SCMPCR Newsletter
Scientific Article

Clinical Implications of Beam Divergence and Field Matching in Multi-Field Radiotherapy: An Update

Md. Reja Ahmed[1] ,Md. Imrul Kaes[2]
[1]Dept. of Oncology, KYAMCH Cancer Center,
[2]Dept. of Pediatric Haematology & Oncology KYAMCH Cancer Center Enayetpur, Sirajganj, Bangladesh

Introduction

Modern radiotherapy depends on a simple but demanding clinical promise: deliver the prescribed dose to the target while minimizing unnecessary dose to surrounding normal tissues. In daily practice, this promise is shaped not only by advanced imaging, contouring, optimization algorithms, and dose-volume objectives, but also by basic geometric principles. One of the most important of these principles is beam divergence. Every external photon beam diverges from its source, and when multiple fields are used, the geometry of field edges, junctions, match lines, and collimator settings can strongly influence whether the target is fully covered or whether hot and cold spots are created at field borders [1] emphasized that failure to account for beam divergence can lead to inappropriate field design and compromised target coverage. This message remains highly relevant in the era of three-dimensional conformal radiotherapy, intensity-modulated radiation therapy (IMRT), volumetric-modulated arc therapy, and complex multi-isocenter or split-field approaches. Multi-field radiotherapy is essential in many anatomical sites, including breast and supraclavicular irradiation, head and neck cancer, large-volume IMRT, and craniospinal irradiation. These treatments often require field matching or field splitting because a single beam arrangement may not adequately cover long or complex target volumes while respecting organ-at-risk constraints. However, field matching introduces a delicate balance: a small overlap may increase dose at the junction, while a small gap may underdose part of the clinical target volume or planning target volume. Therefore, treatment planning must integrate geometric accuracy, dosimetric evaluation, image guidance, quality assurance, and careful physics review according to ICRU reporting requirements & TG 275 recommendation [8, 9].

Beam divergence and its clinical consequences

Beam divergence occurs because radiation fluence spreads outward as it travels from the source to the patient. Although the concept is fundamental, its clinical consequences may be underestimated during treatment planning. When a planner defines a field edge on the patient surface or at a given depth, the beam continues to diverge beyond that point. As a result, two adjacent beams that appear aligned on a simulation image may overlap or separate at depth depending on gantry angle, collimator angle, couch angle, source-to-surface distance, and field size [1] described this issue as a practical cause of target miss, particularly when field borders are placed near regions of microscopic disease or when multiple fields are matched without adequate attention to divergence. The problem becomes more clinically important when field borders lie within or close to target tissue. If a field junction produces a cold spot, the underdosed region may become a site of recurrence, especially in tumors with high microscopic extension risk. Conversely, a hot spot at a junction may increase the risk of acute toxicity, fibrosis, spinal cord injury, brachial plexopathy, dermatitis, or other late effects depending on the treated site. Thus, beam divergence is not simply a geometric inconvenience; it is a patient safety issue. A robust treatment plan should evaluate target coverage not only in a single axial slice or beam's-eye view, but throughout the full three-dimensional dose distribution, including field junctions and dose gradients [1, 8].

Field matching in multi-field treatment planning

Field matching is used when separate fields must meet at a planned junction. The goal is to obtain a clinically acceptable dose transition between fields while avoiding excessive overlap or separation. [2] presented an analytical approach to geometrical field matching and applied it to clinical situations such as craniospinal irradiation and breast irradiation with supraclavicular fields. Their work highlights a key principle: matching is not guesswork. It is a mathematically definable process involving beam angles, field dimensions, divergence, and patient geometry. Traditional field matching methods include half-beam blocking, asymmetric jaws, collimator rotation, couch rotation, skin-gap calculation, and mono-isocentric techniques. Each method attempts to control the location and orientation of beam edges so that adjacent fields meet predictably at depth. However, each method also has limitations. Skin-gap methods may be sensitive to patient thickness and setup reproducibility. Couch and collimator rotations may be technically demanding. Split-field approaches may create match-line uncertainty. Mono-isocentric techniques simplify some junction problems but require accurate mechanical alignment and jaw positioning. Therefore, the best technique is not universal; it depends on target length, anatomical site, machine capability, immobilization, image guidance, and departmental workflow [2, 4].

