Life. Science.

SOLUTION PAPER

DynamicARC®

The Next Revolution in Proton Therapy

FASTER · SIMPLER · SHARPER

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Introduction

Proton therapy has brought meaningful benefits to cancer treatment and is considered the most advanced form of radiation therapy available today.

IBA is committed to making proton therapy accessible to all patients who could benefit from it, through meaningful and sustainable clinical and technical evolutions that will facilitate its adoption and increase its value. DynamicARC* is an important step on this journey to ensure proton therapy reaches its full potential.

DynamicARC consists in simultaneous gantry rotation and beam delivery at variable energies; allowing faster, sharper and simpler treatment workflow. This new treatment modality represents the largest improvement since the evolution from Double Scattering to Pencil Beam Scanning.

To deliver the promise of DynamicARC, IBA has initiated a global DynamicARC Consortium (DAC), in collaboration with leading clinical centers. Together with the Consortium and our Clinical Advisory Board, we are working to bring DynamicARC to life to increase patient throughput.

In this Solution Paper, we look back at the history of arc therapy and share how its future clinical implementation with DynamicARC will improve the treatment landscape. We hope it will help you better understand the opportunities that lie ahead and how you can confidently embrace the future of proton therapy with DynamicARC on the Proteus® platform.

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**DynamicARC is the registered brand of IBA's Proton Arc therapy solution which is currently under research and development. DynamicARC will be available for sale when regulatory clearance is received. Due to a continuous research and development program, IBA reserves the right to make changes in design, technical descriptions, and specifications of its products without prior notice. Some features are under development and may be subject to review by competent authorities.*

The history of arc therapy

There have been significant advances in the delivery of radiotherapy and proton therapy since they were first introduced.

Over the past decades, progress in treatment planning systems and linear accelerator delivery capabilities have led to improved dose distributions and conformity[1]. Imaging techniques have also become increasingly sophisticated, which has resulted in improved accuracy of target volume definition and delineation[2].

One of the most recent advances is the development of arc therapy. With arc therapy, radiation is delivered with a continuous rotation of the radiation source. This allows the patient to be treated with continuous beam delivery as the gantry rotates.

THE EVOLUTION OF RADIOTHERAPY

In radiotherapy, the development of intensity modulated radiotherapy (IMRT) has been an important milestone. IMRT employs variable intensity across multiple radiation beamlets which allows the construction of highly conformal dose distributions. The benefits of this technique include improved target volume dose conformity and sparing of normal tissues and organs at risk[3,4,5].

However, IMRT has some limitations. In addition to the greater complexity and treatment delivery time compared to conventional conformal radiotherapy, IMRT plans use a larger number of monitor units, resulting in an increase in the amount of low dose radiation to the rest of the body of the patient. As such, there have been some concerns of increased risk of secondary radiation-induced malignancies[6,7,8].

Arc therapy sets out to overcome some of the limitations of IMRT. The introduction of Volumetric Modulated Arc Therapy (VMAT) has significantly changed the treatment landscape in conventional radiotherapy, allowing the user to achieve highly conformal dose distributions with improved target volume coverage and sparing of normal tissues compared with standard IMRT[9]. VMAT also offers other advantages, such as reduced treatment delivery time. Today, VMAT is widely used by radiotherapy centers.

However, VMAT also has limitations. Challenges in clinical practice include achieving lower integral dose, greater dose conformity and better sparing of organs at risk.

RADIOTHERAPY MILESTONES

1943	First linac installation in the UK
1960s	Adoption of 2D radiotherapy
1992	First commercial use of IMRT
1995	General adoption of IMRT
2005	General adoption of VMAT

THE EVOLUTION OF PROTON THERAPY

Since its inception, proton therapy has been increasingly used to treat a variety of cancers. Proton therapy offers excellent physical properties and superior dosimetric characteristics. As such, it may improve patient survival by improving the local tumor treatment rate while reducing injury to normal tissues, which may result in fewer radiation-induced adverse effects[10].

Just like photon-based radiotherapy, proton therapy has been evolving to offer greater efficiency and better outcomes. This includes the development of Intensity modulated proton therapy (IMPT) based on Pencil Beam Scanning (PBS) proton therapy, which IBA was the first to introduce on a commercial equipment and which has since then become the standard in proton therapy.

In PBS, the proton beam paints the target volume, one layer at a time, voxel by voxel, to precisely match the shape of the tumor. It allows the user to give a different dose to each voxel of the map. IMPT treats a small section of the tumor at a time, adjusting the proton beam dose and depth to wider and narrower contours of the tumor, section by section. Combined with the appropriate imaging devices and treatment strategies, IMPT is also capable of treating moving tumors.

Today, the next frontier in proton therapy is the development of proton arc therapy which has the potential to further improve dose conformality and distribution, and to optimize treatment delivery time[11].

> *Rotational protons have been a dream for many years. But it was never possible to implement it before. Beaumont, in collaboration with IBA, has developed a novel technology which will allow scanning beam protons to be delivered in a rotational technique.*

DR CRAIG STEVENS
Chief of Radiation Oncology
Corewell Health (then Beaumont),
Royal Oak, Michigan, United States

PROTON THERAPY MILESTONES

1980s First proton therapy facilities with scattering techniques

2008 Clinical use of IMPT/PBS

2018 First Arc proton therapy proof of concept

PROTON ARC THERAPY: THE BEGINNINGS

In 1997, Deasy et al suggested the use of arc therapy in protons using the distal edge tracking principle[12]: “It is proposed to deliver proton therapy in a 'tomotherapy' geometry; that is, by moving an intensity-modulated slit proton beam around the patient in a helical pattern”.

