Proton Beam Radiation Therapy

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➲ Instructions for Use

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Application

UnitedHealthcare Commercial

This Medical Policy applies to UnitedHealthcare Commercial benefit plans.

UnitedHealthcare Individual Exchange

This Medical Policy applies to Individual Exchange benefit plans.

Coverage Rationale

Note: This policy applies to individuals 19 years of age and older. Proton beam radiation therapy (PBRT, PBT) is covered without further review for individuals younger than 19 years of age.

Proton beam radiation therapy is proven and medically necessary for the following:

- Definitive Therapy for the following indications:
  - Base of skull tumors (e.g., chordomas, chondrosarcomas, paranasal sinus, or nasopharyngeal tumors)
  - Hepatocellular carcinoma (HCC) (localized, unresectable) in the curative setting when documentation is provided that sparing of the surrounding normal tissue cannot be achieved with standard radiation therapy techniques, including intensity-modulated radiation therapy (IMRT), stereotactic body radiation therapy (SBRT), and selective internal radiation spheres, and transarterial therapy (for example, chemoembolization) is contraindicated or not technically feasible
  - Intracranial arteriovenous malformations (AVMs)
  - Ocular tumors, including intraocular/uveal melanoma (includes the iris, ciliary body, and choroid)

PBT and IMRT are proven and considered clinically equivalent for treating prostate cancer. Medical necessity will be determined based on the terms of the member's benefit plan.

PBT is unproven and not medically necessary due to insufficient evidence of efficacy for treating all other indications; however, PBT may be covered for a diagnosis that is not listed above as proven, including recurrences or metastases in selected cases. Requests for exceptions will be evaluated on a case-by-case basis when both of the following criteria are met:

- Documentation is provided that sparing of the surrounding normal tissue cannot be achieved with standard radiation therapy techniques; and
- Evaluation includes a comparison of treatment plans for PBT, IMRT, and SBRT for the specific individual

Medical Records Documentation Used for Reviews

Benefit coverage for health services is determined by the member specific benefit plan document and applicable laws that may require coverage for a specific service. Medical records documentation may be required to assess whether the member meets the clinical criteria for coverage but does not guarantee coverage of the service requested; refer to the protocol titled Medical Records Documentation Used for Reviews.

Definitions

Definitive Therapy: Radiation treatments for cancer with a curative intent (Landsteiner et al., 2023).

Applicable Codes

The following list(s) of procedure and/or diagnosis codes is provided for reference purposes only and may not be all inclusive. Listing of a code in this policy does not imply that the service described by the code is a covered or non-covered health service. Benefit coverage for health services is determined by the member specific benefit plan document and applicable laws that may require coverage for a specific service. The inclusion of a code does not imply any right to reimbursement or guarantee claim payment. Other Policies and Guidelines may apply.

CPT Code	Description
77301	Intensity modulated radiotherapy plan, including dose-volume histograms for target and critical structure partial tolerance specifications
77338	Multi-leaf collimator (MLC) device(s) for intensity modulated radiation therapy (IMRT), design and construction per IMRT plan
77385	Intensity modulated radiation treatment delivery (IMRT), includes guidance and tracking, when performed; simple
77386	Intensity modulated radiation treatment delivery (IMRT), includes guidance and tracking, when performed; complex
77387	Guidance for localization of target volume for delivery of radiation treatment, includes intrafraction tracking, when performed
77520	Proton treatment delivery; simple, without compensation
77522	Proton treatment delivery; simple, with compensation
77523	Proton treatment delivery; intermediate
77525	Proton treatment delivery; complex

HCPCS Code	Description
G6015	Intensity modulated treatment delivery, single or multiple fields/arcs, via narrow spatially and temporally modulated beams, binary, dynamic MLC, per treatment session
G6016	Compensator-based beam modulation treatment delivery of inverse planned treatment using three or more high resolution (milled or cast) compensator, convergent beam modulated fields, per treatment session
G6017	Intra-fraction localization and tracking of target or patient motion during delivery of radiation therapy (e.g., 3D positional tracking, gating, 3D surface tracking), each fraction of treatment

Diagnosis Code	Description
C11.0	Malignant neoplasm of superior wall of nasopharynx
C11.1	Malignant neoplasm of posterior wall of nasopharynx
C11.2	Malignant neoplasm of lateral wall of nasopharynx
C11.3	Malignant neoplasm of anterior wall of nasopharynx

Diagnosis Code	Description
C11.8	Malignant neoplasm of overlapping sites of nasopharynx
C11.9	Malignant neoplasm of nasopharynx, unspecified
C22.0	Liver cell carcinoma
C30.0	Malignant neoplasm of nasal cavity
C31.0	Malignant neoplasm of maxillary sinus
C31.1	Malignant neoplasm of ethmoidal sinus
C31.2	Malignant neoplasm of frontal sinus
C31.3	Malignant neoplasm of sphenoid sinus
C31.8	Malignant neoplasm of overlapping sites of accessory sinuses
C31.9	Malignant neoplasm of accessory sinus, unspecified
C41.0	Malignant neoplasm of bones of skull and face
C61	Malignant neoplasm of prostate
C69.0	Malignant neoplasm of conjunctiva
C69.00	Malignant neoplasm of unspecified conjunctiva
C69.01	Malignant neoplasm of right conjunctiva
C69.02	Malignant neoplasm of left conjunctiva
C69.1	Malignant neoplasm of cornea
C69.10	Malignant neoplasm of unspecified cornea
C69.11	Malignant neoplasm of right cornea
C69.12	Malignant neoplasm of left cornea
C69.20	Malignant neoplasm of unspecified retina
C69.21	Malignant neoplasm of right retina
C69.22	Malignant neoplasm of left retina
C69.30	Malignant neoplasm of unspecified choroid
C69.31	Malignant neoplasm of right choroid
C69.32	Malignant neoplasm of left choroid
C69.40	Malignant neoplasm of unspecified ciliary body
C69.41	Malignant neoplasm of right ciliary body
C69.42	Malignant neoplasm of left ciliary body
C69.50	Malignant neoplasm of unspecified lacrimal gland and duct
C69.51	Malignant neoplasm of right lacrimal gland and duct
C69.52	Malignant neoplasm of left lacrimal gland and duct
C69.6	Malignant neoplasm of orbit
C69.60	Malignant neoplasm of unspecified orbit
C69.61	Malignant neoplasm of right orbit
C69.62	Malignant neoplasm of left orbit
C69.8	Malignant neoplasm of overlapping sites of eye and adnexa
C69.80	Malignant neoplasm of overlapping sites of unspecified eye and adnexa
C69.81	Malignant neoplasm of overlapping sites of right eye and adnexa
C69.82	Malignant neoplasm of overlapping sites of left eye and adnexa
C69.9	Malignant neoplasm of unspecified site of eye
C69.90	Malignant neoplasm of unspecified site of unspecified eye
C69.91	Malignant neoplasm of unspecified site of right eye
C69.92	Malignant neoplasm of unspecified site of left eye
D09.20	Carcinoma in situ of unspecified eye

Diagnosis Code	Description
D09.21	Carcinoma in situ of right eye
D09.22	Carcinoma in situ of left eye
D14.0	Benign neoplasm of middle ear, nasal cavity, and accessory sinuses
D16.4	Benign neoplasm of bones of skull and face
D31.30	Benign neoplasm of unspecified choroid
D31.31	Benign neoplasm of right choroid
D31.32	Benign neoplasm of left choroid
D31.40	Benign neoplasm of unspecified ciliary body
D31.41	Benign neoplasm of right ciliary body
D31.42	Benign neoplasm of left ciliary body
Q28.2	Arteriovenous malformation of cerebral vessels
Q28.3	Other malformations of cerebral vessels

Description of Services

Unlike other types of radiation therapy (RT) that use X-rays or photons to destroy cancer cells, proton beam therapy (PBT) uses a beam of special particles (protons) that carry a positive charge. There is no significant difference in the biological effects of protons versus photons; however, protons can deliver a dose of radiation in a more confined way to the tumor tissue than photons. After they enter the body, protons release most of their energy within the tumor region and, unlike photons, deliver only a minimal dose beyond the tumor boundaries [American College of Radiology (ACR) website, updated 2024].

Proton beam radiation therapy (PBRT) is intended to deliver higher, more targeted radiation with less damage to collateral healthy tissue than external beam radiation therapy (EBRT) using photons (X-rays) when used to treat solid tumors. While PBRT has been used for several solid cancer tumor types [e.g., breast, lung, prostate, head and neck, central nervous system (CNS)] in adults and in certain pediatric cancers, evidence is lacking regarding clear benefits over EBRT (ECRI, 2017).

Clinical Evidence

Proven Indications

Base of Skull Tumors

Nie et al. (2022) conducted a systematic review to analyze clinical outcomes and potential toxicities of skull base chordomas and chondrosarcomas after treatment with proton beam therapy (PBT). The review included seven, moderate- to high-quality studies, with a total of 478 individuals diagnosed with chordoma or chondrosarcoma. The follow-up time of the cohort ranged from 21 to 61.7 months. For PBT planning, the median target volume ranged from 15 cc to 40 cc, and the administered median dose varied from 63 to 78.4 gray (Gy) at 1.8 - 2.0 Gy per fraction. The one-, two-, three-, five-, and seven-year local control (LC) and overall survival (OS) rates were 100%, 93%, 87%, 78%, and 68%, and 100%, 99%, 89%, 85%, and 68%, respectively. The late grade 3 or higher toxicities were reported in only two involved articles. The authors concluded PBT demonstrated favorable LC and survival rates with a low incidence of severe radiation-induced toxicities. Limitations included lack of follow-up time longer than seven years and limited studies consisting of mostly retrospective and observational cohort studies. The authors recommended multicenter randomized controlled trials (RCTs) in the future.

In a Cochrane review, El Sayed et al. (2021) compared the effects and toxicity of proton and photon adjuvant radiation therapy (RT) in people with chordoma confirmed by biopsy. The study included six observational studies that were all judged to be at a high risk of bias; four studies were included in the meta-analysis. Adults with pathologically confirmed primary chordoma, irradiated with curative intent, with protons or photons, in the form of fractionated RT, stereotactic radiosurgery (SRS), stereotactic body radiation therapy (SBRT), or intensity-modulated radiation therapy (IMRT) were included. The primary outcomes were LC, mortality, recurrence, and treatment-related toxicity. The authors concluded there was very low-certainty evidence to show an advantage for proton therapy in comparison to photon therapy with respect to LC, mortality, recurrence, and treatment related toxicity. The authors noted that as radiation techniques evolve, multi-institutional data should be collected prospectively and published, to help identify individuals that would most benefit from the available radiation treatment techniques. Limitations included a non-randomized design and small sample sizes.

Lee et al. (2021) conducted a systematic review on proton therapy for individuals with nasopharyngeal cancer (NPC), focusing on the toxicity endpoints. A total of 491 studies were found on the topic (no randomized data), and nine studies were found to have sufficient focus and relevance to be included. Individuals with NPC were examined in all nine retrospective studies, except one, which included paranasal sinus cancer. One study was a reirradiation study. Four studies used three-dimensional (3D) or double scatter technique, while all others used intensity-modulated proton therapy. Oncologic outcomes were similar to IMRT rates, with two-year local and regional progression-free survival (PFS) ranging from 84% to 100%, two-year PFS ranging from 75% to 88.9%, and two-year OS ranging from 88% to 95% in the up-front setting. Four comparison studies with IMRT found significantly lower feeding tube rates (20% versus 65%, p = .015; and 14% versus 85%, p < .001) with proton therapy as well as lower mucositis (G2 46% versus 70%, p = .019; and G3 11% versus 76%, p = .0002). All other acute and late effects were not statistically significant but largely improved with proton therapy. The authors concluded NPC individuals maintained good outcomes with improved toxicity profile, likely due to sparing of dose to normal structures when receiving proton therapy. The authors recommended further prospective studies to better quantify the magnitude of benefit. Limitations included small number of studies, short follow-up periods, and retrospective study design.

In a Hayes technology assessment for PBT for treatment of chordoma and chondrosarcoma of the skull base, PBT was reported to be relatively safe, with a moderate risk of acute toxicities and a lower risk of long-term complications. The assessment notes that PBT has similar efficacy as photon-based EBRT technologies and may reduce the risk of certain complications in adult individuals. Additional well-designed, long-term studies comparing PBT with other therapies is recommended. The 2023 update included eleven new studies, however there was no rating change (Hayes, 2019; Updated 2023).

