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Technical Note

AI segmentation as a quality improvement tool in radiotherapy planning for breast cancer

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ABSTRACT

AI segmentation has been recently introduced in the local department for delineation of targets and organs-at-risk (OAR) for a wide range of tumour sites. For breast radiotherapy, AI segmentation can provide target delineation (breast and lymph nodes) and required OAR, and this has enabled a stepwise series of improvements to the local planning technique.

Clinician feedback deemed 67 - 89 % of nodal target volumes required no edits or only minor edits, so AI breast and lymph nodes volumes were first used to guide tangent and supraclavicular field placement, instead of a bony-anatomy based technique.

Next, evolution from anatomical field-placement to true inverse optimised planning was introduced using AI to create the required target volumes. For internal mammary node (IMN) treatments, the previous 3-field technique prohibited Deep Inspiration breath-hold (DIBH), due to the couch rotation used to match field edges. The roll-out of VMAT (volumetric-modulated arc therapy) with DIBH enabled by AI therefore resulted in a dose reduction to ipsi-lateral lung, and in mean heart dose compared to the old 3-field technique. Median time from CT scan to VMAT IMN plan approval reduced from 12 days (with manual contouring) to 7 days using reviewed and edited AI-generated volumes.

Consistent, high-quality contours for 9 OAR and breast PTVs for all patients facilitates comparison with NHS-E scorecards as a benchmark for plan quality. Workflows have been simplified, with significant time-savings. DIBH radiotherapy is now available to more patients, further improving dose sparing for heart and lung.

Introduction

The high prevalence of breast cancer worldwide, representing 11.7 % of all cancers [1] means that treatment of breast cancer patients generally forms a large proportion of workload in radiotherapy departments. International guidelines from e.g. ESTRO [2] help to define which breast and lymph node regions should be delineated and targeted for treatment, as well as the recommended organs-at-risk (OAR) which should be spared [3]. Awareness of delineation tasks as not only very time consuming, but subject to inter-observer variability has also led to recommendations for routine peer review and quality assurance [4].

Historically, these delineation tasks were not always fully implemented for breast radiotherapy, as many radiotherapy treatment techniques were based on simple forward-planned fields, rather than the full anatomical contour-based inverse optimization used in other tumour sites.

The large number of breast cancer patient treatments coupled with current workforce shortages have meant that fully-delineated inverse-optimized radiotherapy treatments for breast cancer have been slow to be adopted as routine treatment techniques.

AI segmentation can potentially address the challenges related to lack of staff resources [5]. AI segmentation can also harmonise structure definitions and nomenclature, distribute tasks across different staff groups, drive improvements in treatment technique and accelerate adoption of best practice into clinical routine for a larger number of patients.

The introduction of AI segmentation for breast and nodal radiotherapy treatments is described, highlighting the development pathway from commissioning to full implementation, and quality improvements that have been enabled by use of AI segmentation.

Materials and methods

The quality improvement process for breast radiotherapy planning

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was carried out in sequential phases over a 1-year period, and was based upon the DECIDE-AI suggested development pathway for early stage clinical evaluation of AI in healthcare [6] and the recommendations for AI implementation in radiotherapy [7].

Formerly, multiple different treatment techniques and beam geometries for breast radiotherapy were used in the department, all based on bony-anatomy field placement, with no true target volume delineation (Table 1). Local clinical pathways for these techniques are shown in Fig. 1 (top row), which indicates the multiple steps involved in treatment plan preparation, requiring expertise from different staff groups.

Simple breast-only treatments (around 75 % of local breast patient referrals) are carried out with an automated treatment planning process using tangential fields (Autobreast). This is based on a locally customised version of the Raystation Autobreast planning module [8]. Treatments which also include lymph node irradiation (to axillary, supraclavicular or internal mammary nodes) used a geometric field placement technique with a couch rotation (Casebow). The couch rotation ensured correct dosimetric matching of the junction between the breast tangential fields and the field covering the upper lymph nodes [9], but limited the possibility of DIBH for these patients.

MVision Segmentation Service v 1.2.2 (MVision Oy, Helisinki) was investigated for automatic segmentation of planning CT images for breast radiotherapy. CT datasets and AI structure sets were imported into Raystation v 9B (Raysearch Laboratories, AB, Stockholm). The AI structures were then reviewed and edited where necessary, before radiotherapy treatment plans were created and optimized. Configuration of the structure labels for the AI contours to match local protocols was carried out, as this ensured a seamless integration with the existing Autobreast technique, and with dosimetric plan evaluation templates.

