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Review

Issues surrounding the use of helical CT for the imaging and planning of lung tumours

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Abstract

In this article several issues will be discussed. Firstly, the efficacy of using helical CT data to image the thorax, and delineate volumes (clinical target volumes (CTV) and planning target volumes (PTV). Secondly, the practicalities of using CT data sets for dose inhomogeneity corrections and planning in the thorax. And thirdly, the associated problems of organ motion and immobilisation in this region.

Keywords

Helical CT; imaging and planning; organ motion; immobilisation and lung tumours

BACKGROUND

Traditionally, with orthogonal films from conventional simulators, lung tumours have been problematical to plan for several reasons:[1]

- Difficulty in delineation of Clinical Target Volume (CTV) and Planning Target Volume (PTV).
- The close proximity of sensitive organs, for example spinal cord, heart and lungs.
- The anatomy of the thoracic cavity eg. decreased diameter at the thoracic inlet and the slope of the chest wall.
- The presence of different tissues within the thoracic cavity, and the differential densities of bone and lung within the treated volume.
- The organ motion within the thoracic cavity eg. lungs and heart due to respiration.

The development of helical scanning has enabled the use of highly resolved image data sets, which can be incorporated into the treatment planning and evaluation process. In principle this information should enable many of the issues highlighted above to be addressed. As will be discussed later, it is arguable that these high resolution data sets will result in more accurate delineation of anatomical structures, and improve visualisation of the relationships between them. This information is vital for treatment planning, and it is essential to have good geometric definition of anatomical structures. An example of this may be the calculation of dose volume histograms (DV_H), where the 3D boundary of a structure, or the set of image voxels within it are required to evaluate the DV_H given a 3D dose distribution. Evaluation of tumour control probability (TCP) and normal tissue complication probability (NTCP) also require this information.

Numerous papers have been published regarding the use of 3D non coplanar treatments for lung tumours.[1–6]

Sibley et al. concluded:[5]

> "Uncontrolled lung cancer was the primary cause of death in these patients, and local failure alone represented the most common mode of failure (42%). Patients who were locally controlled had a significantly improved cause specific survival over those who failed locally.

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> Because higher doses of radiotherapy appear to provide improved local control, studies of dose escalation are warranted until dose limiting toxicity is observed."

This work was further supported by the findings of Krol et al.: [6]

> "The low regional relapse rate does not support the need for the use of large fields encompassing regional lymph nodes. Using small target volumes, higher doses can be given and better local control rates can be expected"

In an attempt to deal with these pertinent issues there have been recent trends outside the UK to use CT to plan smaller PTVs and escalate doses, using 3D plans and non coplanar beams.[1-6]

If we were, perhaps controversially, to adopt their standards as a benchmark for practice in the UK, it would facilitate an examination of the viability of using helical data sets for planning conformal therapy in the thoracic region. This would aid the assessment of any possible advantages and limitations of this modality.

THE EFFICACY OF USING HELICAL CT DATA TO IMAGE THE THORAX AND DELINEATE CTV, PTV AND TREATED VOLUMES

Work undertaken by Emani et al.[1] defined the volumes which needed to be included if treating non small cell lung cancer clinically staged T3-T4, and NO, M0. This was specified as the primary tumour plus:

> "The lymphatics of the supraclavicular, ipsilateral and contralateral hilar nodes, superior, subcarinal and inferior mediastinal nodes with a margin of 1cm".

They later went on to identify areas which needed careful consideration when 3D planning:

> "Normal tissues which were considered at risk for potential injury were extensive. These included ipsilateral lung, spinal cord, oesophagus, heart, brachial plexus bilaterally, liver and thyroid".

If one were to follow this convention, (which would seem to constitute good practice due to historical evidence of radiation damage to these organs) then it is imperative that these soft tissue structures are well defined.

Undoubtedly helical CT ensures volumetric acquisition of data which facilitates inclusion of the tumour in its entirety, and also enables the anatomy to be related in a 3D construction. Intravenous contrast may also be used to highlight mediastinal vascular and node anatomy, thereby enabling one to distinguish vessels from tumour or other structures in the thorax.

