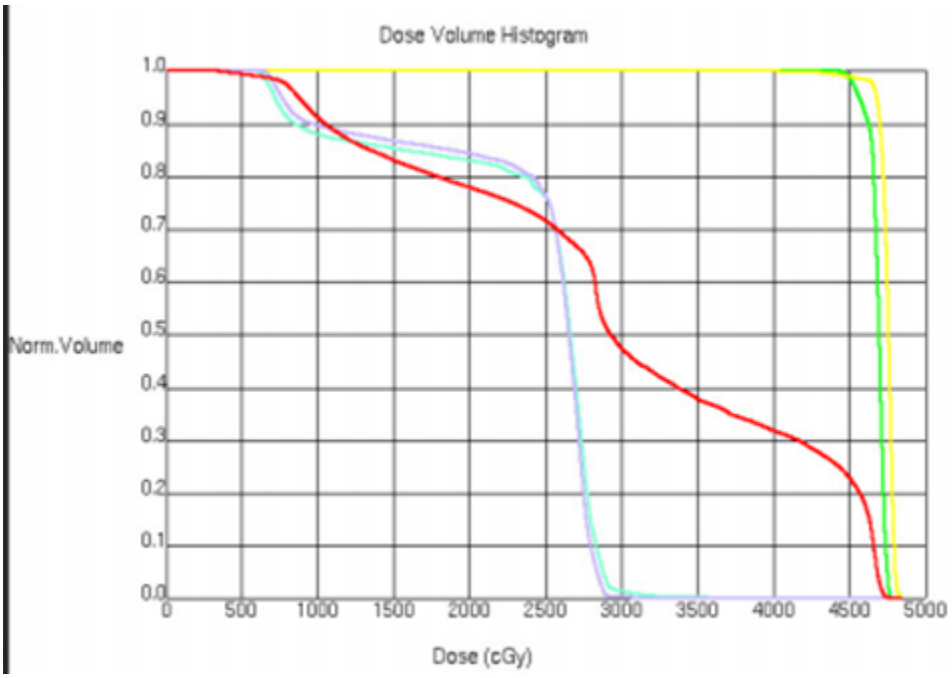
Cervical cancer treatment fields:

- **Superior:** L4-L5 interspace
- **Inferior:** the bottom of the obturator foramen
- **Lateral:** 1-2 cm lateral to the pelvic inlet
- **Anterior:** encompassing the pubic symphysis
- **Posterior:** split the sacrum

*If there is disease superior or inferiorly, the borders are adjusted to include all disease with a 1-2 cm margin.



4-field pelvis isodose plan for cervical cancer with equal weighting.



DVH for cervical cancer to include the para-aortic lymph nodes.

Line Type	ROI	Trial or Record	Min.	Max.
	Rectum	Pelvis	4372.4	4776.5
	Bladder	Pelvis	3358.3	4842.6
	Femur_Head_R	Pelvis	581.3	3567.1
	Femur_Head_L	Pelvis	622.1	3074.9
	Bowel	Pelvis	242.0	4755.3

DVH structures for cervical cancer to include the para-aortic lymph nodes.

Treatments today still follow these general borders but are more conformal to targeted tissues, sparing normal tissues, and reducing toxicity. Please refer to the "Treatment Volume Localization: Pelvis" section.

Treatment Techniques: Endometrium & Cervix

The most common treatment for endometrial and cervical cancer is surgery. Some surgical interventions include a wedge resection and a total or partial hysterectomy. When radiation therapy is used as an adjuvant form of treatment, the tumor and regional lymphatics are typically treated to 45-50 Gy at 1.8-2.0 Gy per day, and the primary tumor can be boosted with intracavitary brachytherapy to doses of 80-85 Gy. Most patients also receive concurrent chemotherapy as a radiosensitizer (the patient needs chemo before RT), which helps produce more favorable outcomes. Late side effects of pelvic irradiation include ulceration or thickening, potentially evolving into a bowel obstruction or fistula.

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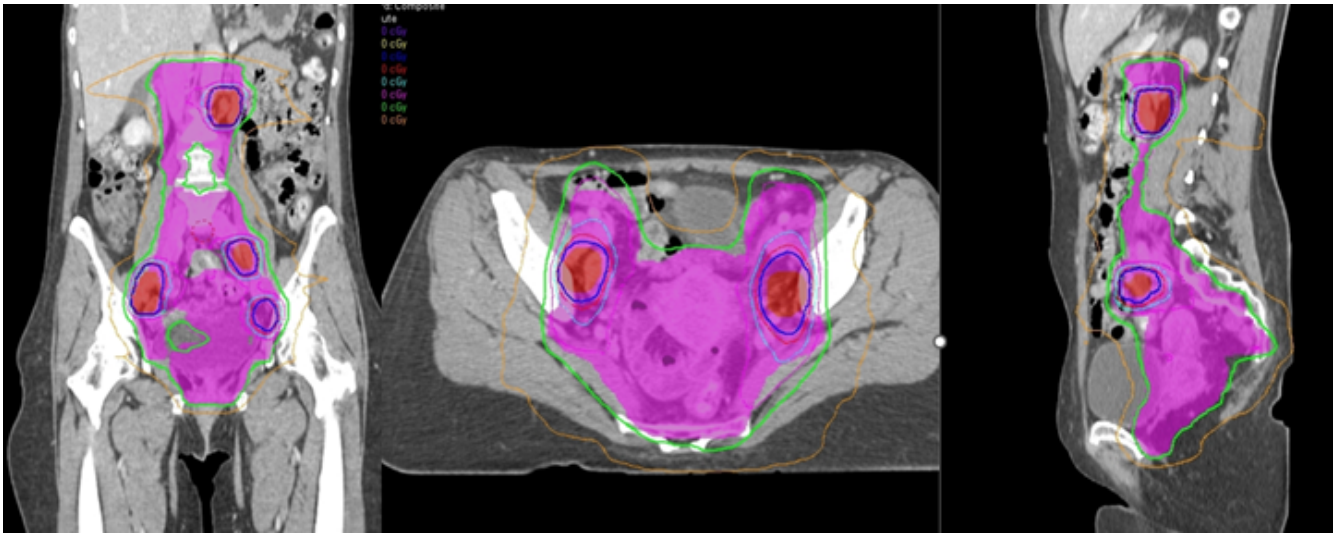
The treatment techniques are consistent with the standard pelvis protocol in treating the endometrium and cervix. Modern treatment techniques are reflected in the "Treatment Techniques: Pelvis" section.



VMAT treatment for cervical cancer to include the para-aortic lymph nodes.

Overview: Vagina

The vagina is a muscular tube about 7.5 inches long that forms a passageway from the vulva to the uterus, and it is located posterior to the bladder and anterior to the rectum. Vaginal cancer is very rare and can be associated with smoking, HPV, and exposure to the drug diethylstilbestrol (DES) in utero. The most common histopathology is squamous cell carcinoma, and the inguinal lymph nodes are the lymph nodes most frequently involved. Some signs and symptoms of vaginal cancer include vaginal bleeding, discharge, mass, pain during intercourse, and painful urination. Vaginal cancer spreads via direct extension into nearby tissues, and squamous cell carcinomas tend to metastasize to the lungs, the liver, and the supraclavicular lymph nodes. Vaginal cancers use the FIGO staging system: Vaginal Cancer Stages.

Patient Simulation & Special Considerations: Vagina

Patients are positioned supine with their legs abducted slightly to reduce perineal skin reactions from treatment. Legs are immobilized with custom-made vaclok or alpha cradle, using a radiopaque marker placed on the inferior extent of the vaginal tumor to help identify the GTV margin dosimetrically. Lateral positioning marks reduce leg rotation and improve reproducibility. Intravenous contrast administration enhances the visibility of the blood vessels on the CT images. The simulation process is otherwise consistent with the typical pelvis. Please refer to the "Patient Simulation: Pelvis" section.