Zhou et al. (2018) performed a meta-analysis to compare the effectiveness of photon therapy, PBT, and carbon ion therapy for chordoma. Twenty-five studies were included, with results showing that the three-, five-, and 10-year OS rates were higher for stereotactic RT, PBT, and carbon ion therapy than for conventional RT. The 10-year OS was higher for PBT than for stereotactic RT. The analysis revealed that particle therapy was more effective following surgery for chordoma than conventional RT. After ten years, PBT was more beneficial than stereotactic RT. However, future studies should include more studies to enable accurate meta-analysis and a better exploration of prognosis.

The use of PBT to treat chondrosarcoma of the skull base after surgery is widely accepted, but studies demonstrating the need for PBT and its superiority in comparison to RT with photons are lacking. In a systematic review, Amichetti et al. (2010) reported that studies of PBT for skull-based chondrosarcoma resulted in LC ranging from 75% to 99% at five years. There were no prospective trials (randomized or non-randomized), but four uncontrolled single-arm studies with 254 individuals were included. The authors concluded that PBT following surgical resection showed a very high probability of medium- and long-term cure with a relatively low risk of significant complications.

A systematic review of seven uncontrolled single-arm studies concluded that the use of protons has shown better results in comparison to the use of conventional photon irradiation, resulting in the best long-term (10 years) outcome for skull-based chordomas with relatively few significant complications (Amichetti et al., 2009).

Clinical Practice Guidelines

American Society for Radiation Oncology (ASTRO)

ASTRO's model policy states PBT is considered reasonable in instances where sparing the surrounding tissue cannot be adequately achieved with photon-based RT and is of added clinical benefit to the individual. Disease sites that frequently support the use of PBT include tumors that approach or are located at the base of skull, including chordoma and chondrosarcomas (ASTRO, 2022).

National Comprehensive Cancer Network (NCCN)

NCCN guidelines for bone cancer states that specialized techniques, including particle beam RT with protons, should be considered as indicated in order to allow high-dose therapy while maximizing normal tissue sparing in individuals with chondrosarcoma or chordoma (NCCN, 2025).

NCCN guidelines on HNC state that use of proton therapy is an area of active investigation. In cancers of the oropharynx, nasopharynx, supraglottic larynx, paranasal sinus, salivary glands, mucosal melanoma, and other primary tumors of the head and neck, proton therapy can be considered when normal tissue constraints cannot be met by photon-based therapy or when photon-based therapy causes compromise of standard radiation dosing to tumor or postoperative volumes. Additionally, either IMRT or proton therapy is recommended for maxillary sinus or paranasal/ethmoid sinus tumors to minimize dose to critical structures (NCCN, 2024).

Hepatocellular Carcinoma (HCC)

In a systematic review and meta-analysis, Bae et al. (2024) performed a comprehensive search of multiple databases, including PubMed, Embase, and Cochrane Library, up to February 2024, in order to identify studies that reported on OS, PFS, LC, and treatment related toxicities of PBT in individuals with liver-confined HCC. The meta-analysis included data from 22 studies for a total of 1,858 individuals. Inclusion criteria were prospective or retrospective studies that treated liver-confined HCC with PBT with curative intent, studies with 10 or more subjects, and reporting of at least one endpoint of interest. Exclusion criteria were studies in which PBT applied to pediatric individuals, those with distant metastases, and individuals with a history of prior RT to the liver. The median proportion of Child-Pugh class A was 86% (range, 41-100), and the median tumor size was 3.6 cm (range, 1.2-9.0). The median total dose ranged from 55 gray-equivalent (GyE) to 76 GyE (median, 69). The pooled rates of three- and five-year local PFS after PBT were 88% and 86%, respectively. The pooled three- and five-year overall rates were 60% and 46%, respectively. The pooled rates of grade 3 hepatic toxicity, classic radiation induced liver disease, and non-classic radiation induced liver disease were 1%, 2%, and 1%, respectively. According to the authors, this study endorsed PBT for HCC, highlighting its favorable long-term survival rates and lower hepatic toxicities compared to other RT modalities. However, the authors noted additional research was necessary to pinpoint the specific individual subgroups that would most benefit from PBT. Limitations included the heterogeneity of studies and lack of RCTs. (Kim 2021, which was previously cited in this policy, is included in this review).

Parzen et al. (2021) conducted a nine-institution multicenter study to evaluate the safety and efficacy of hypofractionated PBT for HCC and intrahepatic cholangiocarcinoma (ICC). The study evaluated the prospective registry of the Proton Collaborative Group for individuals undergoing definitive PBT for liver tumors. Information compiled included demographic, clinicopathic, toxicity, and dosimetry data. Between 2013 and 2019, 63 participants were treated, 30 participants had HCC and 25 had ICC. The median dose and biological equivalent dose (BED) delivered was 58.05 GyE and 80.5 GyE, respectively. The median mean liver BED was 13.9 GyE. At least one grade ≥ 3 toxicity was experienced by three participants. With median follow-up of 5.1 months the LC rate at one year was 91.2% for HCC and 90.9% for ICC. The one-year LC was significantly higher (95.7%) for participants receiving BED greater than 75.2 GyE than for participants receiving BED of 75.2 GyE or lower (84.6%, p = 0.029). The OS rate at one year was 65.6% for HCC and 81.8% for ICC. The authors concluded hypofractionated PBT resulted in low toxicity, sparing of the uninvolved liver, and excellent LC, even in the setting of dose-escalation. The study found higher dose correlated with improved LC. Limitations included lack of comparison group and limited follow-up time.

Fukuda et al. (2017) performed an observational study to assess the long-term efficacy of PBT in individuals with previously untreated HCC. Between January 2002 and December 2009, 129 participants at a single institution received PBT via one of three protocols based on tumor location with dose volumes of 77.0 GyE in 35 fractions, 72.6 GyE in 22 fractions and 66.0 GyE in 10 fractions for the gastrointestinal (GI), hilar and standard protocols, respectively. Primary outcome measures were local tumor control (LTC), OS, and PFS. All 129 participants completed PBT without experiencing severe complications, and no treatment-related deaths were observed. The median participant observation period was 55 months. The five-year LTC, PFS, and OS rates were 94%, 28%, and 69% for participants with 0/A stage disease (n = 9/21), 87%, 23%, and 66% for participants with B stage disease (n = 34), and 75%, 9%, and 25% for participants with C stage disease (n = 65), respectively. The five-year LTC and OS rates of fifteen participants with tumor thrombi in major vessels were 90% and 34%, respectively. The major study limitation cited was the heterogeneous participant population, with most subjects selecting receiving PBT because they refused surgery or conventional interventional RT. The authors concluded that PBT achieved long term tumor control with less toxicity and is a viable treatment option for localized HCC. The authors were planning a multicenter controlled study comparing PBT and hepatectomy.

Bush et al. (2016) conducted a single-center, prospective RCT, comparing outcomes of 69 individuals with newly diagnosed HCC who received either transarterial chemoembolization (TACE) or PBT as definitive or bridge therapy while awaiting transplantation. Thirty-three subjects were randomized to PBT, and 36 subjects were randomized to TACE. Participants randomized to TACE received at least one TACE with additional TACE for persistent disease. The PBT group had proton therapy delivered to all areas of gross disease to a total dose of 70.2 Gy in 15 daily fractions over three weeks. The median follow-up for all subjects was 28 months. The primary endpoint was PFS, with secondary endpoints including OS, local disease control, transplant outcomes, and toxicity including days of hospitalization after treatment. The two-year OS for the entire group was 59%, with no significant difference between treatment assignments. Regarding LC and PFS between treatment groups, there was a trend toward improved two-year LTC (88% versus 45%, p = .06) and PFS (48% versus 31%, p = .06) favoring the PBT group. For the entire group of study subjects, 22 went on to have liver transplantation. The two-year OS after transplantation was 82% for the entire group, with no difference seen between proton and TACE groups. The authors concluded that this study indicates similar OS rates for PBT and TACE. While there was a trend toward improved LTC and PFS favoring proton therapy, it was too early to determine whether the trend will be maintained.

Hong et al. (2016) conducted a single-arm, phase II, multi-institutional study to evaluate the safety and efficacy of high-dose, hypofractionated PBT for HCC and ICC. Eighty-three participants ≥ 18 years with unresectable or locally recurrent HCC or ICC were included. With 42 HCC participants (95.5%) and 36 ICC participants (92.3%) having completed their prescribed dose, the median dose delivered was 58.0 GyE (in 15 fractions; range, 15.1 to 67.5 GyE). Of the 83 participants, 71 (85.5%) experienced at least one radiation-related toxicity event while in the study, most commonly fatigue (54/83, 65.1%), rash (51/83, 61.4%), nausea (25/83, 30.1%), or anorexia (21/83, 25.3%). Median follow-up among the 50 survivors was 19.5 months (range, 0.6 to 55.9 months). For participants with HCC, the one-year and two-year PFS rates were 56.1% and 39.9%, respectively. The one- and two-year OS was 76.5% and 63.2%, respectively. Three participants with HCC underwent successful liver transplantation, two of whom remain alive. For participants with ICC, one-year, and two-year PFS rates were 41.4% and 25.7%, respectively; with one-year and two-year OS rates of 69.7% and 46.5%, respectively. The authors concluded that high dose, hypofractionated PBT is safe and associated with high rates of LC and OS for both HCC and ICC. These data provide the strong rationale for RCTs of proton versus photon RT for HCC, and for chemotherapy with or without RT for ICC.

A phase III randomized trial comparing PBT to RFA (NCT02640924) was in progress, but the study has passed its completion date and status has not been verified in more than two years. Another clinical trial that compares protons to photons (NCT03186898) is in the recruiting stage. For more information on this and other clinical trials studying PBT and HCC, go to www.clinicaltrials.gov. (Accessed March 20, 2025)

Clinical Practice Guidelines

American Society for Radiation Oncology (ASTRO)

An ASTRO clinical practice guideline states that for individuals with HCC receiving dose-escalated ultra- or moderately hypofractionated EBRT, IMRT or proton therapy is strongly recommended, with choice of regimen based on tumor location, underlying liver function, and available technology. For individuals with unresectable IHC receiving dose-escalated ultra- or moderately hypofractionated EBRT, IMRT or proton therapy is conditionally recommended with choice of regimen based on tumor location, underlying liver function, and available technology (Apisarnthanarax et al., 2022).

National Comprehensive Cancer Network (NCCN)

NCCN guidelines state that hypofractionation with photons or protons at an experienced center is an acceptable option for unresectable intrahepatic tumors (NCCN, 2024).

Intracranial Arteriovenous Malformations (AVM)

Zuurbier et al. (2019) updated a previously conducted systematic review (Ross, 2010) that aimed to determine the effectiveness and safety of the different interventions, alone or in combination, for treating brain AVMs in adults compared against either each other, or conservative management, in RCTs. A search was conducted using the Cochrane Stroke Group Trials Register, the Cochrane Central Register of Controlled Trials, the Cochrane Library, MEDLINE, OVID and Embase OVID. The search identified fourteen eligible RCTs and of those, thirteen were excluded (ten did not meet the inclusion criteria and three were still ongoing), and one RCT with 226 participants was included (Mohr, 2013). The study titled, A Randomized trial of Unruptured Brain Arteriovenous malformations (ARUBA) was an international, multi-center, randomized, controlled, open, prospective clinical trial comparing interventional treatment (endovascular, surgical, and/or RT) to conservative management for unruptured brain AVMs in adults. The primary outcome was death or dependence from any cause (modified Rankin Scale score ≥ two), and secondary outcomes included symptomatic intracranial hemorrhage, epileptic seizure, symptomatic radiation necrosis detected by MRI, and quality of life (QOL). Data on functional outcome and death at twelve months of follow-up were provided for 218 (96%) of the participants. Intervention compared to conservative management increased death or dependency with a risk ratio (RR) of 2.53, 95% confidence interval (CI) 1.28 to 4.98, and higher proportion of participants with symptomatic intracranial hemorrhage (RR 6.75, 95% CI 2.07 to 21.96). There was no difference in the frequency of epileptic seizures (RR 1.14, 95% CI 0.63 to 2.06). The authors reported that moderate-quality evidence from one RCT (of adults with unruptured brain AVMs) showed that conservative management was superior to intervention with respect to functional outcome and symptomatic intracranial hemorrhage during the one-year period after randomization however, more RCTs are needed to confirm or refute these findings.

