Changes in Respiratory-induced Motion Patterns of Primary Liver Tumors using an Abdominal Compression Device
Objective

- Comparison of tumor motion suppression afforded by an abdominal compression plate added to a whole-body immobilization system (BodyFix) in patients undergoing respiratory-correlated computed tomography (4DCT) simulation for stereotactic body radiation therapy (SBRT) of hepatocellular carcinoma (HCC).
Primary Liver Cancer

• SBRT has become fairly established, characterized by
  – Highly conformal rapid fall-off ablative dose distributions
  – Few (1 to 5) fractions
  – Potent non-invasive physically-targeted therapy for primary and metastatic liver cancers with demonstrably high local control rates and acceptable toxicity
SBRT Challenges

• Breathing-induced residual excursions
  – Up to 38 mm
Solutions

- Conventionally
  - CTV to PTV

- However, the requirement of increasing PTV margins for SBRT may be undesirable due to involvement of potent doses with consequential greater risk of toxicity to increased volume of normal tissue...
Solutions

- At our institution
  - Medical intelligence BodyFix system with or without Abdominal compression
BodyFix System

- Double vacuum system for patient immobilization and breathing motion suppression
Abdominal Compression

- Restriction of diaphragmatic motion by application of abdominal compression force
Methods

• 27 HCC patients with 30 lesions
• All patients had previously undergone Ethiodol-based transarterial chemoembolization (TACE)  
  – A radio-opaque stain of the HCC.
• Automatically delineated using a threshold based segmentation routine on all 10 respiratory phases of the respective 4DCT data sets.
• The range of tumor motion, GTV volumes in all 10 4DCT phases, and resulting ITV volumes were compared.
Methods

- The mean/median age was 63/60 years
  - Range: 52–87 years
- All 27 patients underwent 4DCT with followed by without abdominal compression at least once
  - Mean/median (range) vacuum pressure applied for the BodyFix system was 70/70 mBar (70–80 mBar)
  - Mean/median (range) screw reading for abdominal compression was 97/89 cm (50–156 cm).
Methods: Motion-induced Artifacts
Methods

Messy TACE = Bad Case

Clean TACE = Good Case
Methods

Before

After
Methods
Results

- Motion was predominant in the cranio-caudal direction with or without abdominal compression
  - 27 out of 30 cases showed CC motion excursions significantly larger than LR or AP motion
    - p<0.001
• Motion patterns were patient-specific and generally approximated a plane in 50% of the cases.
Results

- In all but 5 cases, tumor motion trajectory was altered considerably with/without abdominal.
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Results

• While motion was predominant in the cranio-caudal direction with or without abdominal compression
  – Significant motion amplitude suppression was observed with abdominal compression
    • $6.9\pm3.1$ mm (0.9–16.2 mm) vs.
    • $8.8\pm3.6$ mm (2.4–16.6 mm)
      – $p=0.002$
Results

- Similarly, overall motion amplitude was significantly smaller with abdominal compression
  - $7.8 \pm 3.6$ mm ($1.8–17.9$ mm) vs.
  - $10.3 \pm 4.9$ mm ($2.6–24.8$ mm)
  - $p=0.001$
Results

• Nevertheless, overall motion amplitude, like cranio-caudal motion excursion, as well as its suppression, was apparently patient-specific and non-site-specific.
Overall Motion Amplitude Difference [%]

Patient ID
Results

- Furthermore, 5 out of 30 lesions (16.7%) showed paradoxical increase in overall/cranio-caudal motion excursion with abdominal compression
  - Overall Motion: 2.5±1.5 mm (0.4–4.6 mm)
  - Cranio-caudal Motion: 2.3±1.3 mm (0.5–3.9 mm).
In Summary: Motion in any Direction

- **With Abdominal Compression**
  - 20 out of 30 lesions (66.7%), ≥5 mm
  - 4 out of 30 (13.3%), ≥10 mm

- **Without Abdominal Compression**
  - 26 out of 30 lesions (86.7%), ≥5 mm
  - 11 out of 30 (36.7%), ≥10 mm
In Summary

• As expected, motion amplitude was least in the medio-lateral direction.

• Furthermore, no meaningful laterally motion amplitude suppression was observed with abdominal compression:
  – 1.8±1.6 mm (0.3–6.3 mm) vs.
  – 2.2±2.1 mm (0.4–8.7 mm)
    • p=0.274.
In Summary

- Nonetheless, on at least one case, motion in the medio-lateral direction exceeded that in the antero-posterior and cranio-caudal directions without abdominal compression, although not with abdominal compression.
In Summary

• As expected, there was no significant difference between corresponding GTVs with and without abdominal compression
  – All p>0.072
  – post-hoc pair-wise comparison showed no meaningful difference amongst GTVs different 4DCT phase datasets.
In Summary

• On the other hand, significant ITV reduction was observed with abdominal compression by on average
  – 17.0±13.2% (range: 1.3%–44.7%, p<0.001)
  • 24 out of 30 cases.
In Summary

- In direct correspondence with overall motion amplitude, a significant paradoxical increase in ITV was observed with abdominal compression in 5 out of 30 tumors
  - $13.7 \pm 11.3\%$ (range: $1.6\%–30.4\%$, $p=0.042$)
In Summary

• Finally, a significant, albeit weak, linear relationship was observed between the overall reduction of motion amplitude and its corresponding reduction in target motion envelop with abdominal compression:
  – $r=0.604$
  • $p<0.001$
Limitations

• No comparison between fluoroscopic and 4DCT analysis was performed in the current study
  – Data should be interpreted with caution
Conclusions

- Addition of abdominal compression to the BodyFix system resulted in smaller overall, cranio-caudal, and antero-posterior motion amplitude, as well as ITV reduction in the majority of patients.
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- Addition of abdominal compression to the BodyFix system resulted in smaller overall, cranio-caudal, and antero-posterior motion amplitude, as well as ITV reduction in the majority of patients.

- The induction of a paradox effect is a possibility in up to 16.7% of cases, and should prompt systematic evaluation on an individual basis.
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