For brachytherapy procedures, patients are simulated with the applicator, a "cylinder" inserted, and an external fixation device to prevent the applicator from moving. A Foley catheter is inserted into the bladder at the beginning of the procedure. During the simulation and treatment, the doctor will fill the bladder to

move surrounding structures away from the source and reduce the dose to normal tissues. During the planning phase, the bladder can drain empty.

Treatment Volume Localization: Vagina

For external beam radiation therapy, the PTV, bowel, rectum, bladder, femoral heads, and bone marrow are organs-at-risk. For three-dimensional conformal radiation therapy, the field-in-field technique is utilized to decrease the occurrence of hot-spots and to reduce the bowel dose. For brachytherapy, the CTV, the sigmoid, rectum, and bladder are all considered organs-at-risk. When creating a brachytherapy plan, the treatment planning system provides a manual optimization plan to reduce dose to the critical structures. Treatments are either intracavity and using an applicator called a cylinder, or interstitial using needles and catheters.

Treatment Techniques: Vagina

Carcinoma of the vagina is typically treated using external beam radiation therapy to the entire pelvis, which includes the associated lymph nodes, to a dose of 45-50.4 Gy in 25-28 fractions at 1.8 Gy per fraction. If a boost is necessary and delivered via an external beam, the dose is an additional 15-20 Gy in 8-11 fractions.

Brachytherapy, if used as the primary form of treatment, uses either a low-dose-rate to 60 Gy or a high-dose-rate to 33 Gy in 6 fractions over 10-19 days. If used as a boost, low-dose-rate (LDR) brachytherapy is given in doses of 15-25 Gy, depending on the location of the applicator. High-dose rate (HDR) brachytherapy is given in doses of 11 Gy in 2 fractions or 16.5 Gy in 3 fractions depending on technique, either intracavitary or interstitial. Interstitial applicators are used when intracavitary applicators do not fit correctly, the tumor is too large, or the tumor is too superficial or deep. Interstitial treatments have improved coverage of the diseased area and decreased the dose to the organs at risk.

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Palliative treatment is also an option for affected patients. The doses and fractionation schemes for vaginal disease are:

Palliative External Beam Radiation Therapy (EBRT):

- 20 Gy in 5 fractions

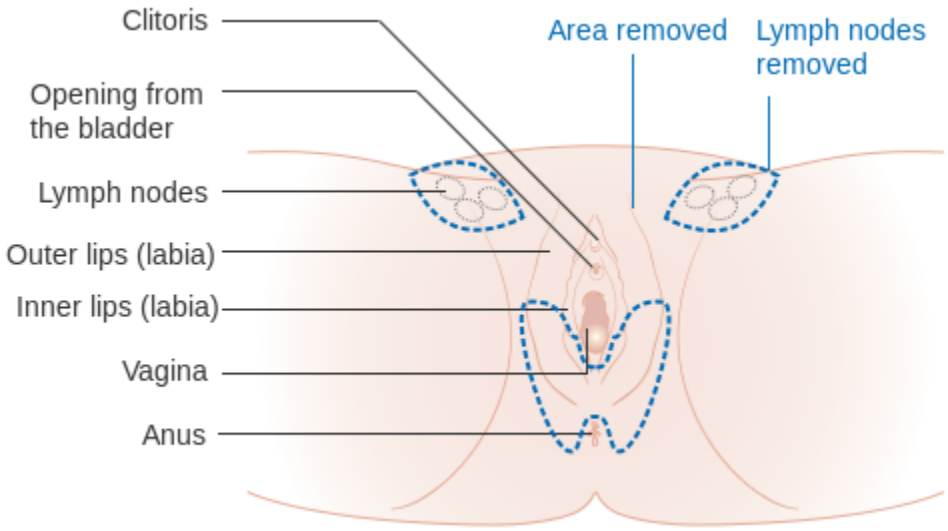
- 30 Gy in 10 fractions
- 8-10 Gy in 1 fraction for hemostasis

Brachytherapy (interstitial or intracavitary):

- LDR: 20-30 Gy
- HDR: 18-24 Gy in 3-4 fractions

Overview: Vulva

The vulva is the outer portion of female genitalia, including the labia, the clitoris, the vaginal opening, and the opening to the urethra. Vulvar cancer accounts for 4% of all gynecological cancers, it most commonly affects women over the age of 70, and 90% of all vulvar cancers are squamous cell carcinoma. Carcinoma of the vulva are primarily treated by surgical resection, with or without adjuvant radiation therapy. Early-stage disease is treated with wide, local excision. Postoperative external beam radiation therapy is recommended for residual or recurrent disease.