The first in-silico study showing the potential of proton arc therapy to improve dose conformity was published in 2013, looking at non-small cell lung cancers[13]. Seco et al concluded: **“Stereotactic body radiation therapy with proton arc and Photon-VMAT generate significantly more conformal high-dose volumes than standard proton SBRT, without loss of coverage of the tumor and with significant sparing of nearby organs,** such as chest wall. In addition, both proton arc approaches spare the healthy lung from low-dose radiation relative to photon VMAT. Our data suggest that IMPT-Arc should be developed for clinical use.”

The first proton spot-scanning arc optimization method compatible with existing proton therapy systems was described by Ding and al in 2016 using a ProteusONE system[14]. It was “based on an interactive approach, solving the main obstacles in proton arc therapy, producing plans with fine control point sampling spacing for potential continuous arc delivery; robust plan quality with a practical achievable delivery time; and finally, a reasonable plan workflow and plan calculation time”.

In 2018, IBA in partnership with Corewell Health (formerly William Beaumont Hospital) successfully performed the first prototype of dynamic proton arc delivery on a Proteus proton therapy system[15]. The study conclusions were that “the measurements and simulations demonstrated the feasibility of spot-scanning arc treatment within the clinical requirements.”

The promise of DynamicARC

DYNAMICARC PRINCIPLE

IBA's DynamicARC program aims to bring the full potential of proton arc therapy to clinicians and patients, making treatment sharper, faster and simpler and contributing to greater proton therapy accessibility for patients who could benefit from it.

With DynamicARC, treatment is delivered during gantry rotation. The patient positioning system and couch remain fixed throughout the arc delivery.
To optimize delivery time and dose conformity, the gantry speed is variable as well as the energy delivered. The gantry decelerates when many spots must be delivered in a short angle span. On the contrary, the gantry accelerates when few or no spots need to be delivered in a larger angle span.

In a nutshell, DynamicARC allows dynamic continuous irradiation while the gantry is rotating, with the advantages of both PBS and Bragg Peak without the exit dose.

CLICK OR SCAN THE QR CODE TO WATCH OUR DYNAMICARC VIDEO

IBA was granted a patent for this unique technology.

> *DynamicARC proton therapy offers a more targeted approach compared to photon-based techniques. It provides more flexibility in optimizing the conformality of the treatment to the tumor and will streamline further the treatment delivery improving drastically the patient experience.*

PR HANS LANGENDIJK
Radiotherapeutic Oncologist
University Medical Center Groningen (UMCG), Netherlands

DYNAMICARC CONSORTIUM

Committed to shaping the future of proton therapy together with its users, IBA has initiated a global DynamicARC Consortium, in collaboration with eight leading clinical centers who are pioneers in proton therapy. The Consortium is a unique platform to exchange and tackle the application challenges to make DynamicARC a successful clinical reality.

The members of the Consortium are highly experienced clinicians, physicians, and physics representatives from leading international centers:

CONSORTIUM MEMBERS*

Baptist Health South Florida

Corewell Health™

Inova™

Massachusetts General Hospital
Founding Member, Mass General Brigham

PARTICLE
PROTON THERAPY CENTER • LEUVEN

quirónsalud

UFHealth
PROTON THERAPY INSTITUTE

umcg

*January 2024 - this list may be subject to changes.

DYNAMICARC ECOSYSTEM

To support DynamicARC and obtain the full benefits in clinical practice, IBA is working on developing a DynamicARC ecosystem by integrating with Oncology Information Systems (OIS), Treatment Planning Systems (TPS) and dosimetry solutions.

Treatment Planning Systems for DynamicARC are an active research area, with a growing number of scientific publications. They are decisive to fully benefit from the potential advantages of DynamicARC. DynamicARC removes the need for complex beam arrangements. Treatment planning is fully automatic (VMAT-like), allowing the optimization of delivery time and linear-energy-transfer (LET).

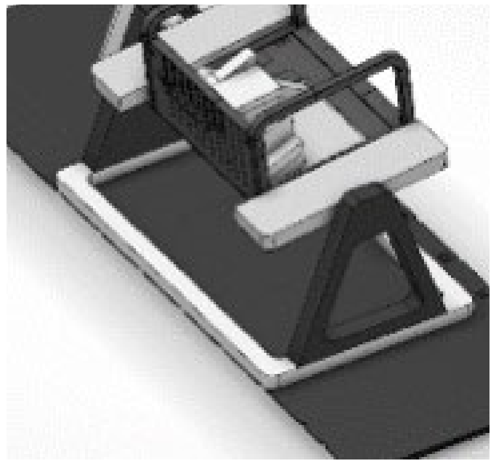
Several algorithms and methods on arc optimization are being researched at the moment, with a focus on conformity and speed. IBA is working closely with two partners, Elekta and RaySearch Laboratories, to ensure the commercial availability of Treatment Planning Solutions for DynamicARC at launch.

