Comparison of UTE, PETRA and SPI sequences in MRI of Ancient Remains

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Introduction: MRI of ancient remains is challenging due to the very short T2* values of the dehydrated embalmed tissues. Recently feasibility of MRI in ancient remains has been shown in a comparison study with CT [1]. In general, acquisition strategies for MRI of short T2* samples can be separated in two groups: Frequency encoding and phase encoding. Ultrashort echo time (UTE) imaging is a pure frequency encoding technique and, therefore, it is subject to frequency domain artifacts. Single Point Imaging (SPI) is a pure phase encoding technique which is especially useful to avoid filtering effects in k-space [2]. However, SPI has very long scan times, and it exceeds the limits of clinical gradient hardware for samples with extremely short T2*. Pointwise Encoding Time Reduction with Radial Acquisition (PETRA) is a hybrid technique based on radial frequency encoding of k-space with center of k-space being acquired with SPI [3]. PETRA and UTE have been compared in simulations and *in vivo* [3]. Purpose of this study is to compare UTE, PETRA and SPI sequences in terms of SNR per unit time and image quality based on anatomical detail extraction performance on a mummified sample using a clinical scanner.

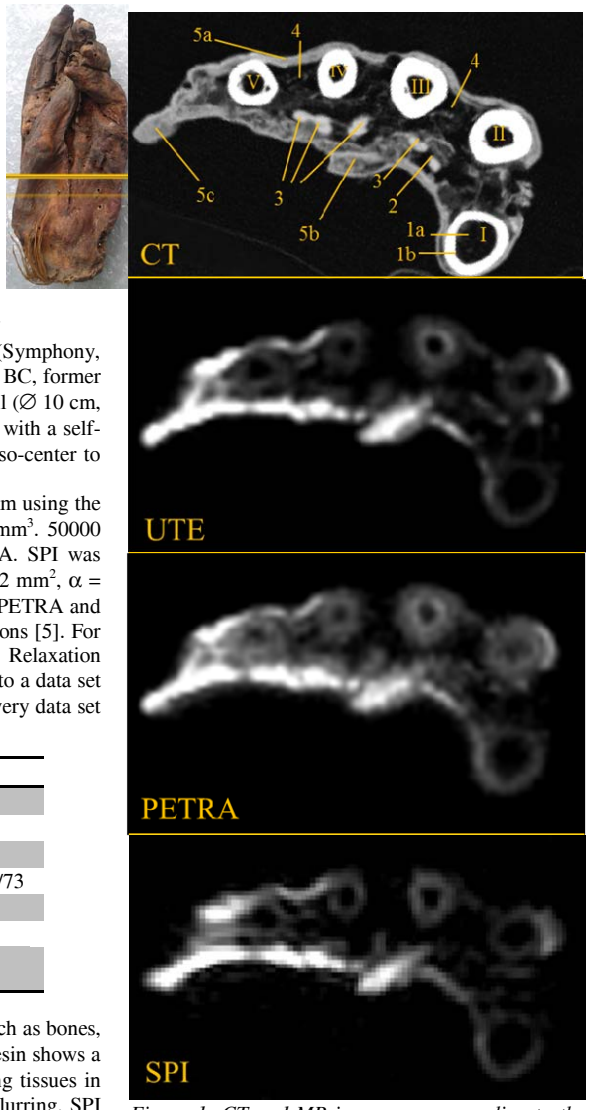

Figure 1: CT and MR images corresponding to the slice shown in the photo of the mummified hand. Significant structures are labeled on the CT image. See Table 1 for structural descriptions and local SNR calculations.

Materials and Methods: All imaging experiments were conducted on a 1.5T clinical MR system (Symphony, Siemens AG, Erlangen). The left hand of an embalmed ancient Egyptian mummy (ca. 1500 – 1100 BC, former collection of Musée d'Orbe, Orbe, Switzerland) was placed in a home-made solenoid Tx/Rx RF coil (∅ 10 cm, length: 18 cm, 6 turns). The ring-down time of the coil was measured to be 3.4 µs in combination with a self-made Tx/Rx switch (50 dB isolation is reached in 2.4 µs). The coil was placed at the system's iso-center to avoid off-center shifts in radial sequences [4].

