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Original Research Article

# Optimal and actual rates of Stereotactic Ablative Body Radiotherapy (SABR) utilisation for primary lung cancer in Australia

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ABSTRACT

*Background and purpose:* Radiotherapy utilisation rates considerably vary across different countries and service providers, highlighting the need to establish reliable benchmarks against which utilisation rates can be assessed. Here, optimal utilisation rates of Stereotactic Ablative Body Radiotherapy (SABR) for lung cancer are estimated and compared against actual utilisation rates to identify potential shortfalls in service provision.
*Materials and Methods:* An evidence-based optimal utilisation model was constructed after reviewing practice guidelines and identifying indications for lung SABR based on the best available evidence. The proportions of patients likely to develop each indication were obtained, whenever possible, from Australian population-based studies. Sensitivity analysis was performed to account for variations in epidemiological data. Practice pattern studies were reviewed to obtain actual utilisation rates.
*Results:* A total of 6% of all lung cancer patients were estimated to optimally require SABR at least once during the course of their illness (95% CI: 4–6%). Optimal utilisation rates were estimated to be 32% for stage I and 10% for stage II NSCLC. Actual utilisation rates for stage I NSCLC varied between 6 and 20%. For patients with inoperable stage I, 27–74% received SABR compared to the estimated optimal rate of 82%.
*Conclusion:* The estimated optimal SABR utilisation rates for lung cancer can serve as useful benchmarks to highlight gaps in service delivery and help plan for more adequate and efficient provision of care. The model can be easily modified to determine optimal utilisation rates in other populations or updated to reflect any changes in practice guidelines or epidemiological data.

## Introduction

Stereotactic Ablative Body Radiotherapy (SABR) plays an important role in lung cancer treatment as the standard of care for patients with inoperable, early-stage NSCLC [1,2]. Approximately a third of NSCLC patients are diagnosed with potentially curable stage I-II tumours [3,4]. While resection is the standard of care for such patients, >25% do not undergo surgery due to poor performance status, associated comorbidities, or patients' refusal [5,6]. Since its introduction, SABR has significantly increased curative radiotherapy utilisation and reduced the number of patients left untreated due to its convenience and tolerability by those unable to undergo surgery or conventional radiotherapy [7–9].

Practice pattern studies have revealed wide variations in radiotherapy utilisation across different populations as well as service providers [10–15], highlighting the need for establishing valid benchmarks of optimal utilisation rates that reflect actual demands within the population. Evidence-based models have previously been used to determine optimal utilisation rates for different radiotherapy and chemotherapy treatments [3,16,17].

Here, we apply the same approach to determine the optimal

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utilisation rates for lung SABR within the Australian population. Optimal rate is defined as the proportion of lung cancer patients who are likely to develop clinical attributes indicating the use of SABR, at least once during the course of their illness, based on the best available evidence. To identify potential shortfalls in service delivery, these rates will also be compared against actual utilisation rates of lung SABR within our local centre as well as rates reported by practice pattern studies from Australia and other developed nations.

## Materials and Methods

### *Evidenced-based optimal utilisation model*

Following the evidence-based approach, this study identified lung SABR indications based on best available evidence and most recent practice guidelines issued by national and international organisations and radiation oncology working groups (Appendix I).

Evidence supporting the use of SABR for each indication were ranked based on the Australian National Health and Medical Research Council (NHMRC) hierarchical levels of evidence [18]. To show the level of agreement among guidelines, a recommendation strength was assigned to each indication; “Strong” represents confidence that most informed people would make the same recommendation, while “Conditional” means the balance between risks and benefits is less certain and a substantial number may not make the same recommendation [19].

Subsequently, an optimal utilisation model (in the form of a decision tree) was constructed by combining all identified clinical indications for lung SABR, with each branch in the tree representing a specific attribute such as stage, operability or nodal involvement. The terminal of each branch indicates whether SABR is recommended for that scenario (Appendix II). The model was independently reviewed by two expert clinicians to provide validation before commencing further analysis.

### *Epidemiological data*

The proportions of lung cancer patients with different indications for SABR were obtained from population-based studies and cancer registries. When available, Australian based studies (national or state-wide) were prioritised to improve model generalisability to our population of interest. In cases where population-based data was not available, comprehensive multi-centre databases or practice pattern studies were used instead. The quality of epidemiological data was ranked based on a previously described ranking/hierarchy system [3,18](Table 1). If variations among different sources were>10%, a sensitivity analysis was performed to model their effects.

