Optimisation of oncology imaging using dual energy computed tomography

Abstract

Objective: Computed Tomography (CT) is a common diagnostic technique used in the detection and staging of tumors in patients. Multi-phasic follow-up scans are routinely performed in oncology patients and the consequent cumulative exposure to ionising radiation remains of clinical concern. However, reduction in dose to patients has become possible with the emergence of ongoing innovative multi-detector technologies such as Dual Energy Computed Tomography (DECT) and the various post-processing algorithms it entails. The aim of this paper is to perform a critical review of the current published data addressing the various possibilities in the use of DECT relevant to oncology imaging.

Results: A number of studies were analysed and discussed. The overall consensus demonstrated promising dose saving and image optimising possibilities with the utilisation of DECT over conventional single energy CT. However, technical and patient’s physical parameters where of limitation in producing accurate dose saving possibilities in oncological patients over a large consensus.

Conclusion: DECT has proven to significantly reduce radiation dose to oncology patients whilst still maintaining the diagnostic acceptability required to make a diagnosis. Nevertheless, optimisation of images is only possible in patients that have a relatively low body mass index, due to the technical constraints imposed by DECT scanners.

Introduction

Computed Tomography (CT) is routinely favoured by physicians as an imaging modality of choice for the diagnosis, staging and accurate treatment monitoring of oncology patients due to its fast acquisition time, reliability and widespread availability (Mettler et al, 2009).

Through recent years with ongoing technological advancement and increasing awareness of the radiation risks associated with ionising radiation imposed by CT scans, the lenience towards dose optimising strategies has become more warranted (Henzler, Fink, Schoenberg, & Schoepf, 2012).

Since its introduction in 2006, dual energy computed tomography (DECT) has achieved ongoing clinical significance and widespread diagnostic application throughout the healthcare system. DECT utilises two different x-ray tubes, each utilising two different voltages, to simultaneously acquire multiple energy data of a given anatomic area in a single CT acquisition (Henzler, Fink, Schoenberg, & Schoepf, 2012).

These technical specifications of DECT provide information on the different chemical composition of tissues based on differences in photo absorption. The utilisation of two x-ray tubes operating at different tube potentials, one high and one low, allows for the exploitation of the attenuation differences of materials in relation to their atomic number (Graser et al, 2009).

This paves the way for a spectrum of post processing techniques that enable the ‘ 3 material decomposition’ of iodine, calcium, or uric acid in the image (Graser et al, 2010). These post processing algorithms enable specific materials, such as iodine to be identified on contrast scans and either selective removed to produce virtual unenhanced images or selectively displayed as material specific data set to produce iodine maps (Mileto, Nelson, Paulson & Marin, 2014). This offers promising applications in imaging of oncology patients for accurate tumour detection and characterisation while concurrently reducing radiation dose (Simmons, Kachelrib & Schlemmer, 2014).

The calculation of virtual unenhanced images may obviate the need for conventional pre-contrast scans. This is of particular significance for oncology patients who often require follow up scans. Virtual unenhanced images provide the possibility of reducing routinely done tri-phasic scans to bi-phasic scans, eliminating the extra radiation dose imposed by the pre-contrast scan (De Cecco et al, 2010).

Furthermore, colour coded iodine maps can be used to assess tumour vascularity and has potential application in the assessment of treatment response of tumours to chemotherapy by measuring the iodine distribution within active tumors (Simons, KachelrieB & Schlemmer, 2014).   Additionally, iodine maps could potentially allow radiologists to determine the presence of enhancement within anatomical masses such as renal without the need for CT Hounsfield quantification on both pre-contrast and contrast enhanced images (Graser et al, 2010). This allows for better management of workflow and provides addition information in the management of patient’s response to radiation therapy for better planning and prediction of tumour recurrence (Odisio et al, 2018).

The promising possibilities for optimising oncology imaging using DECT has sparked interest in the medical and research community and numerous studies have been published on this topic. The purpose of this review is to assess the image quality and dose reduction possibilities of DECT scans in reference to oncology patients, as well as the potential shortcomings.

