Comparison of volume and motion definition in helical CT, 4DCT and MR imaging in upper gastrointestinal radiotherapy

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Background

Respiratory motion during radiation can be significant, especially for upper gastro-intestinal (GI) malignancies and could lead to geometrical miss and treatment failure. Accurate volume definition in the presence of motion is therefore a crucial step in the RT planning process. This can be particularly challenging in e.g. liver or pancreatic cancers where a contrast agent is needed to visualise the tumour. This limits the benefits of 4DCT or other time-dependent imaging modalities.

Furthermore, as deformable registration might be needed to assess GI motion, it should be verified that the registration technique conserves mass. Time-correlated imaging could provide additional information in this matter especially in a dual-input organ such as the liver.

Objectives

The aim of this study is therefore to compare current CT and MR scanning techniques for:

- Target **volume definition**
- Quantification of **intra-fraction motion** of both abdominal tumours and organs at risk (OAR).
- Quantification of cranio-caudal (CC) motion of the diaphragm on different image modalities
- **Tissue density** through stability of Hounsfield unit (HU) measurements of X-ray attenuation.

Methods

Patients, receiving radiotherapy for liver, pancreas and gastro-oesophageal malignancies that were part of a research ethics-board approved protocol underwent different planning scans in this order:

- Contrast-enhanced exhale breath-hold CT
- 4D CT: Inhale, Exhale, AIP and MIP
- Cine-MRI [1] (repeated after 1 week)
- Inhale, exhale breath-hold T1 & T2 MRI
- Fluoroscopy

Volumes of interest were tumour (if able to identify), liver, kidneys, pancreas, gastro-oesophageal junction and spleen. The volume, centre of mass (COM), diaphragm motion and average HU were calculated for each volume on all possible modalities.

Results

A total of 4 patients with liver metastases were analysed. GTV mobility could not be accurately assessed on 4DCT due to the finite slice thickness (2.5 mm) and the lack of soft tissue contrast despite some occasional contrast agent residue from the breath-hold scan. The motion was therefore assessed on cine-MRI as shown in Table 1. The Sup-Inf variation of the liver COM between inhale and exhale [r: 0.4 - 5mm] did not correlate well with the motion of the diaphragm seen during cine-MR. This is also due to liver deformation as seen in Figure 1.

	Diaphragm excursion (mm)			MRI GTV motion (mm)		
	4DCT	MRI	Fluoro	CC	AP	LR
Pt 1- Week 1	10	13	12	7	7	3
Pt 1- Week 2	-	14	-	7	7	3
Pt 2- Week 1	4	20	18	14	7	4
Pt 2- Week 3	-	18	-	13	7	4
Pt 3- Week 1		20	10	12	6	4
Pt 3- Week 2	-	18	-	10	6	4
Pt 4- Week 1	24	35	32	26	4	3
Pt 4- Week 2	-	19	-	15	5	3
Mean	**12.5**	**19.6**	**18.0**	**13.0**	**6.1**	**3.5**
SD	8.4	6.7	9.9	6.0	1.1	0.5

Table 1. Overview of GTV and diaphragm mobility.

Organ Volume (cc)	Inhale (4D)	Exhale (4D)	MIP	AIP	Contrast BHe	Mean	SD (%)
Liver	1383.7	1465.7	1467.0	1362.5	1578.0	1451.4	5.9
L KIDNEY	151.0	162.8	167.4	160.3	136.0	155.5	8.0
R KIDNEY	143.5	149.0	145.5	136.4	136.1	142.1	4.0
SPLEEN	106.9	111.3	117.3	98.9	201.6	127.2	33.1
PANCREAS	5.4	5.9	6.4	5.1	15.1	7.6	55.5

Table 2. Average organ volume for different CT scan types.