Target coverage: the first responsibility of planning

The primary purpose of radiotherapy is tumor control, and tumor control requires adequate target coverage. ICRU Report 83 provides a standardized framework for prescribing, recording, and reporting IMRT, emphasizing clear definitions of target volumes, dose-volume reporting, and plan evaluation [8]. In the context of beam divergence and field matching, target coverage must be assessed with special attention to the planning target volume near junctions. A plan that meets global dose-volume histogram goals may still have a clinically meaningful cold spot if the junction region is not carefully reviewed slice by slice. This issue is especially relevant in long targets or targets treated with split fields. In head and neck radiotherapy, for example, the target may extend from the primary tumor and upper neck to the lower neck and supraclavicular region. If the upper IMRT field is matched to a lower anterior neck field, the junction may lie near nodal regions at risk [4] reviewed the mono-isocentric split-field technique for conventional and IMRT head and neck treatments and noted that match-line homogeneity can be affected by mechanical and setup uncertainties. Similarly, [5] compared split-field and whole-field IMRT techniques in head and neck cancer and showed that both approaches can produce acceptable plans, but each has different advantages and trade-offs for target coverage and normal tissue dose.

Normal tissue sparing and junction-dose management

Normal tissue sparing is the second half of the radiotherapy equation. Multi-field arrangements are often chosen because they improve the ability to shape dose away from organs at risk. However, when fields are matched, the normal tissue near the junction may receive unintended high dose if field overlap occurs. The clinical significance depends on the site. In breast and supraclavicular radiotherapy, the junction between tangential breast fields and supraclavicular fields may influence dose to the lung, heart, brachial plexus, and skin. [3]

dosimetry study and field matching for breast and supraclavicular fossa irradiation, reinforcing that careful matching is necessary to achieve acceptable dose distribution across the target and adjacent normal tissues. In head and neck treatment, normal tissue sparing involves multiple critical structures, including spinal cord, brainstem, parotid glands, larynx, oral cavity, mandible, and swallowing structures [5] found that whole-field IMRT may reduce uncertainty at the match line, while half-beam or split-field approaches may reduce laryngeal dose in selected cases. This illustrates a practical planning truth: eliminating a junction may improve geometric robustness, but it may also change the dose distribution to organs at risk. Therefore, treatment technique should not be selected only to simplify planning. It should be selected after comparing target coverage, junction robustness, organ-at-risk dose, treatment delivery efficiency, and patient-specific anatomy [5, 6].

Breast and supraclavicular radiotherapy

Breast radiotherapy with supraclavicular nodal treatment is a classic example of field matching. Tangential breast fields are often matched to an anterior supraclavicular field. The planner must consider divergence from the tangential fields and from the supraclavicular field so that the superior border of the tangents and the inferior border of the supraclavicular field do not create a significant gap or overlap. This junction is clinically important because it may cross regions of nodal drainage and nearby normal tissues [3]. Specifically, addressed dosimetry and field matching in this setting, showing the importance of matching technique in achieving clinically acceptable treatment. The practical lesson is clear: breast and supraclavicular planning should not be treated as a routine "set and forget" process. The field junction should be reviewed in three dimensions, and dose homogeneity should be evaluated across the match region. If deep inspiration breathes hold, field-in-field tangents, IMRT, or VMAT are used, the planner should still verify how the nodal and breast targets join dosimetrically. Modern planning tools can improve conformity, but they do not remove the need for geometric understanding [2, 3].

Large IMRT target volumes and fixed-jaw solutions

Large IMRT target volumes introduce another planning challenge. Some treatment planning systems split large fields, which can increase the number of multileaf collimator segments, monitor units, treatment time, and match-line dose uncertainty. [6] Split-field and fixed-jaw techniques for large head and neck IMRT target volumes, reported that target and organ-at-risk dose-volume coverage could be similar between techniques, but the fixed-jaw technique reduced issues associated with match lines and improved delivery efficiency. The clinical implication is important for departments treating extended head and neck volumes or other large targets. If two plans appear equivalent by standard DVH metrics, the planner and physicist should also examine deliverability, monitor units, segment complexity, treatment time, and junction robustness. A plan with slightly simpler geometry may be safer and more efficient if it maintains target coverage and normal tissue constraints. This is consistent with the broader philosophy of treatment planning: plan quality is not only about numerical optimization; it is also about reproducibility, quality assurance, and safe delivery [6].