Discussion

The selective literatures reviewed all collectively highlight that there is no additional increase in radiation exposure when DECT is employed over conventional single energy CT. However, it is the capability of DECT to provide additional post-processing flexibility compared to conventional single energy CT scans which allows for additional clinical information to be gained which subsequently enables the optimisation of radiation dose to patients (Henzler, Fink, Schoenberg & Schoepf, 2012).

Virtual unenhanced imaging and its dose saving potentials to patients within its use in clinical practice, is one primary example of a post processing techniques widely investigated among the literature reviewed. Typical CT examinations, in particular of lesions characterisation of the liver and kidney parenchyma, tri-phasic scans are performed consisting of; pre-contrast, arterial and portal venous phase scans. With virtual unenhanced imaging, DECT allows the creation of the equivalent of a pre-contrast scan from a contrast enhanced DECT dataset. This poses significant radiation dose optimising possibilities, particularly for follow up examinations in oncology patients, as it eliminates the need for any prior non-contrast scans.

De Cecco et al (2010) published a study assessing the image quality and noise comparatively between conventional and virtual unenhanced images in subjects who underwent DECT of the liver. In this study, triple study protocols were compared to dual-phase protocols, with the replacement of liver unenhanced CT with virtual unenhanced CT. The study was conducted using 40 participants with known or suspected liver lesions who all underwent tri-phasic abdominal imaging consisting of a conventional unenhanced, arterial and DE portal venous phase scan. Iodine was subsequently subtracted from the DE portal venous phase scan to obtain virtual unenhanced images. Qualitative and quantitative analysis of the conventional and virtual unenhanced images were made using two expert radiologists and a five-point grading system to analyse the results. The study found no significant difference in image quality between the conventional versus the virtual unenhanced images of the liver. An acceptable quality for diagnostic significance was observed in 95% of the virtual unenhanced images and the inter-observer agreement for image quality rating on the Cohen kappa statistical scale was 0. 8, deeming the quality of the virtual unenhanced images to be of excellent quality. Additionally, the omission of the conventional unenhanced acquisition and replacement with the DECT virtual unenhanced post processing image had an overall 30% reduction in effective radiation dose to patients.

A similar study was performed by Graser et al (2009) in which the study also assessed the performance of virtual non-enhanced images derived from DECT with true non-enhanced CT images, in the characterisation of renal masses using first generation DECT. The study found an effective dose reduction of 35% to patients when routine triple-phase renal CT protocols were reduced to dual-phase scans by omitting the true non-enhanced acquisition and replacing the protocol with the virtual unenhanced DECT followed by the nephrogenic and delayed phase protocol sequence. The following year in 2010 using a second generation DECT scanner, Graser et al confirmed the omission of a separate pre-contrast scan in multi-phasic scans and its replacement with a single phase contrast enhanced DECT scan with the ability to produce a virtual unenhanced image through post processing, demonstrated dose savings of up to 50% .

Both these studies highlight the advantage DECT encompasses, particularly for younger patients suspected of having renal or liver lesions who undergo multiple follow up examinations for management. The omission of a phase in a multiphasic CT scan, without any significant reduction in the diagnostic quality of the examination allows for a substantial reduction in effective dose to the patient whilst also saving investigation time (De Cecco et al, 2010).

Despite these findings, both studies had their limitations. The small cohort size making up De Cecco et al 2010 investigation puts into question the studies robustness, marking the statistical significance questionable. The need for a larger number of subjects for such a study is imperative to obtain more convincing results. Both studies also recognised pitfalls associated with DECT within their study. It was found that the study conducted would only be applicable to particular patients who met a certain criteria. The smaller detector size of the second x-ray tube within the DECT limited the body habitus selection of the patients that could be imaged as it was found the anatomy of interest fell outside the smaller FOV with larger patients, in particular patients with BMI more than 30kg/m2 (De Cecco et al 2010, Graser et al 2009). The quality of DECT was also found to be suboptimal in patients with large body habitus, with increased image noise due to the lower tube voltage output from the second x-ray tube. Thus patient size and technical constraints of DECT scanners has been demonstrated as a distinct drawback within both these studies which could be investigated further.