To our knowledge, there are currently no population-based studies reporting on the distribution of peripheral, central and ultra-central tumours. To estimate this, we relied on a local dataset of 234 stage I-II NSCLC patients treated at our local centre between 2002 and 2019. A previously described [20] in-house tool for automatically segmenting the proximal bronchial tree (PBT) and measuring the minimum distance to the tumour was used to assess tumour centrality for patients in this dataset. Based on RTOG-0813 definitions, tumours>2 cm away from the PBT were classified as peripheral, those within 2 cm from PBT or where the planning target volume (PTV) overlaps the PBT, heart, oesophagus, trachea, or great vessels were classified as central, while tumours directly abutting the PBT were classified as ultra-central. The term ultra-central is relatively more recent and therefore is not uniformly applied throughout the literature.

All identified clinical indications for lung SABR, along with the proportions of patients likely to develop them, were combined to generate the optimal utilisations model. TreeAge Pro™ Software (Williamstown, MA) was used to facilitate model construction and calculating optimal rates of utilisation.

### *Comparison to actual utilisation rates*

Practice-pattern studies reporting on lung SABR utilisation were reviewed to obtain actual rates of lung SABR utilisation within Australia and other developed nations. Additionally, we investigated lung SABR utilisation at Liverpool and Macarthur Cancer Therapy Centres for patients with stage I-II NSCLC treated between 1995 and 2019. Liverpool and Macarthur Cancer Therapy Centres provide tertiary level oncology care within a local health district located in metropolitan South Western Sydney, which has population of 1,051,964 people (14.5% of the population of New South Wales (NSW), Australia) [21][21]. SABR treatments were defined as a total dose of > 40 Gy delivered over 3 + fractions and/or with a fraction dose of > 8 Gy; conventional treatments were defined as a total dose of ≥ 40 Gy with a fraction dose of 1.5–3 Gy given over 10 + fractions, while palliative treatments were defined as a total dose of > 8 Gy with a fraction dose of > 3 Gy. Based on local protocols, all stage I-III NSCLC patients receiving definitive radiotherapy should have

**Table 1**
Guideline Indications for stereotactic ablative body radiotherapy (SABR) in non-small cell lung cancer (NSCLC).

| Population | Guidelines | Recommendation strength | Evidence | Level of evidence | Proportion of all lung cancer |
|---|---|---|---|---|---|
| NSCLC, stage I, good PS, inoperable, peripherally located tumour. | NCCN [1], BCCA [39], ASTRO/ASCO [2], ESTRO/ACROP [40], ACCP [41], NICE [42], UK Consortium [43], ESMO [44], EviQ [45], Cancer Council Australia [46], DEGRO [47], CARO [48], London Cancer [49]. | Strong | CHISEL [50] | II | 3.9% |
| NSCLC, stage I, good PS, inoperable, centrally located tumour. | ASTRO/ASCO [2], UK consortium [43], DEGRO [47], CARO [48], London Cancer [49]. | Conditional: use > 3 fractions. | RTOG-0813 [51], Yu-2019 [52] | III | 1.0% |
| NSCLC, stage II, good PS, inoperable, node-, <5cm, peripherally located tumour. | ATRO/ASCO [2], NCCN [1], NICE [42], UK Consortium [43], EviQ [45], DEGRO [47], CARO [48], London Cancer [49]. | Strong | Xia-2006 [53], Yan-2019 [37], | III | 0.6% |
| NSCLC, stage II, good PS, inoperable, node-, <5cm, centrally located tumour. | ASTRO/ASCO [2], UK consortium [43], DEGRO [47], CARO [48], London Caner [49]. | Conditional: use>3 fractions | Xia-2006 [53], Yan-2019 [37], | III | 0.2% |
| **The total proportion of lung cancer patients for whom Stereotactic Ablative Body Radiotherapy (SABR) is recommended** | | | | | **5.7%** |

**Abbreviations:** NSCLC Non-small Cell Lung Cancer, PS Performance Status, NCCN National Comprehensive Cancer Network, ASTRO American Society of Radiation Oncology, BCCA British Columbia Cancer, ASCO American Society of Clinical Oncology, ESTRO European Society of Radiotherapy and Oncology, ACROP Advisory Committee of on Radiation Oncology Practice, ACCP American College of Chest Physicians, NICE National Institute of Health Care and Excellence, UK United Kingdom, ESMO European Society of Medical Oncology, DEGRO German Society of Radiotherapy and Oncology, CARO Canadian Association of Radiation Oncology, RTOG Radiotherapy and Oncology Group, Level of evidence: I evidence obtained from a systematic review of all relevant randomised controlled trials; II – evidence obtained from at least one properly conducted randomised controlled trial; III evidence from well-designed controlled trials without randomisation (e.g. trials with ‘pseudo-randomisation’ where a flawed randomisation method was used (e.g. alternate allocation of treatments) or comparative studies with either comparative or historical controls; IV evidence from case series [3,18].

