# Impact of various motion state identification methods on simulated 4D dose distributions in scanned ion beam therapy.

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## Introduction

External (surrogate) motion monitoring data, e.g., from a pressure sensor in a waist belt, are commonly used to facilitate image reconstruction of time-resolved computed tomography (4DCT)[1]. In the GSI 4D treatment planning system, TRiP4D, these data are required for 4D simulation of dose delivery to mobile tumors with scanned ion beams[2]. For each delivered raster point the surrogate signal is correlated to the respective phase of the 4DCT. Motion state identification (ID) can, e.g., be based on the relative signal amplitude, the time between successive breathing cycles or the signal phase[2]. In this work, we assess the impact of these methods on the 4D dose distribution for irregular and regular breathing trajectories.

## Materials and Methods

We performed 4D dose simulations for one patient using four measured breathing trajectories (pressure sensor). One regular $\cos^2$ motion acc. Lujan et al.[3] with a 3.6 s breathing period was also included. Relative amplitude-based (RB), time-based (TB) and phase-based (PB) motion state ID was performed for each trajectory. The signals were pre-processed with in-house software to obtain the relative amplitude, time and signal phase for each breathing cycle. The derived signals featured a fixed amplitude range (e.g. 0 % to 100 %) per cycle. State ID in TRiP4D was based on the pre-processed trajectories using 14 equally distributed motion states over the amplitude range. Irradiation timing was simulated for typical beam pauses and spill lengths used at the Heidelberg Ion Therapy Center. The resulting 15 dose distributions were assessed with respect to dose coverage ($V_{95}$), over dose ($V_{107}$) and dose homogeneity ($HI = D_5 - D_{95}$). $V_X$ denotes the target volume fraction receiving at least $X$ % of the planned dose, $D_X$ is the dose covering $X$ % of the target volume.

## Results

Table 1 lists the resulting $V_{95}$, $V_{107}$ and HI values for the different trajectories and state ID methods. $V_{107}$ and HI in all cases are larger for the RB method (less than 5 % and 3 %, respectively). While for the Lujan trajectory $V_{95}$ values are similar for all state ID methods, differences of up to 9 % occur for the irregular trajectories, e.g., for fraction 3. Variability of all parameters between different breathing trajectories due to modulated interplay patterns was also observed, as expected.

| trajectory | method | $V_{95}$[%] | $V_{107}$[%] | HI[%] |
|---|---|---|---|---|
| fraction 1 | RB | 92.7 | 11.9 | 15.1 |
| | TB | 93.9 | 8.7 | 13.7 |
| | PB | 94.1 | 9.4 | 13.6 |
| fraction 2 | RB | 88.6 | 2.5 | 12.4 |
| | TB | 93.1 | 2.3 | 11.6 |
| | PB | 89.1 | 1.3 | 11.4 |
| fraction 3 | RB | 80.3 | 10.5 | 17.2 |
| | TB | 86.2 | 5.7 | 14.3 |
| | PB | 89.3 | 8.0 | 14.9 |
| fraction 4 | RB | 92.1 | 11.5 | 15.2 |
| | TB | 88.8 | 6.5 | 14.3 |
| | PB | 92.7 | 9.6 | 14.3 |
| Lujan | RB | 92.3 | 10.1 | 14.7 |
| | TB | 93.7 | 5.3 | 12.6 |
| | PB | 92.9 | 6.3 | 13.1 |

Table 1: $V_{95}$, $V_{107}$ and HI values for the 4D simulations using different motion trajectories and state ID methods.

## Discussion

In this study the employed state ID methods had a non-negligible impact on the simulated 4D dose distribution, especially for irregular motion trajectories. For the RB method, frequency distributions of the motion state per raster point featured pronounced maxima around the extrema of the motion trajectory. This is a likely cause for the dosimetric differences observed in this case w.r.t to the TB and PB methods, especially in $V_{107}$. It can be assumed that the employed state ID method should ideally match the one used during 4DCT reconstruction. However, these methods are vendor-specific and can be difficult to access.

## Conclusion

The selected motion state ID method in 4D treatment simulations for scanned beam delivery can have a non-negligible impact on the simulated 4D dose distributions.

## References

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