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Clinical Applications and Recent Advances in Radiotherapy for the Management of Neoplasia in Companion Animals

Hamed Charkhian[a,b], **Seref Bugra Tuncer**[b], **Sule Karaman**[c], **Rabia Nergiz Dağoğlu Sakin**[c], **Mahsa Hallaj-Salahipour**[d,*]

[a] Institute of Graduate Studies in Health Sciences, Istanbul University, Istanbul, Türkiye
[b] Department of Cancer Genetics, Oncology Institute, Istanbul University, Istanbul, Türkiye.
[c] Department of Radiation Oncology, Oncology Institute, Istanbul University, Istanbul, Türkiye.
[d] Department of Basic Sciences,Faculty of Veterinary Medicine, Urmia University, Urmia, Iran.

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Abstract

Cancer is among the most common causes of illness and death in companion animals, creating a strong need for effective and accessible treatment strategies. Radiation therapy (RT) has become a cornerstone in veterinary oncology, applied as an adjuvant following incomplete surgery, as a curative option for tumors not amenable to resection, and as palliative care to reduce pain or dysfunction while improving quality of life. Recent advances in treatment planning and delivery have significantly improved the safety and precision of RT. Modern imaging, computer-assisted planning, and image-guided techniques now allow more accurate targeting of tumors while sparing surrounding normal tissues. Alongside conventional external-beam therapy, selective use of brachytherapy, plesiotherapy, and radionuclide-based approaches—such as radioiodine for feline hyperthyroidism—offer further opportunities for tailored treatment. Despite promising clinical outcomes in dogs and cats, broader application is limited by equipment costs, anesthesia requirements, and the need for specialized expertise. Future priorities include prospective clinical studies, refinement of species-specific dose constraints, and integration of RT with surgery, chemotherapy, and targeted therapies.

1. Introduction

Improvements in the husbandry and medical care of companion animals have led to longer lifespans for dogs and cats and, consequently, a greater clinical burden of neoplastic disease (Sarver et al., 2022). Cancer is now recognized as a leading cause of death in dogs and cats in the USA (Farrell et al., 2024), although robust epidemiological data from many regions—including Iran—remain limited (Abbaszadeh Hasiri et al., 2019). Several tumor types in companion animals closely parallel those seen in humans, providing opportunities for translational insight (Surjan et al., 2011). In dogs, neoplasia ranges from benign to highly malignant lesions; skin tumors are among the most frequently diagnosed, followed by neoplasms of the gastrointestinal tract, mammary gland, urinary and reproductive systems, and the lymphoid and immune systems (Sarver et al., 2022).

The principal modalities for the management of

*Corresponding author: M. Hallaj-Salahipour
E-mail address: mahsa.hallaj14@gmail.com
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solid tumors in veterinary practice are surgery, radiation therapy (RT), and chemotherapy. Surgery and RT primarily provide local–regional control, whereas chemotherapy—and, increasingly, targeted and immunotherapeutic approaches—address systemic disease. Despite cancer's prominence in the public consciousness, RT and its applications in veterinary medicine remain comparatively specialized and unfamiliar to many general practitioners and owners (Gasymova et al., 2017; Kent, 2017). Nevertheless, RT has become an integral component of multimodal cancer care for companion animals, with expanding indications for definitive, adjuvant, and palliative treatment of malignant tumors (Elliott, 2022).

Technical capabilities in veterinary radiation oncology have advanced substantially over the past two decades. Historical approaches that delivered dose with a single beam and relied on simple shielding to spare normal tissues have been superseded by conformal planning and delivery techniques. Contemporary practice increasingly employs dedicated small-animal radiotherapy platforms and medical linear accelerators with computed tomography–based planning, three-dimensional conformal radiotherapy, intensity-modulated and volumetric-modulated arc therapy, image-guided radiotherapy, and, where appropriate, stereotactic protocols that permit hypofractionation with steep dose gradients (Dunfield et al., 2018; Gasymova et al., 2017; Vanhaezebrouck & Scarpelli, 2023). These innovations can improve tumor coverage and normal-tissue sparing, broadening the therapeutic window. Importantly, however, earlier technologies still retain advantages for selected indications and settings, and the guiding principle remains tailoring the technique to the clinical objective, patient factors, and resource context.