The 'lung window' settings on the helical scanners allow manipulation of the data thus facilitating the viewing and demonstration of soft tissue anatomy in the mediastinum and other areas of the thorax. This enables clear visualisation of fat, fluid, tissue, calcium and contrast media. These window levels also provide information regarding lung consolidation, the hila, pleural disease and other structures of the chest wall. Demonstration of lung anatomy and pathology contrasts well with surrounding air filled lung, in theory enabling the accurate delineation of CTV, and therefore PTV.

However, despite the very accurate data provided for visualisation of anatomy, interpretation of this for planning can be problematical:

> "Not all of the region interpreted as tumour on CT is actually tumour, but could include surrounding oedema or inflammatory tissue. This is true for most CT assessments of malignancy and is an accepted error".[7]

Arguably, therefore, there may be a tendency to specify a larger CTV/PTV, thereby increasing the size of the treatment volume. This is obviously open to misinterpretation and is dependent on the skills of the Clinical Oncologist who delineates the CTV. Liang's findings[7] regarding delineation of CTV, and therefore PTV, could well be an area of concern. Increases in treated volumes may limit the delivery of a sufficiently high tumouricidal dose. Work published by Martel et al.[8] predicted a trend towards a high incidence of pericarditis for a group of patients who have high complication probabilities. The aim of Martel's paper was to discuss the dose/volume effect on the heart. One could argue the relevance of Martel's findings within the context of this article as it was only applied to the treatment of the oesophagus and not

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the lung. However, the author believes that the findings are applicable if we are to use the work of Emani et al.[1] which identified the heart as a critical normal structure.

In Martel's[8] work the volume was defined by CT evaluation, including any 'suspicious involvement'. This supports Liang's[7] scepticism regarding the ability to accurately delineate tumour from oedema.

Martel concluded that the influence of treatment parameters such as fraction size, average and maximum doses derived from 3D plans did predict a trend towards a high incidence of radiation pericarditis. Martel also stated that:

> "Compared to fraction size, dose factors uncorrected for lung densities were not the most significant variables related to complication factors".[8]

This is very controversial and warrants further discussion.

THE PRACTICALITIES OF USING CT DATA SETS FOR DOSE INHOMOGENEITY CORRECTIONS AND PLANNING

Martel's findings contrast other literature which supports the assertion that lung density corrections do make a significant difference to dose effectiveness.[9–11]

Mah et al.[9] compared 100 patients who had standard thoracic dose calculations, with and without inhomogeneity corrections. They found that even for simple AP fields the difference in calculated dose was between + or – 5 to 16% for energies varying between 25MV and 60 Cobalt. They concluded that inhomogeneity corrections should be implemented, and that "CT based calculations are warranted when accurate dose information is critical".

This is further supported by Van Dyk[10] who cited in his paper that:

> "A 5% increase in dose to lung increases the incidence of radiation pneumonitis by more than 20%".

As highlighted earlier, the work of Emani[1] strongly advocates care when determining critical structures. One specified organ at risk being healthy lung. Other studies[12,13] have assessed the link between radiation and pneumonitis and identified certain 'risk factors' which lend weight to Van Dyk's work.

Van Dyk's[10] work was undertaken as early as 1983 and his data supported the belief that "a single uniform lung density for dose calculations within or beyond the lung will not yield accurate results for the majority of patients". This should perhaps be of no surprise, indeed patients' lung densities may change throughout a course of treatment due to infection, inflammatory responses and even the effects of certain chemotherapeutic agents.

Van Dyk also found a wide variation in the densities of individual patients lungs.[10] The anterior part of the lung having a lower density than the posterior in a supine patient. This is an interesting discovery as the convention is to treat patients in the supine position and raises the question of whether and how we should incorporate this into current practice?