The service improvement in this paper focussed on breast and nodal radiotherapy patients (axillary nodes BR-AX, approximately 10 % of patients), (supraclavicular nodes BR-SCF, ~15 % of patients) and internal mammary nodes (BR-IMN, where patient numbers are small, but increasing).

Table 1
Radiotherapy planning techniques for breast (including chest wall), showing limitations of previous techniques based on manual segmentation. Improvements enabled by the introduction of AI segmentation were applied only to patient cohorts in **BOLD** in the left-hand column.

Patient group (dose/fr)	Manual segmentation		With AI segmentation	
	technique	limitations	technique	Improvements
Breast (incl. partial breast, Chest Wall) (26 Gy/5fr)	Autobreast 2 field IMRT	• No true target contours	Autobreast 2 field IMRT	• True target contours • More OAR contours
Breast + nodes: Axilla (40.05 Gy/15fr) BR-AX	2 field IMRT (Casebow)	• additional staff training • couch rotation (collision risk) • difficult to minimise OAR dose	Autobreast 2 field IMRT	• Better OAR sparing • Couch = 0
Breast + nodes: Axilla ± SCF (40.05 Gy/15fr) BR-SCF	3 field IMRT (Casebow)	• additional staff training • couch rotation (collision risk) • no DIBH (SCF couch = 90°) • match plane position variable • difficult to minimise OAR dose	3 field IMRT (Casebow) Selected patients: VMAT	• Better OAR sparing • Couch = 0 • DIBH
Breast + nodes: Axilla, SCF, IMN (40.05 Gy/15fr) BR-IMN	3 field IMRT (Casebow)	• additional staff training • couch rotation (collision risk) • no DIBH (SCF couch = 90°) • difficult to minimise OAR dose	VMAT	• Better OAR sparing • Couch = 0 • DIBH

Phase 0 – commissioning and offline evaluation

This phase used a combination of qualitative and dosimetric metrics to look at the acceptability of AI contours on a broad range of breast and nodal radiotherapy patients with a range of age, body habitus, and arm positions for CT scanning and treatment.

A qualitative evaluation by 2 experienced breast consultant oncologists for AI-generated contours was carried out on 15 consecutive breast and SCF nodal patients. A categorization system from 1 (acceptable 'as is') to 7 (gross error, >75 % of slices need editing) [10] was used.

As local historical practice did not routinely include delineation of target nodal levels, and in order to obtain an *indication* of resource requirements for manual delineation, the same 2 clinicians also logged the time required for manual delineation on the same cohort of 15 patients (clinician 1 for 5 patients including 1 bilateral breast, and clinician 2 for 10 patients).

Dosimetric analysis performed for 25 retrospective BR-AX patients, planned using bony-anatomy field placement of tangential beams only, and with no pre-existing nodal contours. AI segmentation to the pre-existing plan was applied without edits, to assess dose coverage of a retrospectively generated nodal PTV by 38.05 Gy (90 % isodose).

Additionally, during a short period of 'shadow running' on a wider range of breast and nodal patients, AI contours were created (but not used in clinical decision making), and were monitored for any performance errors, or failure modes for specific patients. This was to allow a decision about whether to continue to the next phase in the implementation and improvement process.

Phase 1 – live prospective clinical evaluation

Using 25 prospective BR-AX patients planned with AI contour-guided field placement, dose coverage of nodal volumes by 38.05 Gy (90 % isodose) was recorded and compared with the retrospective patients studied in phase 0.

For BR-AX and BR-SCF patients, the planning technique (2 or 3-field IMRT) remained the same, but the routine field evaluation step by a clinician was eliminated (unless specifically requested by the dosimetrist) (Fig. 1b). The number of field evaluation tasks performed by clinicians during a 3-month period (January to March) over 3 consecutive years was analysed before and after this improvement change.

65 patients (BR-AX and BR-SCF) were *prospectively* planned using AI segmentation of nodal volumes to directly guide field placement and plan optimisation. Treatment plans were checked and approved by an independent planner and a clinician at the end of the pathway, following standard procedures, with both AI contours and plan acceptability reviewed at the end of planning.

A further 31 patients who had undergone axillary dissection were highlighted for review by clinicians *prior* to treatment planning, as it was anticipated that AI segmentation for these patients could require more careful review and editing. The feedback from clinicians for these individual patients was recorded.