histological proof, when possible, otherwise contemporary PET scans should be performed within 4 weeks (for stage II-III) or 6 weeks (for stage I). Where histological proof cannot be obtained, a lung multidisciplinary team needs to be satisfied that with the clinical diagnosis based on contemporary CT and PET imaging and underlying patient risk factors.

## Results

### *Optimal utilisation rates*

The model estimated the optimal utilisation rates of lung SABR to be 7% of all NSCLC patients and 24% of stage I-II NSCLC patients. The optimal utilisation rate varied from 32% for stage I to 10% for stage II. Fig. 1 depicts the decision tree in its entirety with all SABR indications along with the calculated SABR optimal utilisation rates by stage, ECOG status, nodal status, operability, etc. (represented in green). The numbers below each branch represent the proportions of patients with the corresponding attribute. Table 1 summarises all the evidence and clinical guidelines supporting the use of SABR for each indication.

### *Epidemiological data*

Table 2 lists the epidemiological data used in the model, with the proportions of patients likely to develop each lung SABR indication along with the sources and quality of data obtained. Table 3 provides a summary of all epidemiological studies in the model, along with their population, sample size and year of publication.

The distributions of lung cancer types (i.e. small cell versus non-small cell), as well as different stages, were based on data from the New South Wales (NSW) cancer registries of all lung cancer patients [4,22]. For the proportions of patients with acceptable performance status (PS) (EGOG of 0–3 for SABR), multiple sources were identified [23–26]. In the NSW cancer registry, 94% of stage I-II NSCLC patients have acceptable PS at diagnosis [23]. Two studies based on South Western Sydney cancer registry reported 95–93% of stage I-II NSCLC patients to have acceptable PS [24,25], while a large UK study reported this at 90% [26].

Assessing patients' operability is a complex issue that involves considerations of both tumour resectability and patients' ability to tolerate the procedure. Currently, most centres rely on multi-disciplinary teams (MDT) meetings to assess patients on an individual level. Therefore, the proportion of operable patients used in the model is based on the resection rates observed in clinical practice. For stage I, resection rates ranged between 59% in Australia [27] to 52–70% in other countries [28–31]. In stage II, resection rates were at 34% in the US [29], 47% in the UK [28] and 49% in The Netherlands [31]. In the absence of Australian data for this cohort, the model used the data from the UK study [28] as it included the largest dataset of 161,231 patients diagnosed between 2012 and 2016.

The ratio of node-positive versus node-negative disease in stage II was based on a recent, population-based (NCDB) study including 10,081 stage IIB (AJCC 8th edition) NSCLC patients [32]. The study also provided estimates of the ratio of tumours larger and smaller than 5 cm, which were also included in the model. Finally, based on our local dataset, 65% of stage I NSCLC patients had peripheral tumours, compared to 17% and 18% who had central and ultra-central tumours, respectively. For stage II, 45% were peripheral, 17% central and 38% ultra-central tumours (Appendix III).

### *Sensitivity analysis*

A total of four variables showed significant uncertainty in the overall estimated optimal utilisation. Appendix IV shows tornado plots indicating the extent of uncertainty caused by each variable. The largest variability was related to the proportion of patients with operable versus