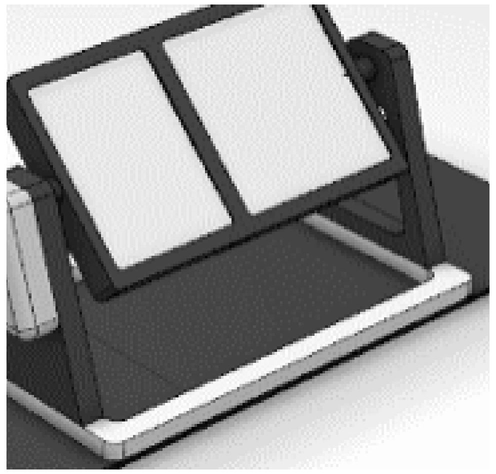
In addition, IBA Proton Therapy teams are collaborating closely with IBA Dosimetry on integrated machine and patient Dosimetry tools to support DynamicARC.

These include nozzle and couch holders for calibration, commissioning, Machine QA and Patient QA detectors (Phoenix, Sphinx Compact, Zebra, Giraffe and MatriXX). Patient-specific log-based QA is also currently being developed, thanks to the integration of the read-out of the gantry angle in the IBA Proteus logs.

PHOENIX

SPHINX





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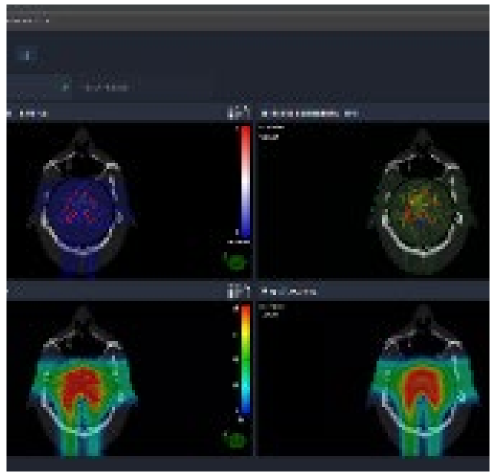


MYQA ION

DynamicARC: towards sharper, faster and simpler treatment

DynamicARC has the potential to significantly improve treatment delivery, allowing sharper, faster and simpler treatment.

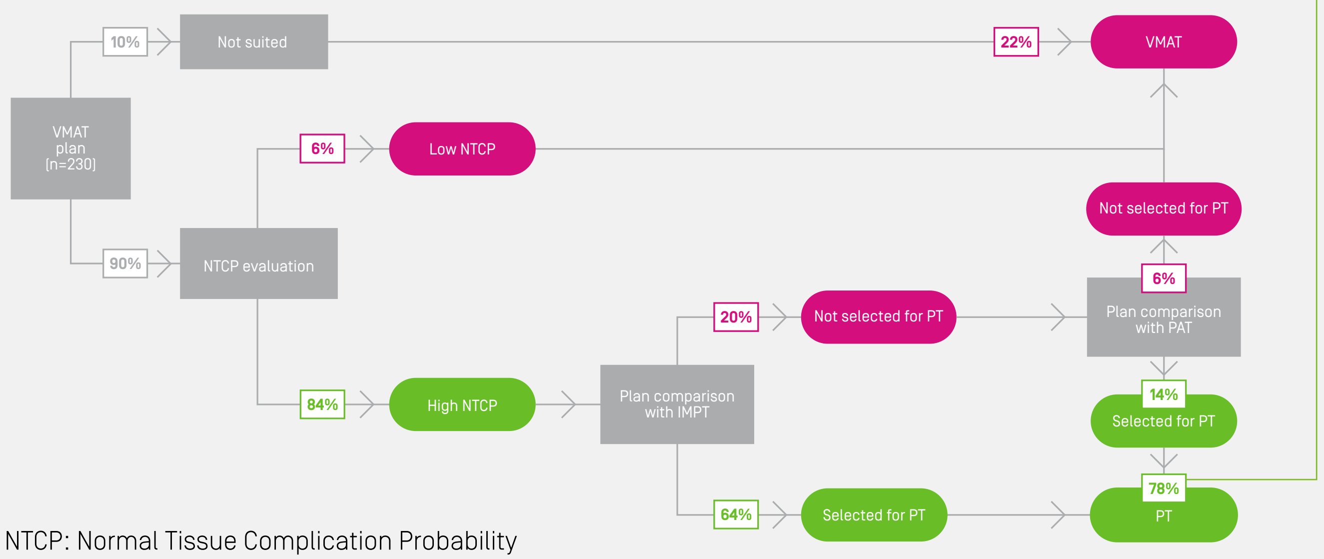
SHARPER

DynamicARC could make treatment sharper by delivering an expected lower integral dose and offering better dose conformity[16].

In oropharyngeal cancer patients for example, this may lead to a **22%** increase in patient qualification for proton therapy compared to conventional IMPT and VMAT in the model-based approach as practiced in The Netherlands[17].