At this time, sub-models of the AI segmentation module were also

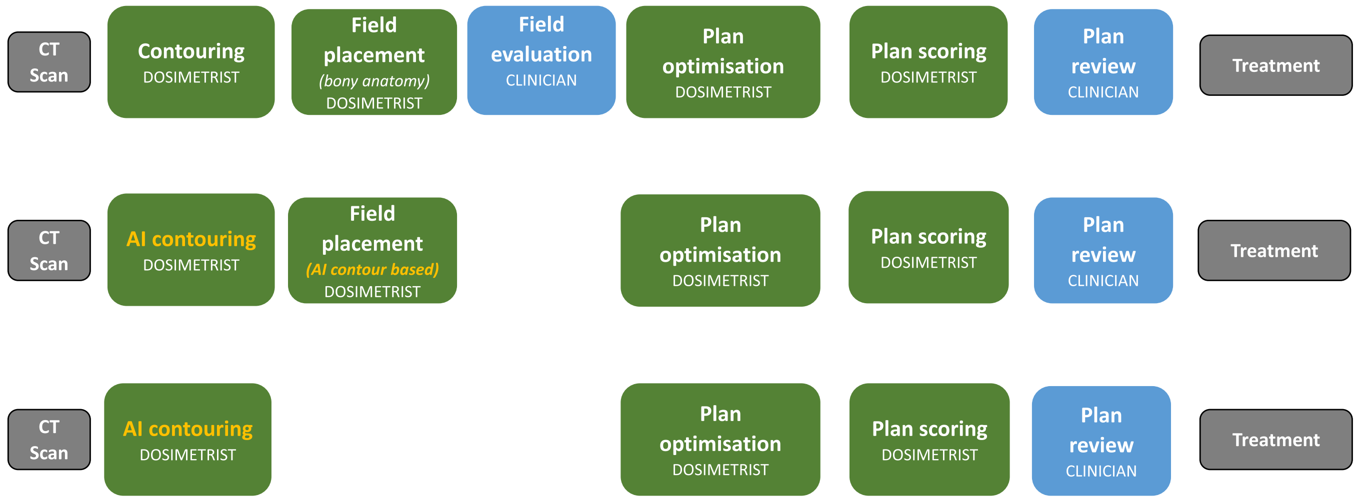

Fig. 1. *Top row:* Previous radiotherapy treatment planning pathway for all breast cancer patients before implementation of AI segmentation.
Middle row: Improved radiotherapy treatment planning pathway for breast and axillary or supraclavicular lymph node patients following implementation of AI segmentation.
Bottom row: Fully optimised radiotherapy treatment planning pathway for breast and internal mammary node (IMN) patients enabled by implementation of AI segmentation.

configured for left-sided, right-sided and bi-lateral breast. This allowed removal of unwanted structures, and to ensure recommended target and OAR structure dose metrics were being recorded, as per the recent NHSe Quality Improvement metrics [11] . The helped to streamline the work of planning dosimetrists in AI contour review and plan optimisation.

Phase 2 – improvement enabled by AI segmentation

The increased confidence in AI contour quality and the efficiency gains achieved over the preceding months allowed reflection on the technique used for high risk IMN patients, where balancing acceptable target dose and OAR sparing was challenging. A new VMAT treatment technique was introduced for BR-IMN patients (Fig. 1c). For 48 BR-IMN patients (11 patients with 3-field Casebow and 37 patients with VMAT), mean heart dose and lung V 17 Gy (%) were analysed, and days elapsed from CT scan to treatment plan approval in Raystation were compared.

Phase 3 - harmonisation of planning techniques

A period of consolidation and harmonisation of planning techniques was undertaken to fully exploit the gains enabled by AI segmentation. This included work to simplify the number of different planning techniques used in the department (Table 1), to expand the number of staff able to plan different treatment techniques, and to maintain the efficiency improvement observed in the previous phases.

Results

Phase 0 – commissioning and offline evaluation

The results of the qualitative and dosimetric metrics, a demonstration of staff resource requirements, and of compatibility with local clinical processes are outlined briefly below. These results from phase 0 were intended to inform a stop-go decision about the continued implementation of AI segmentation by the local team.

The qualitative assessment of AI contours on 15 patients showed that 76 % of all breast lymph node volumes were scored as category 1or 2 (acceptable as is or with minor edits). The worst category 5 (moderate edits) being assigned to supraclavicular level 4 nodal volumes and observed in 3 different patients. Not all patients required level 1 and level 2 axillary nodal contours, so it is not possible to draw more definitive conclusions on this small number of patients.