Blomquist et al. (2016) performed a retrospective review of 65 individuals with AVMs treated with PBT. Information collected from medical records, treatment protocols and radiological results included gender, age, presenting symptoms, clinical course, and AVM nidus size and rate of occlusion. Outcome parameters were the occlusion of the AVM, clinical outcome, and side effects. The overall rate of occlusion was 68%. For target volume zero-two cm^3 it was 77%, for three-10 cm^3 80%, for 11-15 cm^3 50% and for 16-51 cm^3 20%. Those with total regress of the AVM had significantly smaller target volumes ($p < 0.009$) higher fraction dose ($p < 0.001$) as well as total dose ($p < 0.004$) compared to the rest. The target volume was an independent predictor of total occlusion ($p = 0.03$). There was no difference between those with and

without total occlusion regarding mean age, gender distribution or symptoms at diagnosis. Mild radiation-induced brain edema developed in 41 individuals and was more common in those that had total occlusion of the AVM. Brain hemorrhage after treatment was experienced by two individuals. Two thirds of those presenting with seizures reported an improved seizure situation after treatment. The authors concluded that PBT is a treatment alternative for brain AVMs due to the high occlusion rate even in large AVMs. Limitations included the retrospective study design, lack of comparative group and small study size.

Hattangadi-Gluth et al. (2014) evaluated the obliteration rate and potential adverse events of single-fraction proton beam stereotactic radiosurgery (PSRS) in individuals with cerebral AVMs. From 1991 to 2010, 248 consecutive individuals with 254 cerebral AVMs received single-fraction PSRS at a single institution. The median AVM nidus volume was 3.5 cc, 23% of AVMs were in critical/deep locations (basal ganglia, thalamus, or brainstem) and the most common dose was fifteen Gy. At a median follow-up time of 35 months, 64.6% of AVMs were obliterated. The median time to total obliteration was 31 months, and the five- and 10-year cumulative incidence of total obliteration was 70% and 91%, respectively. On univariable analysis, smaller target volume, smaller treatment volume, higher prescription dose and higher maximum dose were associated with total obliteration. Deep/critical location was also associated with decreased likelihood of obliteration. On multivariable analysis, critical location and smaller target volume remained associated with total obliteration. Post-treatment hemorrhage occurred in thirteen cases (five-year cumulative incidence of 7%), all among individuals with less than total obliteration. Three of these events were fatal. The most common complication was seizure. The authors reported that this is the largest modern series of PSRS for cerebral AVMs and concluded that PSRS can achieve a high obliteration rate with minimal morbidity. Post-treatment hemorrhage remains a potentially fatal risk among individuals who have not yet responded to treatment.

Hattangadi et al. (2012) evaluated 59 individuals with high-risk cerebral AVMs, based on brain location or large size, who underwent planned two-fraction PSRS. Median nidus volume was 23 cc. Seventy percent of cases had nidus volume ≥ 14 cc, and 34% were in critical locations (brainstem, basal ganglia). Many individuals had prior surgery or embolization (40%) or prior PSRS (12%). The most common dose was sixteen Gy in two fractions. At a median follow-up of 56.1 months, nine individuals (15%) had total, and twenty individuals (34%) had partial obliteration. Individuals with total obliteration received higher total dose than those with partial or no obliteration. Median time to total obliteration was 62 months, and five-year actuarial rate of partial or total obliteration was 33%. Five-year actuarial rate of hemorrhage was 22% and 14% (n = eight) suffered fatal hemorrhage. Lesions with higher AVM scores were more likely to hemorrhage and less responsive to radiation. The most common complication was headache. One individual developed a generalized seizure disorder, and two had mild neurologic deficits. The authors concluded that high-risk AVMs can be safely treated with two-fraction PSRS, although total obliteration rate is low, and individuals remain at risk for future hemorrhage. Future studies should include higher doses or a multistage PSRS approach for lesions more resistant to obliteration with radiation.

Ocular Tumors

Hartsell et al. (2016) conducted a case series study to determine feasibility of treating individuals with ocular melanoma using volumetric imaging and planning for PBT. Twenty-six subjects met eligibility criteria, and all were able to complete and tolerate treatment. Visual outcomes were assessed on routine ophthalmologic follow-up over a median time frame of 31 months. Four subjects had poor vision in the treated eye prior to PBT; three of those four subjects had serous retinal detachment prior to treatment. None of those subjects had significant improvement in visual acuity after treatment. Of the remaining 22 subjects, nine had visual acuity equal to pre-treatment acuity at the most recent follow-up visit, four had stable vision with a loss of two to five lines on the Snellen chart, and eight subjects had lost more than five lines of visual acuity. The visual acuity status for one subject was unknown prior to his death from metastatic melanoma. The treatment was well tolerated by subjects with minimal acute toxicity. Relatively low mean doses to the anterior structures (ciliary body and lens) were maintained, even in subjects with large tumors. The authors concluded that while they continue evaluating outcomes of these individuals in a prospective manner, this treatment technique appeared to be feasible with excellent early outcomes.

Verma and Mehta (2016c) conducted systematic review to identify studies on PBT and uveal melanoma. The search was conducted using PubMed, EMBASE, abstracts from meetings of the American Societies for Radiation Oncology and Clinical Oncology, and the Particle Therapy Co-Operative Group. Articles included addressed clinical outcomes of proton RT for ocular melanoma with the following headings: proton, proton RT, proton beam therapy, ocular melanoma, uveal melanoma, choroidal melanoma, eye melanoma, and were published from 2000 to 2015. Articles excluded were those without specific assessments on clinically relevant outcomes of proton RT for previously untreated melanoma of the eye, letters to the editor, direct commentary to other articles, and small reports (< 25 individuals). A total of fourteen original investigations from 10 institutions were analyzed. Results revealed that the majority of tumors were choroidal and medium to large-sized, and received 50-70 Gy equivalent doses however, more recent data reported use of lower doses. The five-year LC rates exceeded 90% and remained high at fifteen years. The five-year OS rates ranged from 70-85%, and five-year metastasis-free survival and disease-specific survival rates ranged from 75-90%, with more recent series reporting

higher values. With the removal of smaller studies, five-year enucleation rates were consistently between seven and ten percent. Many individuals (60-70%) showed a post-PBT visual acuity decrease but still retained purposeful vision (> 20/200). Complication rates were variable but showed improvements compared with historical plaque brachytherapy data. The authors concluded that PBT has shown excellent oncological and ophthalmological outcomes, and these have been sustained in the long-term.

Clinical Practice Guidelines

American Society for Radiation Oncology (ASTRO)

ASTRO's model policy states PBT is considered reasonable in instances where sparing the surrounding tissue cannot be adequately achieved with photon-based RT and is of added clinical benefit to the individual. Disease sites that frequently support the use of PBT include treatment of ocular tumors, including intraocular melanomas (2022).

National Comprehensive Cancer Network (NCCN)

In the NCCN guidelines on uveal melanoma, particle beam therapy is noted as a common form of definitive RT for the primary tumor. It is considered appropriate as an upfront therapy after initial diagnosis, after margin-positive enucleation, or for intraocular or orbital recurrence. It should be performed by an experienced multidisciplinary team including an ophthalmic oncologist, radiation oncologist, and particle beam physicist (NCCN, 2024).

Prostate Cancer

An ECRI Clinical Evidence Assessment for PBT and localized prostate cancer concluded PBT is relatively safe for treatment of prostate cancer; however, it is unclear whether PBT is more effective than photon EBRT or brachytherapy, or has fewer adverse effects or complications (ECRI, 2022).

Liu et al. (2021) performed a national database study comparing the effect of PBT on OS compared to photon-based EBRT and brachytherapy in individuals with localized prostate cancer. Men (n = 276,880) with clinical stage T1–3, N0, M0 prostate cancer treated with radiation, without surgery, or chemotherapy, between the years of 2004-2015 were included. A total of 4900 (1.8%) received PBT, while 158,111 (57.1%) received photon-based EBRT and 113,869 (41.1%) brachytherapy. Compared to EBRT and brachytherapy, PBT individuals were younger and were less likely to be in the high-risk group. On multivariable analysis, compared to PBT, men had worse OS after EBRT or brachytherapy. After propensity score matching, the OS benefit of PBT remained significant compared to EBRT but not brachytherapy. The improvement in OS with PBT was most prominent in men ≤ 65 years old with low-risk disease compared to other subgroups (interaction $p < .001$). The median follow-up time was 80.9 months. The authors concluded PBR had similar outcomes to brachytherapy but was associated with more favorable OS than EBRT. Limitations include the retrospective nature of the study. The authors encourage future prospective comparative clinical trials to further define the role of PBT in the treatment of localized prostate cancer.

Vapiwala et al. (2021) conducted a multi-institutional analysis that compared late toxicity profiles of individuals with early-stage prostate cancer treated with moderately hypofractionated PBT and IMRT. The study included subjects (n = 1850) with low- or intermediate-risk biopsy-proven prostate adenocarcinoma treated from 1998 to 2018. The subjects were treated with moderately hypofractionated radiation, defined as 250 to 300 cGy per daily fraction given for four to six weeks, and stratified by use of IMRT or PBT. Late genitourinary (GU) and GI toxicity were the primary outcomes. Adjusted toxicity rates were calculated using inverse probability of treatment weighting, accounting for race, NCCN risk group, age, pretreatment International Prostate Symptom Score (GU only), and anticoagulant use (GI only). Of the 1850 subjects included, 1282 had IMRT and 568 had PBT. The majority of subjects experienced no late GU or GI toxicity, with late grade 3 + GU toxicity of 2.0% versus 3.9% and late grade 2 + GI toxicity of 14.6% versus 4.7% for the PBT and IMRT cohorts, respectively. Only anticoagulant use was significantly predictive of GI toxicity and no factors were significantly predictive of GU toxicity. The authors concluded that treatment with moderately hypofractionated IMRT and PBT resulted in low rates of toxicity in individuals with early-stage prostate cancer. No difference was seen in late GI and GU toxicity between the modalities during long-term follow-up and both treatments were well tolerated and safe.

A Hayes report assessed 20 studies, including four RCTs, two prospective cohort studies, two retrospective registry analysis studies, and twelve retrospective comparative or case-matched cohort studies that evaluated the efficacy and safety of PBT in individuals with localized or locally advanced prostate cancer. The report concludes that the best available studies of PBT for localized prostate cancer have consistently found that most or nearly all individuals remain free from cancer progression for five years or longer after treatment. These results are promising but none of the reviewed studies assessed the efficacy of PBT as the sole or primary therapy for prostate cancer relative to the efficacy of other common methods of RT. Ten of the reviewed studies found that the safety of PBT as sole or primary therapy was usually similar to the safety of other common RT; however, these studies are of low quality since they were retrospective. Moreover, these ten studies do not provide sufficient evidence of comparative safety since they were divided between

evaluations of PBT relative to brachytherapy, conformal X-ray therapy, and IMRT. The other available studies do not provide clear evidence concerning the relative safety and efficacy of PBT for prostate cancer since these other studies evaluated it as an adjunct to X-ray therapy or did not compare it with another common RT. Additional well-designed studies are needed to establish the clinical role of PBT relative to other widely used therapies for localized prostate cancer. The 2023 updated annual review included seven newly published studies, however, there was no change in the current rating (2020, updated 2023).

