ULTRA-SHORT DETECTION TIME IMAGING OF THE CURING OF COMPOSITES FOR DENTAL CARE USING PARAMETER SELECTIVE T2* MR-MICROIMAGING ON A HUMAN UHF-SCANNER

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Purpose and target audience Our contribution is dealing with an interdisciplinary application of the newly offered class of MR pulse sequences for the detection of tissue with very low T2, i.e. Ultra-short Encoding Time: UTE[1]. The implementation on microimaging equipment in combination with quantitative parameter mapping (T2*) of theses pulse sequences and application to the material class of polymer composites (fig.1) demonstrates: a) the principle possibility to visualize biocompatible materials such as polymers for the purpose of quality control and detection of manufacturing damage within non-destructive material analysis considering also possible pitfalls and limitations, b) the high spatial resolution which can be achieved in principle also on UHF human scanners using additional hardware equipment and c) the capability for the combination of ultra-short encoding time detection with parameter selective, quantitative parameter mapping, thereby offering information on manufacturing processes and possibly also degradation in this type of biocompatible materials. An additional aim is represented by quality control (QC) on resolution, SNR and artefacts associated to UTE microimaging.
This contribution is therefore targeted for scientists and engineers developing and applying pulse sequences for UTE and seeking for applications but also medical doctors and scientists involved in the quality control of a) UTE pulse sequences for tissues and b) of biopolymers and implant material, especially material for dental care. Also mechanical engineers and chemists might be interested in the perspectives and limitations of the parameter selective non-invasive 3D-MR-imaging methodology for the non-destructive characterization of polymer based materials for usage in the human body for questions of pre-surgical quality control but also performance in the human body.

Materials and methods

.1 MRI: The very short detection times starting at about 70µs (encoding time TE) are achieved using a radial projection sampling (Siemens WIP: S Vallespin, P. Speier et. al. CV-3DRAD, 2009, investigational) based on the pulse sequence designed by S. Nielles-Vallespin[2]. The complete 3D-k-space is sampled in a spiral path (fig. 2). QC based on the point spread-function, SNR and artifacts is performed. The small voxel volumes, typically $(180\mu m)^3$, down to $(75\mu m)^3$ in parallel with acceptable SNR were achieved on a 7T human MR-scanner, equipped with a small sized (i.d. 90mm) prototype strong gradient system (G=750 mT/m) and a sensitive quadrature coil resonator (i.d. 18mm)[2].

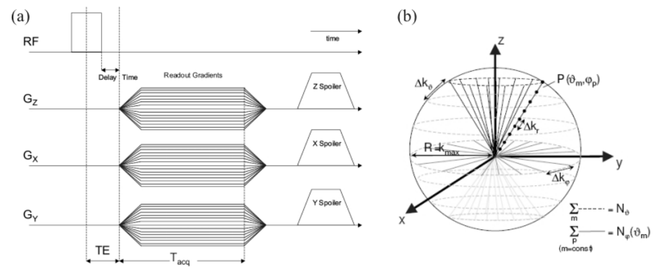

Fig. 2a) Scheme of 3D-UTE pulse sequence for ultra short detection time imaging. b) Corresponding radial sampling of k-space (reproduced from [2]). TE_{min}=70µs. Typical measurement parameters: profile resolution: 96, nr projections: 30000, FOV: 18 mm, interpolated voxel size after regridding: $(188\ \mu m)^3$, bw/pixel: 500-600 Hz.

.2 Material: Dental composites: The three different material batches are composed mainly of methacrylic acid derivatives as monomer material and an inorganic mineral filler for hardness. The commercially available products are intended for the usage on human dentition: a) Z100 (3M) is a mixture of bis-GMA und TEGDMA (15.5 weight-%, 29 vol.-%) and zirconium/silicon filler; b) X-tra fill (Voco) is a hybride-composite with inorganic silicate fillers (70.1 vol-%) within a matrix of bis-GMA, UDMA und TEGDMA; c) Admira (Voco) is a composite based on Ormoceres® and dimethacrylate monomers, containing inorganic micro-fillers (56 vol.-%) with a particle size of about 0.7µm. The samples of about 5mm thickness are illuminated from bottom with blue light (fig.1) and cure to about half of the thickness to a very solid state of hardness, sufficient for resisting the high biting forces.

Fig.1 Composite for dental care. By illumination with blue light the polymer part is cured.

Results QC on reference samples for UTE sequence unmasked mainly 3 sources of image distortion: 1.) an edge enhancement in direction of the profiles, which can be traced back to a gradient switching delay, 2.) blurring of the image, which is attributed to non-perfect switching of gradients and/or eddy currents and 3.) a ring-type artifact, if an offset in excitation vs. emission frequency is present. Polymer material with strongly split spectral peaks as e.g. in rubber also exhibits this artifact.
At shortest encoding time TE = 70µs the complete cured composite material on top of the samples cannot be visualized due to its extremely short T2*, presumably smaller than 25µs. However, the transient regions between incompletely cured and semi-rigid paste of composite can be delineated (fig.3). Dark spots most likely due to agglomerates of the inorganic filler particles can be localized. These might be origins of breakage during load after polymerization. An increase in T2* with increasing distance to the solid surface can be observed, indicating a reduced degree of polymerization (table1).

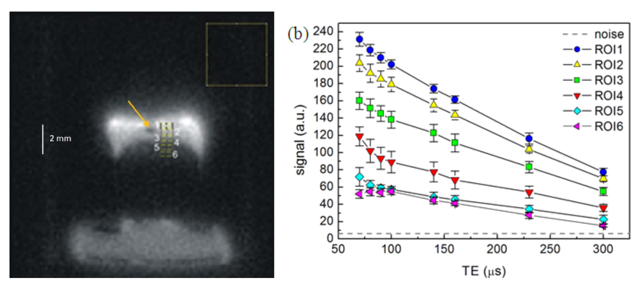

Fig. 3 left UTE image (TE =70µs, FOV: 18mm; Mtx: 96. On top: Composite sample. Note the dark spot in the middle most probably due to an agglomeration of the ceramic filler particles (see arrow). ROIs 6-1 for determination of signal intensity and T2 with illumination depth are indicated.*
Bottom: Hot glue slice as marker for the top illumination side of the composite.
***Right:** Mean signal strength of the ROIs as a function of the encoding time TE: The noise level is indicated by the dashed line.*

ROI	Position (mm)	$T2^\star$ (μs)	$\sigma T2^\star$ (μs)	I_0 (a.u.)	$\sigma I_0(a.u.)$
1	7.75	203.8	5.4	319.5	6.3
2	8.16	169.8	8.3	295.6	12.0
3	8.57	165.2	6.3	250.8	9.9
4	8.88	159.4	5.2	172.6	6.0
5	9.19	142.2	14.0	116.0	10.1
6	9.67	135.5	10.4	88.4	6.2

***Table 1** T2* evaluated from UTE signals starting from ROIs (1) on the bottom of the composite with hardly any polymerization up to the middle part (6), where light induced polymerization already reduces T2*.*

Discussion/Conclusion T2*-imaging for polymer materials with short T2* above about 70µs can be implemented, even at sub $(200\mu m)^3$ voxel size using additional hardware components on UHF human 7T-scanners. UTE microimaging might still suffer from artifacts, arising mainly from gradient delays and imperfect switching. Composites for dental care in complete cured state cannot be visualized due to their T2* below about 25µs. Quantitative T2*-micro-imaging can be applied for the delineation of the polymerization process in biocompatible materials down to about T2* of 140µs as a tool for quality control in non-invasive material analysis.

References

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