The median time for manual delineation of uni-lateral patients was 35 min (range 30–45 mins) and up to 60 min for bilateral breast patient). This represents an *indicative* timing measure, as manual delineation for breast nodal levels was not part of standard workflow prior to the investigation of AI contouring.

For the dosimetric analysis of 25 retrospective BR-AX patients, AI generated lymph node PTV coverage by 38.05 Gy (90 % isodose) showed a range of 89.4 % to 99.76 %, with only one patient below the optimal 90 % coverage value.

The monitoring of failure modes or performance errors across a broader range of patients with with unusual anatomy (e.g. shoulder metal implants, post-surgery) or in arms-down position showed slightly inferior quality AI contours. Nonetheless, AI contours were still considered helpful in the planning pathway, as long as there was mandatory review and editing before clinical use.

These qualitative and quantitative results of the commissioning and offline evaluation were considered acceptable by the multi-disciplinary AI implementation group before moving forward to the live clinical implementation.

Phase 1 – live prospective clinical evaluation

For 25 prospective BR-AX patients planned with AI guided field placement, lymph node PTV coverage by 38.05 Gy was between 91.7 and 99.9 % - all patients were above the optimal 90 % value. Mean heart dose and lung V 17 Gy dose metrics met the recommended limits – which was as good as, or better than the 25 retrospective plans.

Expanding the use to a further cohort of prospectively planned patients, 58/65 patients (89 %) had treatment plans and dose distributions accepted without modifications. The small number of patients requiring modifications to AI contour-guided field placement were mostly regarding edits to the cranial limit of the SCF field. These small discrepancies in the SCF level 4 lymph node volumes concurs with the results seen in the initial qualitative assessment phase 0 prior to clinical implementation.

For the more challenging axillary nodal dissection patients, 21/31 (67 %) required no edits or only minor edits to the AI segmentation. Reviewing and editing of AI contours was considered by clinical staff to be less time consuming than *de novo* manual delineation.

The number of field evaluation tasks (before use of AI segmentation) for Jan - Mar 2021 as a proportion of all plans was 44/62 plans (64 %), and in 2022 was 65/101 plans (70 %). The variation in absolute number of plans in 2021 and 2022 reflects changes in overall activity related to the end of the pandemic, although the proportion of field evaluation tasks 64–70 % is similar. In Jan-Mar 2023 (with AI segmentation as routine, and after process improvements) there were 4 field evaluation tasks for 106 plans (3.8 %). The 4 patients where clinician advice was requested by dosimetry staff were due to e.g. surgical dissection or previous radiotherapy to the contralateral breast.

Benchmarking the number of structures routinely contoured for breast patients before and after introduction of AI segmentation showed a significant improvement, especially when compared to the recent NHS England QI toolkit for breast radiotherapy [11]. All lymph node targets are now contoured with AI (previously no true target contours were created), and all required OARs (heart, lung, contralateral breast and humeral head) are delineated, whereas previously only heart and lung were routinely created.

Phase 2 – improvement enabled by AI segmentation

The introduction of a VMAT BR-IMN technique allowed for better optimisation of nodal target coverage and OAR sparing. For the 3-field Casebow technique, the optimal 4 Gy mean heart dose limit was met by 9/11 patients (82 %), and 1/11 patient also failed the mandatory 6 Gy limit. For patients treated with VMAT, the optimal mean heart dose limit of 4 Gy was met for 34/37 patients (92 %), and the mandatory limit of 6 Gy was met for all patients. The ipsi-lateral lung V 17 Gy target value of 35 % was exceeded for 9/11 (82 %) of 3-field Casebow plans, but exceeded for only 1/37 (2.7 %) VMAT plans. Although patient numbers are too small to assess the statistical significance of this data, the results were sufficiently encouraging to change the standard treatment technique to VMAT for all BR-IMN patients shortly after the implementation of AI segmentation (Fig. 2a). There has also been a reduction in time for VMAT planning observed, which may be due to several factors both directly and indirectly related to use of AI contours. For example, the time required to review and edit AI contours is more consistent and predictable than *de novo* manual delineation. Contours and naming protocols are now more consistent, and staff can concentrate on plan optimisation and consolidating their experience with the VMAT planning technique (Fig. 2b).

