Coronary CT: a retrospective analysis between ECG-gated prospective adaptive sequential acqui-sition and high pitch spiral acquisition on dual source system

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Abstract

Cardiac CT has a key importance in coronary stenosis and anomalies diagnosis, with a high predictive value and a minor or nulled grade of invasivity. Thanks to the new technological advances, development of du-al-source systems and new iterative algorithms, it has been possible to dramatically reduce doses with a good compromise on image quality, allowing not only diagnostic results in the morphological evaluation, but also in the dynamical analysis. The well-known dichotomy between prospective and retrospective triggering, even in their technical evolution, is nowadays facing new techniques, like the relatively new "high pitch mode" and even more complex iterative reconstructions that allow diagnostic results with im-portant dose savings, finally enabling to have a diagnostic scan with an effective dose even less than 1 mSv. In this article, we'll analyze the performance of a dual-source systems in diagnostics, with quantita-tive analysis of radiogenic doses between the prospective adaptive step and shoot technique and the pro-spective high-pitch helical acquisition, known as " Flash mode".

Introduction

Coronary Cardiac-TC - Overview of Acquisition Techniques

The main problem that is faced during a cardiac CT study is due to the intrinsic movement of the heart muscle, which can't obviously be stopped or at least slowed down enough to allow the ac-quisition of images free of movement artifacts [1,4]. To avoid this limitation, manufacturers have opted for different techniques such as synchronization with ECG tracing and partial scan-ning-based reconstructions. Regarding ECG synchronization, the best-known techniques in liter-ature are retrospective triggering and prospective triggering. The first case involves simultaneous recording of the ECG trace and a helicoidal acquisition with a very low pitch; Subsequent recon-structions will occur in the later on, with images corresponding to one or more phases of the heart cycle, i.e. any fraction of the R-R interval. [12]
In prospective triggering, however, sequential acquisitions are performed with a predetermined delay on an interval in R-R, assuming that the heart rate is stable for the entire duration of the acquisition. [12]
Thanks to the advent of dual-source technology, it has been possible to dramatically reduce temporal resolution. The particular geometry of the two tubes fitted with an angular offset of 90 °, gives the chance to obtain the images reconstruction with a reduced rotation time of ¼ (there-fore one heartbeat) and use a pitch> 3 due to the overlapping two spirals, dramatically reducing the radiation dose [8].
Furthermore, the use of systems like the "adaptive gating" (Siemens) also allows to modulate the amplitude of the anodic current at specific intervals and to analyze the ECG trace in real time, avoiding acquisition on ectopic or arrhythmic beats [5,7], leading to an important dose reduction thus making retrospective gating in the coronary evaluation, as an increasingly old-fashioned and less-used technique.

Prospective triggering (adaptive) - Key points

The first advantage of the adaptive perspective gating lies in the chance of limiting the acquisition to a predetermined interval, also enabling to choose a "maximum peak" or "modulated" anodic current [7] and so reduce the nominal mA up to the 20% in a predefined padding chosen on the R-R interval. The adaptive algorithm, furthermore, will limit or interrupt the acquisition where the delay or range set by the operator is present an ectopic or arrhythmic beat which would not make any contribution to the diagnostic image but a dose waste.
The main consequence with these smart algorithms is having a reduction in the doses, the chance to study patients without a stable or non-bradycardic rhythm and sharp images, free from arte-facts common to the spiral acquisitions such as interpolation. In addition, the dose modulation with the padding acquisition gives more data, allowing a better functional analysis.
Regarding the acquisition, for patients with a rhythm of up to 60-65 bpm, a good visualization is generally found in the diastolic phase (65/70% R-R interval). Where the frequency is greater than 65-70 bpm, it is generally advisable to acquire a padding between the late-systolic and diastolic phase (range 40% to 70%) and so performing reconstructions with 5-10% increments; if heart rate is higher than 80 bpm, it is advisable to try an acquisition in systolic phase (range 30 to 45%) rather in the diastolic [11]. The main

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disadvantage of this technique consists of possible artefacts due to patient's movements (or abdominal organs in obese patients), blurring/breathing artefacts (due to the increased time of breath holding during table feed) or synchronization errors with the ECG trace. In order to limit them, it is important to remind the patient to keep as still as possi-ble during the breath-hold.
Some authors tend to prefer a caudo-cranial acquisition (especially in the High pitch mode) thus the right coronary artery is imaged before the p-wave; this suggestion could be considered even if the BMI is particularly high, due to the movement of the abdominal viscera during the table feed.