Santos et al. (2019) compared acute and late GU and GI toxicity outcomes in individuals with prostate cancer who received treatment with postprostatectomy IMRT versus PBT. Individuals with prostate cancer who received adjuvant or salvage IMRT or PBT (70.2 gray with an endorectal balloon) after prostatectomy from 2009 through 2017 were reviewed. A case-matched cohort analysis was performed using nearest-neighbor three-to-one matching by age, and GU/GI disorder history. The Kaplan-Meier method was used to assess toxicity-free survival (TFS). Seventy matched pairs were generated from the 307 men identified (IMRT, n = 237, PBT, n = 70). The median follow-up was 48.6 and 46.1 months for the IMRT and PBT groups, respectively. While PBT was superior at reducing low-range (volumes receiving 10% to 40% of the dose, respectively) bladder and rectal doses (all $p \leq .01$), treatment modality was not associated with differences in clinician-reported acute or late GU/GI toxicities (all $p \geq .05$). Five-year grade ≥ 2 GU and grade ≥ 1 GI TFS was 61.1% and 73.7% for IMRT, respectively, and 70.7% and 75.3% for PBT, respectively; and five-year grade ≥ 3 GU and GI TFS was > 95% for both groups (all $p \geq .05$). The authors concluded that postprostatectomy PBT minimized low-range bladder and rectal dose relative to IMRT; however, treatment modality was not associated with clinician-reported GU/GI toxicities. The authors recommended future prospective studies and on-going follow-up to determine whether dosimetric differences between IMRT and PBT lead to clinically meaningful differences in long-term outcomes. Limitations include lack of randomization and retrospective study design.

Several single-institution studies report favorable clinical outcomes of PBT in prostate cancer. Henderson et al. (2017) reported five-year outcomes of a prospective trial of image-guided accelerated hypofractionated proton therapy (AHPT) for prostate cancer from a single institution. Late radiation adverse events/toxicities and freedom from biochemical and/or clinical progression (FFBP) were the outcome measurements for the 215 participants categorized as low and intermediate risk. Median follow-up was 5.2 years, with FFBP rates overall noted at 95.9%. For the subsets of low and intermediate risk, FFBP was 98.3% and 92.7%, respectively. Actuarial five-year rates of significant (≥ grade 3) late radiation-related GI adverse events/toxicities were 0.5%, and 1.7% for GU adverse events.

Bryant et al. (2016) performed a single-center study on 1,327 men with localized prostate cancer who received image guided PBT between 2006-2010. The five-year FFBP rates were 99% for low-risk, 94% for intermediate-risk, and 76% for high-risk individuals. The authors concluded that PBT provided excellent control of disease with low rates of GU/GI toxicity. Large prospective comparative studies with longer follow-up times are necessary for a true comparison between PBT and other types of RT.

In a case-matched analysis, Fang et al. (2015) assessed prospectively collected toxicity data on participants with localized prostate cancer who received treatment with IMRT and PBT techniques and similar dose-fractionation schedules. A total of 394 participants were treated with either PBT (n = 181) or IMRT (n = 213). Participants were case matched on risk group, age and prior GI and GU disorders, resulting in 94 matched pairs. The risks of acute and late GI/GU toxicities did not differ significantly after adjustment for confounders and predictive factors.

Mendenhall et al. (2014) reported five-year clinical outcomes from three prospective trials of image-guided PBT for prostate cancer conducted at a single institution. From August 2006-September 2007, 211 participants (low risk n = 89, intermediate risk n = 82, and high-risk n = 40) were enrolled in one of the three trials. Dosages delivered were 78 cobalt gray equivalents (CGE) for low risk and 78 to 82 CGE for intermediate risk. Participants with high-risk disease received 78 CGE with weekly concomitant chemotherapy, followed by six months of androgen deprivation therapy. Five-year OS of 93%, 88%, and 86% were reported for low, intermediate, and high-risk participants, respectively. Freedom from biochemical and/or clinical progression rates for the same time period were 99% for both low and intermediate risk and 76% for high-risk participants. There was a single instance of acute grade 3 GU toxicity. One acute grade 3 and two late grade 3 GI events throughout the entire group resulted in a five-year incidence of 1%. Limitations to this study include overall study design and lack of a control group. The authors concluded that image-guided PBT was highly effective with minimal toxicities. While outcomes were favorable, the lack of control group limited interpretation of the studies and did not allow assessment of PBT outcomes compared to other forms of RT.

Yu et al. (2013) conducted a retrospective cohort analysis using data from the Chronic Condition Warehouse, a national database for Medicare fee-for-service claims from individuals with specific conditions. The investigators identified individuals who were age 66 and older with prostate cancer and treated with IMRT or PBT. To evaluate toxicity, each individual who received PBT was matched with two individuals who received IMRT based on similar sociodemographic

and clinical characteristics. Toxicity was reported at six months post-treatment and included 421 individuals who received PBT matched to 842 individuals who received IMRT, and at twelve months post-treatment and included 314 individuals who received PBT matched to 628 individuals who received IMRT. At six months, GU toxicity was significantly lower in individuals who received PBT vs. IMRT (5.9% vs. 9.5%; OR = 0.60, 95% CI = 0.38 - 0.96, p = 0.03). However, there was no difference at twelve months post-treatment (18.8% vs. 17.5%; OR = 1.08, 95% CI = 0.76 - 1.54, p = 0.66). At six months and twelve months post-treatment, there was no difference in GI or other toxicities. The authors concluded that in a national sample of Medicare beneficiaries, individual who were treated with IMRT or PBT for prostate cancer had no difference in toxicity rates at twelve months post-treatment, and that additional longitudinal studies evaluating the effectiveness of PBT in comparison to IMRT are needed prior to widespread use of PBT for prostate cancer.

Sheets et al. (2012) evaluated the comparative morbidity and disease control of IMRT, PBT and conformal RT for primary prostate cancer treatment. Main outcomes were rates of GI and GU morbidity, erectile dysfunction, hip fractures, and additional cancer therapy. In a comparison between IMRT and conformal RT (n = 12,976), men who received IMRT were less likely to experience GI morbidity and fewer hip fractures, but more likely to experience erectile dysfunction. IMRT individuals were also less likely to receive additional cancer therapy. In a comparison between IMRT and PBT (n = 1,368), IMRT individuals had a lower rate of GI morbidity. There were no significant differences in rates of other morbidities or additional therapies between IMRT and PBT.

Several large population-based cohort studies using Surveillance Epidemiology and End Results (SEER) data, have found greater GI toxicity with PBT than IMRT. Kim et al. (2011) reported that individuals treated with RT are more likely to have procedural interventions for GI toxicities than individuals with conservative management, and individuals treated with PBT therapy experienced greater GI morbidity relative to IMRT individuals. The elevated risk persisted beyond five years.

To further elucidate the clinical advantages and disadvantages between various types of RT used in prostate cancer, additional clinical trials are underway (NCT01617161, NCT00969111, and NCT03561220). For more information, go to www.clinicaltrials.gov. (Accessed March 20, 2025)

Clinical Practice Guidelines

American Urological Association (AUA)/American Society for Radiation Oncology (ASTRO)

In a 2022 systematic review, the AUA and ASTRO developed a clinical guideline regarding localized prostate cancer. This guideline was endorsed by the Society of Urologic Oncology (SUO). Individuals with clinically localized prostate cancer, defined as up to clinical stage T3 prostate cancer without nodal or distant metastasis (N0M0) on conventional imaging, were the target population. The guideline conditionally recommended proton therapy as a treatment option for prostate cancer but states it had not been found to be superior to other radiation modalities in terms of cancer outcomes or toxicity profile (Eastham et al., 2022).

National Comprehensive Cancer Network (NCCN)

The NCCN Panel believes that photon and PBRT are both effective at achieving highly conformal RT with acceptable and similar biochemical control and long-term side effect profiles for individuals with prostate cancer. No clear evidence supports a benefit or decrement of one treatment over another. Conventionally fractionated PBT can be considered a reasonable alternative to X-ray-based regimens at clinics with appropriate technology, physics, and clinical expertise (NCCN, 2024).

Unproven Indications

Quality evidence in peer-reviewed medical literature evaluating PBRT for the following indications is limited. Future robust RCTs are warranted along with long-term outcomes to establish the safety and efficacy of this treatment.

Age-Related Macular Degeneration (AMD)

Evans et al. (2020) updated a previously conducted systematic review (Evans, 2010) that examined the effects of RT on neovascular AMD. A search was conducted using CENTRAL, MEDLINE, Embase, LILACS and three trials registers for RCTs in which RT was compared to another treatment, sham treatment, low dosage irradiation or no treatment in people with choroidal neovascularization (CNV) secondary to AMD. Outcomes included best-corrected visual acuity (loss of three or more lines, change in visual acuity), contrast sensitivity, new vessel growth, QOL and adverse effects at any time point. A total of eighteen studies (n = 2,430 people, 2,432 eyes) were included, and the RT with dosages ranging from 7.5 to 24 Gy. Three of these studies investigated brachytherapy (plaque and epimacular), the rest were studies of EBRT including one trial of stereotactic RT. The authors concluded that the evidence is uncertain regarding the use of RT for neovascular AMD. They stated that: 1) most studies took place before the routine use of anti-vascular endothelial growth factor (anti-VEGF), and before the development of modern RT techniques such as stereotactic RT; 2) visual outcomes with

epimacular brachytherapy are likely to be worse, with an increased risk of adverse events, probably related to vitrectomy; 3) the role of stereotactic RT combined with anti-VEGF is currently uncertain; and 4) further research on RT for neovascular AMD may not be justified until current ongoing studies have reported their results.

In a systematic review, Bekkering et al. (2009) evaluated the effects and side effects of PBT for indications of the eye. All studies that included at least ten individuals and that assessed the efficacy or safety of PBT for any indication of the eye were included. Five controlled trials, two comparative studies and 30 case series were found, most often reporting on uveal melanoma, choroidal melanoma, and AMD. Methodological quality of these studies was poor. Studies were characterized by large differences in radiation techniques applied within the studies, and by variation in individual characteristics within and between studies. Results for uveal melanoma and choroidal melanoma suggest favorable survival, although side effects are significant. Results for choroidal hemangioma and AMD did not reveal beneficial effects from proton radiation. There is limited evidence on the effectiveness and safety of due to the lack of well-designed and well-reported studies.

A RCT by Zambarakji et al. (2006) studied 166 individuals with angiographic evidence of classic CNV resulting from AMD and best-corrected visual acuity of 20/320 or better. Participants were assigned randomly (1:1) to receive 16-CGE or 24-CGE PBT in two equal fractions. Complete ophthalmological examinations, color fundus photography, and fluorescein angiography were performed before and three, six, twelve, eighteen, and 24 months after treatment. At twelve months after treatment, 36 eyes (42%) and 27 eyes (35%) lost three or more lines of vision in the 16-CGE and 24-CGE groups, respectively. Rates increased to 62% in the 16-CGE group and 53% in the 24-CGE group by 24 months after treatment. Radiation complications developed in 15.7% of participants receiving 16-CGE and 14.8% of participants receiving 24-CGE. The authors concluded that no significant differences in rates of visual loss were found between the two dose groups.

Clinical Practice Guidelines

American Academy of Ophthalmology (AAO)

AAO preferred practice patterns state that RT has insufficient data to demonstrate clinical efficacy and is not recommended in the treatment of AMD (Flaxel et al., 2019).

Bladder Cancer

Araya et al. (2023) performed a registry data analysis designed to assess the safety and efficacy of PBT for individuals (n = 36) with muscle-invasive bladder cancer (cT2-4aN0M0) who received PBT with concurrent chemotherapy. Additionally, a systematic review was performed that compared PBT with photon RT. Individuals underwent radiation to the entire bladder or pelvic cavity using photon or proton beams followed by a boost to all tumor sites in the bladder along with either Cisplatin alone, or in combination with Methotrexate, or Gemcitabine. Overall survival, PFS and LC rates were 90.8, 71.4 and 84.6%, respectively, after three years. Only one case (2.8%) experienced a treatment-related late adverse event of Grade 3 urinary tract obstruction, and no severe GI adverse events occurred. According to the findings of the systematic review, the three-year outcomes of photon RT were 57 - 84.8% in OS, 39 - 78% in PFS and 51 - 68% in LC. The weighted mean frequency of adverse events of Grade 3 or higher in the GI and GU systems was 6.2 and 2.2%, respectively. The authors concluded PBT is expected to have the same toxicity as photon based combined modality therapy for stages II-III muscle-invasive bladder cancer. The authors note that data from long-term follow-up is needed to validate efficacy. Limitations included short-term follow-up and small sample sizes. The Takaoka et al. (2017) retrospective review is included in this systematic review.