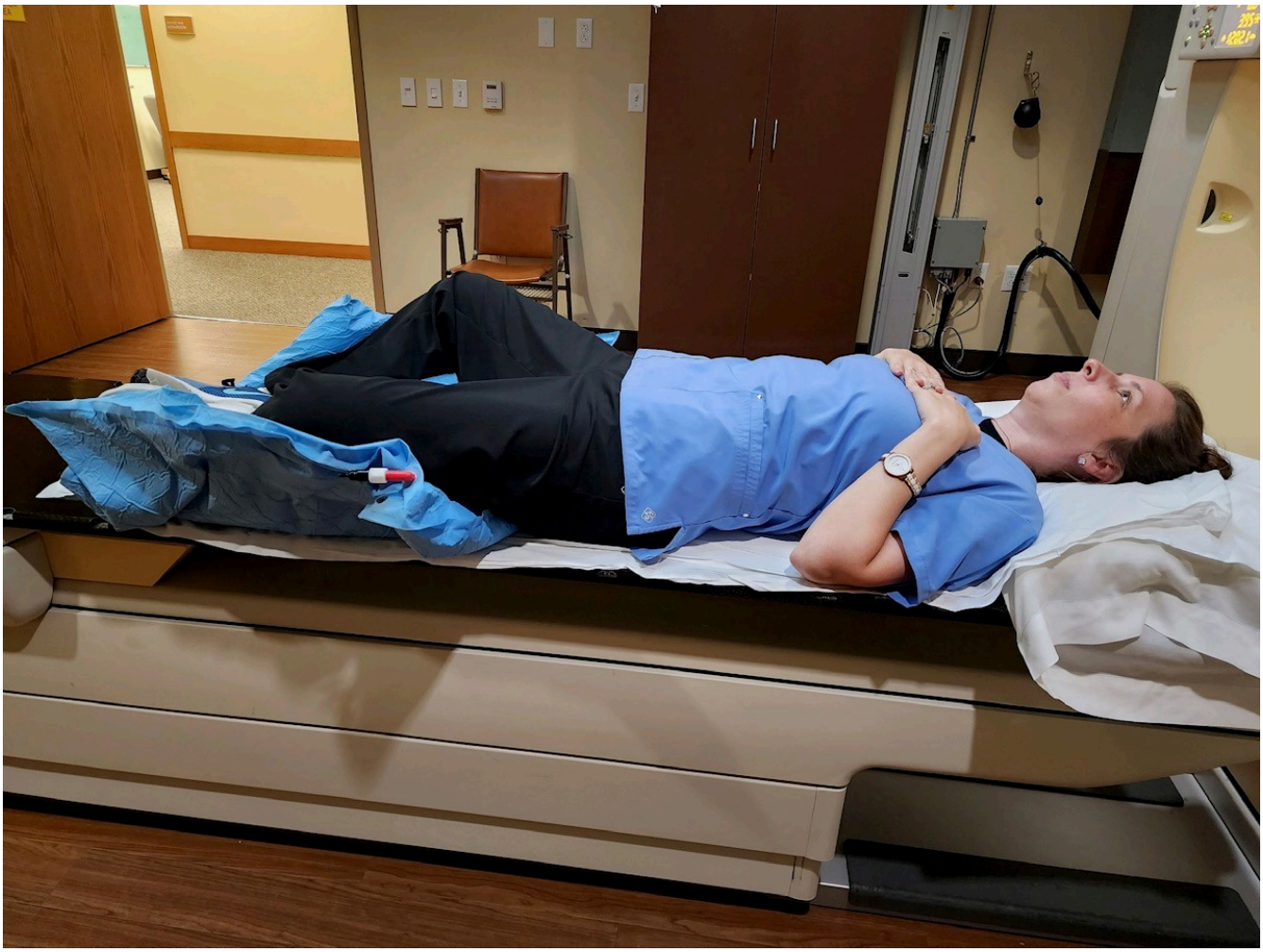


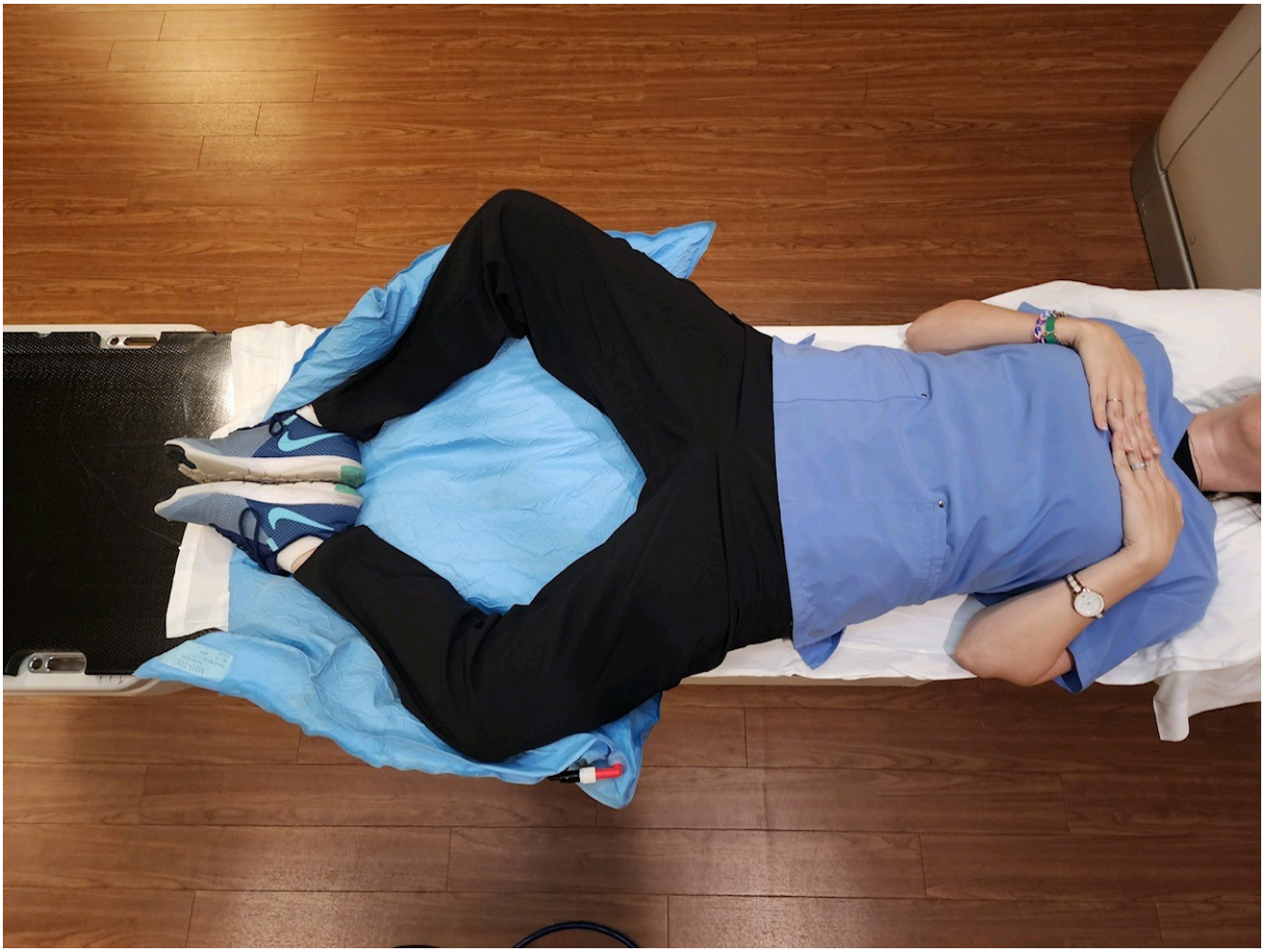
Surgical technique for Vulvular cancers.

Vulvar cancer spreads via lymphatics to the superficial inguinal lymph nodes, deep femoral lymph nodes, and pelvic lymph nodes. Spread can also occur by direct extension to neighboring structures like the urethra, anus, or vagina. Hematogenous spread is rare. Vulvar cancer is associated with smoking and HPV, and some signs and symptoms include red, white, or pink bumps, itching, bleeding, and discharge. Vulvar cancer uses the FIGO staging system: Vulvar Cancer Stages.

Patient Simulation & Special Considerations: Vulva

Patients are typically positioned supine with legs akimbo or "frog leg" to reduce skin folds and scatter dose. Bolus placement is also easier. Bolus will bring the dose more superficial to the surface tissues and eliminate cold spots in the treatment area. During simulation, stirrups and a custom-made vaclok can immobilize the patient's legs and increase reproducibility in subsequent treatments. If treating with an electron, a feet-first position on the table may be necessary. For additional information regarding the simulation of the pelvis, please refer to the "Patient Simulation: Pelvis" section.





Treatment Volume Localization: Vulva

Beam arrangements for advanced cancers of the vulva are AP/PA. Treatment borders for a 3D conformal plan are:

