4D CT protocol optimisation on the Philips Big Bore: Practical experience and pitfalls

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CT Optimisation
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Hull and East Yorkshire Hospitals NHS Trust
Overview

• Introduction
  – What is wrong with 3DCT for ‘chest planning’ scans
  – So what does 4DCT give us?
  – How do we use the 4DCT dataset?

• The Philips Big Bore with Varian RPM
  – The default acquisition protocol
  – The test phantoms

• Identifying the problems…
  – 4DCT and ring artefacts

• How do we optimise 4DCT scans?
  – How do 4DCT scans compare with 3DCT?
  – Potential optimisation strategies – mAs reduction and pitch optimisation

• Conclusions
Introduction

When three dimensions just aren’t enough…
What is wrong with 3DCT for ‘chest planning’ scans?

• In RT, chest planning CT scans are performed with the patient free-breathing
  – Since the treatment can be quite long, breath-hold techniques are generally not used

• The potential problems with the 3D image dataset are:
  – What part of the breathing cycle you have captured?
  – Are any distortions due to the direction of motion relative to the scan direction?

3DCT scans of a 2 cm ‘tumour’ with peak-to-peak amplitude of 2 cm at 20 & 10 bpm
So what does 4DCT give us?

- Retrospective 4DCT allows reconstruction of a number of breathing phases that demonstrate the motion of the tumour and surrounding tissue.
- The tumour can then be outlined on individual phases to define Clinical Target Volumes (CTVs).
- These are combined to give the Internal Target Volume (ITV), which is expanded due to the (reduced) uncertainties in treatment delivery to create the Planning Target Volume (PTV).

4DCT of a 2 cm ‘tumour’ with peak-to-peak amplitude of 2 cm at 20 bpm.
How do we use the 4DCT dataset?

- After acquisition of the 4DCT dataset, we get:
  - An **UnTagged Reconstruction** – this is essentially the standard (blurred) 3DCT reconstruction using all of the acquired data
  - **10 individual phase image sets** that correspond to equally spaced breathing points (0%, 10%,..., 90%). The temporal resolution of each phase is fixed, and given to be about 0.33 s for a 0.5 s rotation time on the Philips Big Bore (independent of patient breathing rate)
  - A **Maximum Intensity Projection (MIP)** constructed from the phase data (to assist with *contouring*)
  - An **Average Intensity Projection (AvIP)** constructed from the phase data. *This data is used to generate the final treatment plan.* Provided all 10 phases are used, this is equivalent to the UnTagged Recon (but this may not be the case if the RT treatment is to be gated)
UnTagged Reconstruction

Phase data x 10

AvIP

MIP
The Philips Big Bore with Varian RPM

When two manufacturers collide…
At Castle Hill Hospital, we have two 16 slice Philips Big Bore scanners for acquiring RT planning data.

Our version of the software only allows phase reconstruction. Amplitude reconstruction is only possible on the latest version.

For 4DCT acquisition, the Varian RPM system is used to acquire a breathing trace. Philips can provide an integrated bellows system.

The resulting trace is used as a surrogate for internal motion of the tumour.
The default acquisition protocol

- Philips provide a single protocol for 4DCT, and a lookup table of pitch factors for different breathing rates
  - New scanners recommend much lower pitch factors
- mAs/slice is effective mAs i.e. mAs per tube rotation, divided by the pitch
  - Hence tube mA is very low
- A 120 s time limit for scans restricts maximum scan length

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Thickness (mm)</td>
<td>3</td>
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<tr>
<td>kV</td>
<td>120</td>
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<tr>
<td>mAs/slice</td>
<td>400</td>
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<tr>
<td>Resolution</td>
<td>Standard</td>
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<td>Collimation (mm)</td>
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<tr>
<td>Rotation time (s)</td>
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<td>FOV (mm)</td>
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<tr>
<td>Filter</td>
<td>Standard (B)</td>
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<td>Matrix</td>
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</tr>
<tr>
<td>CTDI_{vol} (mGy)</td>
<td>21.1</td>
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</table>
The default acquisition protocol

