Article:
Beasley, M, Brown, S, McNair, H et al. (5 more authors) (2019) The advanced radiotherapy network (ART-NET) UK lung stereotactic ablative radiotherapy survey: national provision and a focus on image guidance. The British Journal of Radiology, 92 (1098). ARTN 20180988. ISSN 0007-1285

https://doi.org/10.1259/bjr.20180988

Title Page:

The Advanced Radiotherapy Network (ART-NET) UK lung Stereotactic Ablative Radiotherapy survey: national provision and a focus on image guidance

Shortened title: UK ART-NET lung SABR survey

Type of manuscript: Full paper

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Author conflicts of interest: This study was supported by a Cancer Research UK Centres Network Accelerator Award Grant (A21993) to the ART-NET consortium.

Acknowledgements: This study was supported by a Cancer Research UK Centres Network Accelerator Award Grant (A21993) to the ART-NET consortium. Additional thanks to the Leeds Cancer Centre, The Christie Hospital, The Royal Marsden Hospital, Oxford University Hospitals, and University College London Hospital for their contribution to the pilot study and all public and private radiotherapy centres who took the time and effort to contribute to this survey. The authors would also like thank Dr Marianne Aznar and Dr David Cobben for their guidance.

Manuscript:

The Advanced Radiotherapy Network (ART-NET) UK lung Stereotactic Ablative Radiotherapy survey: national provision and a focus on image guidance

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Abstract:

Objective
Stereotactic ablative radiotherapy (SABR) has become the standard of care for suitable patients with peripherally located early stage non-small cell lung cancer. Lung SABR requires strict image guided radiotherapy (IGRT) protocols to ensure its safe delivery. The aim of this survey was to provide an assessment of current lung SABR practice in the UK.

Methods
An online semi-structured survey containing a maximum of 32 questions regarding lung SABR, focussing on treatment image verification processes was piloted, developed and disseminated to the radiotherapy managers of 62 NHS centres across the UK.

Results

The survey had a 100% complete response from NHS centres. Thirty-six centres (58%) currently deliver lung SABR, with half treating fewer than 50 patients per year. Six centres deliver SABR despite not being commissioned by the NHS to provide this service. There is wide variation in the use of IGRT. Eight different permutations of CBCT order within the workflow were reported. Almost half of lung centres (17/36, 47%) believe there is a need to update national image guidance associated with lung SABR, such as the use of ‘day zero’, mid treatment and post treatment CBCTs.

Conclusions

Our results demonstrate wide variation in IGRT for lung SABR. There is an opportunity to develop existing IGRT workflows and the optimal approach to image guidance. Further work is required to investigate lung SABR provision and potential barriers to its implementation.

Advances in knowledge

This survey represents the most comprehensive and accurate assessment of lung SABR practice in the UK since the 2014 SABR consortium survey.

The Advanced Radiotherapy Network (ART-NET) UK lung Stereotactic Ablative Radiotherapy survey: national provision and a focus on image guidance

Introduction

Stereotactic ablative radiotherapy (SABR) is the delivery of high-dose hypo-fractionated radiotherapy in one or a few treatment fractions to an extra-cranial tumour with high levels of precision.(1–4) SABR has become feasible due to advances in intensity modulated and image guided radiotherapy (IMRT and IGRT).

SABR has become the standard of care for patients with peripherally located early stage non-small cell lung cancer (NSCLC) that is medically inoperable or for patients refusing surgical resection.(5) A high biologically effective dose (BED) >100Gy is delivered producing local control rates of approximately 90% at 5 years.(6–8) The delivery of high dose radiotherapy is potentially associated with serious risks and strict IGRT protocols are required to ensure safe delivery.(1) Therefore, the widespread adoption of SABR by the National Health Service (NHS) requires careful consideration.

