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Review article

Maintaining image quality and reducing dose in prospectively-triggered CT coronary angiography: A systematic review of the use of iterative reconstruction☆

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ABSTRACT

Introduction: Coronary computed tomography angiography (CCTA) is a reliable, minimally invasive technique used in the diagnosis and characterisation of coronary artery disease. Within this modality iterative reconstruction has the potential to maintain image quality whilst reducing radiation dose.
Methods: *A priori* search terms and inclusion/exclusion criteria were developed.
Results: Three studies were included in the review which analysed a total of 227 participants. As $CTDI_{vol}$ decreased there was no significant change in objective image quality, although some subjective image quality scores decreased.
Discussion: The decrease of subjective image quality scores may be explained as a reaction to the difference in image appearance of the iterative reconstruction images; a potential reduction in dynamic range; and the number of scorers used.
Conclusion: Iterative reconstruction can be utilized as a tool to significantly reduce patients' exposure to ionising radiation; however there may be implications for radiologists/cardiologist in the interpretation of these images.

Introduction

The control of coronary artery disease (CAD) requires reliable diagnosis, intervention, and regular follow-up. Each of these may involve some form of radiological investigation.[1] One such investigation is coronary computed tomography angiography (CCTA) as this has the potential to produce high quality diagnostic images of the entire coronary anatomy[2] without the invasiveness and arterial contrast administration of an interventional diagnostic procedure. CCTA is capable of evaluating lesion morphology and disease severity which is important for informing invasive interventions such as percutaneous coronary intervention (PCI).[3] In addition, CCTA may also be used for follow-up investigations such as the evaluation of in-stent stenosis.[4] CCTA is advantageous because it is minimally-invasive, fast, and has few complications.[5] Furthermore, CCTA is accurate in the detection of CAD with a sensitivity of 88–100% and a specificity of 64–92% which is comparable with invasive coronary catheter angiography.[6]

CCTA has an effective dose ranging between 4 and 19 mSv per investigation; this does vary and is dependent upon the patient, the protocol used and manufacturer of the computed tomography (CT) scanner.[7] In patients who are scanned repeatedly throughout the course of their disease, this may increase the risk of developing a potential malignancy, especially when considered against the potential effective dose received from PCI (potentially >50 mSv).[8] Concerns regarding these risks have been raised by the International Commission on Radiation Protection (ICRP),[7] and the International Atomic Energy Agency (IAEA).[9] These concerns are justified due to the radiosensitive tissues, such as the lungs and female breasts, which are included within the CCTA scan field.[10] Understandably, the ICRP are prioritising the development and validation of methods that keep the ionising radiation dose in cardiac CT as low as reasonably achievable (ALARA).[7] Examples of dose-reduction techniques include prospective ECG-triggering[11];

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automated exposure control[12]; and a reduction of the Z-axis length.[13]

The efficiency of these dose reduction techniques can be restricted by filtered back projection (FBP). In FBP the image reconstructions are based upon ideal assumptions and approximations which can leave the acquired data inaccurate and undersampled, particularly when radiation dose is not sufficient. In turn this produces images which are susceptible to noise and streak artefact. Ultimately, when using FBP in clinical practice, radiation dose reduction can only be achieved at the expense of image quality.[14] Iterative reconstruction (IR) differs as it interrogates the acquired CT data iteratively and converges upon the solution which is closest to the real object.[15] Despite being slower and more computationally demanding, IR is suggested to reduce radiation dose without compromising image quality.[16] Research to date has explored the application of IR in chest CT[17] and coronary stent analyses.[18] Both of these studies suggest that IR is able to reduce radiation dose while maintaining diagnostic image quality.

A recent systematic review explored the application of IR across a range of clinical examinations, including CCTA.[19] This review provides a valuable overview of the available research relevant to the application of IR in CCTA. There has been a focus on the ability of IR to improve image quality rather than reduce dose[20,21]; however there have been studies which have shown that CCTA with FBP is already sufficient to diagnose coronary artery stenosis.[2,22] What is now required are focussed systematic reviews which isolate the effect of IR on reducing patient dose in CCTA examinations to achieve the ALARA principle. Therefore the aim of this systematic review is to assess whether IR techniques are able to reduce radiation dose whilst maintaining image quality.

Method

Inclusion and exclusion criteria

Studies meeting the following criteria were included:

- Symptomatic patients (>18 years) with known or suspected coronary artery disease (CAD) undergoing routine CCTA.
- Only those studies which use prospective ECG triggering were included.
- Studies must have used ≥64 slice CT. Those studies which used dual-source CT were also included.
- Assessed outcomes in terms of objective measures of image noise, subjective image quality and $CTDI_{vol.}$
- Studies included were prospective experimental studies which compare CCTA using IR and FBP.
- Peer reviewed publications.

As retrospective ECG gating has been identified as a variable responsible for the increased dose in CCTA[23] it was felt that this could add to the heterogeneity of the studies, and for that reason only prospectively triggered ECG CCTAs were included. Prospective studies were included due to the opportunity for bias in data collection and data analysis that exists within retrospective studies.[24]

Studies that were excluded included those studies that included patient cohorts recruited specifically with BMI's outside of the normal range. Also excluded were studies that focussed solely on reducing the ionising radiation dose on phantoms, as these were not felt to adequately reflect the clinical environment. Studies that included phantoms and human participants were included, although only the data from human participants were extracted from the papers and included in the review.

Search strategy and article selection

A comprehensive literature search was undertaken using the keywords detailed in Table 1 using a PICO methodology.[25] The search terms were developed prior to the searching the databases (*a priori*). MEDLINE, EMBASE, CINAHL, Science-Direct, and Scopus were electronically searched between January 2009 (when the first iterative reconstruction technique was approved by the FDA) and October 2013. Searches were restricted to English language and human participants only.

A hand search was undertaken of the following journals between August and October 2013: Clinical Radiology; Radiology; European Journal of Radiology; European Radiology; International Journal of Cardiovascular Computed Tomography; and JACC: Cardiovascular Imaging. These were searched as they regularly publish studies pertinent to the topic area. The reference lists of all the studies identified were also reviewed for extant literature.

Steps taken to reduce bias

Two independent reviewers were used to ensure that the included studies met the inclusion criteria. Any disagreements resolved by discussion or arbitration by a third reviewer. Conference proceedings, theses, and other forms of grey literature were not searched, leading to the possibility of publication bias within the review.

Methodology quality assessment

Quality assessment was undertaken using a modified McMaster's tool,[26] using two reviewers. The tool was adapted to: challenge the reproducibility of the scanning and reconstruction protocols; identify any affiliation or funding biases; and assess the ethical implications of the study design.

Data extraction

Only studies that were deemed of good quality were included within the review and had data extracted. This was performed by the primary reviewer using a previously developed extraction proforma to extract relevant data. The primary outcomes were the objective measure of image noise; the subjective measure of image quality; and the $CTDI_{vol}$. Other data collected was limited to the variables that could affect these measures. This included study design; participant data; heart rate and medication used; scan protocols; scanner type; and IR technique.

Data analysis

Due to the heterogeneity of the studies a meta-analysis was not possible. Bar charts and tables were produced to show the different outcome measures (i.e. objective image noise, subjective image quality, $CTDI_{vol}$) for the different studies. Inferential statistical data was also extracted from the individual reviews.

Results

Results of the search

A total of 216 papers were identified by the initial search of electronic databases (see Fig. 1). Following the removal of duplicates a total of 164 titles and abstracts were assessed using the *a priori* inclusion/exclusion criteria. Following this process a total of 33 studies were included for full text analysis. Hand searches were performed of relevant journals, which returned no results. Of these