Takaoka and colleagues (2017) conducted a retrospective review to assess outcomes, prognostic factors, and toxicities of PBT as a component of trimodal bladder-preserving therapy for muscle-invasive bladder cancer. Trimodal bladder-preserving therapy consisted of maximal transurethral resection of the bladder tumor, small pelvis (conventional) photon radiation, intra-arterial chemotherapy and PBT. Seventy individuals with cT2-3N0M0 muscle-invasive bladder cancer were included who received treatment from 1990 to 2015 at a single institution. The OS and PFS rate, time to progression, predictive factors for progression and toxicities were analyzed. Progression was defined as when muscle-invasive recurrence, distant metastasis or upper urinary tract recurrence was observed. The individuals' median age was 65 (range 36 - 85) years. The median follow-up period was 3.4 years (range 0.6 -19.5 years). The five-year cumulative OS rate, PFS rate and time to progression rate were 82%, 77%, and 82%, respectively. In univariate and multivariate analyses, tumor multiplicity and tumor size (≥ 5 cm) were significant and independent factors associated with progression (hazard ratio 3.5, 95% CI 1.1 - 12; hazard ratio 5.0, 95% CI 1.3 - 17; $p < 0.05$ for all). As for toxicity, 26 (18%) individuals had grade 3-4 acute hematologic toxicities, and two (3%) individuals had grade 3 late GU toxicity. No individual had to discontinue the treatment due to acute toxicity. The authors concluded that trimodal therapy including both conventional and proton radiation was well tolerated and may be an effective treatment option for selected muscle-invasive bladder cancer individuals. Further studies are needed to determine whether PBT is integral to this multi-modality therapy.

Miyanaga et al. (2000) conducted a small prospective uncontrolled clinical study to assess the efficacy and safety of PBT and/or conventional photon therapy for bladder cancer. The study involved 42 participants who received PBT to the small pelvic space following intra-arterial chemotherapy. At five-year follow-up, the bladder was preserved in 76% of participants and 65% were free of disease. The disease-specific survival rate was 91%. Participants with large and multiple tumors were more at risk of cancer recurrence than participants with single, small tumors. Nausea and vomiting, irritable bladder and ischialgia were the main side effects.

Clinical Practice Guidelines

National Comprehensive Cancer Network (NCCN)

NCCN guidelines do not address the use of PBT for treating bladder cancer (NCCN, 2024).

Brain and Spinal Cord Tumors

The systematic review by Goliot et al. (2024) focused on evaluating outcomes and toxicities related to PBT for treating adult-type diffuse gliomas. The review analyzed various studies to compare PBT with conventional RT in terms of survival outcomes, toxicity, and dosimetry. Preclinical studies, study protocols, reviews, case reports, letters, editorials, and meta-analyses were excluded from the review. Twelve studies from 2013 to 2023 were selected, consisting of three prospective and nine retrospective studies. The analysis covered 570 individuals with WHO grade 2 - 3 gliomas and 240 individuals with glioblastoma or WHO grade 4 gliomas. Proton therapy was found to be comparable to conventional RT in terms of survival outcomes. Its main advantage is the ability to minimize radiation exposure to healthy tissues. The authors concluded PBT provided survival outcomes similar to those of conventional RT for adult diffuse gliomas and may improve treatment tolerance, particularly in terms of neurocognitive function, with most individuals experiencing only grade 1 toxicity. The authors noted a significant limitation of this review is the heavy reliance on retrospective studies; future randomized trials with extended follow-up periods were recommended to validate the therapeutic potential of PBT.

Petr et al. (2018) assessed structural and hemodynamic changes of healthy brain tissue in the cerebral hemisphere contralateral to the tumor following conventional (photon) and proton radiation with concurrent chemotherapy. Sixty-seven adult individuals diagnosed with glioblastoma undergoing adjuvant conventional (n = 47) or proton (n = 19) RT with temozolomide after tumor resection underwent T1-weighted and arterial spin labeling magnetic resonance imaging. Changes in volume and perfusion before and three to six- months after were compared between therapies. A decrease in gray matter (GM) and white matter (WM) volume was observed in individuals receiving conventional radiation compared to the pre-RT baseline. In contrast, for the proton therapy group, no significant differences in GM or WM volume were observed. GM volume decreased with 0.9% per 10 Gy dose increase and differed between the radiation modalities. Perfusion decreased in conventional RT individuals, whereas the decrease in proton therapy individuals was not statistically significant. There was no correlation between perfusion decrease and either dose or radiation modality. The authors concluded that proton therapy may reduce brain volume loss compared to photon therapy, with decrease in perfusion being comparable for both modalities. As this was an uncontrolled retrospective study with a surrogate endpoint (brain volume loss on imaging), prospective randomized trials are needed to compare the effect of proton and conventional radiotherapy on imaging and clinical outcomes.

Kabolizadeh et al. (2017) conducted a single-center, retrospective, case series to evaluate LC, OS, disease-specific survival, and distant failure in 40 individuals with unresected chordoma and treated with photon/proton RT. Tumor response was assessed using the modified Response Evaluation Criteria in Solid Tumors (mRECIST). To characterize tumor response the soft tissue and bone compartments of the tumor were defined separately as the soft tissue target volume, bone target volume and combined total target volume. Twenty-seven individuals had sacrococcygeal chordoma, and the remaining individuals had mobile spine tumors, which included nine cervical, one thoracic, and three lumbar. Thirty-nine individuals underwent proton therapy only or predominantly proton therapy mixed with photons to limit the radiation dose to adjacent critical normal structures. Only four individuals received either concurrent or neoadjuvant systemic treatments. The median age was 67 years (range, 36 - 94 years) and median follow-up, after completion of RT, was 50.3 months (range, two - 216.4 months). At five-years, LC, OS, disease-specific survival, and distant failure were 85.4%, 81.9%, 89.4%, and 20.2%, respectively. Nineteen individuals had complete sets of regular imaging scans (a total of 84 CT and MRI scans were reviewed) and of those, only four local failures had occurred at 34, 46, 78 and 82 months after treatment. The authors concluded that their results supported the use of high-dose definitive RT in select individuals with unresected spine and sacral chordomas, and that soft tissue target volume is the best indicator of tumor response. Limitations of this study included its design, the small number of individuals with local failure, and limited follow-up periods.

Indelicato et al. (2016) conducted descriptive analysis using data from a single institution. In this prospective case series study, researchers sought to evaluate the effectiveness of definitive or adjuvant external beam proton therapy in individuals with chordomas and chondrosarcomas of the spine. Outcomes of interest included distant metastases, OS,

cause-specific survival, LC, and disease-free survival. A total of 51 individuals participated with a median age of 58 years (range, 22 - 83 years) and median follow-up of 3.7 years (range, 0.3 - 7.7 years). There were 34 individuals with chordomas, and seventeen individuals with chondrosarcomas, which were all grade 2 or higher. The anatomic distribution was as follows: sacrum (n = 21), cervical spine (n = 20), and thoracolumbar spine (n = 10). The median dose of RT was 70.2 Gy (range, 64.2 - 75.6 Gy). The four-year LC, freedom from distant metastases, disease-free survival, cause-specific survival, and OS rates were 58%, 86%, 57%, 72%, and 72%, respectively. A total of 25 individuals experienced disease recurrence: eighteen local recurrences, six local and distant recurrences, and one distant metastases. In individuals with a local relapse, the median time to progression was 1.7 years (range, 0.2 - six years). The median survival after local progression was 1.7 years (range, 0.1 - 4.9 + years). Regression analysis results showed that younger individuals had a significantly higher risk for local reoccurrence and that individuals whose initial management was only surgery also had a higher rate of reoccurrence however, these individuals may represent a high-risk subset. The authors concluded that high-dose proton therapy controls more than half of spinal chordomas and chondrosarcomas and compares favorably with historic photon data. Local progression is the dominant mode of treatment failure, and it may be reduced by treating individuals at the time of initial diagnosis. Limitations of this study included its design, small sample size, and small number of select events, which may have impacted the statistical validity of the regression analysis results.

Shih et al. (2015) conducted a prospective single arm trial to evaluate potential treatment toxicity and PFS in individuals (n = 20) with low-grade glioma who were treated with PBRT. Individuals with World Health Organization (WHO) grade 2 glioma who were eligible for RT were enrolled in the study. All individuals received proton therapy at a dose of 54 Gy in 30 fractions. Baseline and regular post-treatment evaluations of neuroendocrine function, QOL, and neurocognitive function were performed. PBRT was tolerated without difficulty by all twenty individuals. The median follow-up after proton therapy was 5.1 years. Intellectual functioning was within the normal range for the group at baseline and remained stable over time. Executive functioning, attention/working memory, and visuospatial ability also were within normal limits; however, eight individuals had baseline neurocognitive impairments observed in language, memory, and processing speed. There was no overall decline in cognitive functioning over time. New endocrine dysfunction was detected in six individuals, and all but one had received direct irradiation of the hypothalamic-pituitary axis. No changes were noted in QOL over time. The PFS rate at three years was 85% but fell to 40% at five years. The authors concluded individuals with low-grade glioma tolerate proton therapy well, and a subset develops neuroendocrine deficiencies. Additionally, there was no evidence for overall decline in QOL or cognitive function. The authors recommended larger studies that include the integration of standardized, contemporary chemotherapy regimens with randomization of proton versus photon therapy to characterize potential differences in radiation late effects. Limitations of this study included small sample size, lack of comparative group and randomization.

Noel et al. (2002) conducted a retrospective review of seventeen individuals with meningioma to evaluate the efficacy and the tolerance of an escalated dose of external conformal fractionated RT combining photons and protons. Five individuals presented a histologically atypical or malignant meningioma, twelve individuals had a benign tumor that was recurrent or rapidly progressive. In two cases, RT was administered in the initial course of the disease and in fifteen cases at the time of relapse. A highly conformal approach was used combining high-energy photons and protons for approximately 2/3 and 1/3 of the total dose. The median total dose delivered within gross tumor volume was 61 CGEs (25 - 69). Median follow-up was 37 months (17 - 60). The four-year LC and OS rates were 87.5 +/- 12% and 88.9 +/- 11%, respectively. Radiologically, there were eleven stable diseases and five partial responses. The authors concluded that in both benign and more aggressive meningiomas, the combination of conformal photons and protons with a dose escalated by 10 - 15% offers clinical improvements in most individuals as well as radiological long-term stabilization. Limitations of this study included small sample size and study design.

Several clinical trials studying PBT in individuals with various types of brain tumors are active or recruiting. For more information, go to www.clinicaltrials.gov. (Accessed March 20, 2025)

Clinical Practice Guidelines

American Society for Radiation Oncology (ASTRO)

ASTRO's guideline regarding RT for IDH-mutant WHO grade 2 and grade 3 diffuse glioma conditionally recommends proton therapy as an option to reduce acute and late toxicity, especially for tumors located near critical organs at risk (OARs) (Halasz et al., 2022).

National Comprehensive Cancer Network (NCCN)

NCCN guidelines for CNS cancers states that when toxicity is a concern during management of spinal ependymoma or medulloblastoma in adults, PBRT should be considered if available. Highly conformal fractionated RT techniques may be conditionally considered for meningiomas to spare critical structures and uninvolved tissue. Proton therapy for individuals with good long-term prognosis to better spare uninvolved brain and preserve cognitive function may be conditionally

considered for anaplastic gliomas/glioblastoma high-grade and astrocytoma IDH-Wild Type. Preliminary data suggest that proton therapy could reduce the radiation dose to developing brain tissue and potentially diminish toxicities without compromising disease control. For leptomeningeal metastases, the volume and dose are determined by the primary tumor's histology and the care objectives. For craniospinal irradiation (CSI) in individuals with metastatic solid tumors, techniques that maximize bone marrow sparing, such as using protons when available or conformal photon-based techniques/IMRT may be considered (NCCN, 2024).

