Optimisation of scan and injection protocols to the individual patient in CT angiography

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The image quality of CT scans depends on various factors, i.e. scan parameters, contrast media (CM) parameters, and patient-related parameters. These parameters can be tailored to the individual patient characteristics to ensure a diagnostic intravascular enhancement for every patient. In this thesis, we have investigated several strategies to optimise CM injection protocols by using scan- and patient characteristics and scan timing as input determinants for optimizing iodine delivery rate (IDR) and overall contrast volume. Herein, the main goals were I) to optimise (i.e. reduce CM volume) CM injection protocols and scan timing for patients undergoing CT angiography (CTA) without giving up intravascular attenuation, and II) to create a practical and robust scan- and injection protocol for use in daily clinical practice.

With faster scan acquisitions and increased image quality due to personalised scan and CM injection protocols, radiologists are able to diagnose incidental cardiac findings on regular chest CTs. In this thesis we have examined whether the heart and coronary arteries could be assessed on chest CTs acquired for non-cardiac indications, and consequently the prevalence of incidental cardiac findings on chest CT scans.

In **Chapter 2,** we tested CM injection protocols based on automated tube voltage selection (ATVS) in patients undergoing CTA of the aorta. First, ATVS was used to automatically adjust kV and mAs settings to deliver images at a certain contrast-to-noise ratio (CNR) for a patients' size and tissue density. Adjustment was performed such that optimal image quality was reached with lowest radiation dose. Consequently, the iodine delivery rate (IDR) was adapted to the tube voltage. The optimal IDR for an 80 kV protocol is described previously and was used to calculate the IDR for the other kV settings, by reducing the IDR with 10% for 70 kV and increasing with increments of 10% for 90-120 kV. This optimisation method resulted in a diagnostic image quality in 99% of scans. Furthermore, by using ATVS, the majority of scans could be performed on the lower end of the kV spectrum (70 – 90 kV), resulting in a decrease in radiation dose. We concluded that optimisation of CM injection protocols by adaptation of IDR to ATVS is feasible, and moreover, favourable in light of the 'as low as reasonably achievable' (ALARA) principle; if a patient needs to receive radiation dose, one should keep it as low as possible whilst maintaining diagnostic image quality.

In **Chapter 3**, we used estimated total blood volume and ATVS to optimise the CM injection protocol in cardiac CTA (CCTA). A high pitch protocol or an adaptive sequence protocol were used, dependent on patient heart rate. For each protocol, a fixed scan time was used. A formula was developed to calculate the required IDR for each patient. Adaptation to total blood volume proved feasible; diagnostic attenuation was reached in the 98.2% of scans. Furthermore, we found that CM volumes as low as 20 mL (total iodine load [TIL] of 6 gI) can be used in CCTA scanning with a high pitch protocol without compromising image quality.

Chapter 4 aimed to answer the question whether various complex CM injection protocols used nowadays actually result in relevant differences in CM volumes between each other. We assessed whether these complex protocols outperform less intricate protocols of CM adaptation in terms of contrast enhancement and other image quality parameters (e.g. CNR, subjective image quality). We hypothesise that no differences would exist between these protocols. CM injection protocols were adapted with the same formula used in **chapter 3,** in combination with three patient parameters, i.e. body weight, lean body weight and cardiac output. The formula based on body weight had a significantly higher mean intravascular attenuation compared to the formula based on lean body weight (Δ 20 HU), although no significant difference in TIL and IDR was found. However, it is not clear whether a difference of 20 HU would be relevant in daily clinical practice, as all protocols performed well above the diagnostic threshold (325 HU). Furthermore, no significant differences in overall diagnostic scans (325 – 500 HU) were found between the three different CM injection protocols supporting the hypothesis that all aforementioned methods can be used for optimisation. Optimisation of CM injection protocols by adapting to body weight works equally as well as by adapting to more intricate patient parameters, such as cardiac output.

In **chapter 5**, we assessed new bolus tracking software to automatically calculate patient-specific scan delays in CTA of the chest. This software was compared with a standard, fixed post monitoring delay of 6 seconds. The new software performed equally as well as the control group. The software did not outperform the standard operating procedures of our department; however, it may function appropriately in other, less experienced institutions willing to start with individual adaptation of protocols. The software may lead to a decrease in non-diagnostic scans in this respect.

Chapter 6 outlined the aim and rationale of the "*Cardiac Pathologies in standard thoracic CT imaging trial [CaPaCT]*" study (chapter 7). Due to an increased image quality on newer scanners, as a result of faster scan technique and higher temporal resolution, more cardiac pathologies can be detected on non-ECG gated, non-cardiac chest CTs. The aim of this trial was to assess the prevalence of coronary calcifications on non-ECG gated chest CTs made for non-cardiac indications.

Chapter 7 discussed the results of the CaPaCT trial. The prevalence of CAD on routine non-ECG gated chest CTs was investigated. Furthermore, subjective image quality of chest CTs was assessed in patients with coronary calcifications and a CAD severity score was applied when feasible. Clinically important information on the heart and coronary arteries can be found on chest CTs intended for non-cardiac evaluation. Assessment of coronary calcifications was feasible in all patients, and in more than half of patients, presence of coronary calcifications was reported. This provides insight in the coronary status of the patient. With regard to image quality, in about half of the patients the heart and coronary arteries could be assessed in detail. A CAD-RADS classification (severity of coronary calcifications) was applied to the patients with coronary calcifications and a diagnostic image quality. In 57.4% of these patients, a clinically relevant severity score was applied. The severity scores may help to guide further diagnostics and therapy. These patients would benefit from further cardiac assessment and/or treatment. Cardiac findings should not be neglected any longer on routine chest CT.

Chapter 8, the discussion, focuses on the results of the various studies in relation to the existing literature and discusses directions for future research.