Diagnostic quality of time-averaged ECG-gated CT data

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ABSTRACT

Purpose: ECG-gated CTA allows visualization of the aneurysm and stentgraft during the different phases of the cardiac cycle, although with a lower SNR per cardiac phase than without ECG gating using the same dose. In our institution, abdominal aortic aneurysm (AAA) is evaluated using non-ECG-gated CTA. Some common CT scanners cannot reconstruct a non-gated volume from ECG-gated acquired data. In order to obtain the same diagnostic image quality, we propose off-line temporal averaging of the ECG-gated data. This process, though straightforward, is fundamentally different from taking a non-gated scan, and its result will certainly differ as well. The purpose of this study is to quantitatively investigate how good off-line averaging approximates a non-gated scan.

Method: Non-gated and ECG-gated CT scans have been performed on a phantom (Catphan 500). Afterwards the phases of the ECG-gated CTA data were averaged to create a third dataset. The three sets are compared with respect to noise properties (NPS) and frequency response (MTF). To study motion artifacts identical scans were acquired on a programmable dynamic phantom.

Results and Conclusions: The experiments show that the spatial frequency content is not affected by the averaging process. The minor differences observed for the noise properties and motion artifacts are in favor of the averaged data. Therefore the averaged ECG-gated phases can be used for diagnosis. This enables the use of ECG-gating for research on stentgrafts in AAA, without impairing clinical patient care.

1. INTRODUCTION

In recent years major advancements are made in computed tomography (CT). Shorter rotation times and the development of multi detector CT (MDCT) enable the technique of ECG gating, often referred to as cardiac CT.[1] ECG gating uses the ECG signal of the patient to divide the raw scan data into bins that correspond to consecutive phases of the heartbeat. The data is reconstructed to a number of volumes, corresponding to the pertinent phase of the heart cycle. This allows 4D visualization of the scanned object and enables investigation to its temporal behavior.[1,2] ECG gating is used extensively in cardio CT, and is increasingly popular for research to aortic abdominal aneurysms (AAA).[3–7] Our research focuses on the possibilities and limitations of ECG-gated CTA for investigating motions in AAA.

In our institution, when patients are recruited for research to stentgraft motion in AAA, the non-ECG-gated scan that the patient normally receives is replaced by an ECG-gated scan. A drawback of ECG gating is that less data is available per volume, which results (as the dose is kept the same for both protocols) in relatively noisy data and artifacts being more common. Hence, for diagnostic purposes, the clinic requires the result of a non-gated scan. Unfortunately, not all scanners are capable of producing a non-gated three dimensional scan in case ECG-gated scanning was used. Scanning patients twice is not an option considering the extra dose this would imply.

We propose to average the data of the phases off-line (i.e. not on the scanners reconstruction computer) to create the 3D dataset required. This is a straightforward process, yet fundamentally different from combining the sinogram data before the filtered backprojection reconstruction (as happens for a non-gated scan). Due to non-linearities in the reconstruction process of the scanner, the results may be similar, but will never be exactly the same.

The purpose of the experiments described in this document is to quantitatively investigate how good off-line averaging approximates a non-gated scan. A positive outcome of our research implies that studies using ECG gating can be performed

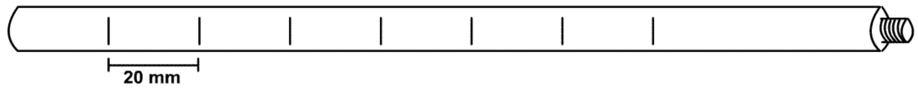

Figure 1 – Diagram of the phantom used for detecting motion. The phantom consists of a perspex cylinder with nitinol wire fragments embedded at 20 mm intervals.

without obstructing patient care, also on scanners that do not support producing regular scan data from an ECG-gated scan. As to our knowledge, this has not yet been investigated.

A comparison is made between three datasets: the non-gated scan, a single phase of the ECG-gated scan, and the averaged phases of the ECG-gated scan. The quality of the different datasets is assessed by comparing noise properties, frequency response, and motion artifacts. Noise properties are best compared based on the Noise Power Spectrum (NPS): it provides a better method for investigating noise properties compared to calculating the standard deviation, because it shows in what frequencies the noise is expressed.[8] Frequency response is compared based on the Modular Transfer Function (MTF). For ECG-gated studies, motion is generally present (or ECG gating would not be necessary). Therefore it is of importance to know the effect of motion artifacts and how they are expressed in an averaged ECG-gated dataset compared to a dataset obtained with a non-gated scan.

2. METHODS

Experiments have been performed using a non-ECG-gated protocol and an ECG-gated protocol. The settings of the first were chosen as similar to the ECG-gated protocol as possible. Both experiments were performed on a Siemens Somaton 64 CT scanner (Siemens Medical Solutions, Erlangen, Germany). A fixed effective mAs of 180 was used at 120 kVp, and with $2 \times 32 \times 0.6$ collimation. The slices had a thickness of 2 mm and were spaced 1 mm apart. For the ECG-gated protocol a rotation time of 0.37 seconds and a pitch of 0.34 were used. For the non-ECG-gated protocol the rotation time and pitch were chosen as close to the ECG-gated protocol as the scanner allowed: 0.5 s and 0.45 respectively.