Clinical knowledge regarding outcomes and toxicity profiles of RT in dogs and cats has grown markedly, enabling more precise counseling about expected tumor control, acute effects, and late sequelae under both definitive and palliative fractionation schemes (Militi et al., 2024; Yoshikawa et al., 2023). By contrast, evidence for exotic and non-traditional species is sparse; in many such patients, current uncertainties still outweigh established knowledge, underscoring the need for prospective data collection and species-specific dose–response characterization. Practical considerations—anesthesia requirements for immobilization, quality-assurance infrastructure, cost, and access to trained personnel—also shape real-world utilization.

This article provides an up-to-date overview of the applications and recent technological advances of RT in the treatment of cancer in companion animals. It highlights the expanding role of radiation within multimodal veterinary oncology and identifies gaps that warrant coordinated research efforts. Given ongoing investment in veterinary RT infrastructure, these developments are poised to further integrate radiation therapy into everyday clinical practice and improve outcomes and quality of life for animal patients.

2. Radiation Therapy in Companion Animals

Radiation therapy is primarily employed as a localized treatment modality in veterinary oncology. Its effectiveness in controlling tumor growth can vary substantially depending on the histological type of cancer, the tumor's biological behavior, and the treatment protocol administered. In many cases, RT is capable of achieving durable local control and prolonging survival, particularly when applied under optimal clinical circumstances (Kent, 2017; Moore, 2002).

One of the most effective applications of radiation therapy is in the management of microscopic residual disease. Following surgical excision, if histopathology reveals incomplete margins or if the tumor is located in an area where complete resection is anatomically challenging, adjuvant radiation therapy is commonly administered to eradicate remaining malignant cells and reduce the likelihood of local recurrence (Grimes et al., 2023; Hildebrandt et al., 2025).

Radiation therapy may also serve as a definitive treatment when tumors are highly radiosensitive or when they are small and localized but unresectable due to anatomical constraints. In such cases, RT can be employed as a sole therapeutic modality, providing long-term local control (Hunley et al., 2010; Malfassi et al., 2022; Yoshikawa et al., 2023). Conversely, when tumors are extensive, unresectable, metastatic, or when surgery is declined or not feasible, RT is frequently administered with palliative intent. Palliative protocols are designed to alleviate clinical signs, such as pain, bleeding, or obstruction, thereby improving the animal's quality of life even when cure is not possible (Fu et al., 2023; Militi et al., 2024; Tollett et al., 2016).

In addition, radiation therapy is often integrated into multimodal treatment strategies alongside chemotherapy. Chemotherapy may be administered systemically or by intralesional injection, depending on the tumor type and clinical context. The rationale for combining chemotherapy with radiation includes enhancing local tumor control through radiosensitization, addressing micrometastatic or disseminated disease, and improving overall treatment efficacy (Baja et al., 2022; Tellado et al., 2022; Woodruff et al., 2019). Such combined protocols are particularly valuable in aggressive or advanced-stage malignancies.

Overall, radiation therapy occupies a versatile role in veterinary oncology, functioning as an adjuvant, definitive, or palliative treatment, either alone or in combination with systemic therapies. Its application continues to expand as protocols are refined and evidence on treatment outcomes accumulates, reinforcing its importance as a cornerstone of cancer management in companion animals.