At the time of Van Dyk's publication in 1983, it was felt to be impractical to perform precise inhomogeneity corrections on a pixel by pixel basis from CT data as commercially available systems were not able to process this data. Technology in the past 16 years has now evolved sufficiently to cope with this, but the question still remains as to whether this is appropriate?

Mah et al.[9] suggested:

> "The reason for not performing inhomogeneity corrections range from unavailability of precise tissue density information to the assumed lack of accurate calculation algorithms".

Undoubtedly with the helical data sets and the commercially available planning systems there should be no technical reason as to why this information cannot be used. However, perhaps Mah's[9] subsequent argument is more pertinent:

> "Ultimately, the question reduces to a cost benefit analysis. Are the extra effort and cost of obtaining anatomic and density information and performing accurate dose calculations worth the benefit of improved patient outcome either for tumour control or normal tissue complications?"

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This is difficult to assess in the context of the literature used for this article, and the current working practices adopted in the UK for treating lung tumours. If the practices adopted in the following studies[1–6] were to become commonplace in the UK, then after a substantial period of evaluating patient outcomes, an informed opinion could be formulated. However with the inherent economic constraints of the NHS and limited scanner times for most centres, CT scanning patients still remains a controversial issue, especially for tumours with traditionally poor 'cure' rates such as lung.

To conclude this section Essers et al.[11] make an appropriate observation. They investigated the accuracy of CT based inhomogeneity corrections and in vivo dosimetry for the treatment of lung cancer and concluded that:

> "Exit dose in the thorax region is quite well predicted for AP-PA beams using dose calculations based on CT densities and a simple path length model. Organ motion of eg., heart and lung, due to the ventilatory cycle or cardiac cycle cause an uncertainty in exit dose of 2.5% (1SD)".

It is this pertinent aspect of organ motion and the difficulties it presents when planning and treating lung tumours, which will be examined next.

ORGAN MOTION AND IMMOBILISATION

One of the major constraints of treating any lesion in the thoracic region is the organ motion of both the lungs and the heart. In an attempt to contain the whole CTV, allowing for organ motion, there will conceivably be an increase in the PTV. This may result in an increased dose to the 'normal' surrounding tissues and limit or reduce the dose delivered in an attempt to eliminate complications.[8,12]

Respiratory motion is a major issue within the context of this article. Respiration not only alters image quality, but the accurate visualisation and delineation of PTVs.

"Respiration condition during the scanning process is an important consideration for accurate target volume delineation and dose delivery, especially in the thoracic region".[14]

When 'diagnostic' scans are performed they are often undertaken on full inspiration breath holds. This facilitates enhancement of contrast within the lung region, and helps to keep the patient reasonably still, thereby reducing motion artefacts.

Clearly, this does not reflect 'normal' treatment conditions, where a patient will breathe with quiet respiration (10–14 breaths per min) during treatment delivery.

Work undertaken by Wong et al.[15] demonstrated that:

> "The diaphragm moved non uniformly in the AP direction, ranging from less than 1cm near the dome of the diaphragm, to about 3cm in the posterior direction"

Wong's findings are further supported by Battisa et al.[16] They demonstrated how normal respiration versus full respiration changed the anatomy in the anterio posterior direction by up to 1.5cm. This resulted in a 28% difference in lung density. These findings may not be surprising, but they do raise the question of the way forward.

One possible approach is to 'freeze' organ motion. This may be achieved as a result of gating respiration by utilising breath holding techniques. This practice had been adopted as early as 1982 by Jones.[17] This technique was used when performing diagnostic CT scans in an attempt to reduce motion artefacts when scanning the thoracic region. Since then further work specific to radiotherapy has been undertaken.[15,18] Wong devised a method whereby the patient was given a nose clip and breathed through a mouthpiece only when the ventilator allowed. This technique was termed 'active breathing control' (ABC):

> "Lung patients could maintain comfortably an active breath hold of 15 seconds near the end of normal expiration. When ABC was applied during deep inspiration the breath hold period ranged from 25 seconds to 50 seconds".[15]

Kubo adopted a different approach. Here, the linear accelerator was gated, thus the beam was only switched on during the actual time that the patient was artificially holding their breath.[18]

Both authors had recognised the limitations that organ motion had placed on the accurate delivery of radiotherapy treatments, and had used techniques for breathing control which had been adopted in diagnostic CT and MRI scanning.