The Advanced Radiotherapy Technologies Network (ART-NET) is a multi-centre UK initiative funded by Cancer Research UK (CRUK) to accelerate the clinical translation of innovative radiotherapy techniques, including SABR, which is in various phases of clinical implementation in the UK.(9) Whilst international and UK guidelines have been published on the delivery of SABR for lung cancer,(7,10) the most recent survey conducted by the UK SABR Consortium demonstrated large variance in their implementation.(11) This may reflect variable experience across UK centres and equipment available. [7]

An aim of ART-NET is to develop national treatment protocols to improve radiotherapy in the UK and harmonise practice. Considering a likely increase in SABR provision in the UK, the aim of this survey was to provide an assessment of national lung SABR practice, with a particular focus on provision, personnel and training, technical delivery and IGRT protocols used in lung SABR patients.(11,12)

Materials and methods

A semi-structured survey was created online using the Jisc Online Surveys platform (https://www.onlinesurveys.ac.uk/, Jisc, Bristol, UK) and piloted in the five CRUK ART-NET centres. The final survey had a maximum of 32 questions, provided as supplementary material.

An email inviting centres to participate was sent to the radiotherapy managers of 62 NHS and 17 private centres across the UK. These were identified via the Society of Radiographers UK Radiotherapy Service Managers Group (RSMG).(13) The survey was open from 13th March and closed on the 25th July 2018. Data was analysed using descriptive statistics and Chi-square tests of independence were performed using R (R Foundation for Statistical Computing, Vienna, Austria).(14)

Results

Response

Responses were obtained from 62/62 NHS radiotherapy centres (100%). Responses were received on behalf of 13/17 private centres surveyed (76%). One private provider replied on behalf of its eight affiliated centres as all utilise the same protocols. Therefore data pertaining to the numbers of SABR patients treated at individual private centres was incomplete and resulted in a comparative lack of data compared to NHS data, making combined analysis difficult. Consequently the results focus on responses from NHS centres. Private centre responses are supplied as supplementary material.

SABR provision and barriers

Thirty-six NHS centres (58%) deliver lung SABR. Table 1 illustrates the variation in the number of SABR patients treated. The majority (11, 18%) treat 20-50 patients per year, 8 centres (13%) treat 100-200 patients, and 1 centre treats ≥ 200 patients per year.

Six centres deliver SABR despite not being commissioned by the NHS to provide this service. Twenty-six centres (42%) do not provide lung SABR and state that they refer suitable patients to a SABR centre for treatment. In addition, 16 of these centres (62%) state that they provide conventionally fractionated radiotherapy locally as an alternative option and 12 (46%) expect to commence a SABR service within the next 12 months. The main barrier in setting up a SABR service (12, 86%) was lack of NHS commissioning (Table 2).

Motion management

Two-thirds of centres (24/36) do not use any active form of motion management, as defined by the European Organisation for Research and Treatment of Cancer (EORTC).(15) Four (11%) use spirometry-based breath-hold and external surface gating. Four CyberKnife centres (14%) use kV tumour tracking. Of these, two (8%) use fiducial-based internal tracking.

The most common strategy used is the internal target volume (ITV) approach (22, 61%). Six centres (17%) use abdominal compression.

Tumour localisation and delineation

Almost all centres (35/36, 97%) use 4DCT to localise and quantify tumour motion, 1 centre (3%) reports the use of slow CT. If the 4DCT is deemed unusable, in order to facilitate treatment planning, a number of different approaches are undertaken (Table 3).

Table 4 illustrates the different methods used for target delineation which are dependent on the motion management strategy. When using the ITV approach the gross tumour volume (GTV) is contoured using the maximum intensity projection (MIP) and the volume is then edited to incorporate motion from breathing phases (13, 36%). Eight centres (22%) delineate a motion-adapted GTV, formed from a union of all GTVs delineated on individual phases. Seven centres (19%) construct a motion-adapted GTV using the MIP alone.

Planning target volume (PTV) margin

Most centres (29/36, 81%) use a 5mm isotropic PTV margin around a motion-adapted GTV. 3/36 centres (8%) use anisotropic margins of 5mm axially and 6mm cranio-caudally. Other approaches used in single centres involve a 3mm or 1mm isotropic margin and 1 centre stated their PTV margins were judged and provided by the Consultant Clinical Oncologist.

Personnel

Delivery of SABR is radiographer-led in 26/36 centres (72%). In 10 centres (28%) a multi-disciplinary approach is used with Clinical Oncologists and Medical Physicists present at treatment. One centre has a Clinical Oncologist present for the first fraction to advise on the IGRT. Another stated they had only treated 2 patients and currently require a Clinical Oncologist to be present for all fractions. For complex or unusual cases such as where the tumour is poorly defined, 17/36 (47%) centres rely upon guidance from Clinical Oncology or Medical Physics personnel. One centre uses the support of a Consultant Radiographer.

