# Evaluation of the relationship between respiratory hepatic and renal motion using real-time MRI

**A. Tipirneni[1,2], R. Song[1], R. B. Loeffler[1], and C. M. Hillenbrand[1]**

[1]Radiological Sciences, St Jude Children's Research Hospital, Memphis, TN, United States, [2]Biomedical Engineering, University of Memphis, Memphis, TN, United States

**Introduction:** Free-breathing, navigator gated MRI techniques are used to suppress image artifacts induced by physiological motion. Navigator methods monitor the position of the diaphragm (i.e., lung-liver interface) and trigger the data acquisition only when the interface falls within a user-defined window in the expiratory phase. For navigated slice tracking of a specific organ, an appropriate tracking factor (TF) describing the motion of the organ with respect to the superior-inferior (SI) diaphragm movement needs to be applied [1]. A priori information about TF may improve the image quality, increase the window size, and reduce the total scan time. However, the effectiveness of slice tracking can be degraded due to erroneous TF estimation [1]. It was also reported that although the respiratory motion is dominant in SI direction for liver and diaphragm, it is more complex for the kidneys [2]. Purpose of this study is to estimate the TFs describing the kidney motion in 3 directions [superior-inferior (SI), anterior-posterior (AP), and medial-lateral (ML)] with respect to the SI liver/diaphragm motion for use in MR-navigator sequences.

**Method:** Organ motion was studied in 8 healthy volunteers (20-28 yrs) on a 1.5T MRI scanner (Siemens, Avanto). After informed consent was obtained, the subjects were examined with a trueFISP sequence (TR 3.6 ms, TE 1.8 ms, α 70°, FOV 400mm, matrix $128^2$, slice thickness 7mm). For each subject, ~200 consecutive coronal and sagittal images were acquired at intervals of 470ms under free breathing. This allows tracking of the respiratory cycle with ~6-7 data points per period. The motion path of the liver was tracked in SI direction and both kidneys were tracked in SI, AP, and ML direction by using anatomical landmarks of the organs. In order to quantify the motion, an accurate, repeatable, and user-friendly process was developed utilizing the acquired dynamic MR data sets and a graphical user interface (GUI) written in Matlab. In this study, sagittal slices were used to measure motion along SI & AP directions, whereas coronal slices were used to measure along the ML direction. 3D TFs for each kidney were calculated in relation to the liver SI motion for whole, ±5mm and ±4mm window widths (corresponding to slice-tracking navigator gating window) using a linear least squares (LLS) fitting method.

**Results:** Table 1 summarizes the estimated TFs and mean maximal displacements for different window widths during free breathing obtained from our 8 volunteers. The mean TFs in SI direction (8 subjects), AP & ML directions (4 subjects) were 0.69±0.13, 0.27±0.11 and 0.19±0.09, respectively, for the whole window. Within the same window TF did not vary much between the individuals except for two subjects (V2, V6) in SI and one (V4) in AP direction. For each volunteer, the measured TFs were very similar in SI direction for different windows. However, there was a slight variation in AP & ML directions. For all volunteers, the LLS fitting method produced correlation coefficients ($R^2$) in the range of 0.84 to 0.98 (SI), and 0.7 to 0.91 (AP, ML), indicating a good estimation of the TFs. Figure 1 shows a comparison of true vs. predicted right kidney motion in SI & AP directions for a volunteer (V3).

**Discussion & Conclusion:** As expected**,** the largest motion for all volunteers is observed in the SI direction, with noticeable movement in the AP&ML direction for kidneys. The mean maximal displacements listed are consistent with earlier studies [3]. The mean TFs for kidneys in SI, AP & ML directions range between 0.64-0.7, 0.19-0.3 & 0.16-0.23, respectively. This suggests that although the dominant impact of respiratory motion is in SI direction, the kidneys also show considerable axial (AP, ML) motion which may further degrade the image quality if not accounted for. The estimated TF in SI direction for six volunteers is in good correlation with their mean TF value. However, two volunteers (V2, V6) showed significant variation from the mean value which might be due to inter-subject variability as reported in [1]. We also observed SI TFs did not vary much within subjects for different window widths. However, the tracking factor changed notably in axial direction (AP, ML) for almost every volunteer dependent on the window size. But this may be due to the fact that kidneys undergo a restricted motion in the transverse plane as they are being pressed upwards by the lower abdominal organs [2]. The TFs also changed slightly between left and right kidneys which might be due to their different anatomical location. Standard deviation between true and predicted kidney motion is small in all 3 directions which is evident from the plot (Fig. 1), indicating good estimation for the TF not only in SI direction but also in axial direction. In conclusion, this study sheds light on the importance of estimating the tracking factors for the kidney in all 3 directions (SI, AP & ML). Our results help to better understand the complex, 3-dimensional kidney motion and can serve to optimize the prospective application of MR-navigators to improve image quality.