Patient selection process:
Model-based selection (2018-2021)
Oropharyngeal cancer (n=230)

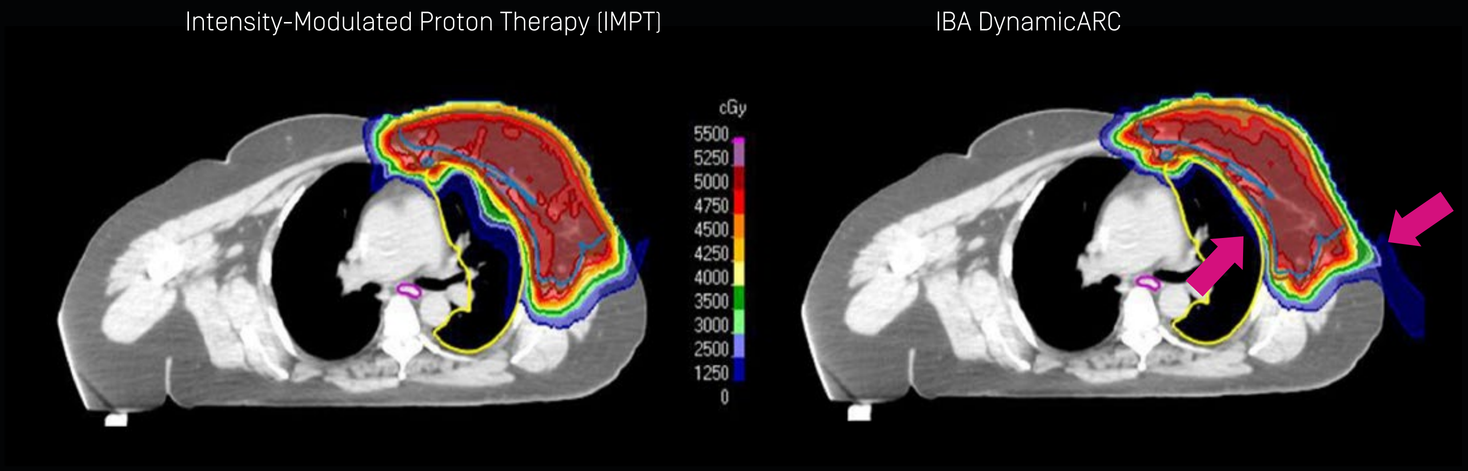
22% Increased qualification of patients for PT with DynamicARC® compared to conventional IMPT and VMAT, in the model-based approach

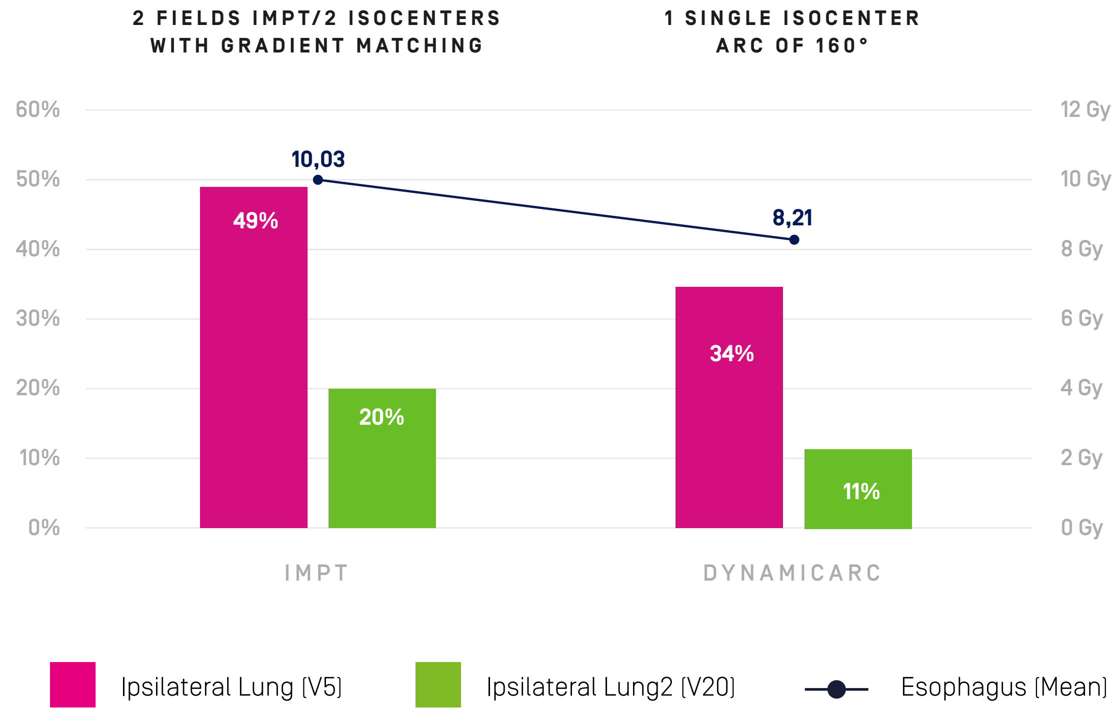


NTCP: Normal Tissue Complication Probability
% shown on the graphic are relative percentages

01 CASE STUDY 1

BREAST TUMOR: OAR SPARING (COPLANAR STUDY)[18]