Data from the ECG-gated protocol was reconstructed to ten cardiac phases. A third dataset was created by averaging the ten phases of the ECG-gated scan, thus producing a three dimensional dataset comparable to the data of the non-gated scan.

To study the noise and frequency response, the Catphan500 phantom (The Phantom Laboratory, Salem, USA) was scanned. From the resulting datasets the Noise Power Spectrum (NPS) and Modular Transfer Function (MTF) were determined. For this purpose automated software developed in-home was used. The NPS was calculated from the uniformity module of the Catphan phantom. The MTF was calculated from the two beads present inside the linepair module. Both the NPS and MTF were calculated via a 2D FFT using a method similar to that described by Boedeker et al.[8]

To study motion artifacts for the different protocols, a device capable of moving in a predetermined pattern was scanned (PC Controlled Phantom Device, QRM, Möhrendorf, Germany). It consists of a motion unit that moves a lever, to which a phantom can be attached. The used phantom (which was developed in-home, see figure 1) consists of a perspex cylinder (length 160 mm, diameter 10 mm) in which pieces of nitinol wire (cut from a stent) are embedded at 20 mm intervals. A standard dose phantom (the CTDI phantom) was used to provide a tissue-like medium and functioned as a guide for the cylindrical phantom. The device was set to produce triangular motions at 60 beats per minute with a (peak-to-peak) amplitude of 3 mm. The setup was such that the motion was lateral (in the x-direction). The resulting motion artifacts were quantified by measuring the full width at half maximum (FWHM) of the nitinol wires as they appear in the scanned data.

3. RESULTS

The NPS signals were determined for the non-gated, single phase, and averaged phases (figure 2). The standard deviation of the three datasets were calculated by taking the square root of the mean of the NPS (table 1). Furthermore, the average of the MTF signals of both beads was determined (figure 3).

In the three volumes resulting from the motion experiment, the slices penetrated by the nitinol wires were selected manually (figure 4), and a profile was selected through the peaks (figure 5). The FWHM of the peaks are shown in table 2.

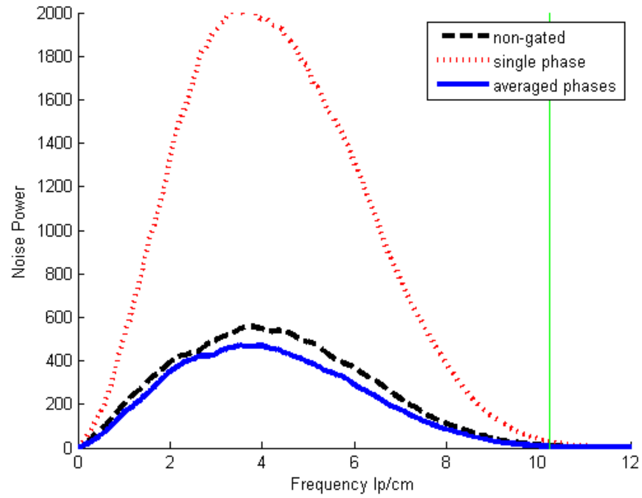

Figure 2 – Illustration of the Noise Power Spectrum (NPS) of each dataset. The straight vertical line indicates the Nyquist frequency.

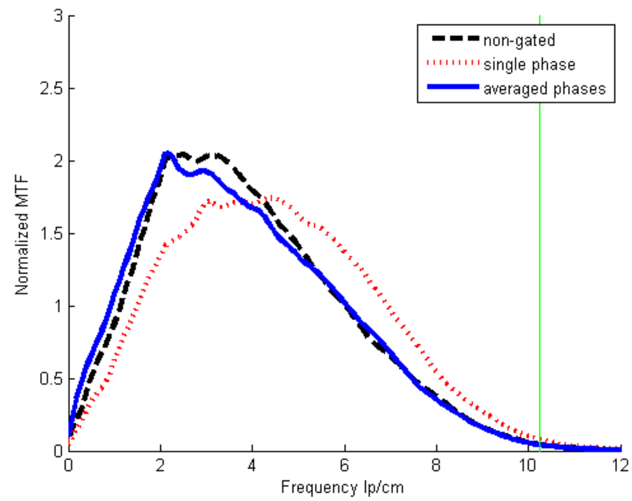

Figure 3 – Illustration of the Modulation Transfer Function (MTF) of each dataset. The straight vertical line indicates the Nyquist frequency.

Method	SD
non-gated	13.6
single phase	26.8
averaged phases	12.5

Table 1 – The standard deviations calculated from the NPS.

Method	FWHM
non-gated	6.6
single phase	4.8
averaged phases	5.9

Table 2 – The average full width at half maximum for the different scans, measured from the wires in the moving phantom.