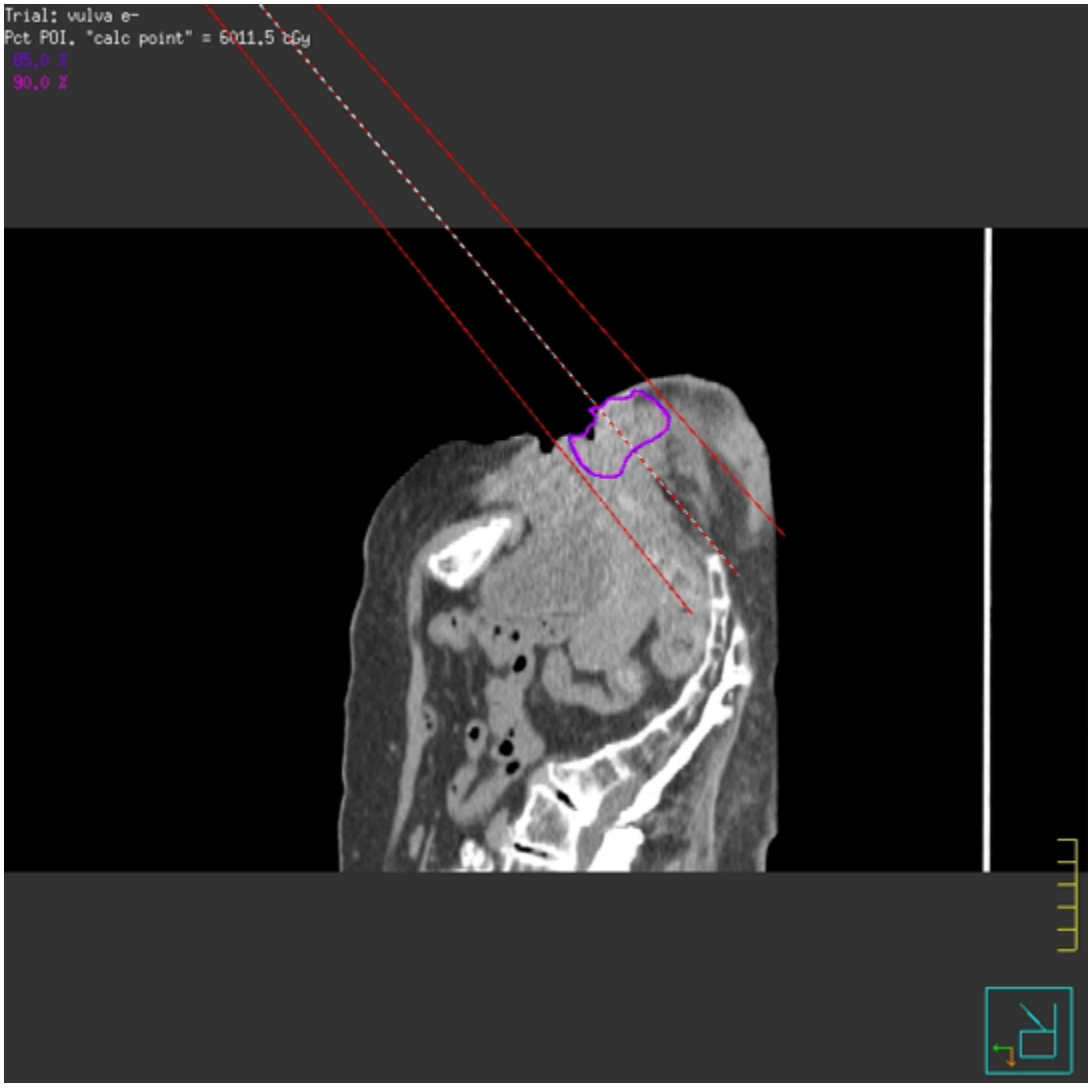
- **Superior:** L5-S1 interspace to include the common iliac lymph nodes
- **Inferior:** Bottom of the obturator foramen or perineum
- **Lateral Anterior:** to include inguinal lymph nodes
- **Lateral Posterior:** narrow to protect femoral necks

If necessary, a radiopaque vaginal localizer is used to ensure appropriate coverage of the upper vagina. Anterior electron fields can treat the inguinal lymph nodes potentially missed by the narrow posterior field. IMRT and VMAT treatment techniques can reduce the dose to the organs at risk and spare healthy tissue. Generally, there is a 2-3cm expansion from the CTV.

Treatment Techniques: Vulva

Vulvar radiation therapy commonly utilizes 3D conformal or IMRT/VMAT 6 MV technique to treat the superficial tissues, lymph nodes, and pelvic disease. Both help shape the radiation beams and limit the dose to healthy tissues like the bowel, rectum, and bladder. Doses beyond 40 Gy often require treatment breaks due to moist desquamation. Doses and fractionation schemes for vulvar disease are as follows:

- When the resection margins are insufficient, the postoperative dose is 45-50 Gy 6 MV with an electron boost of 10-20 Gy.
- For electron treatments, the dose is 50-60 Gy, which includes the boost.



Salvage radiation therapy electron treatment of the vulva. 54 Gy delivered in 30 fractions; 9 MeV with a .5 cm bolus.

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27.

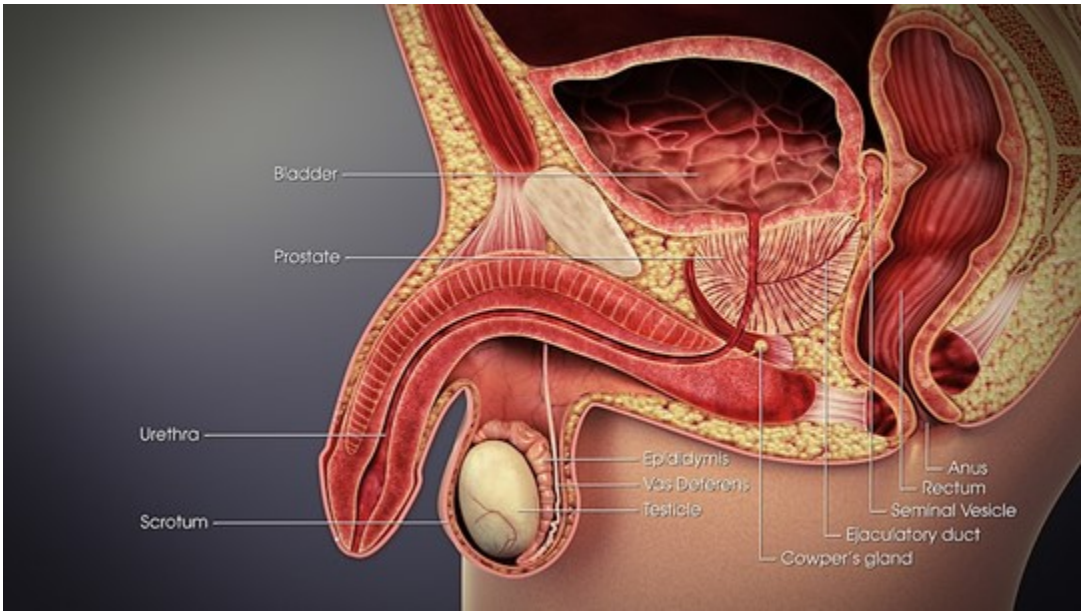
MALE PELVIS

Overview: Male Pelvis

Prostate cancer is the most common cancer in men; approximately one in eight are diagnosed annually. The average age of diagnosis is sixty-six, and it is rare before the age of forty-four. In the US, where screening is standard, less than 5% of men have metastatic disease at presentation. The American Cancer Society recommends screening should begin at age 50 and includes a **digital rectal exam** and blood draw to review the **PSA (Prostate Specific Antigen hormone)**. Other cancers of the male pelvis include penile and testicular cancer.

Overview: Prostate

The prostate is a walnut-shaped and sized gland. The function of the prostate is to produce fluid that supports the nourishment and transportation of sperm. It sits posterior and inferior to the bladder. The prostate also sits anterior to the rectum; this is a crucial detail to understand when localizing the prostate. The prostate's location can shift based on the bladder and rectum's fullness The urethra runs through the prostate, so dysfunction with the urinary stream is a common symptom of prostate cancer.



Anatomy of the male pelvis.

The pathology of prostate cancer is overwhelmingly adenocarcinoma. However, there are instances of squamous cell disease which are rare and aggressive. Etiological factors for prostate cancers include having a diet high in red meat. African American men have a one-and-a-half times higher risk than the general population. BRCA1 and 2 genetic mutations also increase a person's risk of developing this disease over their lifetime.

The seminal vesicles are the most common site of direct local invasion. Lymphatic spread can also occur in the peri-prostatic nodes, followed by the obturator nodes. Further spread can be found in the internal iliac, external iliac, common iliac, and presacral nodes. Lastly, hematogenous metastases are seen with advanced-stage disease, commonly to the bone; these lesions can be **osteoblastic**.

Staging can be complex for prostate cancer; it is based on three key pieces of information: TNM, PSA, and Gleason score.