3. Goals and Rationale for Radiation Therapy

The primary objective of radiation therapy (RT) in veterinary oncology is to deliver a cytotoxic dose of ionizing radiation to malignant cells while minimizing collateral injury to the surrounding normal tissues. Unlike conventional medical terminology that frequently emphasizes "cure," oncologists typically frame therapeutic goals in terms of definitive intent or palliative intent, reflecting the clinical reality that complete eradication of cancer with no risk of recurrence or metastasis is uncommon (Kent, 2017; Vail et al., 2019).

3.1. Definitive Intent

Definitive radiation therapy is administered with the aim of achieving long-term local tumor control and prolonged survival. The treatment plan is based on the histopathological diagnosis, biological behavior of the tumor, and overall clinical evaluation of the patient. In some cases, RT may be prescribed preoperatively to reduce tumor size, thereby facilitating surgical excision, improving the feasibility of wound closure, and decreasing the risk of viable tumor cells being disseminated during surgery (Magalhaes et al., 2021; Yoshikawa et al., 2023). More commonly, RT is used postoperatively when incomplete surgical margins are suspected or confirmed, in order to eradicate microscopic residual disease and minimize the risk of local recurrence (Forrest et al., 2000).

Although surgical resection is often the preferred first-line option when feasible, there are many clinical contexts where radiation therapy offers significant advantages or may even represent the treatment of choice. These include large tumors that are not amenable to resection, neoplasms in surgically inaccessible or high-risk anatomical locations such as the brain, nasal cavity, head and neck region, vertebral column, or pelvic canal, as well as cases where surgical morbidity would be severe or disfiguring. Even when gross removal of a tumor is possible, microscopic extension of neoplastic cells beyond surgical margins is common, particularly in infiltrative tumor types, making adjuvant radiation a critical component of multimodal therapy (Mason et al., 2021; Zabielska-Koczywąs et al., 2017).

3.2. Palliative Intent

In contrast, palliative radiation therapy is directed toward alleviating clinical signs, reducing pain, and improving the quality of life in patients for whom long-term survival or cure is not a realistic expectation (Fan et al., 2018). Palliative protocols typically employ lower total doses of radiation delivered in fewer fractions, with each fraction being larger in size compared to definitive schedules (Militi et al., 2024). This approach aims to provide meaningful symptom relief while minimizing the risk of acute or late radiation-associated toxicities (Rossi et al., 2019).

Palliative RT does not imply a lesser standard of care or therapeutic futility. Rather, it is a powerful intervention for managing pain, discomfort, or functional impairment caused by tumors that are unresectable, metastatic, or advanced at the time of diagnosis. By slowing tumor progression and reducing tumor-associated morbidity, palliative therapy can extend the time animals are able to live comfortably, thereby offering owners more quality time with their pets (Baja et al., 2022; Fu et al., 2023). In many cases, cancer can be managed akin to a chronic disease, where the therapeutic focus shifts from achieving cure to maintaining patient well-being and quality of life (Militi et al., 2024).

3.3. Combined Modalities

Radiation therapy may also be integrated with systemic therapies such as chemotherapy or targeted agents to optimize both local and systemic tumor control. The combination can enhance radiosensitivity of tumor cells, address micrometastatic disease, and improve overall therapeutic efficacy (Wustefeld-Janssens et al., 2021).

4. Types of Radiation Therapy in Veterinary Medicine

Several types of radiation therapy are currently available in veterinary oncology, including teletherapy, brachytherapy, plesiotherapy, and systemic radiotherapy using radionuclides. Among these, teletherapy and plesiotherapy are the most frequently employed in routine clinical practice for the treatment of malignant tumors in companion animals (Kent, 2017). These modalities differ primarily in the way radiation is delivered to the tumor.

4.1. External Beam Radiotherapy (Teletherapy)

External beam radiotherapy, or teletherapy, represents the most common approach to radiotherapy in veterinary medicine. It involves the use of a large external radiation source—most often a linear accelerator—to deliver high-energy radiation selectively to tumors that have been accurately localized with imaging, typically computed tomography (CT). In earlier years, orthovoltage and cobalt-60 machines were used; however, modern practice now relies almost exclusively on linear accelerators (Moore, 2002; Tanabe et al., 2023).