UTE and PETRA sequences were set to extract anatomical details at a nominal resolution of 0.9 mm using the following parameters: TR=10 ms, TE = 70 µs, α =10°, FOV=206x206 mm^2, voxel size = 0.9 mm^3. 50000 radial spokes were acquired with bandwidth of 800 Hz/px for UTE and 600 Hz/px for PETRA. SPI was performed with a larger voxel size of 1.7 mm^3 due to system hardware limitations: FOV=212x212 mm^2, α = 2°, acquisition delay = 300 µs, TR = 2 ms. Total scan times were 10', 10'50'', and 140' for UTE, PETRA and SPI, respectively. To compare the results, these differences are accounted for in the SNR calculations [5]. For anatomical reference, all image data were compared to a CT data set of the specimen. Relaxation measurements were performed with UTE. T2* is calculated by two component exponential fitting to a data set acquired with varying echo time (TE range: 50 µs – 3 ms). T1 is calculated from a saturation recovery data set with varying time of saturation (T_{Sat} range: 10 ms – 300 ms).

	Anatomical structure	UTE	PETRA	SPI
2	Flexor pollicus longus tendons	10.3	19	4
3	Flexor digitorum profundi tendons	8.6	18.3	4.5
4	Dorsal interossei muscles	12	23	7.6
5a/b/c	Dorsal/palmar/ulnar skin with embalming resin	25/52/65	39/60/71	21/42/73
I-V(a)	Metacarpal bones (spongy bone)	4	7	0.5
I-V(b)	Metacarpal bones (cortical bone)	13.6	24	9.4

Table 1: Relative image SNR values of the labeled regions.

Results: In all MR images (Fig. 1) tissue differentiation is feasible; major anatomical structures such as bones, tendons (T1 = 85 ms, T2* = 170 µs) and muscles can be clearly identified. Skin with embalming resin shows a very high signal (T1 = 260 ms,T2* = 850 µs), whereas they appear iso-intense to the neighboring tissues in CT. PETRA offers higher SNR, yet it fails to display some anatomical structures due to image blurring. SPI presents less of the anatomical structures due to longer acquisition delay (i.e. effective TE) but it is free of blurring artifacts. With appropriate parameter scaling based on voxel size, flip angle and TR differences SNR values for corresponding anatomical regions are shown in Table 1. A semi-quantitative comparison of the sequences is summarized in Table 2 in a scale from - - to +++. Radial sequences are more prone to artifacts due to frequency encoding and gridding reconstruction. The last column of Table 2 stands for clinical applicability and PETRA has a plus for the silent scan option with continuous gradient ramp which was applied to SPI as well.

Discussion: UTE and PETRA images show that MRI of ancient remains is feasible in clinical MR systems with a good tissue contrast. UTE acquisitions are advantageous over PETRA as perfectly non-selective excitation can be achieved. Gradient fidelities and limitations are critical for all sequences. In the future, information from SPI and frequency encoding can be integrated over all the k space to avoid blurring as well as compensating for the signal loss. SPI does not present blurring artifacts, yet it is difficult to achieve short scan times and high spatial resolution with standard clinical hardware. Novel gradient systems with G_{max} of 80 – 300 mT/m, however, might be able to overcome some of these limitations in the near future.

Sequence	SNR	sharpness	scan time	artifacts	clinical
UTE	++	++	++	+	++
PETRA	+++	+	++	+	+++
SPI	+	+++	--	+++	-

Table 2: A semi-quantitative comparison of the sequences applied.

References: [1] Ohrström LM et al. Radiographics 33(1): 291-6 (2013) [2] Balcom BJ et al. JMR, A123: 131-4 (1996) [3] Grodzki DM et al. MRM 67:510–518 (2012) [4] Jung Y et al. MRM, 57(1): 206–212 (2007) [5] Edelstein WA et al. MRM, 3:604-6 I8 (1986)