- TNM classification describes the extent of the primary tumor (T), the presence or absence of lymph node disease (N), and if the cancer has spread to other parts of the body (M).
- PSA (Prostate Specific Antigen) level is a measurement, a protein made by the cells in the prostate. Most men have a PSA level under 4ng/ML of blood, but this number rises with age with 10ng/ML still falling in normal limits. Conditions other than cancer can increase one's PSA and no set cutoff point definitively informs you if a man does or does not have prostate cancer.
- Gleason score is a measure of the grade of prostate cancer. If the cell histology looks like normal prostate tissues, a grade of "1" is assigned. If the cancer looks very abnormal, a grade of "5" is assigned. Two different areas of the prostate are biopsied, and each is assigned a score. For example, if the Gleason score is written as 3+4, most of the tumor is grade 3, and less is grade 4. These numbers get added together to give a Gleason score of 7; the higher the score, the more aggressive the cancer.

Current recommendations for treating early-stage prostate cancers vary significantly due to their typically indolent nature. Treatment options include active surveillance, radical prostatectomy, radiation therapy, or **Androgen Deprivation Therapy**/hormone therapy. The patient's age, health, stage of their disease, treatment side effects, and preference will help decide the best treatment course for each patient. For late-stage disease, more radical measures may take place; this may include an increased radiation dose, chemotherapy, and hormone treatment.

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Patient Simulation & Special Considerations: Prostate

Prostate simulation is consistent with the general setup for pelvis patients. It is crucial to have the patient's lower body immobilization to minimize intra-fraction motion. Commonly, patients will have a vaclok formed to their legs and a combination of pillows, blocks, or wedges to support their upper body. Patients should have a comfortably full bladder and empty rectum before the simulation. A full bladder will push small bowel out of the pelvis and the treatment area; an empty rectum will increase reproducibility daily.

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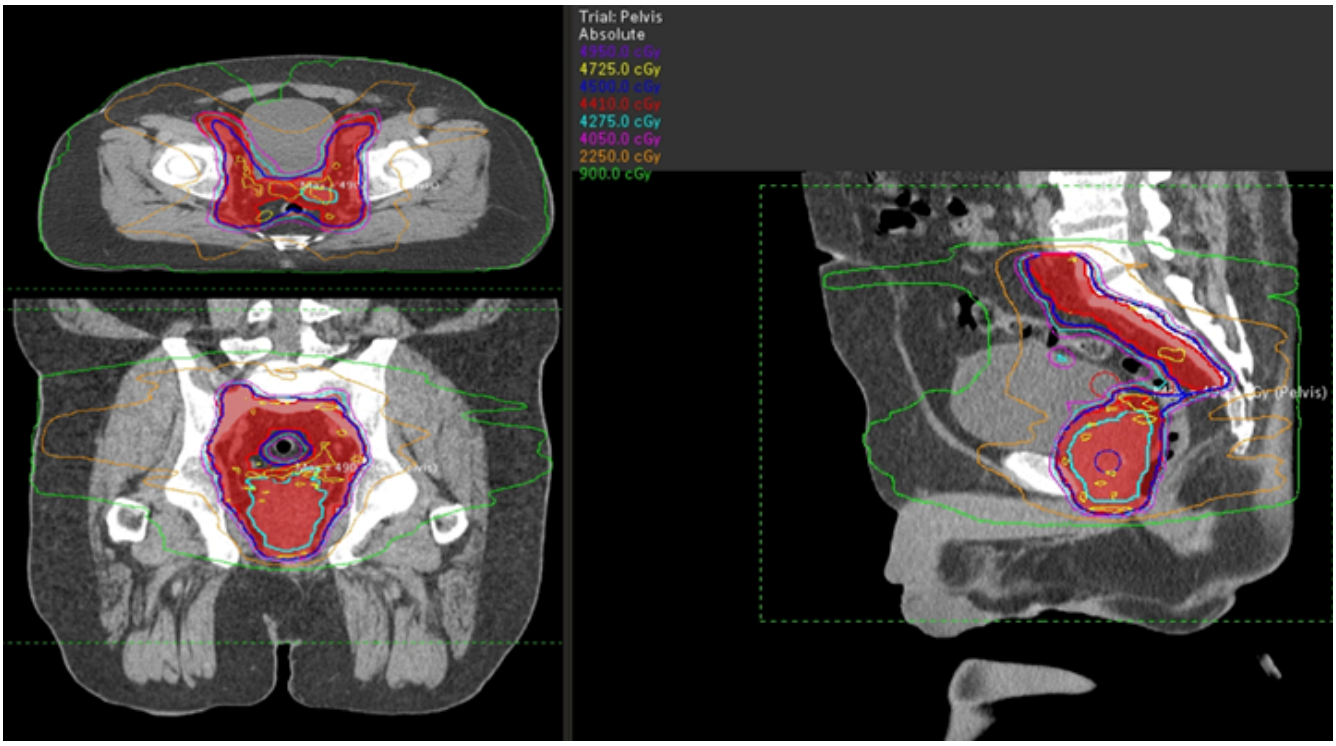
Treatment Volume Localization: Prostate

Historically, a 3D conformal treatment technique known as a four-field box was the standard of care for radiotherapy to the prostate. The field borders depended on the stage of the disease, but in general, were:

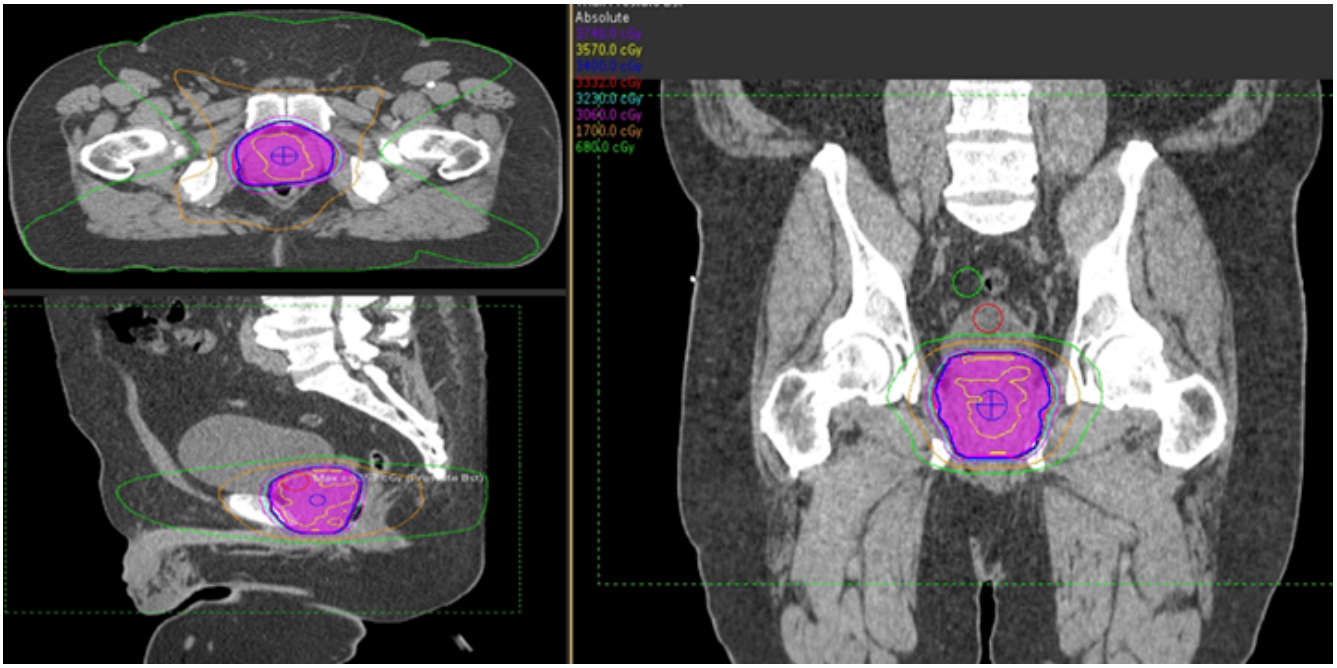
- **Superior:** L4-5 to include the common iliac nodes
- **Inferior:** The inferior aspect of the ischial tuberosities which is about 1.5-2cm below the caudal aspect of the prostate
- **Lateral:** 1.5-2 cm beyond the lateral pelvic brim.

