

Artificial hematomas in subcutaneous fatty tissue: volume estimation by using different MR sequences and manual segmentation of pork belly phantoms

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Introduction: Detection of hemorrhage in organs and visceral cavities using MRI is well established in clinical medicine. In forensic imaging reliable localization and analysis of hematomas in soft tissues such as the subcutaneous fatty tissue is required for the reconstruction of the sequence of events, e.g., following accidents or interpersonal violence. With its good contrast behavior in soft tissues and absence of radiation exposure MRI is particularly suited to examine patients with forensically relevant injuries. However, there is only limited knowledge and experience regarding MRI signal properties of hemorrhage in fatty tissue. The aim of this study was to compare different MRI sequences with respect to their ability to show high contrast between hematoma and subcutaneous fatty tissue, and to reliably estimate their volumes.

Materials & Methods: 10 pork belly phantoms were prepared by injecting freshly drawn venous blood (pH: 7.3, hematocrit 51.2, fractions of: oxy-hemoglobin (Hb) 63.8%, carboxy-Hb 1.4%, deoxy-Hb 34.3%, and met-Hb 0.5%, respectively) from a healthy volunteer into the subcutaneous fatty tissue to create artificial hematomas. Totally 10 hematomas of each volume (0.1, 0.3, 0.6, and 1ml) were injected, each phantom was randomly assigned 4 hematomas. Prior to injection the phantoms were warmed to approx. 37°C. MR images were acquired at 3T (TimTrio Siemens Healthcare, Erlangen, Germany) using a combination of a spine and a small flex coil. The protocol consisted of 4 sequences (40 slices, average slice thickness 2 mm, resolution 0.77mm, matrix 168x152): a proton density weighted turbo spin echo sequence with fat saturation (TSE-PDwFS, TE/TR 8.8/3380ms), a T1 and T2 weighted (TSE T1T2w, TE/TR=53/619ms), an inversion recovery (TIR, TI=200ms, TE/TR=8.5/5610ms), and a FLASH (TE/TR=8.47/100ms, flip angle=44°) sequence. For image analysis the window level was fixed for each series, and kept the same for all observers. 3 blinded observers conducted manual segmentation of the hematomas using the ITK-SNAP software [1] by selecting all hematoma voxels (Fig. 1). For assessment of the intra-observer variability this process was repeated after one week for randomly selected 50% of the hematomas. A Student's t-test was performed for each sequence to assess if the estimated volumes were different from the ground truth ($\alpha=0.05$). An analysis of variance (ANOVA) was performed for each volume with the MR sequence and the observer as factors on the total variance of the volume measurements. The intra-observer and inter-observer correlation coefficients (CC) and the corresponding 95% confidence intervals (CI) were calculated for the 3 observers according to Shrout et al. [2].

Results: Visual comparison of the four sequences (Fig. 2) showed an equally good positive or negative contrast between the hematomas and the subcutaneous fatty tissue, with 38 hematomas being visible in all sequences. The results of the volume estimation (Fig. 3) demonstrate the differences between the estimated volumes and ground truth for the four sequences and the different blood volumes. The TSE T1T2w sequence shows a good agreement for the volume estimation; in the other sequences hematoma volumes are all overestimated (significant differences $p<0.05$ between estimation and ground truth for 0.1ml: TSE-PDwFS, TIR, FLASH; for 0.3ml: TSE-PDwFS, FLASH; for 0.6 and 1ml: TIR, FLASH). Generally, standard deviations are large, particularly for the volume of 0.1ml where they are in the same range as the volume itself. In the 0.1ml hematoma the variance is mainly explained by the error term, neither the sequence nor the observer contributed significantly. The variances of the larger volumes all show a significant contribution from the MR sequence (0.3ml: 43% of the total variance (var) with $F=23.42$, 0.6ml: 40% of var, $F=24.84$, 1ml: 32.7% of var, $F=16.43$), while the influence of the observer is very low (0.3 ml: 0.3% of var, 0.6 ml: 3.6%, 1ml: 5.6%). The reproducibility of the measurements was good with an intra-observer correlation coefficient of over 80% for all observers (Observer 1 (O1): 91.8% [95% CI 79-96%], O2: 81.2% [72-87%], O3: 96.4% [95-98%]), and an inter-observer correlation coefficient of 84.1% [79-88%].