Phase 3 - harmonisation of planning techniques

At the beginning of Jan 2023, a test BR-AX patient was planned using both an Autobreast 2-field IMRT technique and the historic 2-field IMRT Casebow technique. Both plans were submitted to the clinician for review, and the Autobreast plan was chosen for treatment. This Autobreast 2-field technique has now been used successfully for 37 patients in the period Jan-Mar 2023, and will become the standard technique for all BR-AX patients when all planning dosimetry staff have completed training. For some BR-SCF patients with challenging anatomy (e.g. arms down or bilateral breast) the feasibility of using VMAT rather than the historical 3-field Casebow technique has been tested, and found acceptable. Use of VMAT for BR-SCF patients is also expected to increase, as staff training is rolled out.

Discussion

The clinical implementation of AI segmentation in the local department has followed published guidelines [7] to ensure patient safety and reduce staff workload. Previous studies of accuracy of AI segmentation with a range of commercial or in-house developed AI solutions for contouring breast radiotherapy have been demonstrated, and are in broad agreement with findings using MVision AI segmentation [12–16]. The concordance of positive findings for the clinical use of AI segmentation for breast targets and OARs is reassuring, but observed systematic trends in e.g. cranial under contouring observed for breast target [17] may depend on the particular comparison of AI models and local clinical protocols. A local commissioning and evaluation phase is therefore essential for each department. The recommendations for routine clinical use of AI segmentation are also that case specific quality assurance should be carried out: this also concluded that although the AI contours were acceptable for the large majority of patients, a review of contours by suitably trained clinical staff is always required.

Nonetheless, staff satisfaction and confidence in AI segmentation was high after the commissioning and live clinical evaluation phases. Configuration of sub-models and structure names to match existing templates and automated processes greatly helped with reducing workload pressures. The harmonisation of structure names also facilitated use of recently released NHSe Breast Radiotherapy Metrics for target and OAR dose evaluation [11].

The benefits in the initial phases of implementation were relatively

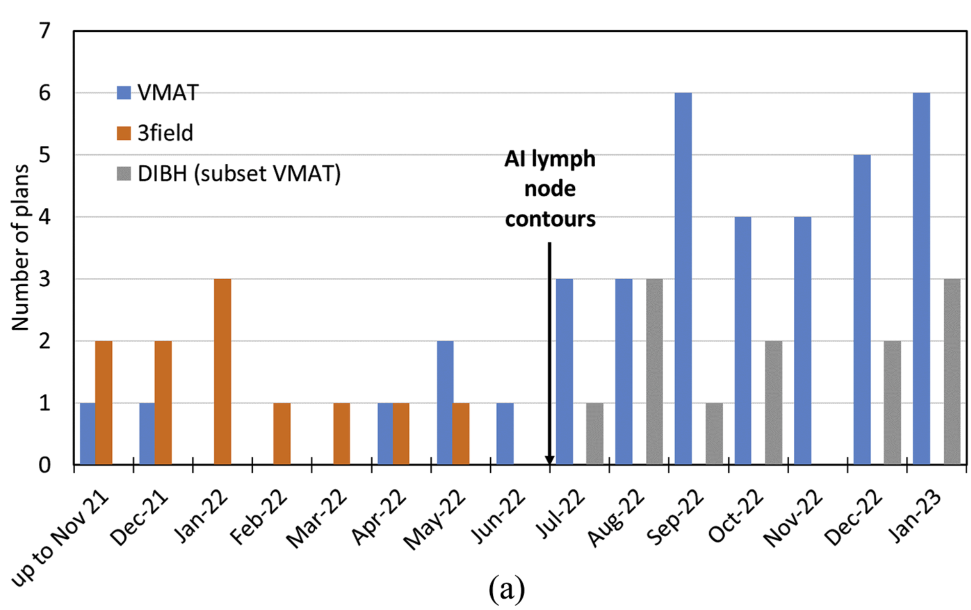

Fig. 2a. Roll-out of VMAT treatment planning for BR-IMN patients enabled by implementation of AI segmentation.