Technological advances such as cone-beam CT (CBCT) have enabled image-guided radiotherapy (IGRT), which permits precise targeting of tumors located anywhere in the body while minimizing damage to adjacent normal structures (Søvik et al., 2010; Yuan et al., 2023). Furthermore, computerized treatment-planning systems are used to model dose deposition and optimize beam distribution, thereby improving tumor control rates and reducing radiation-induced complications. For central nervous system (CNS) tumors, magnetic resonance imaging (MRI) is frequently combined with CT to better delineate tumor boundaries, although MRI images alone cannot typically be used for dose calculation (Chiu et al., 2018).

4.2. Brachytherapy

Brachytherapy involves placing small radioactive sources directly within or adjacent to the tumor, either permanently (e.g., radioactive seeds) or temporarily (via catheters and afterloading devices). This technique provides a very high localized dose to the tumor while sparing surrounding normal tissue (Bloch et al., 2020). Although widely practiced in human oncology, brachytherapy is less common in veterinary medicine due to challenges in maintaining source stability, ensuring radiation safety, and the need to confine patients until the isotope decays or is removed. Nevertheless, when feasible, brachytherapy can achieve excellent local control with reduced collateral tissue damage compared with external beam radiotherapy (Vanhaezebrouck et al., 2025).

4.3. Plesiotherapy

Plesiotherapy is a related technique in which a radioactive source is applied directly onto the tumor surface rather than implanted within it. This approach is particularly useful for treating superficial lesions, such as certain skin tumors, where the tumor lies close to the surface and direct source placement ensures effective dose delivery with minimal exposure to underlying tissues (Goodfellow et al., 2006; Hammond et al., 2007).

4.4. Systemic Radiotherapy (Biologically Targeted Radiotherapy / Nuclear Oncology)

Systemic radiotherapy involves the administration of a radioactive therapeutic agent that localizes to tumor tissue through specific physiological or molecular processes. This approach, often referred to as biologically targeted radiotherapy or nuclear oncology, offers the potential to treat not only primary tumors but also distant metastases—an advantage over conventional radiotherapy, which is typically limited to local or regional treatment (College of Veterinary Medicine, 2025; Peterson & Rishniw, 2021).

A well-established example in veterinary medicine is the use of radioiodine (iodine-131), which is the treatment of choice for feline hyperthyroidism caused by thyroid adenomas and is occasionally used for thyroid adenocarcinomas in dogs. Radioiodine therapy is highly effective because it delivers a relatively low dose with only short-term retention of radioactivity in the patient, making it both safe and practical. Higher doses, however, may be required when treating malignant thyroid carcinomas (McGovern et al., 2024; Morsink et al., 2022; Vanhaezebrouck et al., 2025).

Systemic radionuclides also hold promise for managing bone cancers. Bone-seeking radioisotopes, initially developed for humans with metastatic osseous neoplasia, have demonstrated utility in the treatment of both primary and metastatic bone tumors in dogs and cats. In addition, targeted agents such as monoclonal antibodies and small-molecule isotope carriers—already in clinical use for neuroendocrine and mammary carcinomas in human oncology—are emerging as potential tools in veterinary practice (Barca et al., 2021; Barnard et al., 2007; Selting et al., 2023).

As the range of biologically targeted radiopharmaceuticals expands, systemic radiotherapy is expected to play an increasingly important role in veterinary oncology, potentially broadening the spectrum of tumors amenable to treatment and improving long-term outcomes for companion animals.

5. Emerging Techniques and Future Directions

5.1. Electron Radiotherapy

Linear accelerators are capable of generating both high-energy X-rays and electron beams, typically within the energy range of 4–20 MeV. Whereas X-rays are primarily employed for the treatment of deep-seated tumors, electron beams are more suitable for neoplasms located within the skin and subcutaneous tissues. Modern linear accelerators are designed to deliver both photons and electrons by either scattering accelerated electrons or directing them onto a target within the machine (Arunkumar et al., 2010; Strydom et al., 2006).