**References**: [1] Nguyen TD et al. JMRI 2008, 28:509 [2] Korin HW et al. MRM 1992, 23:172 [3] Brandner et al. Int J Radiat Oncol Biol Phys 2006, 65:554

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**Table 1:** Mean maximal displacements of liver & both kidneys and the tracking factors obtained for both kidneys for different window sizes in eight volunteers. M-Motion SI-superior-inferior AP-anterior-posterior ML-medial-lateral V-Volunteer, TF–Tracking factor, SD-standard deviation (in mm) for true vs. predicted kidney motion ($R^2$ – (0.84-0.98), (0.7-0.91) in SI & (AP, ML) directions respectively.

| M | V | Mean Maximal Displacement (mm) | | | Whole window | | | | Window = ± 5 mm | | | | Window = ± 4 mm | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Liver | Kidney | | Right Kidney | | Left Kidney | | Right Kidney | | Left Kidney | | Right Kidney | | | Left Kidney | |
| | | | Right | Left | TF | SD(mm) | TF | SD(mm) | TF | SD(mm) | TF | SD(mm) | TF | SD(mm) | R-SQ | TF | SD(mm) |
| SI | 1 | 8.66±3.07 | 5.14± 0.91 | 6.62±1.33 | 0.64 | 0.54 | 0.64 | 1.07 | 0.62 | 0.48 | 0.61 | 1.08 | 0.63 | 0.46 | 0.82 | 0.63 | 1.11 |
| | 2 | 15.52±2.44 | 6.55±1.16 | 8.69±0.78 | 0.45 | 0.45 | 0.47 | 0.90 | 0.45 | 0.40 | 0.41 | 0.77 | 0.42 | 0.38 | 0.81 | 0.40 | 0.49 |
| | 3 | 12.98±2.08 | 9.15±1.48 | 10.57±1.24 | 0.77 | 0.70 | 0.74 | 0.55 | 0.64 | 0.50 | 0.75 | 0.50 | 0.62 | 0.49 | 0.83 | 0.78 | 0.49 |
| | 4 | 14.21±2.77 | 12.79±1.45 | 6.18 ±2.78 | 0.69 | 1.02 | 0.67 | 1.11 | 0.66 | 0.55 | 0.70 | 0.71 | 0.70 | 0.56 | 0.71 | 0.68 | 0.75 |
| | 5 | 10.15±4.22 | 7.35±3.04 | 6.63±3.09 | 0.71 | 0.81 | 0.65 | 0.92 | 0.71 | 0.52 | 0.78 | 0.80 | 0.70 | 0.54 | 0.87 | 0.77 | 0.83 |
| | 6 | 16.84±5.42 | 15.09±4.48 | 13.88±7.05 | 0.90 | 1.10 | 0.85 | 1.01 | 0.89 | 0.91 | 0.83 | 0.62 | 0.85 | 0.86 | 0.70 | 0.79 | 0.60 |
| | 7 | 7.84±2.40 | 6.65±0.67 | 4.88±0.84 | 0.67 | 0.44 | 0.61 | 0.46 | 0.66 | 0.44 | 0.65 | 0.40 | 0.65 | 0.42 | 0.80 | 0.64 | 0.37 |
| | 8 | 7.82±2.82 | 4.40±1.55 | 5.67± 0.74 | 0.72 | 0.89 | 0.53 | 0.80 | 0.72 | 0.84 | 0.62 | 0.63 | 0.74 | 0.85 | 0.44 | 0.67 | 0.61 |
| **Mean** | | **11.75±9.4** | **8.39±6.21** | **7.89±5.43** | **0.69 ± 0.13** | | **0.64 ± 0.12** | | **0.67±0.12** | | **0.67±0.13** | | **0.66±0.12** | | | **0.67±0.13** | |
| AP | 1 | N/A | 1.2 ± 0.13 | 1.68±0.31 | 0.16 | 0.27 | 0.17 | 0.38 | 0.21 | 0.27 | 0.23 | 0.32 | 0.21 | 0.21 | 0.57 | 0.24 | 0.33 |
| | 2 | N/A | 2.55±0.38 | 2.40±0.18 | 0.18 | 0.39 | 0.14 | 0.35 | 0.23 | 0.28 | 0.17 | 0.34 | 0.24 | 0.24 | 0.59 | 0.22 | 0.38 |
| | 3 | N/A | 4.38± 0.63 | 3.32±0.56 | 0.36 | 0.43 | 0.22 | 0.46 | 0.27 | 0.39 | 0.19 | 0.27 | 0.28 | 0.39 | 0.67 | 0.22 | 0.26 |
| | 4 | N/A | 6.13 ±0.77 | 2.19 ±0.69 | 0.37 | 0.72 | 0.24 | 0.57 | 0.41 | 0.59 | 0.32 | 0.56 | 0.38 | 0.56 | 0.49 | 0.43 | 0.43 |
| **Mean** | | N/A | **3.56±1.08** | **2.40±0.96** | **0.27±0.11** | | **0.19±0.04** | | **0.28±0.09** | | **0.23±0.07** | | **0.28±0.07** | | | **0.28±0.1** | |
| ML | 1 | N/A | 1.81±0.27 | 1.56±0.32 | 0.15 | 0.32 | 0.12 | 0.24 | 0.19 | 0.28 | 0.17 | 0.14 | 0.21 | 0.27 | 0.43 | 0.21 | 0.13 |
| | 2 | N/A | 2.30±0.41 | 2.33±0.54 | 0.18 | 0.31 | 0.19 | 0.30 | 0.22 | 0.12 | 0.21 | 0.28 | 0.22 | 0.12 | 0.81 | 0.24 | 0.19 |
| | 3 | N/A | 2.01± 0.10 | 3.11± 0.52 | 0.13 | 0.37 | 0.14 | 0.43 | 0.18 | 0.28 | 0.10 | 0.34 | 0.18 | 0.29 | 0.32 | 0.14 | 0.34 |
| | 4 | N/A | 5.77± 0.52 | 4.67± 0.45 | 0.31 | 0.66 | 0.23 | 0.77 | 0.35 | 0.49 | 0.20 | 0.64 | 0.33 | 0.50 | 0.48 | 0.27 | 0.71 |
| **Mean** | | N/A | **2.97±0.72** | **2.92±0.93** | **0.19±0.09** | | **0.17±0.05** | | **0.23±0.08** | | **0.17±0.05** | | **0.23±0.06** | | | **0.21±0.06** | |