Breast Cancer

Holt et al. (2023) conducted a systematic review and meta-analysis aimed to evaluate the clinical outcomes of adjuvant PBT for early breast cancer, comparing it to standard photon RT. A total of 32 studies published between 2000 and 2022, involving 1452 individuals with early breast cancer were analyzed. Scattering PBT was delivered in seven studies (258 individuals) starting 2003 - 2015 and scanning PBT in 22 studies (1041 individuals). Two studies used both types. Adverse events were less severe after scanning than after scattering PBT. They also varied by clinical target. For partial breast PBT, 498 adverse events were reported (eight studies, 358 individuals). None were categorized as severe after scanning PBT. For whole breast or chest wall +/- regional lymph nodes PBT, 1344 adverse events were reported (19 studies, 933 individuals). After scanning PBT, 4% (44/1026) of events were severe. The most prevalent severe outcome after scanning PBT was dermatitis which occurred in 5.7% (95% CI 4.2 - 7.6) of individuals. Other severe adverse outcomes included infection, pain, and pneumonitis (each ≤ 1%). Of the 141 reconstruction events reported (13 studies, 459 individuals), the most prevalent after scanning PBT was prosthetic implant removal (34/181, 19%). There were no RCTs that directly compared PBT with photon RT. The authors concluded that PBT shows promise in reduction of adverse events and providing better dose distributions for early breast cancer. However, the authors recommended future, high-quality RCTs with longer follow-ups to establish the efficacy and safety of PBT compared to standard photon RT. Limitations included lack of randomized trials, heterogeneity of studies, and short follow-up periods. (DeCesaris 2019, Verma 2017, and Bradley 2016, which were previously cited in this policy, are included in this review).

A Hayes Technology Assessment related to PBT for breast cancer treatment states the overall body of evidence is low in quality but suggests PBT is relatively safe and potentially effective for the treatment of non-metastatic breast cancer. A small number of studies compared conventional radiation with PBT and found better QOL, disease control, and safety outcomes with PBT. The assessment suggests additional studies are required to evaluate the effectiveness and safety of PBT compared to other forms of conventional RT in individuals with breast cancer without distant metastasis. The updated 2023 assessment included two newly published studies that met the original inclusion criteria but resulted in no change to the current Hayes rating (Hayes, 2022; updated 2023).

Verma et al. (2016a) performed a systematic review of clinical outcomes and toxicity of PBT for treating breast cancer. Nine original studies were analyzed, however the types of studies and the volume of individuals in those studies were not specifically cited by the authors. Conventionally fractionated breast/chest wall PBT produced grade 1 dermatitis rates of approximately 25% and grade 2 dermatitis in 71% - 75%. This is comparable or improved over the published rates for photons. The incidence of esophagitis was decreased if the target coverage was compromised in the medial supraclavicular volume, a finding that echoes previous results with photon RT. From the limited available data, the rate of grade 2 esophagitis ranged from 12% to 29%. Using PBT-based accelerated partial breast irradiation, the rates of seroma/hematoma and fat necrosis were comparable to those reported in the existing data. Radiation pneumonitis and rib fractures remain rare. PBT offers the potential to minimize the risk of cardiac events, keeping the mean heart dose at ≤ one Gy. However, definitive clinical experiences remain sparse. Results from clinical trials in progress, comparing protons to photons, will further aid in providing conclusions. Limitations to this review included a general lack of data and low number of participants in the available studies.

Cuaron et al. (2015) conducted a single-institution case series study to report dosimetry and early toxicity data in individuals with breast cancer. Retrospectively collected data from consecutive individuals diagnosed with non-metastatic breast cancer, no prior history of chest wall radiation and treated with PBT postoperatively were studied. Individuals with unfavorable cardiopulmonary anatomy were usually referred to this institution. Post-lumpectomy individuals with large breast size were not offered treatment due to a higher propensity for day-to-day measurement differences in the target position. Individuals were evaluated weekly while on RT, four weeks after RT was completed, and at 12 to 24-week intervals thereafter. Toxicity was recorded using the Common Terminology Criteria for Adverse Events (CTCAE, v4.0). A total of 30 women were included in the study with a median age of 49 years (range, 29 - 86 years), cancer staging was as follows: eight had stage II, twenty had stage III and two had chest wall recurrence. The median follow-up was 9.3 months (range, 2.3 - 18.6 months). With PBT, full coverage of the planned target value was achieved, and it significantly spared the heart, lungs, and contralateral breast. Of those with greater than three months of follow-up (n = 28), 71.4% developed grade 2 dermatitis and of those, 28.6% experienced moist desquamation. Eight (28.6%) developed grade 2 esophagitis and one developed grade 3 reconstructive complications. The authors concluded that in this series of 30 individuals, PBT achieved excellent coverage of the target volume while sparing the heart, lungs, and contralateral breast, that the

treatment was well tolerated, and that additional studies assessing long-term outcomes and toxicity are needed. Limitations of this study include its design, exclusion of women with large breast size, and higher toxicity rates compared with other forms of RT, e.g., IMRT.

Bush et al. (2014) performed a single center study of 100 subjects who received postoperative PBI using PBT after undergoing partial mastectomy with negative margins and axillary lymph nodes. After following these individuals for an average of five years, the researchers concluded that ipsilateral recurrence-free survival with minimal toxicity was excellent. While the authors acknowledged that cosmetic results may be improved with PBT over those reported with photon-based techniques, there was nothing in the study demonstrating that PBT outcomes were superior to the current standard of care.

To further elucidate the clinical advantages and disadvantages between PBT and other types of RT used in breast cancer, additional clinical trials are underway, NCT02603341, NCT01245712, and NCT03391388, go to https://clinicaltrials.gov/. (Accessed March 20, 2025).

Clinical Practice Guidelines

National Comprehensive Cancer Network (NCCN)

NCCN guidelines do not address the use of PBT for treating breast cancer (NCCN, 2024).

Choroidal Hemangiomas

Mathis et al. (2021) conducted a retrospective multi-center study that compared the functional and anatomical effectiveness of PBT versus photodynamic therapy (PDT) in a real-life setting for the treatment of circumscribed choroidal hemangioma. The study included a total of 191 individuals with a diagnosis of choroidal hemangioma, 119 individuals (62.3%) were treated by PDT and 72 individuals treated by PBT. The final best-corrected visual acuity did not differ significantly between the two groups ($p = 0.932$) and final thickness was lower in the PBT compared with the PDT group ($p = 0.001$). Fifty-three individuals (44.5%) initially treated by PDT required at least one other therapy and were associated with worse final best-corrected visual acuity ($p = 0.037$). None of the individuals treated by PBT needed second-line therapy. In multivariate analysis, only an initial thickness greater than 3 mm remained significant ($p = 0.01$) to predict PDT failure. The authors concluded PDT and PBT have similar functional and anatomical outcomes for circumscribed choroidal hemangioma ≤ 3 mm, although PDT sometimes requires multiple sessions. Additionally, for tumors > 3 mm, PBT seems preferable as it can treat the tumor in one session with better anatomical and functional outcomes. The authors recommended further large-scale studies to better define a thickness threshold above which PDT is less efficient. Limitations included the retrospective nature of the study, lack of randomization, and small study size.

Hocht et al. (2006) conducted a single-center, retrospective study of 44 consecutive individuals with choroid hemangiomas treated with photon therapy (n = 19) or proton therapy (n = 25). Outcomes were measured by visual acuity, tumor thickness, resolution of retinal detachment, and post-treatment complications. Mean follow-up was 38.9 months and 26.3 months, and median follow-up was 29 months and 23.7 months for photon and proton individuals, respectively. Tumor thickness was greater in the photon group than in the proton group. In the collective groups, 91% were treated successfully, and there was no significant difference in the outcomes between the two groups. The authors concluded that RT is effective in treating choroidal hemangiomas with respect to visual acuity and tumor thickness, but a benefit of proton versus photon therapy could not be detected.

Three additional studies showed some improvement in tumor regression and visual acuity following PBT; however, these studies were small and retrospective in nature (Chan et al., 2010; Levy-Gabriel et al., 2009; Frau et al., 2004).

Esophageal Cancer

A meta-analysis by Zhou et al. (2023) to explore whether PBT provided better efficacy and safety outcomes compared to photon therapy in individuals with esophageal cancer. Forty-five studies were included in the meta-analysis with the primary outcomes being OARs dosimetric outcomes, OS, PFS, objective response rate and radiation-related toxic effects. For dosimetric analysis, proton therapy was associated with significantly reduced OARs dose. Meta-analysis showed that photon therapy was associated with poor OS, but no difference in PFS was observed. Subgroup analysis showed worse OS and PFS in the radical therapy group with photon therapy. The pathological complete response rate was similar between groups. Proton therapy was associated with significantly decreased grade 2 or higher radiation pneumonitis and pericardial effusion, and grade 4 or higher lymphocytopenia. Single-rate analysis of proton therapy found 89% OS and 65% PFS at one year, 71% OS and 56% PFS at two years, 63% OS and 48% PFS at three years, and 56% OS and 42% PFS at five years. The incidence of grade 2 or higher radiation esophagitis was 50%, grade 2 or higher radiation pneumonitis was 2%, grade 2 or higher pleural effusion was 4%, grade 2 or higher pericardial effusion was 3%, grade 3 or higher radiation esophagitis was 8%, and grade 4 or higher lymphocytopenia was 17%. The authors concluded

significantly reduced OARs doses and toxic effects, and improved prognosis were associated with PBT for esophageal cancer when compared to photon therapy. Limitations included significant heterogeneity in the OARs dosimetric analysis, small study sizes, and lack of RCTs. The author's recommended caution was warranted with PBT for esophageal cancer and future RCTs are recommended to verify benefits provided by PBT. (Lin 2020, Xi 2017, and Lin 2017 which were previously cited in this policy, are included in the Zhou systematic review and meta-analysis).

A Hayes Health Technology Assessment for the use of PBT in adults with esophageal adenocarcinoma as an adjunct to chemotherapy and surgery states PBT may have effectiveness that is comparable to both IMRT and three-dimensional conformal radiation therapy (3D-CRT) and results in significantly lower radiation exposure to nearby OARs, with possibly fewer complications in those undergoing esophagectomy. However, the statistical significance of those findings were mixed. PBT and IMRT were found to have similar rates of nonoperative complications. The overall quality of the body of evidence for PBT for the treatment of esophageal adenocarcinoma was rated as low due to limitations of the individual studies, diverse treatment protocols, and scarcity of evidence for efficacy beyond three years. The 2023 annual review included no newly published studies and there was no change in the rating (Hayes, 2022; updated 2023).

A Hayes Health Technology Assessment regarding the use of PBT for the treatment of esophageal squamous cell carcinoma as an adjunct to chemotherapy with or without surgery, suggests PBT may be as effective as conventional (X-ray) photon radiotherapy (XRT). PBT may result in fewer or similar complications and delivers lower doses of radiation to nearby OARs than XRT. Additionally, PBT can reduce the rate of recurrence, improve survival, and induce a complete response. However, the body of evidence is noted as very low-quality, consisting of small- to moderate-sized retrospective studies with limited follow-up, with most studies lacking a comparator group. The assessment found the evidence base was insufficient to evaluate efficacy and safety of PBT, and recommended future studies. The 2023 update included one newly published study that met the inclusion criteria, but no change was made in the Hayes rating (Hayes, 2022; updated 2023).

In a retrospective analysis, Wang et al. (2013) reported that advanced radiation technologies such as IMRT or PBT significantly reduced postoperative pulmonary and GI complication rates compared to 3D-CRT in individuals with esophageal cancer. The authors noted that these results need to be confirmed in prospective studies.

Mizumoto et al. (2011) evaluated the efficacy and safety of hyperfractionated concomitant boost PBT in nineteen individuals with esophageal cancer. The overall one- and five-year actuarial survival rates for all nineteen individuals were 79% and 42.8%, respectively. The median survival time was 31.5 months. Of the nineteen individuals, seventeen (89%) showed a complete response within four months after completing treatment and two (11%) showed a partial response, giving a response rate of 100% (19/19). The one- and five-year LC rates for all nineteen individuals were 93.8% and 84.4%, respectively. The results suggest that hyperfractionated PBT is safe and effective for individuals with esophageal cancer. The authors noted further studies are needed to establish the appropriate role and treatment schedule for use of PBT for esophageal cancer.

Mizumoto et al. (2010) evaluated the efficacy and safety of PBT for locoregionally advanced esophageal cancer. Fifty-one individuals were treated using PBT with or without X-rays. All but one had squamous cell carcinoma. Of the 51 fives, 33 received combinations of X-rays and protons as a boost. The other eighteen individuals received PBT alone. The overall five-year actuarial survival rate for the 51 individuals was 21.1% and the median survival time was 20.5 months. Of the 51 individuals, 40 (78%) showed a complete response within four months after completing treatment and seven (14%) showed a partial response, giving a response rate of 92% (47/51). The five-year LC rate for all 51 individuals was 38% and the median LC time was 25.5 months. The authors concluded that these results suggested that PBT is an effective treatment for individuals with locally advanced esophageal cancer. The authors noted further studies are required to determine the optimal total dose, fractionation schedules, and best combination of proton therapy with chemotherapy.