<table>
<thead>
<tr>
<th>Breathing rate (bpm)</th>
<th>Pitch (0.5 s rotation)</th>
<th>Maximum scan length (cm)</th>
<th>Tube current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.150</td>
<td>83</td>
<td>120</td>
</tr>
<tr>
<td>15</td>
<td>0.110</td>
<td>60</td>
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<td>84</td>
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<td>13</td>
<td>0.090</td>
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<td>12</td>
<td>0.090</td>
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<td>11</td>
<td>0.080</td>
<td>43</td>
<td>64</td>
</tr>
<tr>
<td>10</td>
<td>0.075</td>
<td>40</td>
<td>60</td>
</tr>
</tbody>
</table>

Note, the latest Philips software recommends even lower pitch factors, and hence offers shorter maximum scan lengths and lower mA.
Test phantoms for 4DCT optimisation

LTO QUATTRO phantom (prototype)  LTO CT AEC
Identifying the problems...

And there are a few...
What are the problems?

- Following Apps training, the main concerns were:
  - Why only a single mAs/slice value for all patients, no matter how large or small?
  - What happens if you implement the AEC?
  - Are there any dose/image quality concerns when comparing ‘slow’ and ‘fast’ breathers?
  - What do you do with patients who fall outside the range given in the table?
  - Can the pitch factors be extended lower?

- It soon became clear that ring artefacts are potentially a significant problem in *clinical* datasets!
Ring artefacts in 4DCT

- Pitch is a significant factor in the appearance of rings in the reconstructed images.
- Half pitch = half mA = half the signal per projection
  - Note, overall dose to the patient is the same.
  - Electronic noise starts to become an issue for low pitch images (slow breathers), and hence ring artefacts!
Ring artefacts in 4DCT

- More obvious on larger patients using the standard protocol
- Any new protocol(s) needs to ensure the dose is **high enough** for the given patient size and breathing rate to avoid ring artefacts!

Standard chest(ish)  →  Large abdomen(ish)

Pitch = 0.075
How do we optimise 4DCT scans?

Or at least, what’s the plan in Hull…

Disclaimer: The following has not yet been implemented clinically and so the resulting image quality on real patients has not yet been evaluated
The starting point…

• Up to now, all chest planning scans have been performed with a 3D fast helical CT scan using AEC to determine the required exposure factors (mAs per slice)
  – Typically, this gives 170-190 mAs per slice through the shoulders, and about 75-100 mAs per slice through the lungs
  – Previous to this, all chest scanning was done with a fixed mAs of 200 mAs per slice throughout the imaging volume

• Image quality is appropriate for the task of contouring and generating treatment plans

• Hence, provided other technical factors do not cause any problems (e.g. rings), there should be no need to get images that are of better quality than this for 4DCT
  – With a default exposure factor of 400 mAs per slice, this didn’t seem likely!
So how do 4DCT and 3DCT compare?
Noise in 3D planning scans

- 3D 10 bpm AEC (75 mAs)
- 3D 10 bpm 395 mAs
- 3D 20 bpm AEC (75 mAs)
- 3D 20 bpm 395 mAs
- 3D 20 bpm 200 mAs
3DCT vs 4DCT: Image noise

- **3D AEC**
  - 3D 20 bpm AEC (75 mAs)
  - 3D 20 bpm 200 mAs

- **4D AvIP**
  - 4D 10 bpm AvIP
  - 4D 20 bpm Phases

- **3D 200 mAs + 4D Phases**

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**Graph**

- X-axis: Slice number
- Y-axis: Standard deviation (HU)

Legend:
- • 3D 20 bpm AEC (75 mAs)
- ■ 3D 20 bpm 200 mAs
- ▲ 4D 10 bpm AvIP
- □ 4D 10 bpm Phases
- ● 4D 20 bpm AvIP
- + 4D 20 bpm Phases