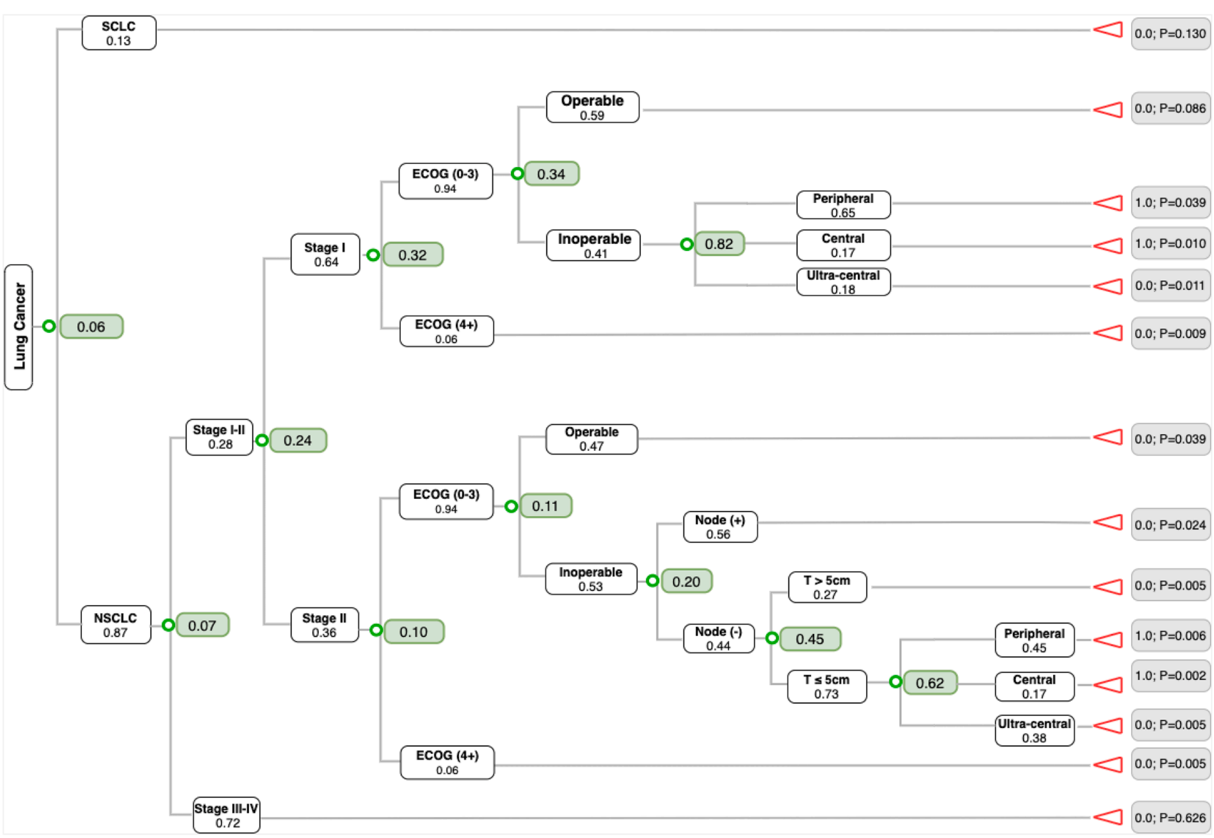


**Fig. 1.** Model depicting optimal SABR utilisation in lung cancer.

**Table 2**
Outline of studies used to determine the proportion of patients with each indication affecting lung SABR use.

| Population | Attribute | Proportion of patients | Quality of Data | Reference |
|---|---|---|---|---|
| All lung cancer | SCLC | 0.13 | β | Walters-2013 [22] |
| NSCLC | Stage I | 0.18 | β | NSWCCR* |
| NSCLC, Stage I | Good PS | 0.94 | β | Vinod-2008 [23] |
| NSCLC, Stage I, Good PS | Inoperable | 0.41 | β | Tracey-2014 [27] |
| NSCLC, Stage I, Good PS, Inoperable | Peripheral | 0.65 | ζ | This study |
| NSCLC, Stage I, Good PS, Inoperable | Central | 0.17 | ζ | This study |
| NSCLC | Stage II | 0.10 | β | NSWCCR* |
| NSCLC, Stage II | Good PS | 0.94 | β | Vinod-2008 [23] |
| NSCLC, Stage II, Good PS | Inoperable | 0.53 | γ | Welch-2020 [28] |
| NSCLC, Stage II, Good PS, Inoperable | Node (-) | 0.44 | γ | Jacobs-2019 [32] |
| NSCLC, Stage II, Good PS, Inoperable, Node (-) | T ≤ 5 cm | 0.73 | γ | Jacobs-2019 [32] |
| NSCLC, Stage II, Good PS, Inoperable, Node (-), T ≤ 5 cm | Peripheral | 0.45 | ζ | This study |
| NSCLC, Stage II, Good PS, Inoperable, Node (-), T ≤ 5 cm | Central | 0.17 | ζ | This study |
| NSCLC | Stage III-IV | 0.72 | β | NSWCCR* |