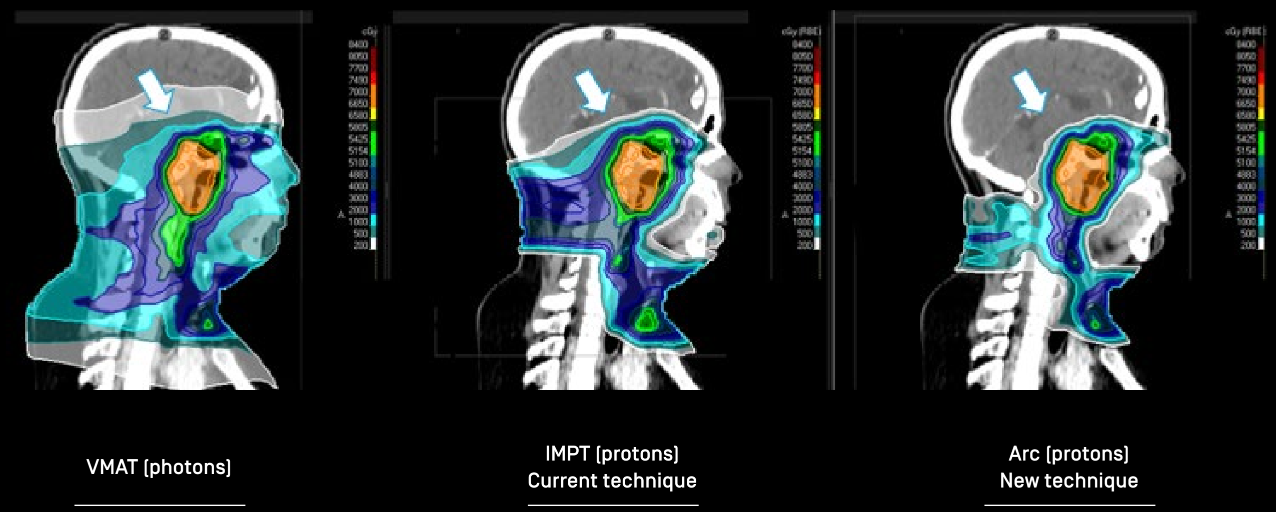


A feasibility study by Chang et al[19] has shown that proton arc therapy can reduce the dose delivered to organs at risk and the probability of normal tissue complications in patients treated for left-sided whole breast radiotherapy.

02 CASE STUDY 2

NASOPHARYNGEAL CARCINOMA: BETTER CONFORMALITY & DOSE DISTRIBUTION

Brain and other intracranial structures



Courtesy of Prof Langendijk - UMC Groningen (UMCG), The Netherlands UMCG research on head & neck patients has shown an at least 14.2% reduction in NTCP grade 2 compared to VMAT, with the potential to qualify more patients for proton therapy[20].

Research shows that DynamicARC may also allow to optimize linear-energy-transfer (LET)[21] and may help mitigating interplay effects for moving tumors[22]. The better dose conformity offered by DynamicARC may favor the move to ultra-hypofractionation in proton therapy[23].

FASTER

With an optimized workflow, DynamicARC can be faster than IMPT, allowing for higher patient throughput. A retrospective study was conducted by Corewell Health[24] on 21 patients treated with IMPT, representative of the typical case mix of the proton therapy center. For each patient, a DynamicARC plan was produced, with similar or better characteristics than the corresponding IMPT plan. The team then estimated the irradiation time for each arc plan using an internal model benchmarked on their current ProteusONE solution. The total delivery time for the 21 patients was added up and compared to IMPT plans.

An average **reduction of 60 % of fraction delivery time per patient** was observed. Considering the same set-up time, if all patients treated with IMPT were treated with DynamicARC.

Up to 30% more patients could be treated on a typical treatment day.

The biggest advantages were seen in the longer treatments, where DynamicARC can have a significant impact in time.

SIMPLER

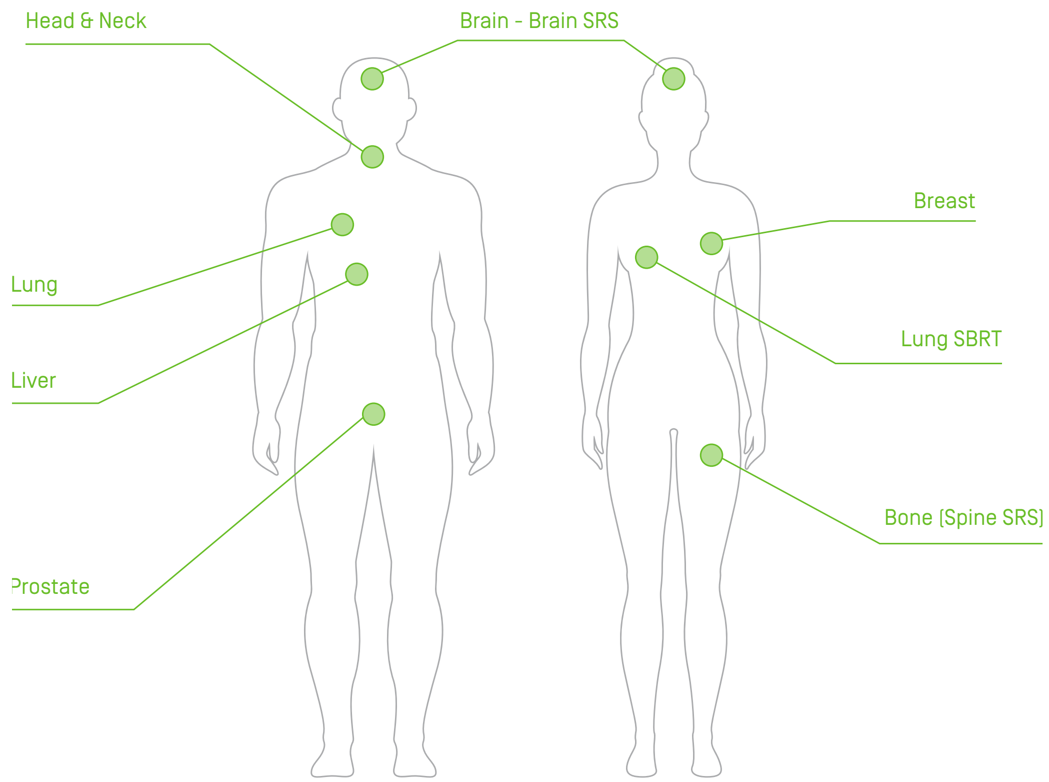
DynamicARC is simpler than IMPT, in the same way that VMAT is simpler than IMRT in conventional radiotherapy. Rotational delivery can significantly simplify treatment planning and delivery workflows in proton therapy centers.