An ongoing phase III study is recruiting individuals to compare the use of PBT to photon therapy in those with esophageal cancer (Clinical Trial ID: NCT03801876). For more information, go to http://www.clinicaltrials.gov/. (Accessed March 20, 2025).

Clinical Practice Guidelines

National Comprehensive Cancer Network (NCCN)

NCCN guidelines state that PBT is appropriate when treating esophageal and esophagogastric junction cancers in settings where dose reduction to OARs is necessary and cannot be achieved by 3D-CRT. Because data is early and evolving, individuals should receive PBT within a clinical trial (NCCN, 2024).

Gastrointestinal (GI) Cancers

Le et al. (2024) conducted a systematic review aimed to investigate the adverse effects, compare dosimetric data, and evaluate the oncological outcomes of PBT versus conventional RT in individuals with non-metastatic rectal cancer (non-stage IV). Inclusion criteria included full-text, peer-reviewed RCTs, prospective or retrospective cohort studies, in English, which evaluated adults with non-metastatic rectal cancer treated with either PBT or conventional RT. Exclusion criteria included those under 18 years of age, those with metastatic rectal cancer or other cancers, and studies that used other RT modalities. Eight studies were included in the review. There was insufficient evidence to determine the adverse treatment outcomes of PBT versus conventional RT. No current studies assessed radiotoxicities nor oncological outcomes. Pooled dosimetric comparisons between PBT and various conventional RTs were associated with reduced radiation exposure to the pelvis, bowel, and bladder. The authors concluded there was insufficient evidence to establish the superiority of PBT over conventional RT in reducing adverse treatment outcomes and improving oncological outcomes for individuals with non-metastatic rectal cancer, due to the limited data available. The authors noted pooled dosimetric analyses indicated that PBT reduces radiation exposure to surrounding tissues; however, these findings were based on a small number of studies with high clinical heterogeneity and a moderate risk of bias. The authors call for more rigorous, prospective, RCTs with larger sample sizes to better evaluate the efficacy and safety of PBT in non-metastatic rectal cancer.

Fok et al. (2021) conducted a systematic review and meta-analysis that compares dosimetric irradiation of OARs and oncological outcomes for PBT versus conventional photon-based RT in locally advanced rectal cancer. Eight articles with a total of 127 individuals met the inclusion criteria. There was significantly less irradiated small bowel with PBT compared to 3D-CRT and IMRT (MD -17.01, CI [-24.06, - 9.96], $p < 0.00001$ and MD -6.96, CI [-12.99, - 0.94], $p = 0.02$, respectively). Similar dosimetric results were observed for bladder and pelvic bone marrow. Three studies reported clinical and oncological results for PBT in recurrent rectal cancer with OS reported as 43 %, 68 % and 77.2 %, and one study in primary rectal cancer with 100 % disease free survival. The authors concluded PBT treatment plans resulted significantly less irradiation of OARs for rectal cancer when compared to conventional photon-based RT. The authors noted there are currently no ongoing clinical trials for primary rectal cancer and PBT, and more research is required to validated PBTs role in organ preservation without increasing toxicity, complete response rate, and dose escalation. Limitations included small sample sizes and lack of RCTs.

Verma et al. (2016b) conducted a systematic review to identify studies on PBT and GI malignancies. The search included PubMed, EMBASE, and abstracts from meetings ASTRO, Particle Therapy Co-Operative Group (PTCOG), and American Society of Clinical Oncology (ASCO). A total of 39 original investigations were analyzed. For esophageal cancer, twelve studies were analyzed and several of those reported that PBT resulted in a significant dose reduction to intrathoracic OARs and is associated with reduced toxicity, postoperative complications while achieving comparable LC and OS. However, for some of the studies, contemporaneous comparison groups were lacking, or comparisons were made between PBT and XRT, which consisted of either 3D-CRT or IMRT rather than IMRT only. For pancreatic cancer, five studies were analyzed. Survival for resected/unresected cases was similar to existing data where IMRT was used and nausea/emesis were numerically lower than what had been reported among individuals who received IMRT however, direct head-to-head comparisons were not made. For hepatocellular carcinoma, ten studies were analyzed, and these had the strongest evidence to support use of PBT. Those studies reported very low toxicities, and a phase III trial comparing PBT to TACE showed a trend toward better LC and PFS with PBT. For cholangiocarcinoma, liver metastases, and retroperitoneal sarcoma, survival and toxicity data is comparable to historical photon controls, and stomach and biliary system/gallbladder cancer studies consisted of case reports and small cohort experiences. The authors concluded that PBT offered the potential of lower toxicities without compromising survival or LC. The authors acknowledged there was limited high quality evidence for select GI malignancies and further multi-institution RCTs are needed.

Clinical Practice Guidelines

National Comprehensive Cancer Network (NCCN)

NCCN guidelines do not address PBT in the treatment of gastric cancers (NCCN, 2024).

Gynecologic Cancers

The efficacy of PBT combined with photon radiation for the treatment of cervical cancer was investigated in a prospective uncontrolled study involving 25 participants (Kagei et al., 2003). In this study, five-year and 10-year survival rates were similar to conventional therapies as reported in the literature. The 10-year survival rate was higher for participants with low stage (89%) compared with advanced stages (40%) of cervical cancer. The treatment caused severe late complications in 4% of participants.

Several clinical trials are recruiting or in progress studying the use of PBT in multiple types of gynecologic cancer (e.g., cervical, ovarian, and uterine). For more information, go to www.clinicaltrials.gov. (Accessed March 20, 2025)

Clinical Practice Guidelines

National Comprehensive Cancer Network (NCCN)

NCCN guidelines do not address the use of PBT when treating any type of gynecologic cancer [i.e., Cervical Cancer (NCCN, 2024), Ovarian Cancer (NCCN, 2024), Uterine Neoplasms (NCCN, 2024), or Vulvar Cancer (NCCN, 2024)].

Head and Neck Cancers (HNC) Not Listed in the Coverage Rationale as Proven

A Hayes report, Proton Beam Therapy for Treatment of Head and Neck Cancer, assessed multiple clinical studies evaluating the efficacy and safety of PBT in individuals with HNC. The majority of the evidence included retrospective studies, data analyses, and systematic reviews. They noted there was some overlap of investigators and, possibly, overlap of individual groups as well. The report concludes that the study abstracts present conflicting findings regarding the use of PBT for treatment of HNC. The updated 2022 Hayes report includes 25 new studies that met inclusion criteria; however, no change was made to the rating (Hayes, 2019; Updated 2022).

Seeking to improve LC rate and reduce late adverse events, Takayama et al. (2016) evaluated therapeutic results and toxicities of PBT combined with selective intra-arterial infusion chemotherapy (PBT-IACT) in individuals with stage III-IVB squamous cell carcinoma of the tongue. Between February 2009 and September 2012, 33 individuals were enrolled. After two systemic chemotherapy courses and whole-neck irradiation (36 Gy in 20 fractions), participants were administered concurrent chemoradiotherapy comprising PBT for the primary tumor and the metastatic neck lymph node with weekly retrograde IACT of cisplatin with sodium thiosulfate by continuous infusion. The median follow-up duration was 43 months. The three-year OS, PFS, LC rate, and regional control rate for the neck were 87%, 74.1%, 86.6%, and 83.9%, respectively. Major acute toxicities > grade 3 included mucositis in 26 cases (79%), neutropenia in seventeen cases (51%), and dermatitis in 11 cases (33%). Late grade 2 osteoradionecrosis was observed in one case (3%). The authors concluded that PBT-IACT for stage III-IVB tongue cancer has an acceptable toxicity profile and showed good treatment results, and that this protocol may be considered as a treatment option for locally advanced tongue cancer. This study was limited by the lack of data comparing toxicity to conventional RT.

Clinical Practice Guidelines

American College of Radiology (ACR)/American Radium Society (ARS)

The ACR/ARS Practice Parameter indicates that PBRT minimizes the radiation dose to vital structures in the head and neck area which may enhance QOL and decrease complications affecting the optic nerves, optic chiasm, pituitary gland, brain, brainstem, spinal cord, salivary glands, pharyngeal constrictor muscles, oral cavity, and emetogenic sites in the posterior fossa (2023).

National Comprehensive Cancer Network (NCCN)

NCCN's HNCs guideline makes no mention of PBRT for cancer of the lip (mucosa), oral cavity, hypopharynx or glottic larynx. (NCCN, 2024).

Lung Cancer

Liao et al. (2018) conducted a single-center randomized trial that compared outcomes of passive scattering proton therapy (PSPT) versus IMRT, both with concurrent chemotherapy, for inoperable NSCLC. The primary end point was the first occurrence of severe (grade ≥ 3) radiation pneumonitis or local failure. Eligible participants had stage IIB to IIIB NSCLC (or stage IV NSCLC with a single brain metastasis or recurrent lung or mediastinal disease after surgery) and were candidates for concurrent chemoradiation therapy. Pairs of treatment plans for IMRT and PSPT were created for each participant. Participants were eligible for random assignment only if both plans satisfied the same prespecified dose-volume constraints for at-risk organs at the same tumor dose. Compared with IMRT (n = 92), PSPT (n = 57) exposed less lung tissue to doses of five to 10 Gy relative biologic effectiveness (RBE), which is the absorbed Gy dose multiplied by the relative biologic effectiveness RBE factor for protons; exposed more lung tissue to ≥ 20 Gy RBE but exposed less heart tissue at all dose levels between 5 and 80 Gy RBE. The grade ≥ 3 radiation pneumonitis was greater for PSPT than IMRT (6.5% for IMRT and 10.5% for PSPT) though the difference did not reach statistical significance; there was no difference observed in local failure (10.9% and 10.5% for IMRT and PSPT, respectively). Exploratory analysis showed that the radiation pneumonitis and local failure rates at twelve months for participants enrolled before versus after the trial midpoint were 21.1% (before) versus 18.2% (after) for the IMRT group and 31.0% (before) versus 13.1% (after) for the PSPT group suggesting that that outcomes for proton therapy improved over the course of the trial as the investigators gained experience. The authors stated that findings from two ongoing trials (NCT01993810 and NCT01629498) may provide additional evidence of the efficacy of proton and photon therapies.

Chang et al. (2017) reported five-year results of a prospective phase II single-institution study evaluating chemotherapy with concurrent high dose PBT in 64 participants with unresectable phase III NSCLC. Five-year OS, PFS, actuarial distant

metastases and locoregional recurrence were 29%, 22%, 54%, and 28%, respectively. Acute and late toxic effects with PBT (compared to historical studies with 3D-CRT and/or IMRT) with chemotherapy were very promising. The authors concluded that the study demonstrated that concurrent PBT and chemotherapy were safe and effective in the long term, and that further prospective studies are warranted.

Chi et al. (2017) conducted a systematic review and meta-analysis to assess hypo-fractionated PBT's efficacy relative to that of photon SBRT for early-stage NSCLC. Seventy-two SBRT studies and nine hypo-fractionated PBT studies (mostly single-arm) were included. Proton beam therapy was associated with improved OS and PFS in the univariate meta-analysis. The OS benefit did not reach its statistical significance after inclusion of operability into the final multivariate meta-analysis, while the three-year LC still favored PBT. Researchers concluded that although hypo-fractionated PBT may lead to additional clinical benefit when compared with photon SBRT, no statistically significant survival benefit from PBT over photon SBRT was observed in the treatment of early-stage NSCLC.

Harada et al. (2016) conducted a single-institutional, open label, dose escalation phase I trial to determine the recommended dose of PBT for inoperable stage III NSCLC. Two prescribed doses of PBT were tested: 66 Gy RBE in 33 fractions and 74 Gy RBE in 37 fractions in arms one and two, respectively. The planning target volume included the primary tumor and metastatic lymph nodes with adequate margins. Concurrent chemotherapy included intravenous cisplatin (60 mg/m (2), day one) and oral S-1 (80, 100 or 120 mg based on body surface area, days one-14), repeated as four cycles every four weeks. Dose-limiting toxicity (DLT) was defined as grade 3 (severe) toxicities related to PBT during days one - 90. Each dose level was performed in three individuals and then escalated to the next level if no DLT occurred. When one individual developed a DLT, three additional individuals were enrolled. Overall, nine individuals were enrolled, including six in Arm one and three in Arm two. The median follow-up time was 43 months, and the median PFS was 15 months. In Arm one, grade 3 infection occurred in one of six individuals, but no other DLT was reported. Similarly, no DLT occurred in Arm two. However, one individual in Arm two developed grade 3 esophageal fistula at nine months after the initiation of PBT. From a clinical perspective, the authors concluded that 66 Gy RBE was the recommended dose.