**Abbreviations**: SCLC Small Cell Lung Cancer, NSCLC Non-small Cell Lung Cancer, PS Performance Status, Quality of epidemiological data: α- Australian National Epidemiological data; β- Australian State Cancer Registry; γ- epidemiological databases from other large international groups (e.g. SEER); δ- results from reports of a random sample from a population; ε – comprehensive multi-institutional database; ζ – comprehensive single-institutional database; θ – multi-institutional reports on selected groups (e.g. multi-institutional clinical trials); λ – single-institutional reports on selected groups of cases; μ – expert opinion [3].
*Data (unpublished) was based on New South Wales Central Cancer Registry (NSWCCR) of all patients diagnosed with lung cancer in NSW in 2011(Gabriel G, personal communication, Feb 8, 2021).

inoperable tumours, resulting in varying the optimal rate from 3.8% to 6.8%. There was also variability in the proportion of patients with acceptable PS, which varied the optimal rate between 5.5 and 5.9%. To assess the impact of all uncertainties in the model, a multivariate sensitivity analysis was performed using Monte Carlo simulation analysis with 10,000 simulations that gave a 95% confidence interval of 4% to 6%.

*Actual vs optimal SABR utilisation*

Considerable variability was observed in actual utilisation rates of lung SABR for early-stage NSCLC (Table 4). SABR is most commonly used for inoperable stage I NSCLC, ranging between 55 and 74% in The Netherlands [7,33], 27% in the U.S [14]. In Australia, 57% of patients with inoperable stage I-II NSCLC receive radical radiotherapy (14% of whom had SABR) [11]. A recent systematic review of population-based studies estimated utilisation of curative-intent RT to range between 8 and 21% for stage I-III NSCLC [12]. Cohorts that included both operable and inoperable stage I patients reported lower rates of SABR utilisation at approximately 6–13% [34–36]. SABR is used less commonly for stage II NSCLC, with most studies reporting only 0.8–2.0% of patients receiving SABR. [37,38].

Within our local dataset of 430 stage I-II patients treated between 1995 and 2019, a total of 14.6% received SABR, 58% received conventional RT while 27.4% received palliative RT (Appendix V). Most patients receiving SABR were IA lesions (89%) while 6% and 5% were IB and IIB lesions, respectively. Comparing the calculated optimal rates against actual reported rates of lung SABR utilisation has identified marked shortfalls in service provision (Table 5). In stage I NSCLC, for example, the optimal SABR utilisation rate was 32% compared to 6–20% observed in practice pattern studies.

Time-trend analyses revealed rapid increases in lung SABR utilisation since its introduction in the early 2000s [7,11,14,30,32,36]. In Australia, the introduction of SABR has increased curative radiotherapy utilisation from 51% to 64% in patients with inoperable stage I-II NSCLC [11]. In the U.S, SABR utilisation for stage I NSCLC increased from 3% to 44% between 2003 and 2011, while the proportion of those receiving conventional RT dropped from 42% to 21% [14]. In The Netherlands, radiotherapy use for stage I NSCLC (mostly SABR) increased from 31% to 52% between 2008 and 2018, while resection rates decreased from 58% to 40% [33]. Similar trends were observed within our dataset of 430 NSCLC patients treated at our local centre, with SABR utilisation increasing by 12% for stage I patients treated between 2014 and 2019 compared to those treated between 2000 and 2005 (Appendix VI). When considering only those patients treated in 2005 onwards, i.e. after wider uptake of SABR and likely higher rates of pathological/imaging staging, the rate of SABR utilisation was observed at 16% compared to 58% and 26% for conventional and palliative radiotherapy, respectively.

## Discussion

This study is the first to estimate demand for SABR in lung cancer and reports the first evidence-based estimations of optimal utilisations rates of lung SABR within the Australian population. Based on the best available evidence, 24% of stage I-II NSCLC were estimated to require SABR at least once during the course of their illness.

SABR remains a less established treatment compared to other modalities, which is evident by the scarcity of high-level evidence as well as variations among practice guidelines. Currently, the strongest available evidence recommends SABR for inoperable, stage I peripherally located NSCLC lesions where it showed superior outcomes compared to conventional radiotherapy in a randomised phase III trial (CHISEL) [50]. Centrally located tumours remain a controversial issue with some guidelines precluding the use of SABR, while others recommend using more protracted dose schedules based on data from RTOG-0813 [51]. Similarly, there is a lack of consensus regarding tumours > 5 cm, most RTOG trials have excluded such lesions, though large retrospective studies have not reported significantly increased toxicity [56,57]. ASTRO/ASCO guidelines allow SABR use for such tumours provided that maximum dose constraints are respected [2], while Australian guidelines do not recommend its use in such cases [45].