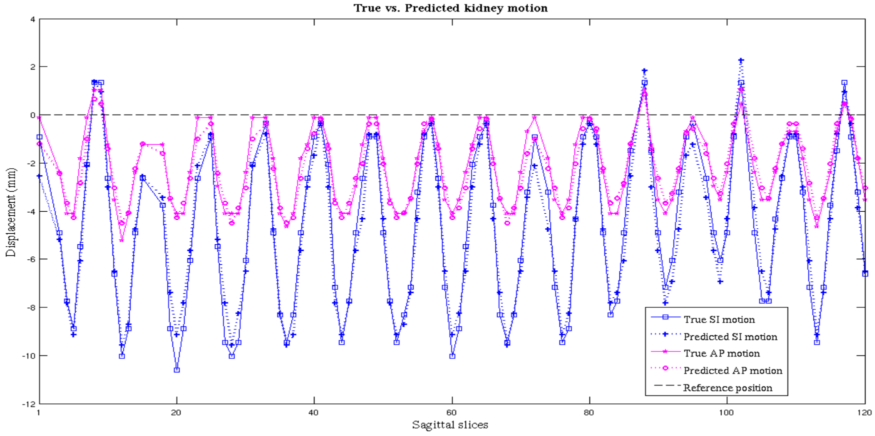

**Figure 1:** Comparison of measured vs. predicted motion patterns in the kidney using the lung/liver interface as a reference position in volunteer 3.