The additional benefits in image optimisation of oncology patients using DECT and its unique lesion characterisation abilities have been also investigated by researchers.   The differentiation between hyper-attenuating cysts from a minimally enhancing neoplasm may be difficult without any reference to a non-contrast acquisition, in cases specific to incidental finding of lesions (Agrawal et al, 2014). Further imaging may often be suggested for definitive workup and a repeat examination including a pre-contrast scan may be warranted for adequate characterisation. This results in additional radiation exposure to the patient and overall poor time management in the patient’s diagnosis (Brown et al, 2009).

However, direct visualisation of iodine enhancing colour maps from DECT post-processing acquisitions has shown to facilitate in the differentiation between enhancing lesion from a hyper attenuating non-enhancing cyst, rendering obsolete the need for ROI placement, and Hounsfield Unit measurement on both pre- and post-contrast images. (Brown et al 2009, Graser et al 2010, Song et al 2011, Milento et al 2014).

A phantom study conducted by Brown et al 2009 investigated the ability of DECT iodine overlay mapping in characterisation of renal masses as cyst or solid. The result of the study was that of the 36 enhancing masses, 35 were correctly identified and 10 out of the 12 renal cysts were correctly identified by two genitourinary radiologists. Brown et al 2009 equated these findings to a sensitivity and specificity of 97% and 83% respectively.

Despite further investigation needed in improving the specificity of these findings, Brown et al 2009 demonstrated the promising abilities of DECT iodine overlay techniques possesses in detecting enhancing renal lesions. The study’s results are based off on phantoms, which demeans the results being applicable to clinical practice as further research would be needed on real patients. Thus Brown et al 2009 momentous phantom study highlighted the feasibility of a similar study to be conducted in real patients to validate the results more concurrent within clinical practice and potentially obviate the need for unenhanced acquisitions for renal lesion characterisation.

Virtual unenhanced images can also be used to provide supplementary morphological and structural information about a lesion such as fat, calcification or necrosis, likewise in performance to true non-enhanced images.

Ho et al 2012 confirmed in a retrospective study involving 60 patients that measurements obtained of adrenal nodules on the virtual unenhanced images had strong linear correlation with the true unenhanced attenuation measurements. Indicative of the fact that virtual unenhanced images provided the same necessary information a true non-contrast scan demonstrates in order to correctly differentiate a lesion as being either a cysts, hemorrhagic cysts, angiomyolipomas, or renal cell carcinomas. Therefore the accurate imaging evaluation and characterisation of lesions on post-processed DECT scans, has the potential to mitigate the need for any further imaging, resulting in an overall reduction in radiation dose to patients and substantially improve the medical success of DECT being used for tumor screening and staging (Agrawal, 2014).

Although Ho et al 2012 made innovative findings; their study design had several limitations which were recognised by the authors. The relatively small cohort size of the study population demeans the validity of the claims delineated by the study findings. Another limitation of the study was the focus on only 4 different disease entities encompassing renal lesions i. e. cysts, hemorrhagic cysts, angiomyolipomas and renal cell carcinomas. Ho et al 2012 recognised the need for further studies in which a larger study population is used and an investigation assessing the effectiveness of DECT in the characterisation of an extensive and more convoluted renal masses and malignancies is needed to increase the robustness of the study.

Conclusion:

The innovative post-processing capability that DECT provides has sparked a marked interest in the research and medical community. Supportive possibilities have been assessed based on the use of DECT to optimize images and reduce the effective dose to patients, particularly oncology patients who often require multiple follow up CT scans.   The progressive endeavor to obtain clinically relevant and functional imaging through virtually unenhanced images derived from DE contrast CT scans and colour coded iodine mapping for lesion characterisation increases the future application of DECT in oncology imaging. However, research results are limited to certain patient criteria as large patients produce counterproductive results due to the technical restrains making up DECT scanners.

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