Other approaches of calculating optimal utilisation, such as criterion-based benchmarking, have the advantage of not relying on epidemiological data which may not always be accurate or available. In this approach, optimal utilisation rates are assumed to be achieved in well-resourced centres, which are then used as the benchmark against which utilisation rates at other centres are assessed [58]. While this approach has the advantage of relying on empirical “real-world” data, it does assume the presence of optimal utilisation and therefore, may only be applicable to well-resourced and publicly funded healthcare systems and difficult to reproduce in other jurisdictions. Also, unlike criterion-based benchmarking, evidence-based models rely solely on the proportion of patients recommended to receive lung SABR (based on guidelines’ recommendations) and the proportion of the population likely to develop such indications (based on population data). As such, evidence-based optimal utilisation rates are independent of variations in actual utilisation rates observed across different geographical areas and the

**Table 3**
Summary of all epidemiological studies included in model development and sensitivity analysis.

| Study | Country | Population | Diagnosis year | Staging | N | Data used in model Proportion of: | Quality |
|---|---|---|---|---|---|---|---|
| Walters –2013 [22] | AU-NSW | Lung cancer | 2004–2007 | Not defined | 12,233 | NSCLC: 87%<br>SCLC: 13% | β |
| NSWCCR* | AU-NSW | Lung cancer | 2011 | Not defined | 2240 | NSCLC stage:<br>I: 18%<br>II: 10%<br>III-IV: 72% | β |
| Vinod-2008 [23] | AU-NSW | Lung cancer | 2001–2002 | Pathologic (91%), PET (17%) | 1812 | ECOG (4 + ): 6% | β |
| Boxer-2011 [24] | AU-SWS | Lung cancer | 2005–2008 | Pathologic (92%) | 988 | ECOG (4 + ): 7% | δ |
| Duggan-2011 [25] | AU-SWS | Lung cancer | 2006–2008 | Not defined | 815 | ECOG (4 + ): 5% | δ |
| Moller-2018 [26] | UK | Lung cancer | 2012–2014 | Not defined | 176,225 | ECOG (4 + ):10.4% | γ |
| Tracey-2014 [27] | AU-NSW | NSCLC, Stage I | 2001–2008 | Pathologic (83%) | 3240 | Operable: 59% | β |
| Wouters-2010 [31] | NT | NSCLC | 2001–2006 | Pathologic (for operable) | 43,544 | Operable:<br>Stage I: 70%<br>Stage II: 49% | γ |
| Danesh-2020 [30] | CA-Ontario | NSCLC, Stage I | 2007–2015 | Pathologic (for operable) | 11,910 | Operable: 62.8% | γ |
| Li-2008 [5] | NT-Amsterdam | NSLC | 1998–2003 | Pathologic (for operable) | 5846 | Operable:<br>Stage I: 74%<br>Stage II: 50% | γ |
| Kravchenko-2015 [29] | US (SEER) | NSCLC, age 65+ | 1992–2007 | Not defined | 95,167 | Operable:<br>Stage I: 58%<br>Stage II: 34% | γ |
| Welch-2020 [28] | UK | NSCLC | 2012–2016 | Not defined | 161,231 | Operable:<br>Stage I: 52%<br>Stage II: 47% | γ |
| Jacobs-2019 [32] | US (NCDB) | NSCLC, Inoperable, IIB | 2004–2015 | Pathologic (14.1%) | 10,081 | Node (+): 56%<br>T > 5 cm: 27% | γ |

**Abbreviations**: SCLC, Small cell Lung Cancer; NSCLC, Non-small Cell Lung Carcinoma; ECOG, Eastern Cooperative Oncology Group. The calculated optimal rates are highlighted in green.

