Personalised CT scan protocols for the detection of pulmonary embolism

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Chapter 8

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Issues at hand

On a daily basis, patients present themselves to the hospital with shortness of breath or pain during breathing, all requiring a diagnostic work-up. Some of these patients suffer from blood clots (emboli) in the arteries of the lung (pulmonary arteries), which is a potentially fatal disease and requires urgent diagnosis and treatment.

In order to detect if a patient is suffering from a pulmonary embolism, several blood tests are performed, and physicians can order a computed tomography (CT) scan. Given the vast amount of patients in need of diagnostic testing, a CT of the pulmonary arteries (CTPA) is a widely and commonly used tool. To visualise the pulmonary arteries, iodinated contrast media (CM) is injected intravenously during the CT scan, previously achieved with a one-size-fits-all protocol. All patients -small or large, young or old- were given the same amount of CM and the same CT scan protocol.

This translates into an overuse of CM and radiation in some patients, and insufficient image quality in others. To address these issues, this thesis focused on individualising CTPA scan protocols.

Relevance

The stepwise implementation in this thesis allowed for a careful, evidence-based evolution of CM injections and scanner protocols to suit the individual patient. The use of individualised CM protocols in emergency CTPA led to a significant CM volume reduction compared to a fixed CM protocol while maintaining diagnostic image quality (**Chapter 2**). The combination of these new CM protocols with individualised CT scan protocols led to an even greater reduction of CM volumes together with a low radiation dose (**Chapter 3**). We have created a simple rule of thumb; The 10-to-10 Rule for other clinicians to follow when adjusting their CTPA protocols (**Chapter 4**).

The resulting individualised approach has been rigorously tested (**Chapter 5 & 6**) and has several benefits for patients, hospital administration and society as a whole.

For patients, the implemented protocols mean a significant reduction of the amount of injected CM for the scan. The exact reduction is related to the patient's body weight and body composition, however for an average 80kg male patient the new injection is around 26-30ml (scanned at 70 or 80kV), compared to 90ml before; a reduction of 66%. This reduction is even more significant for lighter weight patients. This reduction means less strain on kidneys and thyroids, which are the organs that may suffer from high amounts of iodine administration.

For the hospital administration or healthcare providers in general, the work in this thesis combined with the work of other colleagues on CM optimisation has led to a significant reduction in the use of CM. This can be translated to a significant reduction in CM costs on an annual basis. On a societal level the appearance of iodinated CM in water systems through hospital waste water and urine excretion is an ecological problem that we are just starting to understand. Iodinated CM are not readily biodegradable, which means it can persist in water systems for an extended period of time. Next to the implementation of new waste-disposal programs and the development of alternative contrast agents, reduction of CM use is paramount. It is the responsibility of radiology departments everywhere to ensure that protocols don't use any more CM than necessary for diagnostic scans. This thesis provides necessary tools by which to do so and the implementation in the MUMC+ has already taken place.

In 2022, Covid-19 related lockdowns resulted in a shortage of iodinated CM. The world-wide shortage affected all radiology departments. The work that was done for this thesis together with that of others in the department provided the necessary insight to translate all CT protocols overnight to a differently concentrated CM, which was more readily available. Also, this shortage was taken as an opportunity to immediately optimise all protocols that hadn't been optimised yet according to the 10-to-10 rule, as discussed in **Chapter 4**.

Apart from the reduction of CM volume, the protocols and studies in this thesis have allowed for lower radiation doses to all patients, with special techniques for scanning pregnant patients. The theoretical cancer risk rises with cumulative radiation exposure over a lifetime, so making sure the patient receives a dose 'as low as reasonably achievable, ALARA' remains an important principle in the world of medical imaging. This thesis delves into the latest scanner techniques and optimises their application specifically for CTPA.

Within the context of this thesis, several universally applicable tips and tricks have been published in international, peer-reviewed journals. **Chapter 3 and 4** resulted in the 10-to-10 rule, which can be applied by radiologists and technicians everywhere instantaneously, to achieve similar radiation dose and CM volume reduction. **Chapter 5** described a simple but effective method of scan length adaptation specifically for pregnant patients undergoing CTPA, which has been shown to reduce ~30 % radiation dose for the mother and ~80 % for the foetus. This method can also be applied instantaneously on any CT scanner.

Ultimately, the investigations within this thesis have enhanced the understanding of the requirements for diagnostic image quality in CTPA. This has been shown in **Chapter 6** to lead to a very high reliability of diagnostic quality, which means very few scans have to be repeated.

All of the articles in this thesis have been presented in oral form or as posters on national and international conferences to aid visibility of the methods and results.