# Unsupervised Reconstruction for Ungated Ghost Angiography by Clustering of Image Features

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**Introduction:** Ghost magnetic resonance angiography (MRA) has been proposed as an unenhanced and ungated method for angiography that is based on the presence of ghost artifacts resulting from pulsatile blood flow (1). Although the method is simple to acquire in that cardiac gating is not required, it requires manual post-processing to identify suitable slices in a large stack from which to create an interpretable angiogram. To maximize the contrast of the final angiogram it is necessary to eliminate slices located within the body and to carefully select the slices that contain conspicuous ghost artifacts. This manual post-processing step is time-consuming and can introduce unwanted inter- and intra- observer variability. The purpose of this work was to completely automate the reconstruction process during ungated and non-contrast-enhanced Ghost MRA using image analysis and clustering.

**Methods:** Experimental Setup and Imaging: Ghost MRA (1) was performed in 16 human subjects (14 male, age 20-45) after consent and approval by the review board, using a coronal non-cardiac-gated 3D Turbo Spin Echo (TSE) pulse sequence centered at the calf. Imaging parameters were: FoV=35x50cm; matrix=224x320; GRAPPA x4, 176-256 partitions of 4mm spacing after interpolation (slab thickness = 704-1024mm); phase and slice Partial Fourier factors of 6/8$^{th}$; TR/TE=1.2s/90ms; spatially non-selective radiofrequency excitation, flip= 90 degrees; BW=975 Hz/pixel; and acquisition time of 1.3-2min. Image Processing: Each image in the stack was loaded into Matlab and a series of steps were performed to retrieve the strength (energies) of prevalent image features, characterizing ghost presence. The method identified and compiled slices containing ghost artifacts based on each slice's (i) total logarithmic energy (log of the total squared intensity of the slice), (ii) cumulative cross-correlation energy (the sum of the normalized cross-correlation values for that slice with all other slices within the stack), and (iii) vertical ridge energy (summing the positive values of the convolution of the slice with a vertical ridge filter (2), with parameters $w$=25 and $\sigma$=3). Vectors containing the above energies for all slices in the stack were normalized to zero mean and unit standard deviation and collected in a matrix D. Subsequently, the k-means (3) and fuzzy c-means (FCM) clustering (4) algorithms were used to cluster D in four clusters. The slices of the cluster that maximized the combined normalized ridge and cumulative cross-correlation energies were selected for reconstruction. In the k-means case, the reconstruction was a summation of the slices in the cluster, while for the FCM case the reconstruction was a weighted average summation, with the corresponding membership values (of the FCM procedure) used as weights. Data Analysis: The results of the method were compared with manual reconstructions performed by an expert user. An expert observer subsequently evaluated all reconstructions and assigned qualitative and preference scores ranging from 1 to 4 (1: best, 4: worst) and 1 to 3 (1: most preferred, 3: least preferred), respectively. Quantitative apparent arterial-to-background contrast-to-noise ratio (CNR) values were also computed. Friedman tests with Bonferroni correction were performed to identify differences in apparent CNR, image quality scores, and preference rankings between the reconstructions.

**Results:** The mean number of slices used to create the final Ghost MRA images with the manual, FCM, and k-means methods were 61±24, 85±23, and 108±34, respectively. The mean time required by manual reconstruction was 114s (range: 70-142s). Qualitative findings are summarized in Table 1. No difference in diagnostic image quality was identified among the automated and manual reconstructions (P>0.05). All reconstruction methods provided the highest level of diagnostic quality for 15 out of 16 image sets. Friedman tests indicated no significant differences in preference rankings among automated and manual reconstructions (P>0.05). For the majority of the data sets, the manual, k-means, and FCM reconstructions were preferred equally; however, in 4 cases k-means was preferred the least in contrast to 3 cases for FCM. There were two instances where k-means and FCM outperformed manual reconstruction. Fig. 1 shows a montage of ghost angiograms obtained with the three reconstruction schemes. Fig. 2 shows mean apparent CNR values obtained with manual and fully-automated reconstruction for four arteries. Apparent CNR values were roughly equivalent between techniques.

**Discussion & Conclusions:** Our analysis showed that the presented fully-automated k-means and FCM clustering methods produced ghost angiograms with apparent CNR values and diagnostic quality scores rivaling angiograms obtained with manual reconstruction, indicating that they are viable alternatives to time-consuming manual post-processing. The improved performance of the FCM was likely due to the higher selectivity of the method and the weighted reconstruction (accentuating the contribution of slices containing strong ghost artifacts, and suppressing the influence of slices containing weak ghost artifacts.) A cluster size of 4 was found to be optimal. When cluster sizes <4 were chosen, the methods underperformed compared to manual reconstructions, while opting for >4 clusters offered limited improvement and produced obvious outliers (data not shown).

**References:** **(1)** Koktzoglou & Edelman, *MRM* 61:1515-1519 (2009); **(2)** Jacob & Unser, *IEEE PAMI*, 26:1007-1019 (2004); **(3)** MacKay (2003); **(4)** Bezdek (1981)

**Acknowledgement:** The Grainger Foundation

**Table 1.** Qualitative Results

| Metric | Reconstruction Method: Manual | K-Means | FCM | P-Value[a] |
|---|---|---|---|---|
| Diagnostic Image Quality[b] | 1.06 ± .25 | 1.06 ± .25 | 1.13 ± .50 | 0.368 |
| Preference Ranking[c] | 1.25 ± .68 | 1.63 ± .89 | 1.44 ± .81 | 0.353 |

Data presented as mean ± standard deviation; [a]Friedman Test
[b] 1: best, 4: worst ; [c] 1: most, 3: least preferred

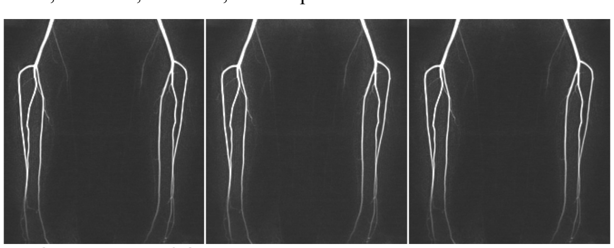

**Fig. 1** Comparison of Ghost angiograms obtained in a 24-yr old volunteer created using manual (left), fully-automated k-means (middle), and FCM clustering (right); cluster size = 4.

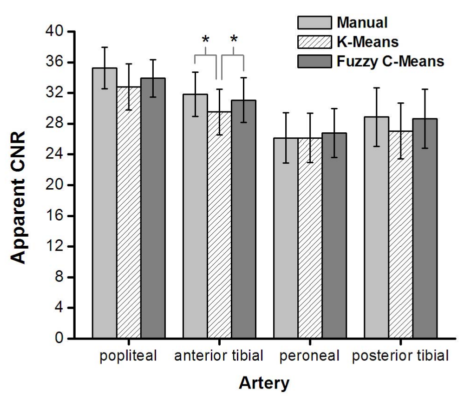


**Fig. 2** Mean apparent arterial-to-back-ground CNR values for the various reconstruction schemes. Fully automated reconstruction with either k-means or FCM clustering (cluster size = 4) performed similar to manual reconstruction in all vessels except in the anterior tibial artery (P = 0.010; Friedman test), where the manual and FCM reconstructions provided larger CNR values than did k-means (P < 0.005 and P < 0.05, respectively). Asterisks indicate statistically significant differences between techniques (P<0.05; Wilcoxon signed-rank test).