**Table 4**
Actual Utilisation rates of lung SABR in stage I and/or II NSCLC based on practice pattern studies.

| Author | Registry | Population | N (%of I-II) | Diagnosis Year | Staging | SABR utilisation rate (%) |
|---|---|---|---|---|---|---|
| Palma-2010 [7] | NT | NSCLC, stage I (75 + ) | 875 | 1999–2007 | Pathologic (76%) | 2004: 23%*<br>2007: 55%* |
| Corso-2015 [34] | US (NCDB) | NSCLC, stage I | 113,312 | 2003–2011 | Not defined | Blacks: 5.5%<br>Whites: 6.1% |
| Koshy-2015 [14] | US (NCDB) | NSCLC, stage I, Inoperable | 39,822 | 2003–2011 | Pathologic | 27%<br>2003–2005: 3%<br>2009–2011: 44% |
| Valle-2015 [54] | US (Multi-centre) | NSCLC, stage I | 1506 | 2007–2011 | Pathologic | 12% |
| Dalwadi-2017 [35] | US (SEER) | NSCLC, stage I (60 + ) | 62,213 | 2004–2012 | Pathologic (for operable) | 18.6%† |
| Nguyen-2018 [11] | AU (Multi-centre) | NSCLC, stage I-II inoperable | 312 | 2008–2014 | Pathologic (84%) | 14% |
| Haque-2018 [55] | US (SEER) | NSCLC, stage IA (T1) | 32,249 | 2004–2012 | Not defined | 19.6%† |
| Jacobs-2019 [32] | US (NCDB) | NSCLC, stage IIB Inoperable | 10,081 | 2004–2015 | Pathologic (14.1%), PET (Not defined) | 22.5% (of T3N0) |
| Brada-2019 [10] | England | NSCLC, stage I-III | 25,659 (53%) | 2012–2013 | Not defined | 6% |
| Phillips-2019 [36] | UK | NSCLC, stage I | 12,348 | 2015–2016 | Pathologic (46%)<br>PET (54%) | 13% |
| Yan-2019 [37] | US (NCDB) | NSCLC, stage II | 56,543 | 2004–2013 | Not defined | 0.8% |
| Moore-2020 [38] | CA | NSCLC, stage II | 535 | 2005–2012 | Not defined | 2% of all patients.<br>8% of inoperable patients. |
| Evers-2021 [33] | NT | NSCLC, stage I-III | 61,621 (56%) | 2008–2018 | Pathologic (72% of stage I, 87% of stage II, 90% of stage III) | 74% of inoperable stage I<br>22% of inoperable stage II |

**Abbreviations:** NT Netherlands, US United States, AU Australia, UK United Kingdom, CA Canada, NSCD National Cancer Database, SEER Surveillance, Epidemiology, and End Results Program, NSCLC Non-small Cell Lung Cancer.
*SABR rate among those receiving radiotherapy.
†Utilisation rate not specific to SABR.

**Table 5**
Comparing actual and optimal utilisation rates of lung SABR for patients with early-stage NSCLC.

| Early-stage NSCLC | | | | | |
|---|---|---|---|---|---|
| | | Actual rates | | Optimal rates | |
| Study | Population | Stage I | Stage II | Stage I | Stage II |
| Corso-2015 [34] | US | 6% | NA | 32% | 10% |
| Valle-2015 [54] | US | 12% | NA | | |
| Dalwadi-2017 [35] | US | 18.6% * | NA | | |
| Haque-2018 [55] | US | 19.6% * | NA | | |
| Phillips-2019 [36] | UK | 13% | NA | | |
| Yan-2019 [37] | US | NA | 0.8% | | |
| Moore-2020 [38] | CA | NA | 2% | | |

| Inoperable early-stage NCSLC | | | | | |
|---|---|---|---|---|---|
| | | Actual rates | | Optimal rates | |
| Study | Population | Stage I | Stage II | Stage I | Stage II |
| Nguyen-2018 [11] | AU | 14% (both I&II) | | 82% | 20% |
| Koshy-2015 [14] | US | 27% | NA | | |
| Jacobs-2019 [32] | US | NA | 22.5% (IIB) | | |
| Palma-2010 [7] | NT | 55% | NA | | |
| Evers-2021 [33] | NT | 74% | 22% | | |
| Moore-2020 | CA | NA | 8% | | |

**Abbreviations:** NSCLC Non-small Cell Lung Cancer, US, United States, UK United Kingdom, CA Canada, AU Australia, NA not applicable.
* SABR rate among those receiving radiotherapy patients.

reasons for such variations (i.e. referral rates, institution types, travel distance and so on).

In clinical practice, lung SABR utilisation was found to greatly vary across populations and different treatment providers (Table 4). Multiple factors were found to influence utilisation of SABR and curative radiotherapy for NSCLC. Patients' associated comorbidities, COPD or poor lung function are major factors accounting for 21–34% of stage I-II patients receiving non-curative treatments in Sydney, Australia [11]. This rate will hopefully decrease with improvements in targeting accuracy and the ability to reduce the amount of healthy tissue receiving high-dose irradiation. Additionally, SABR utilisation was significantly higher at high-volume, academic centres (68%) compared to rural or community centres (25%) ($p < 0.0001$) [14]. Patients discussed at MDT meeting were significantly more likely to receive curative treatment compared to those who were not [59]. Clinicians' biases, referral practices and attitudes towards radiotherapy have also been shown to influence utilisation rates [60–62]. Moreover, patients' travel distance to the nearest centre strongly predicted the rates of undergoing SABR, as 45% of untreated stage I NSCLC would have had to travel around 45 min to the nearest centre [36]. In Australia, patients were 10% less likely to receive radiotherapy for each additional 100 km distance to the nearest department [63]. Socio-economic factors such as race, income, education, insurance/reimbursements have also been shown to affect utilisation [14,54,64,65]. Patients' preferences may also affect treatment patterns, accounting for 11–13% of stage I-II patients receiving non-curative treatments in Australia [11,59].