One of the major advantages of electron therapy lies in its controllable depth of penetration, which reduces unnecessary irradiation of normal tissues beyond the target volume. For instance, a 6-MeV electron beam can effectively deliver radiation up to a depth of 2 cm, with minimal dose beyond 3 cm. This makes electron beams particularly valuable for the treatment of superficial or thoracic wall tumors. The ability to tailor beam energy provides veterinary oncologists with flexibility in matching dose distribution to tumor depth, thereby improving local control while sparing surrounding structures (Chao et al., 2009; Gerbi et al., 2009; Strydom et al., 2006).

5.2. Intensity-Modulated Radiotherapy (IMRT)

Intensity-modulated radiotherapy (IMRT) represents one of the most significant technological advancements in veterinary oncology. By modulating beam fluence during delivery, IMRT allows for highly conformal dose distributions that closely match the three-dimensional geometry of the tumor. This results in steep dose gradients at field margins, effectively reducing exposure to adjacent healthy tissues (Meier et al., 2021; Van Asselt et al., 2020).

IMRT requires advanced treatment planning software, multileaf collimators, and on-board imaging to achieve submillimeter precision. While this technique is resource-intensive and demands strict patient positioning, its clinical benefits include reduced toxicity, increased sparing of critical organs, and the possibility of dose escalation to resistant tumors. As availability of IMRT expands in veterinary oncology centers, it is expected to become a cornerstone of precision cancer therapy for companion animals (Dolera et al., 2018; Meier et al., 2021; Van Asselt et al., 2020).

5.3. Strontium-90 Plesiotherapy

Strontium-90 ($\wedge$90Sr) is a long-lived beta emitter with a half-life of approximately 29 years and an emission energy of 2.27 MeV. Its limited penetration makes it particularly effective for treating superficial neoplasms. In veterinary medicine, $\wedge$90Sr has been successfully applied to oral and nasal planum squamous cell carcinoma and cutaneous mast cell tumors in cats, conjunctival squamous cell carcinoma in dogs and horses, and select cases such as lingual plasmacytoma, limbal melanoma, and hemangiosarcoma in dogs (Goodfellow et al., 2006).

The therapeutic advantage of $\wedge$90Sr lies in its ability to deliver high doses directly to the tumor surface with minimal exposure to deeper normal tissues. While its clinical use is somewhat limited compared to external beam approaches, it represents a valuable option for small, localized, and superficial lesions where conventional radiotherapy would be less effective or overly invasive (Goodfellow et al., 2006; Radioisotopes & No, 2015; Turrel et al., 2006).

5.4. Stereotactic Radiosurgery (SRS)

Stereotactic radiosurgery (SRS) is a specialized form of high-precision radiotherapy in which very large doses are delivered in a single session using a linear accelerator equipped with image-guided systems. This approach employs very narrow margins around the tumor and aims to achieve complete ablation of the lesion (Dunfield et al., 2018).

Although widely applied in human neuro-oncology, SRS remains relatively new in veterinary medicine, with only a limited number of published clinical reports. Its potential advantages include curative treatment of small, well-defined tumors in critical locations, particularly in the brain and spine, where surgery carries significant risks (Rohrer Bley et al., 2024).

5.5. Stereotactic Radiotherapy (SRT)

Stereotactic radiotherapy (SRT), sometimes referred to as stereotactic body radiotherapy (SBRT), extends the principle of stereotactic targeting to multiple treatment sessions—typically three to five fractions. Large, conformal doses are sculpted to the tumor volume with submillimeter accuracy, minimizing toxicity to adjacent structures (Rohrer Bley et al., 2024).