1 BEAM PLANNING | **1 BEAM QA** | **1 BEAM DELIVERY**

With DynamicARC, there is no need for complex beam arrangements, as the Treatment Planning System will offer automatic angle optimization for dose conformity. It is a **linac-like operation** avoiding multiple fields adjustments with only one beam delivered, the removal a lot of couch kicks and less need for accessories.

DynamicARC: clinical indications

DynamicARC is expected to be beneficial to a wide range of clinical indications.



More than 150 patient cases, across 10 studies, have already compared plans with DynamicARC on ProteusONE and other treatment modalities.*

These studies have shown that:

- In brain and head & neck cancer, DynamicARC has the potential to significantly reduce the dose to OARs (except for small central lesions in the brain).
- In large breast cancer, DynamicARC has the potential to greatly simplify the workflow (increase of the lateral field size) and reduce toxicities.
- In thoracic cancer, DynamicARC has the potential to mitigate the interplay effect.
- In abdominal and pelvic cancer, DynamicARC will allow a potentially more favorable LET distribution.

** September 2023*

OVERVIEW OF KEY STUDIES IN DIFFERENT INDICATIONS

BRAIN CANCER

& **SHARPER & FASTER**

Proton arc therapy (PAT) could significantly reduce the dose delivered to the hippocampus and cochlea in patients being treated with whole-brain radiotherapy[25]. PAT plans could also potentially achieve similar or faster delivery time in a modern proton machine with energy-layer-switching-time (ELST) of less than 1 s.

In addition, PAT has a dosimetric advantage in the V12Gy and R50 with target volumes > 9.00 cc compared to VMAT and IMPT[23]. A significant clinical benefit was found in deep centrally located lesions larger than 20.00 cc using PAT because of the superior dose conformity and mean dose reduction in healthy brain tissue. Nine retrospective clinical cases and a blind survey showed good agreement with the in silico dosimetric model and decision tree. Additionally, PAT significantly reduced the treatment delivery time compared to VMAT.

BREAST CANCER

& **SHARPER & SIMPLER**

The PAT technique can further reduce the dose delivered to OARs and the probability of normal tissue complications in patients treated for left-sided whole breast radiotherapy[19].

HEAD & NECK CANCER

SHARPER

PAT could significantly spare OARs while providing a similar or better robust target coverage compared with IMPT in the treatment of bilateral HNC[26]. In a modern proton system with Energy Layer Switching Time (ELST) less than 0.5 s, PAT could potentially be implemented in routine clinical practice with practical, achievable treatment delivery efficiency.

“Step and shoot" proton arc also demonstrates potential to further reduce toxicity compared to IMPT and VMAT in OPC treatment[17]. By employing 360 energy layers (ELs) and 30 beams in the proposed energy layer reduction (ELR) method, delivery time can reach clinically acceptable levels without compromising plan toxicity when automatic beam sequencing is available.

LUNG CANCER

SHARPER

PAT could further improve the dosimetric results in patients with locally advanced-stage non-small-cell lung cancer (NSCLC) and potentially be implemented into routine clinical practice[28].

& **SHARPER & SIMPLER**

PAT can allow to effectively mitigate the interplay effect for proton lung SBRT compared to IMPT with repainting and is associated with normal tissue sparing[27]. It may make delivery of proton SBRT more technically feasible and less complex with fewer concerns over underdosing the target compared to other proton therapy techniques.

PROSTATE CANCER

& **SHARPER & FASTER**

The first systemic dosimetric approach on the concept of proton arc therapy in the treatment of prostate cancer patients demonstrated the potential of SPArc to not only provide a more robust and improved plan quality but also to reduce the beam delivery time into a practical, achievable time[28].

SPINE METASTASES

SHARPER

PAT is an advanced planning and treatment technique to push the dosimetric limits over the current PBS technique method[29]. Compared to IMPT, PAT further improved the target coverage conformity and robustness. Compared to the VMAT technique, PAT would be more efficient, meanwhile providing equivalent and better dosimetric plan quality for spine SBRS.