Image verification training

Specialist SABR image verification training was required in all but one centre (35/36, 97 %) and comprised of varied locally developed training strategies (e.g. single sessions, teaching packages and practical evaluation). An assessment with specific numbers of case studies was required in 11/36 centres (31%). Two centres (6%) require staff to complete the NHS Health Education England's e-Learning for Healthcare courses on IGRT and Stereotactic Radiotherapy and one requires staff to maintain their competencies by attending a regular SABR clinical meeting.(16)

Image verification processes

Two CyberKnife centres (6%) use kV-based tracking to perform image verification. Two centres (6%) use either kV-based tracking or cone beam computed tomography (CBCT)

depending on whether the patient is treated using a CyberKnife or linac platform, respectively. All other centres (32/36, 88%) solely use CBCT with linac delivery, one of which (3%) reported the use of intrafraction monitoring with kV and surface-based tracking.

For various reasons, 17 centres (47%) perform a 'day-zero' image verification session on the treatment machine before fraction 1 (Figure 1). For centres intending on providing a lung SABR service within the next 12 months, 9/12 (75%) intend on performing 'day zero' image registration/verification.

Fifteen centres (42%) utilise 4DCBCT in addition to 3DCBCT.

Image guidance standard operating procedures (SOPs)

Image guidance SOPs for CBCT within centres varied widely; 8 variations of workflow order were reported (Figure 2). Although all centres perform online pre-treatment imaging/registration and apply a correction, some centres would also:

- image after a correction had been applied in all cases, irrespective of the magnitude of error
- image after a correction in cases where the error exhibited was large
- image mid-fraction
- image after the treatment fraction.

To assess if experience (demonstrated by the number of patients treated) influenced frequency of CBCT usage, Pearson's Chi-squared test of independence was calculated. This compared the number of patients treated per annum by each centre, and the frequency of CBCT imaging following treatment, following a correction and mid-treatment ($\chi^2(2) = 4.6468$, $p=0.09794$); ($\chi^2(2) = 0.8026$, $p=0.6694$); ($\chi^2(2) = 3.4236$, $p=0.1805$), respectively. Although no significant relationship was found, there is the weak trend that centres treating more lung SABR patients are not performing a CBCT following treatment.

Of the centres using CBCT for image guidance, 23/35 (66%) use the default manufacturer's exposure settings. Eleven centres (31%) use exposure settings that have been optimised for lung SABR; of those 9 (82%) reduce the nominal dose through reductions in the number of

frames by increasing the scan speed or reducing kV or mAs. Other approaches in single centres include: a selection of pre-sets, a partial arc pre-set for SABR patients treated with a breath hold approach and optimised exposure settings for CBCT based on the patient exposure from the planning CT.(17) One centre routinely uses patient specific exposure settings.

Image guidance protocols

In total, 33/36 centres (92%) have a specific lung SABR image guidance protocol. Of those, 24 (73%) are very satisfied with their own protocols, whereas 9 (27%) are somewhat satisfied. Seventeen centres (52%) have a protocol that provides troubleshooting advice for poor quality imaging and 27 (82%) are provided with matching technique instructions.

Decision support protocols for anatomical changes

Seventeen centres (52%) have a decision support protocol (DSP) for cases where changes in the patient's anatomy may affect the dose distribution or coverage. Of those, 12 (71%) use a DSP in flowchart format; 3 (18%) in text format and two (12%) in the format of a traffic light system with example cases.

All DSPs state if and when to contact members of the multi-disciplinary team. The types of anatomical changes and frequency with which they feature in DSPs are shown in Figure 3.

National image registration guidance

Almost half of lung UK SABR centres (17/36, 47%) believe there is a need to update national image guidance associated with lung SABR. For those intending to set up a lung SABR service within the next 12 months, 8/12 (67%) believe national image guidance requires updating.

