Sparse Dynamic MRI of the Temporomandibular Joint

Stefan Wundrak[1], Jan Paul[1], Johannes Ulrici[2], Erich Hell[2], and Volker Rasche[1]
[1]Ulm University Hospital, Ulm, Germany, [2]Sirona Dental Systems, Bensheim, Germany

Introduction: Assessment of the masticatory motion of the temporomandibular joint (TMJ) is of interest for a variety of pathologies, e.g. the abnormal motion of the articular disc. Current approaches include tracking through external devices [1] and the static visualization through MRI [2]. The dynamic visualization of the TMJ under realistic mastication is still limited by the poor spatiotemporal resolution [3, 4]. Recently, we have shown the feasibility of retrospective gated reconstruction using a device that tracks the angular position of the mandible [5] and a retrospective self-gated reconstruction method [6]. In this contribution we use k-t radial sparse SENSE (k-t RASPS) [7] for the imaging of the TMJ dynamics to increase the achievable temporal resolution.

Methods:

Acquisition: Five healthy volunteers were instructed to open and close the mouth continuously and uniformly during a specific time period. The acquisition was performed using a radial trajectory with a golden angle acquisition scheme [8]. Acquisition parameters were: 3T, steady-state gradient echo, a 2x4 channel carotid coil (Chenguang Medical Technologies, Shanghai, China), TE / TR = 2.3 / 4.6 ms, flip angle = 20°, pixel bandwidth 949 Hz, and spatial resolution 0.75 x 0.75 x 5 mm³.

Reconstruction: Cine images were reconstructed with a sliding window width / step size of 34 / 5 radial profiles, resulting in an undersampling ratio of R ≈ 12 and a maximally achievable temporal resolution of 31 ms. The sliding window reconstruction was performed by a) gridding, b) k-t-RASPS with the spatiotemporal total variation regularization parameter manually optimized to ensure a good trade-off between artifact reduction and temporal resolution, and c) gridding with a post-processing temporal median filter [3] (SW-MED). The size of the Median filter was chosen to match the noise level of the k-t RASPS reconstruction.

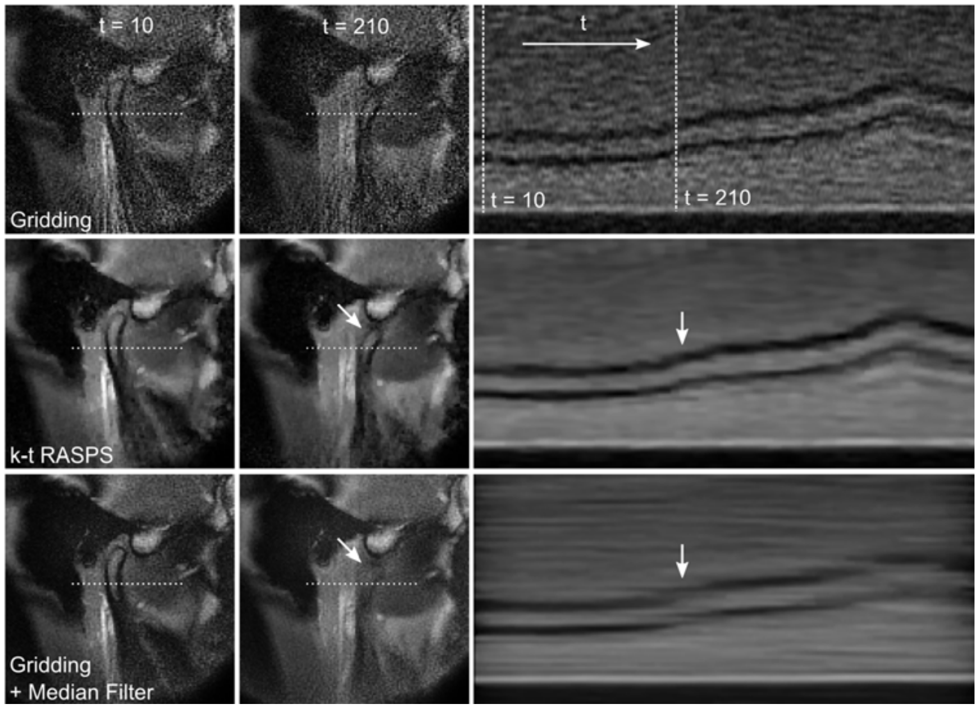

Figure 1: Dynamic sliding window reconstruction of the TMJ opening in about 5 seconds showing snap-shots of the slow-moving condyle at the 10th time frame (left column), the fast moving condyle at the 210th time frame (middle column), and the M-mode plots (right column). The k-t RASPS reconstruction is able to reproduce a high temporal fidelity even during the fast movement of the condyle.

Image Analysis: Two time frames, one with a slow- and one with a fast-moving condyle, were selected from each movie. For these time frames the sharpness of the condyle head was measured inside a region of interests. Sharpness was defined as the average image gradient (calculated via 3x3 Sobel filters) after noise removal. Noise was removed using a threshold calculated from the k-t RASPS time frames with the Otsu-method [9].

Results: Figure 1 shows M-mode-like plots of the moving condyle for one volunteer. For an opening-closing cycle time (OCCT) of 10 seconds the k-t RASPS reconstruction is able to reproduce a high temporal fidelity even during the phase of the fastest condyle movement. The SW-MED reconstruction for the same dataset leads to blurring of the condyle during phases of fast movement. Table 1 summarizes the increase of image sharpness by k-t RASPS over the SW-MED reconstruction. For the phases with a fast moving condyle the sharpness is increased for all five volunteers. For the phases with a slow-moving condyle the increase in sharpness is less pronounced since the SW-MED reconstruction produces equally sharp results.

Opening-Closing Cycle Time	Sharpness Increase Fast Motion[1]	Sharpness Increase Slow Motion[2]
6.7s ± 1.8s	28% ± 17%	2% ± 5%
4s ± 0.2s	23% ± 17%	6% ± 9%
2.7s ± 0.5s	20% ± 16%	19% ± 21%

Table 1: Sharpness increase of k-t RASPS over SW-MED for 5 volunteers. 1) Time frame with fast moving condyle. 2) Time frame with slowly moving condyle.

Conclusion: The combination of parallel imaging and compressed sensing enables the imaging of the TMJ dynamics at a high temporal resolution. While the previously maximally achievable TMJ OCCT that could be measured without motion blur was between 15 to 50 seconds [3, 4], the proposed methods enables the imaging of the TMJ at OCCTs of 4 to 8 seconds without or with only minor motion blur. Methods using gating [5, 6] may still achieve a higher spatiotemporal resolution, but are not applicable in situations where the movement of the condyle is not fully reproducible.

References: [1] Tymofiyeva, et al. An. of Anat. 2007; 189:356-361. [2] Thomas, et al. Radiogr 2006; 26:765-781. [3] Zhang, et al. OMIJ 2011; 5:1-7. [4] Hopfgartner, et al. DFMR 2013; 42: 20120436. [5] Kammer, et al. ISMRM 2012. [6] Wundrak, et al. ISMRM 2014. [7] Feng, et al. ISMRM 2011. [8] Winkelmann, et al. IEEE TMI 2007; 26:68-76. [9] Otsu, IEEE TSMC 1979; 9(1):62-66.