Treatment planning requires advanced imaging, usually CT in combination with MRI for central nervous system tumors, and strict immobilization to ensure reproducibility. The capacity to deliver high biologically effective doses in a limited number of sessions makes SRT an attractive option for tumors in anatomically challenging locations, offering both local control and preservation of quality of life (Dunfield et al., 2018).

5.6. Radioactive Implants (Brachytherapy)

The implantation of radioactive isotopes such as cobalt-60, cesium-137, radium, and iridium-192 in the form of needles or seeds represents another therapeutic modality, although its use in veterinary oncology has historically been limited. These sources can be permanently or temporarily implanted within the tumor, delivering high radiation doses locally with relative sparing of surrounding tissues (Northrup et al., 2004; Wilkie & Burt, 1990).

Brachytherapy has shown clinical promise in treating accessible malignancies, such as malignant perianal tumors in dogs and squamous cell carcinomas of the eyelids in horses and cattle (Bloch et al., 2020). Despite logistical challenges, including radiation safety and technical expertise, advances in afterloading devices and isotope encapsulation may facilitate broader clinical application in veterinary patients in the future.

6. Discussion and Conclusion

Radiation therapy has established itself as an essential modality in the management of neoplasia in companion animals, particularly dogs and cats, and continues to expand in scope as new technologies and clinical evidence emerge. Numerous studies and clinical experiences have demonstrated its ability to provide durable tumor control, improve quality of life, and, in some cases, extend survival. Beyond traditional small animal patients, there is growing recognition that radiation may also offer therapeutic benefits in exotic and non-traditional species; however, systematic data on these groups remain scarce. To fully realize its potential, clinicians must continue to define optimal treatment protocols, dose constraints, and scheduling strategies tailored to the unique physiology of each species.

Veterinary radiation oncology has advanced markedly over the past two decades, paralleling developments in human oncology. The introduction of conformal treatment planning, image guidance, intensity-modulated radiotherapy (IMRT), stereotactic techniques, and the integration of advanced imaging modalities has revolutionized therapeutic precision. These innovations have enabled the safe delivery of higher tumoricidal doses while minimizing exposure to adjacent normal tissues, thereby reducing acute toxicities and long-term complications. In particular, IMRT has demonstrated the capacity to significantly lower radiation-associated side effects, while stereotactic radiotherapy (SRT) and stereotactic radiosurgery (SRS) offer the possibility of hypofractionated treatment courses with minimal toxicity, making therapy more convenient for both patients and owners. Image-guided radiation therapy (IGRT) further extends treatment capabilities to anatomical sites that were previously not considered feasible for radiotherapy.

Nevertheless, important challenges remain. Traditional fractionated radiotherapy continues to serve as the standard of care for many tumor types, and for many practices remains the most accessible form of treatment due to its established efficacy and wider availability. However, access to advanced modalities is often constrained by infrastructure requirements, costs, and the need for highly trained personnel. Furthermore, despite the growing body of literature, questions persist regarding the most appropriate clinical indications, long-term outcomes, and quality-of-life considerations following treatment. As more patients experience extended survival due to improved therapeutic efficacy, managing late effects of radiation and optimizing survivorship care will require increasing attention.

Future research should prioritize multi-institutional collaboration to strengthen the evidence base through prospective studies, long-term follow-up, and species-specific dose–response data, particularly in exotic animals where knowledge gaps remain substantial. Equally important is the continued integration of radiation therapy into multimodal treatment regimens that include surgery, chemotherapy, and emerging systemic and targeted approaches. Such strategies promise not only improved local tumor control but also better systemic management of cancer.

In conclusion, radiation therapy has matured from a specialized and relatively underutilized tool into a cornerstone of veterinary oncology. With the continued adoption of advanced technologies, refinement of treatment protocols, and expansion of clinical research, radiotherapy is poised to further enhance outcomes, extend survival, and, most importantly, improve the quality of life of companion animals affected by cancer.

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