Despite marked increases in lung SABR utilisation rates over time, our analysis shows they remain short of meeting the evidence-based population demand. This gap between actual and optimal utilisation is also evident by the notable proportion of patients with potentially curable lesions receiving palliative or no treatment at all [10–12]. Underutilisation of radiotherapy has been linked to considerable reductions in overall survival and loss of years-of-potential life [10,16,66]. As the proportions of patients diagnosed with early-stage NSCLC increases due to population ageing and the increased use of medical imaging/screening, demands for curative lung radiotherapy are expected to increase in the near future [36]. In NSW, investments in radiotherapy facilities over the past decade have only managed to keep pace with the increasing number of new cancer cases with indications for radiotherapy, as the number of accelerators per 1000 new cases remained static at 1.2 [67].

Long-term planning of radiotherapy service provision using reliable data is important in determining the capacity required in the future, and implementing strategies that ensure adequate and efficient healthcare delivery [15,68–72]. Effective cancer management plans should also consider the changing nature of cancer populations (e.g. due to an ageing population, use of screening programs, varying indications) as well as the fast pace at which radiotherapy technologies are developing. Recently, ESTRO has introduced the value-based health care (VBHC) project, an initiative addressing key issues including defining the outcomes supporting the implementation of new innovations (e.g. clinical, economic and patient-centred outcomes) as well as defining the level of value and evidence needed before implementation into daily practice [73,74]. The model presented here can be easily modified to account for any updates to guideline recommendations as new evidence emerge, or changes in the distribution of epidemiological data within the population. The model can also be easily adapted to be used to calculate the optimal SABR utilisation rate for different populations or countries by substituting their data in the relevant branches.

Limitations of our approach, as with other evidence-based models, include reliance on the availability and quality of the data included. SABR remains a less established treatment compared to conventional radiotherapy and level I evidence are still lacking. Lung SABR is a continuously evolving practice with rapidly growing literature; while there is emerging evidence suggesting the potential of SABR being used for other indications such as operable NSCLC [75], our model was limited to those indications established in current protocols and practice guidelines. We look forward to updating the model in the near future as these guidelines continue to evolve. There was a lack of Australian based epidemiological data for the distribution of stage II patients with operable tumours, as well as those with node-negative-node and $< 5$ cm tumours. The sensitivity analysis performed helped estimate the effects of variability in this data on the overall calculated demands.

Considering patients' preferences requires more detailed investigations to account for other confounding factors; this was beyond the scope of this study and therefore patients' preferences were not incorporated into the model. In Australia, it has been estimated that patients' preference accounted for 4–15% of stage I-II NSCLC patients receiving palliative radiotherapy or no treatment [11]. Finally, our model only considered the proportion of patients requiring SABR as initial therapy, without accounting for those requiring re-treatments. Barton et al. (2014) reported 16% of lung cancer patients requiring re-treatments [76], although this rate included all stages and types/intents of radiotherapy and may be different for SABR treatments. Thorax re-irradiation with SABR has shown to be feasible in retrospective studies, in particularl, for salvaging residual, recurrent or new primary NSCLC in or adjacent to a previous high-dose radiation field [77–81]. Although, limited data is available on dosimetric limits and predictors of toxicity in this setting, especially for central/ultra-central tumours where risk of toxicities may be higher.

## Conclusion

Based on the best available evidence, we estimated 24% of stage I-II NSCLC to require SABR at least once during the course of their illness. Actual rates of lung SABR utilisation considerably vary among different populations, and despite marked increases over time, they remain below evidenced-based demands for the treatment. The estimated optimal SABR utilisation rates can be used as benchmarks when evaluating the provision of care as well as long-term planning of resource allocation to improve the efficiency of service delivery. Future work may also expand on the presented model to estimate the survival benefits associated with optimal SABR utilisation.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ctro.2022.03.001.

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