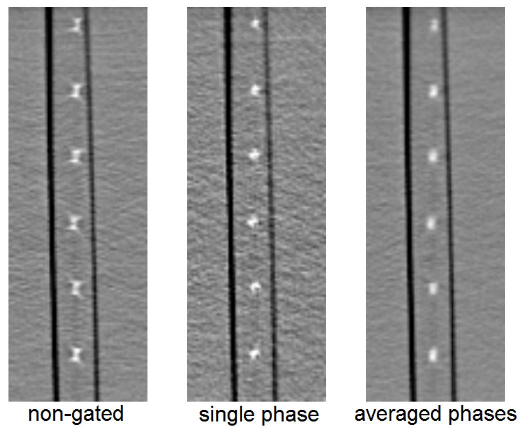

Figure 4 – Illustration of the slices (from the three datasets) containing a moving object.

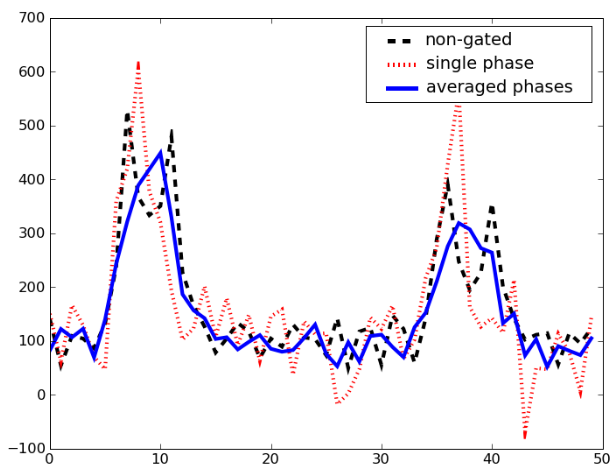

Figure 5 – Profiles through the slices of figure 4.

4. DISCUSSION

The result of the NPS (figure 2) shows that, as expected, for the single ECG-gated phase the noise is high compared to both other measurements. It also shows that averaging the ECG-gated phases leads to a slight reduction in noise, especially for frequencies around 5 line pairs per centimeter. Using a two-sample t-test on measurements from five slices in the uniformity module of the phantom, the standard deviation is indeed found lower ($p<0.0005$). The measured standard deviations show the same relation between the three datasets. The standard deviation of the averaged phases is around 10% lower than the standard deviation of the non-gated scan. As the effective mAs (the tube current divided by the pitch) is equal for both scans, the radiation dose is equal as well. The precise reason for the reduced noise is unknown, but probably can be found in the way that data is combined (averaged) in the reconstruction of a non-gated scan.

The approach for measuring the MTF from the beads differs from Boedekers[8] in the normalization step. When the value at 0 lp/cm is used to normalize, the normalization proofed not to be consistent, and comparison of the three methods not reliable. To solve this problem, we have chosen to normalize by the mean of the MTF, taking into account all frequencies below the Nyquist frequency. The motivation is that an MTF can only show the relative power for each frequency. In our approach the integral over all frequencies (up to the Nyquist frequency) is one.

The results of the MTF (see figure 3) show that the MTF of the single phase differs from that of a non-gated scan. The MTF of the averaged phases is similar to the non-gated dataset, which suggests that the temporal averaging did not have any negative effects on the spatial frequencies of the data.

From the partial slices in figure 4 and the profiles in figure 5 it can be seen that for the single phase the peaks are more narrow because the data acquisition time is lower compared to both other datasets. Due to the motion blur that occurs when multiple phases are averaged in which the object is present at slightly different locations, the profile for the averaged phases is wider. For the non-gated scan, however, the data is “combined” before the reconstruction and thus leads to a different kind of artifact, as can be seen from its profile. From the measured FWHM values (the averages are shown in table 2), it follows that the artifacts of the averaged phases are smaller compared to the non-gated dataset ($p<0.001$).

In these experiments the pitch and rotation time of the non-gated scan could not be set the same as the ECG-gated protocol. While the effective mAs, and therefore the dose, are the same, different results may be found when different scanner settings are used. Larger differences in the results are probably found on different scanner types as their internal reconstruction algorithms will differ.

We can conclude that—on our scanner—the proposed method is better than taking a normal CT-scan. However, we suspect the method is not feasible to replace a normal CT-scan; while the proposed method can be applied in a matter of seconds, reconstructing the data and sending it to a dicom node will take ten times as long (in the case of ten phases). Additionally, the patients ECG must be measured during the scan, and the patient has to hold his/her breath longer. Our result does show, however, that the current reconstruction techniques for non-gated CT are not optimal.

5. CONCLUSIONS

The temporal averaging of ECG-gated CTA data does not have negative effects on image quality in terms of noise, frequency response and motion artifacts. The minor differences observed for the noise properties and motion artifacts are in favor of the averaged data. Therefore the averaged ECG-gated phases can be used for diagnosis. This enables the use of ECG-gating for research on stentgrafts in abdominal aortic aneurysms, without impairing clinical patient care.

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