ACROSS INDICATIONS: LET

SHARPER

Using PAT for LETd-based optimization is feasible and has significant advantages[32]. It could maximize the LETd distribution wherever is desired inside the target and averts the high LETd away from the adjacent critical organs-at-risk.

& SHARPER & FASTER

All PBS arc plans showed a reduced integral dose compared to their respective 2IMPT plans[30]. The average robust target coverage in terms of V95 of the voxelwise minimum dose distribution (evaluated over 42 scenarios) was: 98.0% (2IMPT), 88.6% (1Arc), 92.5% (1Arc_unseq), 97.3% (2Arc). The optimization time, including spot selection and spot dose computation, was longest for the 2Arc plan, but was below 6 min for all patients. The maximum estimated delivery time for all types of arc plans was just above 5 min.

FASTER

The PAT seq optimization algorithm could effectively reduce the beam delivery time (BDT) compared to the original PAT algorithm[36]. The improved efficiency of the PAT seq algorithm has the potential to increase patient throughput, thereby reducing the operation cost of proton therapy.

SIMPLER

The application of bi-criteria optimization to the proton arc therapy problem permits the planners to select the best treatment strategy according to the patient conditions and clinical resources available[32].

FASTER

The first PAT planning framework allows to directly optimize plan quality with the delivery time as an input for the new generation of proton therapy systems[33]. This work paved the road for implementing the technology in a routine clinic and provided a planning platform to explore the trade-off between the delivery time and plan quality.

& SHARPER & FASTER

The first fast-planning framework for proton arc therapy spot-sparsity optimization enables efficient treatment delivery with a balanced plan quality[34]. This work paved the road for clinical implementation in the TPS platform efficiently.

CONCLUSION

DynamicARC provides the opportunity to deliver faster treatment with high proton doses while the gantry is rotating, further improving dose conformity and sparing normal tissue. It could change the future of proton therapy, allowing to increase patient qualification and throughput so more patients can benefit from precise proton cancer care.

IBA is fully committed with its clinical and industrial partners to make DynamicARC a clinical reality, available on our Proteus proton therapy system. We are also developing an integrated ecosystem providing all the tools you need to support this new technology and help you embrace this revolution with confidence while ensuring the profitability of your investment. We will share our milestones on this journey; watch our announcements to learn about our progress!

As always, IBA is fully committed to the upgradability and sustainability of its solutions. As such, a significant proportion of our installed base will be able to upgrade to DynamicARC under specific technical and financial conditions. Together, let's change the future of cancer care for patients and those who care for them!

Learn more on IBA Campus, your proton therapy community

A Journey to DynamicARC: recent breakthrough and future roadmap
A presentation by Xuanfeng (Leo) Ding, Lead Medical Physicist, Corewell Health Proton Therapy Center, United States

What is DynamicARC
An overview by Craig Stevens, Chief of Radiation Oncology, Corewell Health, United States

DynamicARC de Triomphe symposium: complex IMPT and DynamicARC plan comparisons
Presentations from leading experts from Corewell Health and Baptist Health South Florida, United States

References

1. Thwaites DI, Tuohy JB. Back to the future: the history and development of the clinical linear accelerator. Phys Med Biol 2006;51:R343–62 [PubMed].

2. Newbold K et al. Advanced imaging applied to radiotherapy planning in head and neck cancer: a clinical review. Br J Radiol 2006;79:554–61 [PubMed].

3. Staffurth J. Radiotherapy Development Board. A review of the clinical evidence for intensity-modulated radiotherapy. Clin Oncol 2010;22:643–57 [PubMed].

4. Guerrero Urbano MT, Nutting CM. Clinical use of intensity-modulated radiotherapy: part I. Br J Radiol 2004;77:88–96 [PubMed].

5. Guerrero Urbano MT, Nutting CM. Clinical use of intensity-modulated radiotherapy: part II. Br J Radiol 2004;77:177–82 [PubMed].

6. Hall EJ, Wuu CS. Radiation-induced second cancers: the impact of 3D-CRT and IMRT. Int J Radiat Oncol Biol Phys 2003;56:83–8 [PubMed].

7. Verellen D, Vanhavere F. Risk assessment of radiation-induced malignancies based on whole-body equivalent dose estimates for IMRT treatment in the head and neck region. Radiother Oncol 1999;53:199–203 [PubMed].

8. Ruben JD et al. The effect of intensity-modulated radiotherapy on radiation-induced second malignancies. Int J Radiat Oncol Biol Phys 2008;70:1530–6 [PubMed].

9. Teoh M et al. Volumetric modulated arc therapy: a review of current literature and clinical use in practice. Br J Radiol. 2011 Nov;84(1007): 967-96. [PubMed]

10. Tian X et al. The evolution of proton beam therapy: Current and future status. Mol Clin Oncol. 2018 Jan;8(1):15-21. [PubMed]

11. First irradiation of a Spot Scanning Proton Arc Therapy plan at Beaumont Health. Proton Therapy IBA. www.youtu.be/oeG0GNBiLTI?si=uSl8hUOR01sGkhFQ.

12. Deasy JO et al. "Comformal Proton Tomotherapy Using Distaledge Tracking. " Radiotherapy and Oncology 37 (1995): S43. https://doi.org/10.1016/017-8140(96)80599-8.