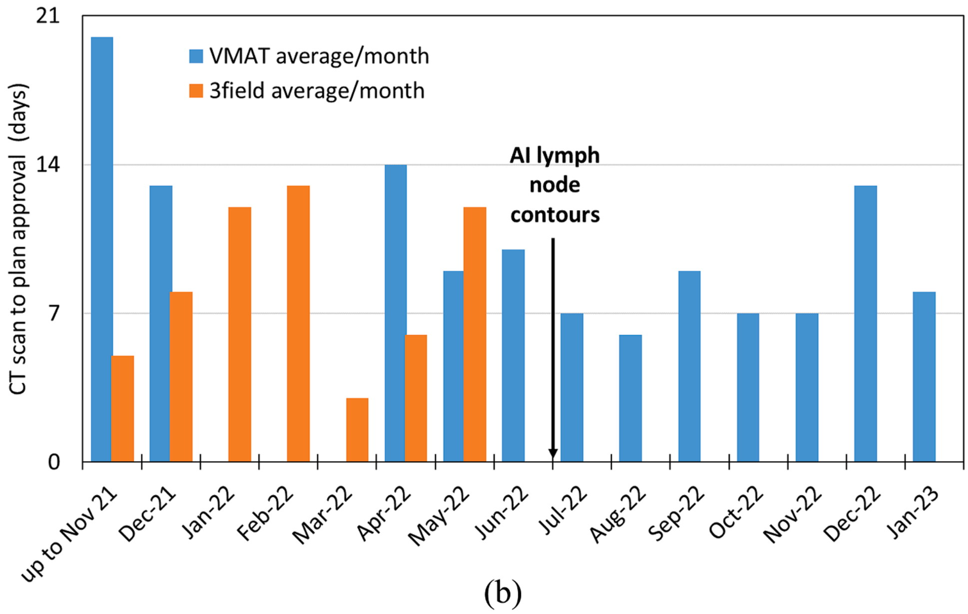

Fig. 2b. Indication of reduced time from planning CT to plan approval of an acceptable plan for BR-IMN patients following introduction of AI nodal contouring. Several factors may contribute to this improvement, directly and indirectly due to the use of AI contours for plan optimisation.

modest, and would best be described as an incremental improvement [18]. But this refining period during clinical roll-out is vital, as it allows time for staff training, and for a detailed assessment of any risks. At the end of phase 1, staff acceptance was high, and the use of real anatomical contours in the routine clinical pathway for all patients had been successfully introduced. It was too early in the development process to demonstrate significant resource saving, or any impact on patient outcomes.

Phase 2 introduced a radical change in treatment technique for high-risk IMN patients, where existing treatment plans often failed to meet optimal dose constraints. This innovation in planning technique was driven by the use of high-quality contours which were rapidly produced by the AI segmentation service. Communication between referring consultants and the dosimetry staff was also enhanced by consistent nomenclature for nodal volumes, which were previously not delineated for all patients. This generated clear evidence of improved OAR sparing (in particular for heart and lung), and for reducing the time required to produce these individualized treatment plans.

The final phase described here is for simplifying the number of treatment techniques used in routine for breast radiotherapy planning in the department. Further staff training is ongoing, facilitated by the use of consistent, reliable contours as generated by AI. The aim is that the future breast treatment planning portfolio will include only 2 techniques (Autobreast IMRT or VMAT) rather than multiple techniques and variations previously used (Table 1).

Conclusion

Breast radiotherapy treatment planning represents around 25 % of the clinical patient population in the local department, so any changes to the pathway need to be carefully managed, but would also have potentially large benefits for the workforce and patients. AI segmentation has been successfully implemented in the department, with particular advantages seen for the breast and lymph node patient pathways. High-quality anatomical contours representing true target volumes and a wider range of OAR are now routinely produced for all patients undergoing breast radiotherapy. This has been achieved with minimal workload for planning dosimetrists, and a reduction in tasks for clinicians. More significantly, this enabled a shift from old methods of treatment planning, (which were based on bony anatomy field placement), to full inverse optimisation, such as use of VMAT for IMN radiotherapy. This stepwise change in planning technique has allowed individualisation of treatment plans, with a meaningful reduction in dose to heart and lungs now achievable for many patients.

Ongoing data collection of quantitative and qualitative metrics in each phase allowed for rapid progression to the next stage, whilst ensuring safety and helped maintain staff confidence and acceptance. Management of this quality improvement process as a series of sequential phases has allowed efficient clinical implementation, with gains in workload reduction and staff skill mix, and produced real dosimetric gains for breast radiotherapy patients.

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Patients undergoing treatment gave their informed consent to the collection and use of data for education, audit and research purposes. All appropriate procedures relating to anonymization of individual patient information have been followed.

Declaration of Competing Interest

S Warren declares travel and accommodation expenses from Xiel and MVision

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