Craniospinal irradiation and feathering

Craniospinal irradiation is one of the most demanding examples of multi-field radiotherapy because the target extends from the brain through the entire spinal canal. Traditional craniospinal techniques require matching cranial and spinal fields and, in many adult patients, matching two spinal fields. Because junction errors can produce high or low dose near the spinal cord, field matching and feathering are central to safe delivery. Feathering intentionally shifts the junction during treatment so that any junction-dose inhomogeneity is spread over a larger region rather than concentrated at a single anatomical level & integrated feathering for craniospinal irradiation as a method to improve patient safety and departmental efficiency [7]. Their work reflects a modern planning priority: technical solutions should not only improve dosimetry but also reduce workflow complexity and opportunities for error. In conventional feathering, multiple plans or shifts may be required, increasing workload for dosimetrists, physicists, physicians, and therapists. Integrated feathering can simplify this process by incorporating junction management into the planning structure, thereby improving consistency and reducing the burden of repeated setup or plan transitions [2, 7].

The role of physicist review and quality assurance

Beam divergence and field matching are vulnerable to small errors, physicist plan review is essential. AAPM TG-275 provides risk-informed recommendations for effective physics plan and chart review and emphasizes that review is a key safety barrier in radiation therapy [9]. For multi-field plans, the physicist review should include a specific check of field borders, match lines, jaw settings, collimator and couch angles, isocenter placement, dose calculation grid, heterogeneity correction, image guidance instructions, and consistency between the approved plan and treatment delivery parameters. A good review should ask practical questions. Does the field junction lie inside or near the target? Is the junction dose acceptable on axial, sagittal, and coronal views? Are hot and cold spots clinically acceptable? Are the jaws or MLCs used in a way that could create delivery uncertainty? Are couch or collimator rotations documented clearly? Is imaging guidance adequate to verify the anatomy near the junction? Are therapists given clear setup instructions? These checks are not administrative details; they are direct safeguards against target miss and normal tissue overdose [8, 9].

Practical recommendations for treatment planning teams

For clinical practice, the first recommendation is to respect geometry. Even in highly automated planning systems, planners should understand where beams diverge, where fields meet, and how dose behaves at depth then field junctions should be evaluated with both geometric and dosimetric tools. A visually neat beam arrangement is not enough; dose distribution across the match region must be reviewed, the team should compare alternative techniques when possible. For example, in head and neck cases, split-field and whole-field approaches may each be reasonable depending on target extent and organ-at-risk priorities. In large IMRT volumes, fixed-jaw techniques may reduce match-line and delivery complexity. In craniospinal irradiation, integrated feathering may improve safety and workflow efficiency [2, 5, 7] every department should standardize their field-matching protocols. Standardization does not mean every patient receives the same plan; it means that beam matching, junction review, documentation, and quality assurance follow a consistent process. Treatment planners, physicists, physicians, and therapists should communicate clearly about junction location and setup sensitivity. Many field-matching errors are not due to lack of knowledge but due to unclear communication or incomplete review. Finally, every department should treat match-line review as a high-risk planning step, especially in breast-supraclavicular, head and neck, and craniospinal cases [3, 9].

Modern Concept

Modern techniques like integrated feathering in a single IMRT/VMAT plan, coplanar field border (CFB) techniques and half-beam block optimizations have significantly minimized hot and cold spots at junctions compared to the convention manual shifting techniques. Advanced image-guided radiotherapy (IGRT) with daily CBCT or MRI-linac verification, as well as robust optimisation algorithms, further reduce setup uncertainties which increase divergence-related mismatches.