13. Seco J et al. "Proton Arc Reduces Range Uncertainty Effects and Improves Conformality Compared with Photon Volumetric Modulated Arc Therapy in Stereotactic Body Radiation Therapy for Non-Small Cell Lung Cancer." International Journal of Radiation Oncology Biology Physics 87, no. 1 (2013): 188–94. https://doi.org/10.1016/j.ijrobp.2013.04.048.

14. Ding X et al. "Spot-Scanning Proton Arc (SPArc) Therapy – The First Robust and Delivery-Efficient Spot-Scanning Arc Therapy." International Journal of Radiation Oncology • Biology • Physics 0, no. 0 (2016): 1107–16. https://doi.org/10.1016/J.IJROBP.2016.08.049.

15. Li X et al. "The First Prototype of Spot-Scanning Proton Arc Treatment Delivery." Radiotherapy and Oncology 137 (2019): 130–36. https://doi.org/10.1016/j.radonc.2019.04.032.

16. de Jong B et al. Proton arc therapy increases the benefit of proton therapy for oropharyngeal cancer patients in the model-based clinic, Radiotherapy and Oncology (2023). [PubMed]

17. de Jong B et al. Both S. Spot scanning proton arc therapy reduces toxicity in oropharyngeal cancer patients. Med Phys. 2023 Mar;50(3):1305-1317. [PubMed]

18. Ding et al. PTCOG 58 (2019).

19. Chang S et al. Feasibility study: spot-scanning proton arc therapy (SPArc) for left-sided whole breast radiotherapy. Radiat Oncol 15, 232 (2020). https://doi.org/10.1186/s13014-020-01676-3

20. Ongoing study at UMCG presented at NAPT 2022. IBA Campus. https://www.campus-iba.com/webinars/napt-2022

21. Li X et al. Linear Energy Transfer Incorporated Spot-Scanning Proton Arc Therapy Optimization: A Feasibility Study. Front Oncol. 2021 Jul 12;11:698537. doi: 10.3389/fonc.2021.698537. PMID: 34327139; PMCID: PMC8313436. [Frontiers]

22. Li X et al. Improve dosimetric outcome in stage III non-small-cell lung cancer treatment using spot-scanning proton arc (SPArc) therapy. Radiat Oncol. 2018 Feb 27;13(1):35. doi: 10.1186/s13014-018-0981-6. PMID: 29486782; PMCID: PMC6389253. [PubMed]

23. Chang S et al. Redefine the Role of Spot-Scanning Proton Beam Therapy for the Single Brain Metastasis Stereotactic Radiosurgery. Front Oncol. 2022 May 19;12:804036. doi: 10.3389/fonc.2022.804036. PMID: 35664795; PMCID: PMC9160604.

24. Gang et al. The First Modeling of the Spot-Scanning Proton Arc (SPArc) Delivery Sequence and Investigating Its Efficiency Improvement in the Clinical Proton Treatment Workflow, AAPM 2021

25. Ding X et al Improving dosimetric outcome for hippocampus and cochlea sparing whole brain radiotherapy using spot-scanning proton arc therapy. Acta Oncol. 2019 Apr;58(4):483-490. [PubMed]

26. Liu G et al. Improve the dosimetric outcome in bilateral head and neck cancer (HNC) treatment using spot-scanning proton arc (SPArc) therapy: a feasibility study. Radiat Oncol. 2020 Jan 30;15(1):21. [PubMed]

27. Liu G et al. Lung Stereotactic Body Radiotherapy (SBRT) Using Spot-Scanning Proton Arc (SPArc) Therapy: A Feasibility Study. Front Oncol. 2021 Apr 22;11:664455. [PubMed]

28. Ding X et al. Have we reached proton beam therapy dosimetric limitations? - A novel robust, delivery-efficient and continuous spot-scanning proton arc (SPArc) therapy is to improve the dosimetric outcome in treating prostate cancer. Acta Oncol. 2018 Mar;57(3):435-437. [PubMed]

29. Liu G et al. Is proton beam therapy ready for single fraction spine SBRS? - a feasibility study to use spot-scanning proton arc (SPArc) therapy to improve the robustness and dosimetric plan quality. Acta Oncol. 2021 May;60(5):653-657. [PubMed]

30. Engwall E et al. Fast robust optimization of proton PBS arc therapy plans using early energy layer selection and spot assignment. Phys Med Biol. 2022 Mar 17;67(6). [PubMed]

31. Liu G et al. A novel energy sequence optimization algorithm for efficient spot-scanning proton arc (SPArc) treatment delivery. Acta Oncol. 2020 Oct;59(10):1178-1185. [PubMed]

32. Wuyckens S et al. Bi-criteria Pareto optimization to balance irradiation time and dosimetric objectives in proton arc therapy. Phys Med Biol. 2022 Dec 13;67(24). [PubMed]

33. Zhao L et al. An evolutionary optimization algorithm for proton arc therapy. Phys Med Biol. 2022 Aug 16;67(16). [PudMed]

34. Zhao L et al. The first direct method of spot sparsity optimization for proton arc therapy. Acta Oncol. 2023 Jan;62(1):48-52. [PubMed]

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