High pitch mode ("Flash") - Key Points

Through the use of high pitch spiral or "Flash" (Siemens), the two tubes with their particular ge-ometry acquire simultaneously by reducing the rotation needed to obtain diagnostic reconstruc-tions at 90 ° (normally the cardiac-CT is performed in half scan, i.e. with 180 ° tube rotation plus Fan angle). As in prospective gating, the acquisition is synchronized to the diastolic phase of the ECG trace. The method has proved to be particularly reliable even for those patients whose weight could cause step artifact in the step and shoot (sequential triggering method) [14], how-ever, it is important that patients with large body habitus or very tall could be challenging to scan with this technique, since the acquisition window in diastole will become longer and therefore run in the p-wave causing a motion artifact [17].
It is possible to use high pitches as the gap in a spiral will be covered by the contemporary acqui-sition of the second tube with 90° angular offset; this allows to cover the whole heart volume in a single spiral acquisition with significant dose savings, allowing full coverage of the heart muscle with a temporal resolution of 75ms. Given the different acquisition technique, gated high pitch spirals are more susceptible to interpolation artefacts [4], especially for those structures with high atomic weight elements such as stents and calcium plaques (blooming artifact). In order to obtain good quality images, however, it is advisable to use this technique with stable cardiac heart rates <65 bpm, gating the exposure for a diastolic phase acquisition (60-70%) [3,7].
Double Flash technique increases the reliability of the scan, giving by the way a disadvantage in terms of dose. To optimize this protocol, it could be useful to reduce the kVp of one of the spirals to moderate the dose and increase the contrast due to the low k-edge of the iodine. Some inves-tigators suggest moreover to reconstruct the images with 0.75 mm slice width (instead the classic 0.50 mm) to slightly increase the signal to noise ratio. In relation to calcium plaques study, an im-portant application not to be underestimated for the Flash technique is calcium scoring [2]. The reduced dose makes this technique particularly useful for the study of intraluminal plaques, ei-ther as a screening procedure or preliminary index before the angiographic study. In this case, blooming artefacts or blurring caused by the high heart rate could be negligible.

Materials and Methods

In our analysis, we retrospectively analyzed 20 acquisitions on a randomized population of 20 in-dividuals (10 men, 10 women, mean age = 54 SD = 8.8). The population was divided into two groups depending on the technique of study, adaptive perspective or high pitch mode spiral. The two samples are represented by:

- Prospective Adaptive Sequential technique: 10 individuals (7 men, 3 women);
  Average age 54.7 - SD 10.3
  Average weight 85.1 Kg - SD 16.1
- High pitch mode Prospective Spiral technique: 10 individuals (3 men, 7 women);
  Average age of 53.0 - SD 6.97
  Average weight 75.2 Kg - SD 16.1