- **Anterior:** include the pubic symphysis.
- **Posterior:** transect the rectum

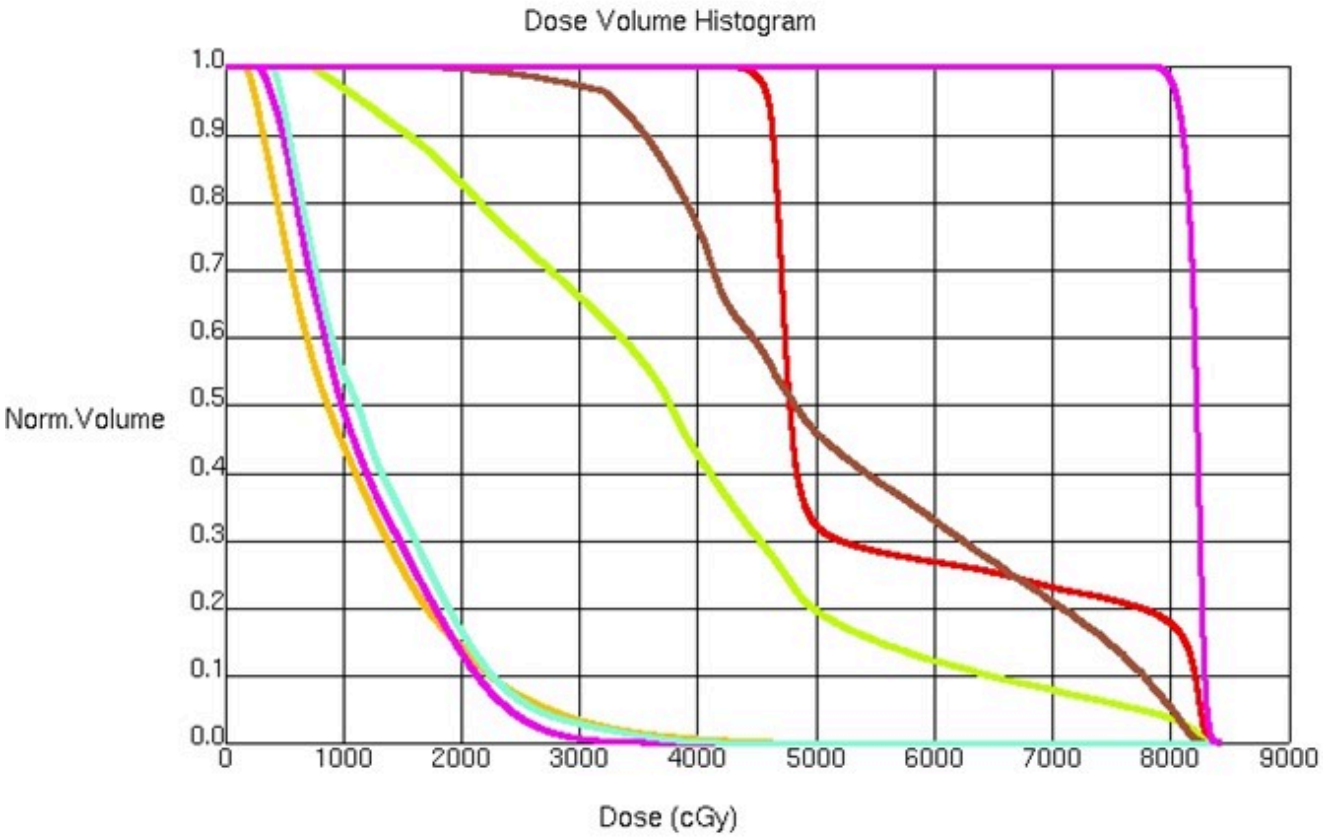


VMAT plan of the prostate and pelvic nodes; Red: PTV 4500 (Dose prescribed such that 96% of PTV4500 receives 45 Gy).

Treatments today still follow these general borders but are more conformal to targeted tissues, sparing normal tissues, and reducing toxicity. Please refer to the "Treatment Volume Location: Pelvis" section.



VMAT boost to the prostate. Pink: PTV 7900 (100% of the volume is receiving 79 Gy).



DVH for a VMAT of the prostate. Pink: PTV 7900 (100% of the volume is receiving 79 Gy); Red: PTV 4500 (Dose prescribed such that 96% of PTV4500 receives 45 Gy); Brown: Rectum (Majority of the rectum receives less than 60 Gy); Green: Bladder (90% of the bladder receives less than 65 Gy).

Treatment Techniques: Prostate

Radiation doses can vary significantly based on treatment delivery and patient risk profile.

External Beam:

- An external beam dose of 75.6-79.2 Gy at standard fractionation is recommended for low-risk patients.
- Intermediate and high-risk patients can receive doses up to 81 Gy to the prostate using standard fractionation. 45 Gy is delivered to the prostate, seminal vesicles, and nodes, while a simultaneous integrated boost to the prostate.
- Post-prostatectomy patients, a dose of 64-68Gy in standard fractionation is recommended for the prostate bed.
- A dose of 45-50 Gy to the prostate, seminal vesicles, and nodes is recommended when combined with a brachytherapy (HDR or LDR) boost to the prostate.

HDR:

HDR (High-Dose Rate) radiation therapy is a highly effective treatment option for prostate cancer. In this technique, a small, radioactive source, typically iridium-192, is temporarily placed inside or near the prostate gland using thin catheters. The source emits high-energy radiation for a short time, delivering precise and targeted doses to the cancerous cells. The advantage of HDR is that it allows for customized treatment plans, enabling doctors to adjust the dose distribution according to the tumor's shape and location.

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://pressbooks.uiowa.edu/radiationtherapy/?p=826#oembed-3

The total dose delivered during HDR radiation therapy to the prostate varies depending on the case. Two common HDR regimens for interstitial brachytherapy treatments use 18-20 catheters in one or two fraction treatments.

- For one fraction treatments, the prescribed dose is 15 Gy.
- For two fraction treatments, each fraction is 13.5 Gy to a total dose of 27 Gy, 1 week apart

It is common for the D90 (the minimum dose covering 90% of the volume) to receive a slightly higher dose than one hundred percent of the prescribed treatment dose between both fractionation schemes – the total is around 30 Gy. Additionally, the V100 (volume of the prostate that receives 100% of the prescribed dose) will commonly be in the range of ninety-five percent of the volume of the CTV.

Learn more about the HDR treatment procedure by watching: The High-Dose Rate (HDR) Brachytherapy Procedure to Treat Prostate Cancer

LDR:

LDR's (Low Dose Rate) radiation therapy's goal is to destroy cancer cells while minimizing damage to surrounding healthy tissues. It involves the use of *permanently* implanted radioactive sources "seeds" – typically, 50 to 125 of either iodine-125 or palladium-103. These seeds deliver a continuous low dose of radiation over a prolonged period until they are stable or no longer radioactive. The total dose of radiation delivered depends on several factors but is usually in the range of 150-200 Gy; this varies by case.

Watch this video review of treatment options and considerations in the treatment of prostate cancer: Prostate cancer: Brachytherapy's fight for survival.