Discussion & Conclusion: Our results support a clear preference of the TSE T1T2w sequence for the assessment of hematoma in fatty tissue using MRI as it shows the best average volume estimation with reasonable standard deviation. The variance of the volume estimations was high in all measurements. Partly, this may be attributed to errors in the ground truth resulting from incomplete blood injection, leakage into the muscle tissue or diffuse distribution between the fat lobules. The ANOVA confirms our assumption that the variability of volume estimation is mainly due to the used MR sequence as opposed to the observer rating. Reproducibility within and between the observers was very good. In conclusion hematoma segmentation of very small blood amounts in subcutaneous fatty tissue is generally difficult with all tested MR sequences. However, usually larger volumes are expected whose analysis may be facilitated using the proposed sequence.

References: [1] <http://www.itksnap.org>; [2] Shrout PE et al. Psychological Bulletin 1979;86:2.

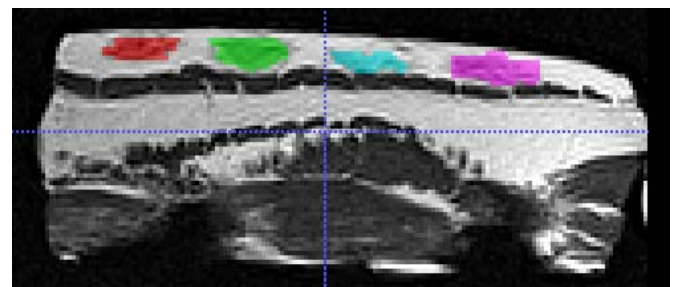


Fig. 1 Pork belly phantom (TSE T1T2w) and the manual segmentation result of 4 artificial hematomas

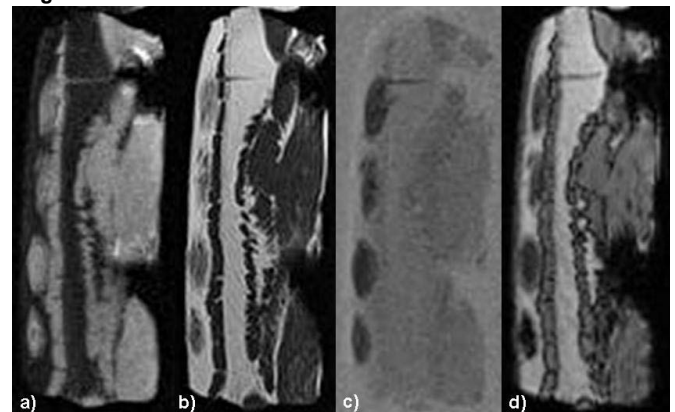


Fig. 2 Contrast between hematoma and subcutaneous fatty tissue in different sequences: a) TSE-PDwFS, b) TSE T1T2w, c) TIR, d) FLASH

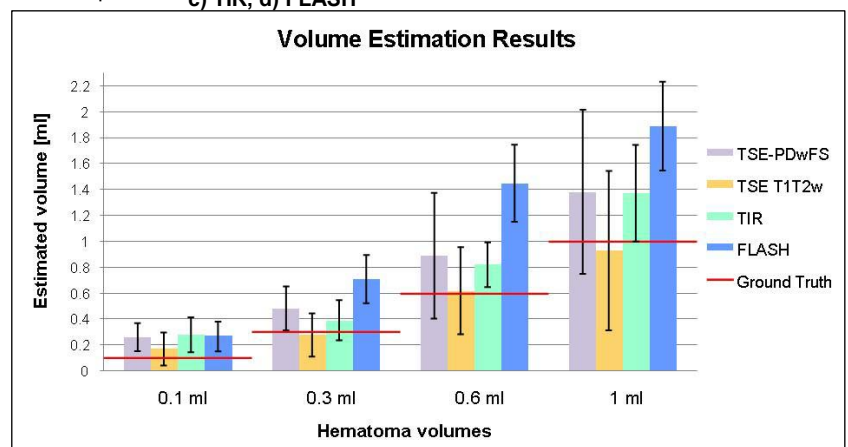


Fig. 3 Mean volumes averaged over all observers and the corresponding standard deviations (error bars) for the different hematoma volumes compared to ground truth (red line)