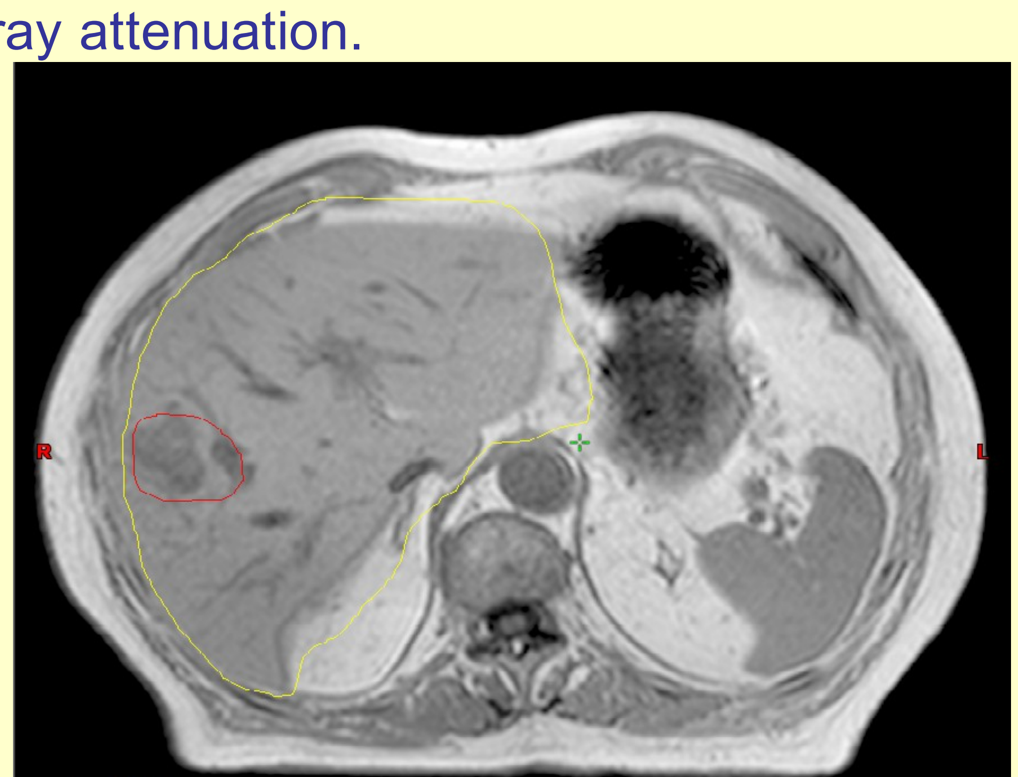

Fig 1. Liver and GTV contour from contrast CT overlaid on MRI.

The mean organ volume over the different patients is shown in Table 2. The MR volumes were not complete due to the limited range covered within the time that the patients could hold their breath.
The change in mass between inhale and exhale was generally within 5%. In the normal liver the MIP / AIP mass could differ up to 13% / 30%.

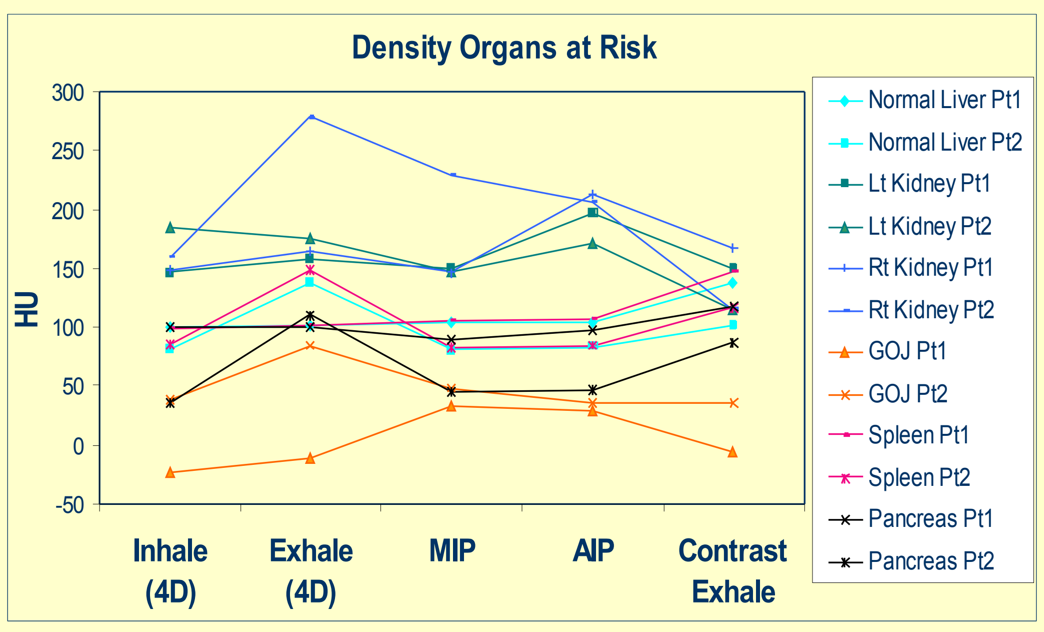

Fig 2. HU for different organs at risk for two patients.

Conclusions

- The use of **4DCT alone** is **not** seen to be **adequate for assessing** organ **motion**, particularly when imaging liver tumours without contrast agent.
- Cine-MR and fluoroscopy of the diaphragm were in good agreement and indicate the possible superiority of using fast MRI to assess tumour motion although still subject to breathing reproducibility.
- Free-breathing CT or of a single phase of the CT could give rise to inaccurate volume definition as well as the use of intensity modifying tools (MIP, AIP).
- A dedicated **breath-hold contrast enhanced CT** will give a **more precise volume** for the tumour and OAR.
- Differences in HU due to the use of a contrast agent are unlikely to affect dose calculations. **Differences in liver mass are visible between inhale and exhale** but more data is needed to establish its origins.

References

1. "Free breathing liver gated radiotherapy with external markers using MRI derived models of hepatic motion", 2007, Coolens C., M White, D Hawkes, D Atkinson, L Charles-Edwards, D Tait, M Hawkins, *Proceedings XVth ICCR*, p496.

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