Those who believe guidance requires updating were asked to highlight areas that require expansion. The most common suggestion was for greater advice on image frequency and the necessity of 'day-zero', mid-treatment or post-treatment imaging. The second most common theme was the encouragement of sharing and harmonisation of practice. This was suggested by both current and future lung SABR providers. Some responses suggested that it was likely that centres had developed their own protocols based on local data and this contributed to a disparity in practice. Other suggestions included a need for advice on when 4DCBCT and robotic couches should be used and advice on modification of CBCT parameters, matching strategies and acceptable levels of deviation from planning constraints.

Discussion

This UK wide survey provides the most comprehensive account of lung SABR IGRT since that published by the SABR UK Consortium in 2014.(11) The complete response rate of 100% from NHS centres provides an accurate assessment of current UK practice. Information from non-SABR centres also provides an insight into the barriers to setting up this service.

In 2012, 15 NHS centres delivered lung SABR, and it was predicted this would increase to 33 centres by 2014.(1,11) Currently 36 NHS UK centres deliver SABR. The NHS Commissioning Board policy (2013) advises that SABR should be routinely commissioned for lung patients and states that it has a duty *'to have regard to the need to reduce health inequalities in access to health services'.*(5) However, it is also stipulated that a centre should not provide a SABR service unless a minimum caseload of ≥25 patients can be treated per year.(10) Six centres have chosen to establish a lung SABR service despite not being commissioned to do so.

All 26 non-SABR centres have stated they will refer eligible patients to a SABR centre and 16 (62%) centres would offer conventionally fractionated radiotherapy as a local alternative. Given randomised evidence demonstrating both superior local control and survival benefit associated with SABR when compared to conventional radiotherapy, this suggests some patients may be receiving inferior treatment.(18,19) While the survey does not explore the reasons for this, some non-SABR centres serve a geographically large catchment area and the additional travel time to a SABR centre might be a factor.(20) An ageing UK population and

new screening programme initiatives are likely to increase the number of early lung cancers identified.(12) Therefore this warrants further investigation to explore the potential barriers from the perspective of both centres and patients to ensure this important treatment is accessible to all.

For the purpose of tumour localisation, most centres use 4DCT. This is in keeping with UK and international guidelines that advocate 4DCT to incorporate patient specific tumour motion into treatment.(7,10) Whilst a number of centres will use other 4D-imaging techniques, should 4DCT fail, three centres state at this point they would consider abandoning SABR. It's unclear whether these centres consider other approaches (as advised in the 2017 ESTRO-ACROP guidelines(7)) prior to concluding that SABR is not a feasible option. An alternative solution, given the relatively small motion of most lung tumours and the fact that image guidance is tumour based, would be to base the plans instead on fast 3D CT scans (which would 'freeze' the tumour in an arbitrary position), using a generic margin rather than an ITV.(21) An exception would be when the tumour is very close to an organ at risk.

When delineating the target volume, most centres use an approach that considers respiratory motion on all breathing phases (e.g. by delineating on the MIP and individually modifying the volume on each phase). However, 7 (19%) centres solely delineate on the MIP. In certain situations (e.g. tumours adjacent to tissue of a similar density such as the mediastinum), this approach risks under-estimating the tumour volume.(22) An approach which generates target volumes constructed from delineations on all breathing phases of the 4DCT is likely to be more accurate and reduce the risk of geographical miss.

Centres use PTV margins that range from 1-5mm. The majority (29/36, 81%) use a 5mm isotropic margin to expand the motion-adapted GTV. Practice at one centre is to use individualised PTV margins assessed by the Consultant Clinical Oncologist. This approach is considered sub-optimal as PTV margins should be based on population random and systematic errors derived from each centre's local data, rather than on an individual patient basis with limited evidence.(23)

Strong emphasis is made within the SABR UK Consortium and ESTRO-ACROP guidelines that staff should receive specialist training to ensure they are competent to deliver

SABR.(7,10) The majority of centres provide this training, however, considerable variation exists in the extent of training and methods used. These include single sessions, teaching packages, practical evaluation and 31% (11/36) of centres use a case-based assessment. Two centres (6%) use the IGRT and Stereotactic Radiotherapy NHS Health Education England e-learning resource.(16) As 12 centres intend to offer a SABR service within the next year there is an opportunity to potentially reduce the burden of developing in-house training resources. By sharing experience and best practice this will increase efficiency and help ensure high-quality treatment provision.