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Wong discussed how ABC could be used to escalate doses (up to 100 Gy), without increasing the risk of normal tissue complications, and hopefully eliminating the possibility of local failure.

So one is left with the question, is this the way forward; to minimise organ motion, more accurately define and delineate CTV and PTV, and escalate doses?

One of the biggest criticisms of the work of Wong[15] is that they only did feasibility studies on 10 patients. This is not a large sample of the typical patient group and it is questionable as to whether all patients with lung tumours could tolerate the process of ABC. Until a larger sample group is tested it is doubtful there will be any conclusive evidence as to the efficacy of this technique.

One thing is certain however, and that is the equipment manufacturers are responding to the research published in America and they are developing linear accelerators with intensity modulation software. In this context, a dose rate of 600 MU/minute allows quick treatment of lung tumours, which together with breath holding, minimises organ movement.

It is appropriate also to briefly consider the issue of immobilisation. This is perhaps the last link in the chain, but is a very important area for us to evaluate. Much work has been undertaken (again in the USA) regarding patient immobilisation, especially in the pelvis for prostate patients. There is much documentary evidence which demonstrates how clinical misses reduce the chance of a cure. One can argue: what is the point in all the complex CT scanning, planning and ABC devices if we cannot reproduce patient position on a daily basis?

Sherouse et al.[19] looked at the practical considerations when adopting virtual simulation in the clinical setting. They considered how to immobilise the patient and accurately transfer geometric co-ordinates from the CT scanner onto the patient for references when treating. The methods utilised were both simple and effective. A large cast for each patient was fixed onto both the CT couch and treatment couch in such a manner that co-ordinates in the x origin and z axis could be referenced accurately. However, much of this work was undertaken using an anthropomorphic phantom with articulated joints rather than actual patients. It must also be acknowledged that a number of studies have been undertaken with respect to immobilisation of this region and as yet there is little compelling evidence to recommend a particular method.

It is interesting to note however, that equipment manufacturers are developing their own couch indexing systems, and some have produced couch tops which can be used on CT scanners and linear accelerators. This is a step forward in the context of increasing reproducibility.

CONCLUSION

Helical CT scanning undoubtedly is the ideal imaging modality for a complex anatomical region such as the thorax, and there is a wealth of evidence to support the use of CT data sets for inhomogeneity corrections. There are some areas for concern however, including, the clinicians ability to accurately define tumour, the status of the patient's respiration when scanned and treated, and the issue of positional reproducibility from CT scanning through to treatment.

There are other issues which need resolving. The aperture size of helical scanners range from 68–72cm. This is far from ideal since most patients have to be scanned in the supine position with their arms up. This may mean that there is a practical constraint on accommodating the patient and any immobilisation devices through the scanner.

CT number accuracy can be affected by beam hardening from the patient immobilisation devices and care should be taken if using inhomogeneity corrections, since they may affect the resultant dose. CT scanners also have a limited field of view, with an approximate reconstruction circle of 50cm. This can mean that parts of large patient's contours are outside the reconstruction circle. This raises the question of what method to use to reconstruct the missing outline?

Though some of these issues are being addressed by our colleagues outside the UK, not much work has yet been published in this country relating to the use of CT scanning in the planning and subsequent treatment of lung tumours. Evidence based medicine is one of the 'buzz' phrases at the moment, where we should rely on empirical evidence for the benefits and costs for a patient with a given presentation. So it would seem evident that in the UK we perhaps need to evaluate the validity of using CT for the planning of conformal therapy for lung tumours. Perhaps the following may give us all some food for thought:

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"The true impact of 3D CT simulation and treatment planning should come from prospective randomised studies in which patients will be treated with either conventional simulation/planning and treatment delivery or 3D planning and conformal therapy."[20]

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