Oshiro et al. (2014) initiated a phase II study to evaluate the safety and efficacy of high-dose PBT with concurrent chemotherapy for unresectable or medically inoperable advanced NSCLC. Participants (n = 15) were treated with PBT and chemotherapy with monthly cisplatin (on day one) and vinorelbine (on days one and eight). The treatment doses were 74 Gy RBE for the primary site and 66 Gy RBE for the lymph nodes without elective lymph nodes. The median follow-up period was 21.7 months. None of the participants experienced Grade 4 or 5 non-hematologic toxicities. Acute pneumonitis was observed in three participants (Grade 1 in one, and Grade 3 in two), but Grade 3 pneumonitis was considered to be non-proton related. Grade 3 acute esophagitis and dermatitis were observed in one and two participants, respectively. Severe (≥ Grade 3) leukocytopenia, neutropenia and thrombocytopenia were observed in ten, seven, and one participant, respectively. Late RP (grades 2 and 3) was observed in one participant each. Six participants (40%) experienced local recurrence at the primary site and were treated with 74 Gy RBE. Disease progression was observed in eleven participants, with the mean survival time being 26.7 months. The authors cited short follow-up period as a limitation to this study and concluded that high-dose PBT with concurrent chemotherapy was safe and useful in the multimodality therapy for unresectable NSCLC.

Sejpal et al. (2011) conducted a single-center, retrospective case series study to evaluate the use of PBT plus concurrent chemotherapy in individuals with NSCLC. Outcomes included acute and subacute toxicity and were evaluated using Common Terminology Criteria (version 3.0) at least weekly during treatment, at four to six weeks after treatment, every three months for two years and then, every six months. Survival, time to progression and failure patterns were also collected. Comparisons between other radiation treatment modalities (IMRT and 3D-CRT, each with concurrent chemotherapy) were made using historical controls from the same center. A total of 202 individuals were included in the analysis: 74 received 3D-CRT, 66 IMRT and 62 PBT. Median follow-up periods were 17.9 months 3D-CRT, 17.4 months (IMRT) and 15.2 months (proton). Median total radiation dose was higher in the PBT group at 74 Gy versus 63 Gy for the other groups. Despite the higher radiation dose in the PBT group, rates of severe (grade ≥ 3) pneumonitis and esophagitis were lower (2% and 5%, respectively) compared with the other groups (3D-CRT, 30% and 18%; IMRT, 9% and 44%, respectively). Due to the short follow-up periods, tumor control and survival were not reported. The authors concluded that in this early and promising study, higher doses of PBT could be delivered to lung tumors with a lower risk of esophagitis and pneumonitis, and that additional clinical trials may further clarify the benefits and risks of PBT in individuals diagnosed with NSCLC.

Pijls-Johannesma et al. (2010) conducted a systematic review to test the theory that RT with beams of protons and heavier charged particles (e.g., carbon ions) leads to superior results, compared with photon beams. The authors searched for clinical evidence to justify implementation of particle therapy as standard treatment in lung cancer. Eleven studies, all dealing with NSCLC, mainly stage I, were identified. No phase III trials were found. For PBT, two- to five-year LC rates varied in the range of 57% - 87%. The two- and five-year OS and two- and five-year cause-specific survival rates

were 31% - 74% and 23% and 58% - 86% and 46%, respectively. Radiation-induced pneumonitis was observed in about 10% of individuals. For C-ion therapy, the overall LC rate was 77%, but it was 95% when using a hypofractionated radiation schedule. The five-year OS and cause-specific survival rates were 42% and 60%, respectively. Slightly better results (at 50% and 76%, respectively) were reported when using hypofractionation. The authors concluded the current findings with protons and heavier charged particles are encouraging. However, the absence of substantial evidence regarding the clinical effectiveness of particle therapy highlights the necessity for thorough investigation into its efficiency. Until such data is available for lung cancer, the authors noted charged particle therapy should be considered experimental.

A phase III RCT comparing photon to proton chemoradiotherapy for individuals with inoperable NSCLC (NCT01993810) is in progress. For more information, go to www.clinicaltrials.gov. (Accessed March 20, 2025)

Clinical Practice Guidelines

American College of Radiology (ACR)

ACR appropriateness criteria addressing nonsurgical treatment for locally advanced NSCLC states that while PBT may have the potential to spare critical normal tissues, more prospective studies are needed (Chang, et al., 2014).

National Comprehensive Cancer Network (NCCN)

NCCN guidelines state that advanced technologies such as 4D-CT and/or positron emission tomography–computed tomography (PET/CT) simulation, IMRT/volumetric modulated arc therapy (VMAT), image-guided radiation therapy (IGRT), motion management, and PBT are appropriate when needed to deliver curative RT safely when treating NSCLC (NCCN, 2024) and may be appropriate to limit normal tissue toxicity in the treatment of small cell lung cancer (NCCN, 2025).

Lymphomas

Multiple small, lower quality studies have been published on the management of lymphomas with PBT, particularly focused on long term radiation toxicity (König et al., 2019; Horn et al., 2016; Sachsman et al., 2015; Hoppe et al., 2012). Early outcomes are encouraging, but larger prospective studies are needed to confirm long term efficacy.

Clinical Practice Guidelines

National Comprehensive Cancer Network (NCCN)

NCCN guidelines for Hodgkin, B-cell, and T-cell lymphomas state that PBT may be appropriate, depending on clinical circumstances. It also states that advanced RT technologies, such as PBT, may offer significant and clinically relevant advantages in specific instances to spare important OARs and decrease the risk for late, normal tissue damage while still achieving the primary goal of LC. NCCN is silent on the use of PBT in the treatment of primary cutaneous lymphoma (NCCN, 2024).

Pancreatic Cancer

There is a lack of robust clinical evidence evaluating PBT for treating pancreatic cancer although research continues (Kim et al., 2018, Hong et al., 2014; Terashima et al., 2012; Hong et al., 2011). Further larger scaled prospective studies are warranted to determine the long-term safety and efficacy of this treatment modality.

Numerous clinical trials are currently in progress studying the use of PBT in multiple types of GI cancer (e.g., esophageal, pancreatic, and retroperitoneal sarcoma). For more information, go to www.clinicaltrials.gov. (Accessed March 20, 2025)

Clinical Practice Guidelines

National Comprehensive Cancer Network (NCCN)

NCCN guidelines do not address PBT in the treatment of pancreatic adenocarcinoma (NCCN, 2024).

Vestibular Tumors

The systematic review and meta-analysis by Santacroce et al. (2023) examined the effectiveness of PBRT for vestibular schwannomas (VS) treatment of tumor control and cranial nerve preservation, particularly in terms of facial and hearing preservation. The study included both retrospective and prospective studies written in English that reported on individuals with VS treated with PBRT, regardless of their history of previous surgery. Studies in languages other than English were excluded. Eight studies (587 individuals) met the inclusion criteria; two were single arm prospective studies and six were retrospective studies. Overall rate of tumor control (both stability and decrease in volume) was 95.4% (range 93.5–97.2%,

p heterogeneity = 0.77, p < 0.001). Overall rate of tumor progression was 4.6% (range 2.8–6.5%, p heterogeneity < 0.77, p < 0.001). Overall rate of trigeminal nerve preservation (absence of numbness) was 95.6% (range 93.5–97.7%, I^2 = 11.44%, p heterogeneity = 0.34, p < 0.001). Overall rate of facial nerve preservation was 93.7% (range 89.6–97.7%, I^2 = 76.27%, p heterogeneity < 0.001, p < 0.001). Overall rate of hearing preservation was 40.6% (range 29.4–5 International Stereotactic Radiosurgery 1.8%, I^2 = 43.36%, p heterogeneity = 0.1, p < 0.001). The authors concluded that PBRT for VS achieved high tumor control rates, but the existing literature did not show an advantage in hearing preservation compared to standard SRS techniques. Additionally, the likelihood of facial nerve preservation is lower compared to most radiosurgery techniques. The authors noted that overall, PBRT for VS did not offer a significant benefit for facial and hearing preservation when compared to most currently reported SRS series. Limitations included a limited number of studies, most of which were retrospective in nature. (Authors Saraf 2022, Bush 2002, and Harsh 2002, which were previously cited in this policy, are included in this review).

In a critical review, Murphy, and Suh (2011) summarized the radiotherapeutic options for treating VS, including single-session SRS, fractionated conventional RT, fractionated stereotactic RT and PBT. The comparisons of the various modalities have been based on single-institution experiences, which have shown excellent tumor control rates of 91-100%. Early experience using PBT for treating VS demonstrated LC rates of 84 -100% but disappointing hearing preservation rates of 33 - 42%. The authors reported that mixed data regarding the ideal hearing preservation therapy, inherent biases in subject selection, and differences in outcome analysis have made comparison across radiotherapeutic modalities difficult.

Clinical Practice Guidelines

Congress of Neurological Surgeons (CNS)

CNS developed an evidence-based guideline on the role of radiosurgery and RT in the management of individuals with vestibular schwannomas. CNS notes that no studies that compare two or all three modalities (Gamma Knife versus LINAC-based radiosurgery versus proton beam) were identified, therefore, no recommendations on outcome could be made (Germano et al., 2018).

Combined Therapies

No evidence was identified in the clinical literature supporting the combined use of PBT and IMRT in a single treatment plan.

U.S. Food and Drug Administration (FDA)

This section is to be used for informational purposes only. FDA approval alone is not a basis for coverage.

Radiation therapy is a procedure and, therefore, is not subject to FDA regulation. However, the accelerators and other equipment used to generate and deliver PBRT are regulated by the FDA. Refer to the following website for more information (use product code LHN): http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfPMN/pmn.cfm. (Accessed March 20, 2025)

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Policy History/Revision Information

Date	Summary of Changes
06/01/2025	**Coverage Rationale** • Revised coverage criteria for proton beam radiation therapy (PBT) for a diagnosis that is not listed [in the policy] as proven; replaced criterion requiring "evaluation includes a comparison of *Definitive Therapy* plans for PBT, intensity-modulated radiation therapy (IMRT), and stereotactic body radiation therapy (SBRT)" with "evaluation includes a comparison of *treatment* plans for PBT, IMRT, and SBRT for the specific individual" • Removed list of examples (not all inclusive) of unproven and not medically necessary indications for the use of PBT **Medical Records Documentation Used for Review** • Updated list of Medical Records Documentation Used for Reviews; replaced "evaluation includes a comparison of *Definitive Therapy* plans for PBT, IMRT, and SBRT" with "evaluation includes a comparison of *treatment* plans for PBT, IMRT, and SBRT *for the specific individual*" **Supporting Information** • Updated *Clinical Evidence* and *References* sections to reflect the most current information • Archived previous policy version 2025T0132JJ

Instructions for Use

This Medical Policy provides assistance in interpreting UnitedHealthcare standard benefit plans. When deciding coverage, the member specific benefit plan document must be referenced as the terms of the member specific benefit plan may differ from the standard plan. In the event of a conflict, the member specific benefit plan document governs. Before using this policy, please check the member specific benefit plan document and any applicable federal or state mandates. UnitedHealthcare reserves the right to modify its Policies and Guidelines as necessary. This Medical Policy is provided for informational purposes. It does not constitute medical advice.

This Medical Policy may also be applied to Medicare Advantage plans in certain instances. In the absence of a Medicare National Coverage Determination (NCD), Local Coverage Determination (LCD), or other Medicare coverage guidance, CMS allows a Medicare Advantage Organization (MAO) to create its own coverage determinations, using objective evidence-based rationale relying on authoritative evidence (Medicare IOM Pub. No. 100-16, Ch. 4, §90.5).

UnitedHealthcare may also use tools developed by third parties, such as the InterQual® criteria, to assist us in administering health benefits. UnitedHealthcare Medical Policies are intended to be used in connection with the independent professional medical judgment of a qualified health care provider and do not constitute the practice of medicine or medical advice.