There is also considerable variation in the approach to IGRT delivery; a total of 8 different permutations of CBCT use within the workflow were described (Figure 2). SABR UK Consortium guidelines provide guidance on the use of CBCT.(10) For example they recommend a trial setup session ('day-zero CBCT') to assess for unforeseen practical issues. Only 17/36 (47%) of centres, however, perform this step and 3/12 (25%) of centres intending to offer SABR in the next 12 months do not intend to use a day-zero scan. There is also heterogeneity in the use of post correction, mid and post treatment CBCTs.

Centres have adapted their IGRT workflow based on interrogation of their local data, resulting in reduction in the number of CBCTs acquired. Evidence-based guidance on the optimal approach would be welcomed by the UK community; particularly given this was the most commonly suggested area of national guidance that was considered to require updating in our survey.

In total, 33/36 centres (92%) have a specific lung SABR image guidance protocol, yet only 17 (52%) have a protocol that provides troubleshooting advice for poor quality imaging, and only 11 (31%) have optimised their CBCT exposure settings. Similarly, just 17 (52%) centres use a decision support protocol for dealing with anatomical changes that might affect treatment dosimetry.

A recent audit within one of the ART-NET centres demonstrated that a large proportion of CBCT adaptive assessments were performed due to anatomical changes in lung patients.(24) Yet, these rarely resulted in a re-plan of radiotherapy treatment. This finding suggests that by incorporating advice on management of anatomical changes it should be possible to reduce the need for additional medical physics and/or clinician input and streamline workflow. In

SABR patients there are, however, risks of serious toxicity should the carefully balanced dosimetry of SABR be affected by anatomical changes.(25,26) Comprehensive protocols are needed to support staff in assessing these changes.

Conclusion

This survey represents an accurate assessment of the approach to IGRT for lung SABR in the UK. There is potential disparity in equitable access to SABR and this warrants further investigation. A large number of centres have requested that guidance be updated. This should reduce the burden of SABR implementation and is an excellent opportunity to share best practice and harmonise IGRT approaches.

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Tables and figures:

Number of lung SABR patients treated per year	Number of centres	Percentage of NHS centres
0	26	42%
<10	4	6%
10-20	3	5%
20-50	11	18%
50-100	9	15%
100-200	8	13%
>200	1	2%

Table 1. Numbers of patients treated with SABR across NHS centres

Barriers	Frequency
Commissioning	12
Low numbers	5
Lack of medical physics	3
Close proximity to an already established centre	3
Lack of guidance	2
Machine technology	2
New centre	1
Lack of clinical interest	1

Table 2. Barriers faced by radiotherapy providers in implementing a SABR service

If you have performed a 4DCT, what do you do if it was not deemed usable for treatment planning?	Number of centres
Repeat the 4DCT process	18 (50%)
Perform 4D CBCT to aid localisation	4 (11%)
Perform 3DCT and adapt margins	4 (11%)
Assess root cause of failure and provide additional coaching (if breathing rate was the cause) before repeating 4DCT process	3 (8%)
Consider abandoning SABR and provide conventional RT	3 (8%)
Use abdominal compression or consider spirometry breath hold equipment if required	2 (6%)
Perform multiple helical scans at specified phases of the breathing cycle	1 (3%)
Reconstruct the 4DCT into a slow 3D CT	1 (3%)

Table 3. Approaches undertaken if original 4DCT is unusable

How do you delineate a target volume to account for respiratory motion?	Number of centres
Use a maximum intensity projection (MIP) on 4DCT and modify it based on the breathing phases	13 (36%)
Perform a union of all GTVs on individual phases	8 (22%)
Use a maximum intensity projection (MIP) on 4DCT	7 (19%)
Delineate the GTV on min, mid and max inhale	4 (11%)
Use average intensity projection on 4DCT	2 (6%)
Use slow CT	1 (3%)
Use an average intensity projection on 4DCT and modify it based on breathing phases	1 (3%)