The scanner used is a Siemens Definition Flash (Siemens Healthineers – Erlangen) - Dual Source (two tubes with offset of 90°) - 128 slices. The investigations were conducted with the infusion of 80 ml of Iomeprol 400 mg/ml and 60 ml of 0.9% sodium chloride, both with a flow of 6 ml/sec. The scanning delay was set with a test bolus done with 10 ml infusion of Iomeprol 400 mg/ml) and 40 ml of sodium chloride 0.9%, flow rate 6 ml/sec.
Dynamic evaluation with seriated slices (1 sec.) was performed with a ROI located in descending aorta. The images were acquired with AEC systems (Care kV and CareDose4D for Siemens) acti-vated. As for the prospective adaptive sequential technique, several padding with and without modulation of mAs was performed. In relation to the high pitch mode spiral technique, a cra-nio-caudal acquisition was performed, followed immediately by a caudal cranial acquisition (Dou-ble flash protocol) in order to compensate for possible artifacts in the first or second set of im-ages. The images were evaluated by two different radiologists with a score from 1 (poor quality images - no diagnostics) to 4 (High quality images - Diagnostics without artifacts).
The Computed Tomography Dose Index (CTDI) and Dose Length Product (DLP) values of the only acquisitions of interest were recorded and the dose estimates in mSv were calculated using a conversion factor of 0.014 (AAPM Report 96). To evaluate the dose, the topograms, the acquisi-tions for the Calcium score evaluation and test bolus scans for the dynamic evaluation of the de-scending aortic opacification time haven't been considered in the calculation.
Beta-blockers to bradycardize the patient (max 50 ml I.V.) and Nitroglycerin (GTN spray) (max 800 mcg - two puffs with spray dispenser) were used whenever possible and not contraindicated. Af-ter the preparation, the protocol provides that with a

steady-state heart rate of <65 bpm, the use of the Flash technique will proceed, otherwise adaptive sequential technique with variable pad-ding depending on the heart rate and the expected degree of arrhythmia will be used. Padding is therefore the result of variability between the condition of the patient and the radiologist who supervised the examination.

Results

The DLP and CTDIvol data show that the average scan length is 16.51 cm (SD = 2.03); note that the planning box for the adaptive perspective sequential technique is modifiable discreetly with minimum steps of about 4 cm. From the quantitative analysis, in term of dose, the results are:

- Prospective adaptive Step and shoot technique

DLP Average – 234.75 mGycm (SD=125.31)
Effective Dose Average – 3.29 mSv (SD=1.75)

- High pitch mode spiral technique

DLP Average – 115.90 mGycm (SD=62.04)
Effective Dose Average -1.62 mSv (SD=0.87)

From the qualitative analysis, the average results are:

- Prospective adaptive Step and shoot technique

3.0 points over 5 (SD=0.66)

- High pitch mode spiral technique

3.7 points over 5 (SD= 0.46)

Discussion

The analysis confirms that High pitch Mode spiral technique is a reliable and cost-effective technique; the iterative reconstructions improve further the image quality. However, as a limita-tion, a standard unique value for the longitudinal extension along the Z axis could not be used for all scans; patients have declared their weight on screening forms, so this value has to be consid-ered just an estimate; Because this is a retrospective study, it should be noted that all the exami-nations were carried out earlier than this article, following the department protocols.

As already mentioned, high pitch mode can be particularly useful in the evaluation of coro-nary plaques (Calcium Score) thanks to the dose savings (<1mSv in a single acquisition).

On the other hand, adaptive sequential technique, although generically more expensive in term of dose, is confirmed as a valuable ally in patients with a non-stable rhythm or with a heart rate> 65 bpm, providing good diagnostic results with doses no greater than 4 mSv and not limiting the analysis in a diastolic phase, but allowing to select a wider window of freedom that can also rely on systolic phases for successive dynamic evaluations.

The dose in high pitch mode spiral could be further reduced by using a single acquisition rather than two; Another chance might be to make the two acquisitions (double flash protocol) with two different kVp, not only to reduce the dose, but to evaluate images with different con-trast due the low k-edge of the iodine.

About the adaptive prospective sequential technique, it is plausible to further optimize the dose using mA modulation, limiting as much as possible the maximum exposure range in the di-astolic phase and reducing the remaining interval with a minimal value of tension, at the cost of having images with a poor SNR. To this end, it is important to have a constant multidisciplinary collaboration between Radiologist, Medical Physicist and Radiographer [16].

In conclusion, the methods highlighted make retrospective protocols an old fashioned tech-nique in non-functional coronary evaluation posing additional new challenges to the dose reduc-tion, despite already being lower than the ranges known in the literature of 9-20 mSv.

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