Overview: Penile

The penis has both reproductive and urinary purposes. It is comprised of erectile tissues, smooth muscle tissue,

connective tissue, nervous tissue, and skin and epithelial tissues. Penile cancer is commonly squamous cell carcinoma (95%) and accounts for fewer than 1% of cancers in men. Risk factors include: being uncircumcised, HPV, tobacco use, immunosuppression, UV exposure, and age. The average age of diagnosis is 68 years.

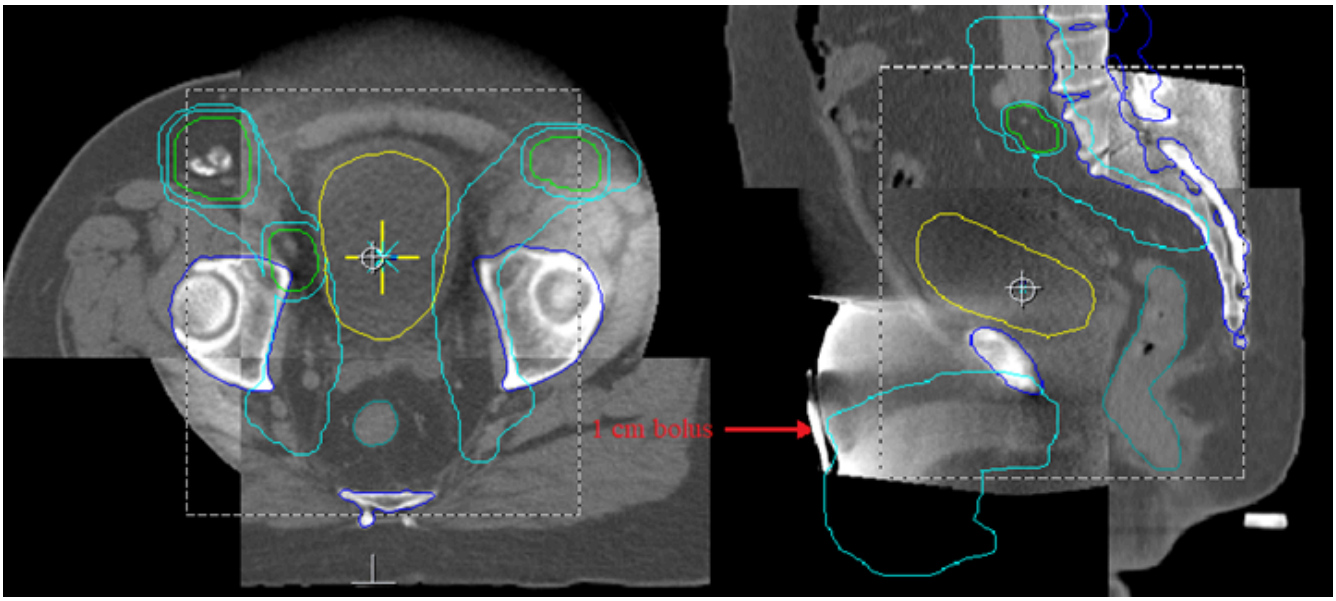
Treatment for penile cancer depends on the type and stage of the cancer as well as the patient's age and health. The primary treatment option for penile cancer is surgery but the size, location, and patient preference may limit its use. Sometimes radiation therapy may be used as the primary treatment or in addition to surgery. Chemotherapy is used for advanced cases or if the cancer has spread. The overall 5-year survival rate is 65%.

Patient Simulation & Special Considerations: Penile

The simulation process for penile cancer is consistent with the general setup for pelvis patients. However, when treating the penis, tissue reproducibility in the shape, size, and location is a unique challenge. Styrofoam molds and a custom bolus may be necessary to position, immobilize, and reproduce the position. Alternatively, patients can be positioned prone on a board to let the penis fall anteriorly into a water bath.

Treatment Volume Localization: Penile

Treatment volumes may include the primary tumor and/or inguinal and pelvic lymphatics to 50-60 Gy. A boost to the primary tumor of 5-10 Gy may be recommended. Bolus is required to bring the dose more superficial when using photon beams.



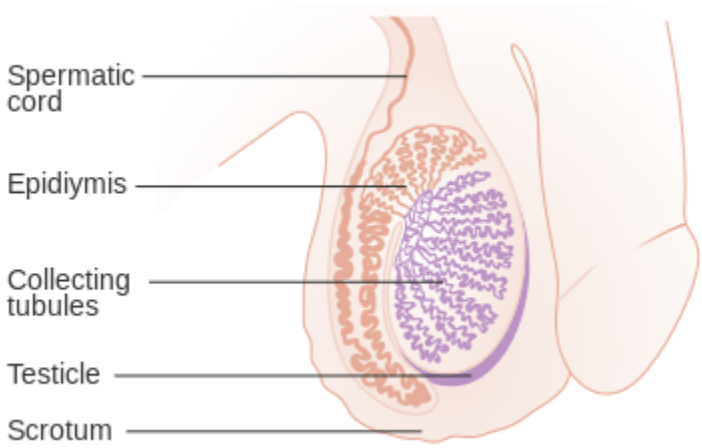
CBCT image of a penile cancer patient. A 1cm bolus was placed over the partial penectomy. The lymph nodes were treated to 5040 cGy (blue) and 6160 cGy (green) with a boost to follow.

Treatment Techniques: Penile

Adaptive Radiotherapy (ART) can generate a treatment plan daily based on the size, shape, and location of the penis. Brachytherapy using a surface mold may be a desirable treatment technique for patients with penile cancer.

Overview: Testicular

Testicular cancer accounts for 1% of cancers in men, but it is the most common malignancy in males age 25-35. Men with a prior history of cryptorchidism have an increased risk. These cancers are most often detected by a palpable asymptomatic mass and are of germ cell histology (90%). These cells produce sperm and can be further classified as seminomas and non-seminomas – each with near equal incidence. These cancers can be further classified by cell-type. In general, testicular cancers have a good prognosis with about a 90% 5-year overall survival. For more information, consult cancer.org.

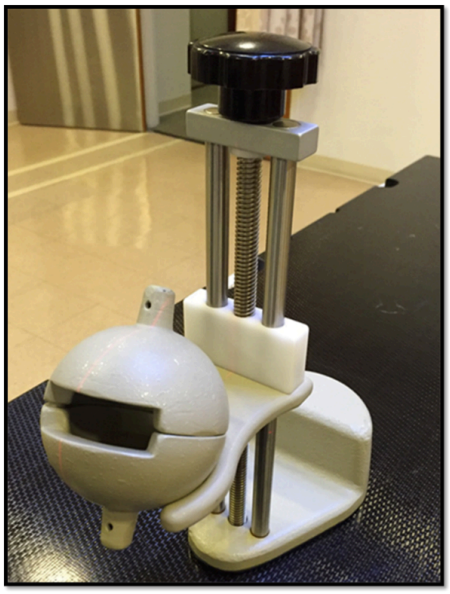


Testicle anatomy.

The management of these cancers can vary based on the pathology and stage. The standard of care for early-stage cancers is radical orchiectomy with a high ligation of the spermatic cord removed through an incision in the low anterior pelvis. Seminoma patients with residual disease are treated with chemotherapy or radiation, each has similar outcomes. However, chemotherapy is associated with less long-term toxicity and is preferred. Radiation therapy may be recommended based on the pathology or positive lymphatic disease after chemotherapy. Generally, seminomas respond well to radiation and are more likely to be treated with radiation than non-seminomas.

Patient Simulation & Special Considerations: Testicular

Simulation for testicular cancer is consistent with the general setup for pelvis patients. However, it's important to position the patient's hands high on their chest or above the head to account for the cephalic field-edge's superior location. The treatment field is long; additional marks to level and straighten the patient are helpful.