Table 4. Methods of target delineation

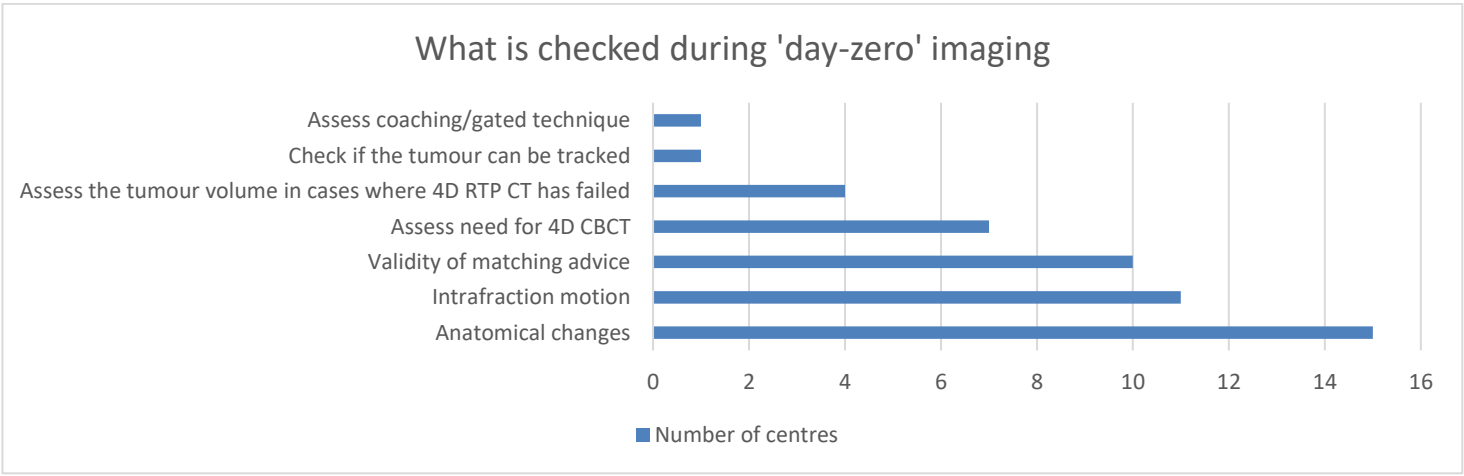

Figure 1. Rationale for performing a 'day-zero' verification session

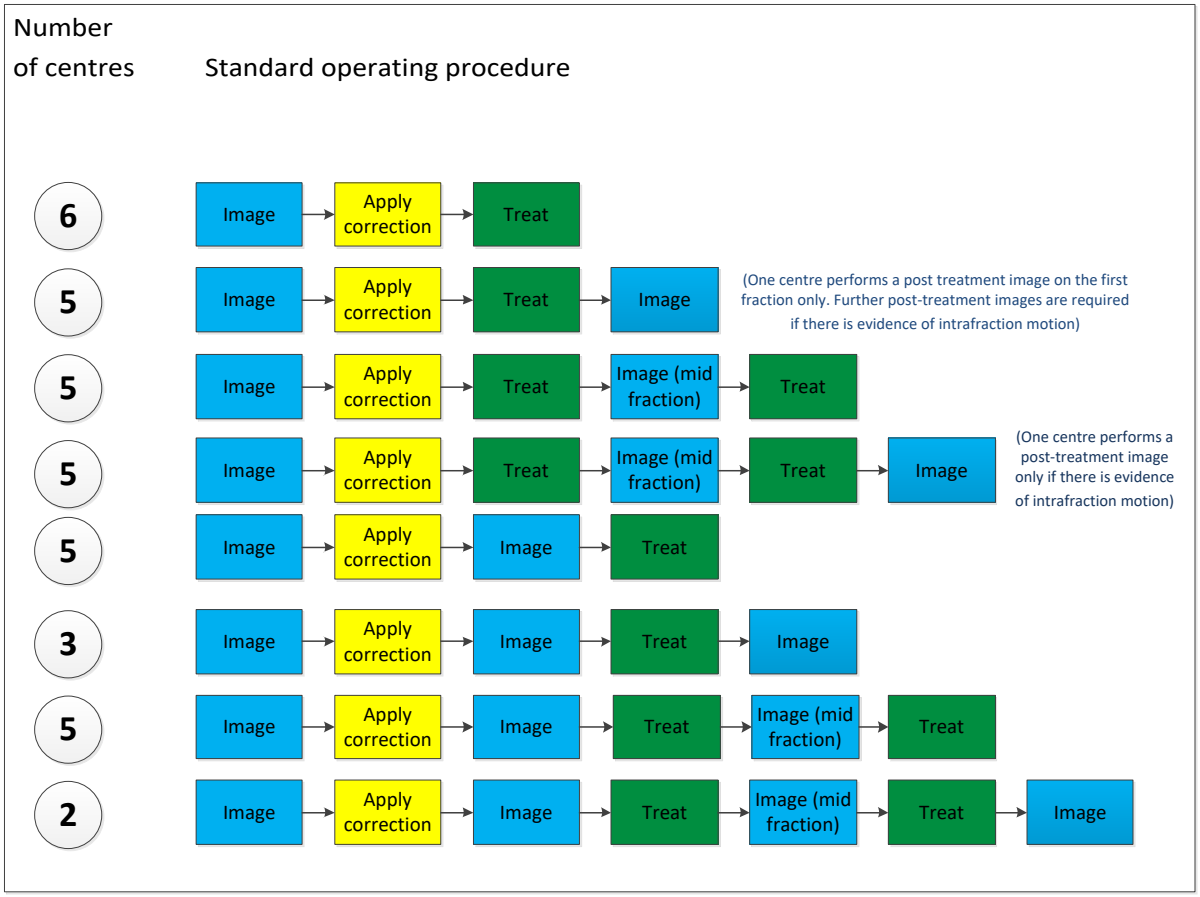