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Can we reduce our doses?
Dose reduction in 4DCT

- 3D AEC + 4D Phases
- 3D 200 mAs + 4D AvIP

- 3D 20 bpm AEC (75 mAs)
- 3D 20 bpm 200 mAs
- 4D 10 bpm 200 mAs AvIP
- 4D 10 bpm 200 mAs Phases
- 4D 20 bpm 200 mAs AvIP
- 4D 20 bpm 200 mAs Phases
Dose reduction in 4DCT

- Halving the mAs per slice results in:
  - Individual phases ≡ 3D AEC protocol
  - The AvIP/UnTagged ≡ old clinical (200 mAs per slice) protocol

- What about artefacts?

20 bpm

10 bpm
And then there’s pitch...
The effect of pitch

• Do we need individual pitch factors for each breathing rate?
  – Very small difference in travel per rotation for 10 bpm vs. 13 bpm (~0.25 mm)
  – **Patients breathing rate may vary throughout the scan** – if the patient breaths more slowly during acquisition, may get artefacts in final images

• The new Philips white paper recommends lower pitch values than those in the manual for our system
  – 0.09 for 20 bpm, to 0.04 for 10 bpm (note, max. coverage only 23 cm)
  – **Latest advice from Apps is to use the min. pitch that gives the required anatomical coverage**

• So what happens if we use 0.075 (10 bpm) for everyone?
  – Note, would rather not go lower than this due to limited scan length
20 bpm, pitch = 0.150 (from manual)

20 bpm, pitch = 0.075 (minimum to give acceptable coverage)

10 bpm, pitch = 0.075 (from manual)
But what about image noise?

<table>
<thead>
<tr>
<th>Slice number</th>
<th>Standard deviation (HU)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 bpm 200 mAs pitch</td>
</tr>
<tr>
<td></td>
<td>0.075 UnTagged</td>
</tr>
<tr>
<td></td>
<td>20 bpm 200 mAs pitch</td>
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<tr>
<td></td>
<td>0.075 AvIP</td>
</tr>
<tr>
<td></td>
<td>20 bpm 200 mAs pitch</td>
</tr>
<tr>
<td></td>
<td>0.075 Phases</td>
</tr>
</tbody>
</table>

Very high noise phases!

AvIP > UnTagged
How do our options compare?

Noise in phase images increases significantly – double the noise for 10 bpm at same mAs and pitch!

- 10 bpm 200 mAs Pitch 0.075 AvIP
- 10 bpm 200 mAs Pitch 0.075 Phases
- 20 bpm 200 mAs Pitch 0.15 AvIP
- 20 bpm 200 mAs Pitch 0.15 Phases
- 20 bpm 200 mAs pitch 0.075 AvIP
- 20 bpm 200 mAs pitch 0.075 Phases
What next?

• We need to establish why the image noise jumps so significantly when the pitch is reduced for 20 bpm
  – Will need to discuss this with Philips

• In the meantime we are going to try and **setup the AEC** to compensate for patient size, based on lower mAs per slice on standard patient
  – Needs to be done very carefully due to the way DoseRight ACS works
  – Can’t use Z-DOM, so makes it a lot harder due to the shoulders being in the scan volume

• When implementing into clinical practice, will probably go for a gradual dose reduction approach
  – Start with 300-350 mAs per slice + AEC?
Conclusions

• 4DCT scans are a unique challenge when it comes to optimisation!
  – Using the manufacturers default protocol, patient dose is relatively high to start with, and there is no compensation for patient size (which can result in significant artefacts)
  – If doses are reduced too much, significant ring artefacts can become a problem
  – If the pitch factor is too small, ring artefacts may be seen in clinical images (extremely slow breathers <10 bpm)

• Need to consider pitch, mAs per slice, patient size (i.e. AEC) and breathing rate when optimising 4DCT protocols
  – Automatic exposure control is (hopefully) the final piece of the jigsaw!
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Any questions?

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