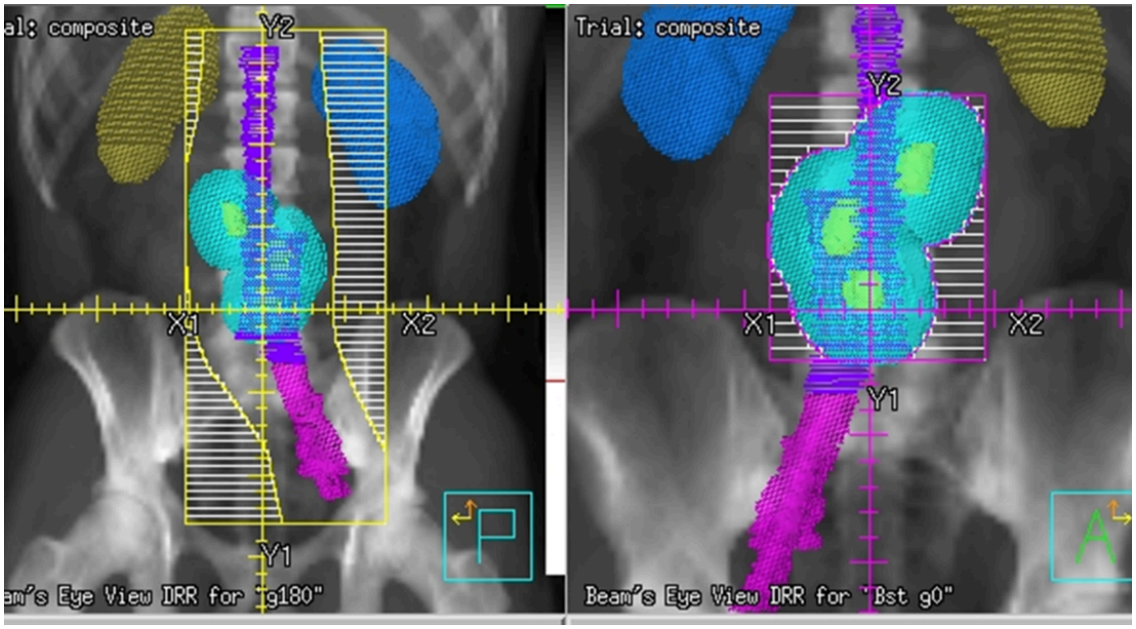
Clamshell with adjustable height used to shield the testis from radiation.

The patient may require the use of a testicular shield (clamshell) to protect the remaining testis and preserve fertility. Forming the base of the shield into the vaclok and frogging the patient's legs is helpful for comfort and reproducibility. Warming the shield by running warm water over it or wrapping it in warm blankets makes it more comfortable for the patient and easier to relax the scrotum and tissues away from the body. Providing instruction on its use to the patient and protecting their modesty as much as possible by keeping them covered is best practice. Remember, part of the patient's body is in the clamshell when attempting to position them. The typical scan parameters should extend from the dome of the diaphragm (T11) to the ischial tuberosities.

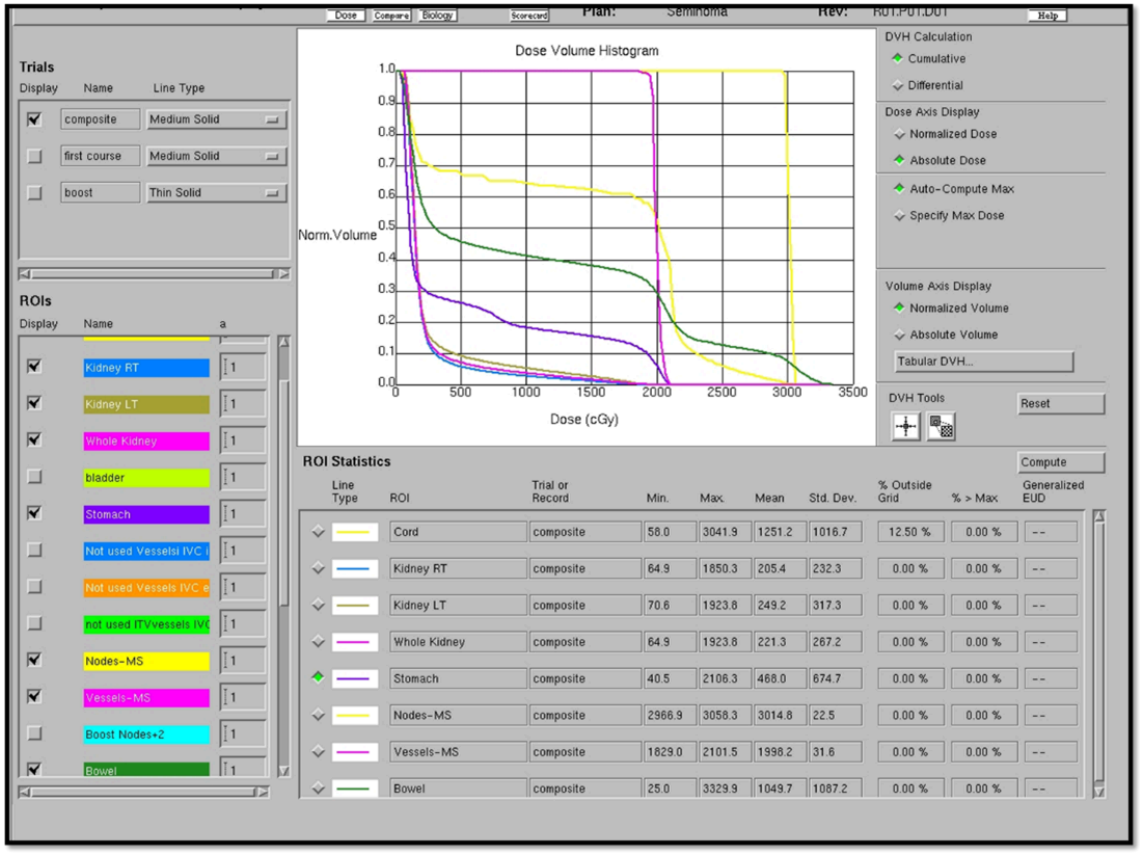
Treatment Volume Localization: Testicular

Historically, and often today, seminomas are treated AP/PA with a treatment field shape termed a "dogleg" or "hockey stick." The first route of spread is to the periaortic lymph nodes; the treatment fields also include the ipsilateral renal hilar nodes, iliac nodes, and the surgical scar. Special attention must be given to the organs at risk, especially the kidneys. Treatment field borders are:

- **Superior:** Bottom of T11
- **Inferior:**
  - **Abdomen (Periaortic) portion:** L5
  - **Pelvic portion:** Pubic symphysis
- **Lateral:**
  - **Abdomen (Periaortic) portion:** Transverse processes of vertebral bodies
  - **Pelvic portion:** To include the ipsilateral common iliac and surgical scar
- **Medial (Pelvis):** Close to midline of the ipsilateral side



DRR dogleg field for a right-sided seminoma (g180 yellow) and a boost field (pink). Note: the scar should be included in the lower aspect of the pelvis field.



DVH for dogleg field (20 Gy) and boost fields (30 Gy).

Treatment Techniques: Testicular

Due to the radiosensitivity of seminomas and the relatively low treatment dose required, traditional field borders remain common today. Treatment doses for the dogleg fields are around 20 Gy at 2 Gy per fraction. Smaller, more conformal, fields are treated AP/PA or using IMRT or VMAT technology to boost bulky disease and avoid critical structures to 30-36 Gy at 2 Gy per fraction.

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PART VII

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28.

REFERENCES & RESOURCES

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