Future work work will involve using artificial intelligence for automated junction optimization, real time adaptive planning and prediction of penumbra and scatter effects in order to increase precision and efficiency in complex multi-field deliveries.[10]

Conclusion

Beam divergence is one of the oldest concepts in external beam radiotherapy; it remains one of the most clinically relevant. Multi-field radiotherapy allows complex target coverage and normal tissue sparing, but it also introduces field-matching challenges that can affect patient safety. The literature reviewed here shows that careful geometric planning, robust dosimetric evaluation, appropriate technique selection, and structured physics review are all necessary reminded the field that ignoring beam divergence can compromise target coverage. Later work on geometrical matching, breast and supraclavicular planning, head and neck split-field methods, large-volume IMRT, integrated feathering, ICRU reporting standards, and AAPM TG-275 review guidance extends that lesson into modern practice for the medical physics community, the message is practical and enduring: good treatment planning is not only about advanced technology. It is about understanding how radiation beams behave, anticipating where errors may occur, and designing plans that are accurate, deliverable, and safe. In every multi-field plan, target coverage and normal tissue sparing meet at the field junction. That junction deserves our full attention.

References

[1] Bentel, G. C., Marks, L. B., & Anscher, M. S. (1999). The effect of beam divergence on target coverage. *Medical Dosimetry, 24*(2), 99–113.

[2] Hernández, V., Arenas, M., Pons, F., & Sempau, J. (2011). Clinical applications of geometrical field matching in radiotherapy based on a new analytical solution. *Medical Dosimetry, 36*(2), 160–165. doi: 10.1016/j.meddos.2010.02.008.

[3] Miles, E. A., Venables, K., Hoskin, P. J., & Aird, E. G. A. (2009). Dosimetry and field matching for radiotherapy to the breast and supraclavicular fossa. *Radiotherapy and Oncology, 91*(1), 42–48. doi: 10.1016/j.radonc.2008.11.016.

[4] Abdel-Hakim, K., Nishimura, T., Takai, M., & Sakahara, H. (2005). Review of monoisocentric split-field technique for conventional and IMRT treatment in head and neck cancers: Technical limitations and approaches for optimization. *Technology in Cancer Research & Treatment, 4*(1), 107–113. doi: 10.1177/153303460500400114.

[5] Dabaja, B., Salehpour, M. R., Rosen, I., Tung, S., Morrison, W. H., Ang, K. K., & Garden, A. S. (2005). Intensity-modulated radiation therapy of cancers of the head and neck: Comparison of split-field and whole-field techniques. *International Journal of Radiation Oncology, Biology, Physics, 63*(4), 1000–1005. doi: 10.1016/j.ijrobp.2005.03.069.

[6] Srivastava, S. P., Das, I. J., Kumar, A., & Johnstone, P. A. S. (2011). Dosimetric comparison of split field and fixed jaw techniques for large IMRT target volumes in the head and neck. *Medical Dosimetry, 36*(1), 6–9. doi: 10.1016/j.meddos.2009.10.002.

[7] Harrison, A. S., Landers, A., Nettleton, V., Palermo, K., Vakhnenko, Y., & Shi, W. (2024). Integrated feathering for craniospinal irradiation improves patient safety and departmental efficiency. *Medical Dosimetry, 49*(2), 77–80. doi: 10.1016/j.meddos.2023.08.008.

[8] International Commission on Radiation Units and Measurements. (2010). Prescribing, recording, and reporting photon-beam intensity-modulated radiation therapy (IMRT) (ICRU Report 83). Journal of the ICRU, 10(1), 1–106. doi: 10.1093/jicru/ndq002.

[9] Ford, E. C., Conroy, L. A., Dong, L., Fong de los Santos, L. E., Greener, A. W., Kim, G. G.-Y., Johnson, J. L., Johnson, P. B., Mechalakos, J. G., Napolitano, B., Parker, S. A., Schofield, D. L., Smith, K., Yorke, E. D., & Wells, M. C. (2020). Strategies for effective physics plan and chart review in radiation therapy: Report of AAPM Task Group 275. *Medical Physics, 47*(6), e236–e272. doi: 10.1002/mp.14030.

[10] Zhang, Y., et al. (2023). Multi-isocenter VMAT craniospinal irradiation using feasibility-enhanced optimization. Journal of Applied Clinical Medical Physics, 24(5), Article e13945. (Discusses advanced VMAT techniques, including junction management optimizations in multi-isocenter plans.)