Figure 2. Summary of the lung SABR image registration workflows and how many centres use these

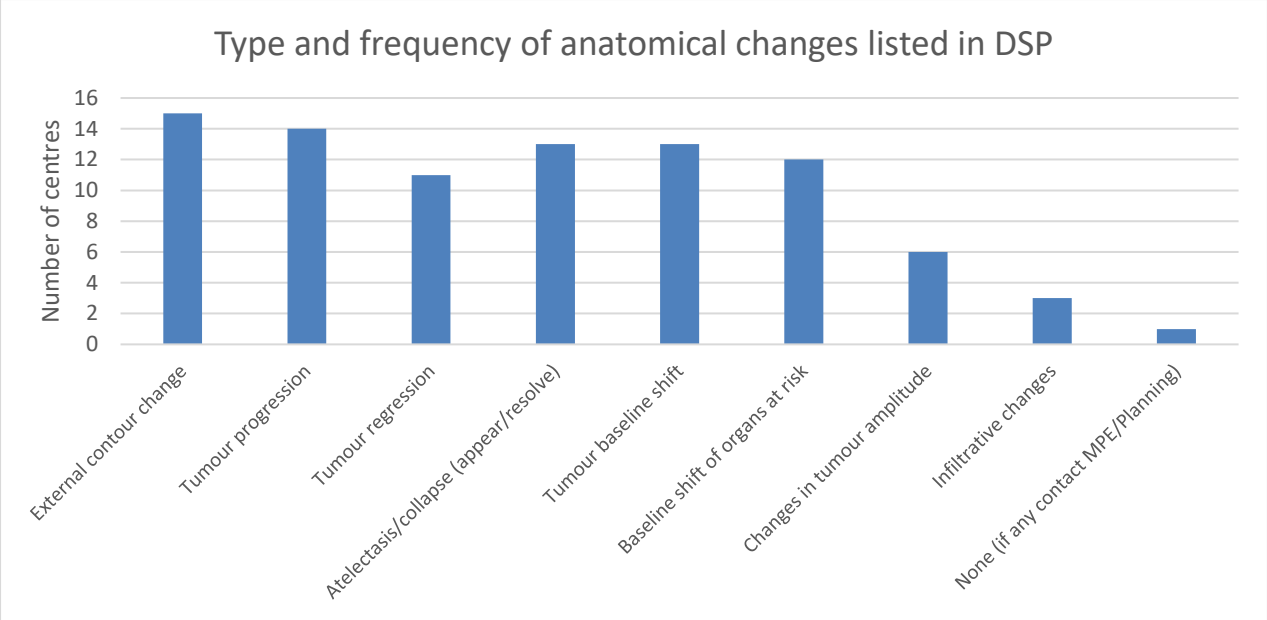

Figure 3. Type and frequency of anatomical changes described in lung SABR centres who use a DSP