"Time Resolved MR Angiography With Limited Projections"

Yuexi Huang and Graham A. Wright

By Kacie Jacklin

Key Points to HYPR

- Data Sparsity/Undersampling - Limited Projections
- Uniformity of Signal Dynamics - This assumption yields the property that the artifacts are proportional between the limited-projection image and the corresponding limited-projection image calculated from the composite and cancel each other out after normalization.
- Bit-reversed ordering of acquiring projections is used.
- Unfiltered backprojection can help limit the artifacts.

Original HYPR

$$HYPRimage(x,y,z) = \frac{1}{N_{pr}} \times C(x,y,z) \times \sum \frac{P(r,\theta,\varphi)}{P_c(r,\theta,\varphi)}$$

N_{pr} - Number of limited projections in the time frame

$C(x,y,z)$ - Time - averaged composite image

$P(r,\theta,\varphi)$ - Unfiltered backprojection of a certain raw projection

$P_c(r,\theta,\varphi)$ - Unfiltered backprojection of the corresponding projection from the composite image

*As the number of limited projections increases to equal the total number of projections,
the HYPR image is equivalent to the composite image.
*This equation leads to constraints in the denominator. If there are pixels with a value of
zero, or near zero, it can lead to artifacts in the HYPR image.

Wright HYPR

$$HYPRimage(x,y,z) = C(x,y,z) \times \frac{\sum P(r,\theta,\varphi)}{\sum P_c(r,\theta,\varphi)}$$

$C(x,y,z)$ - Time - averaged composite image

$P(r,\theta,\varphi)$ - Unfiltered backprojection of a certain raw projection

$P_c(r,\theta,\varphi)$ - Unfiltered backprojection of the corresponding projection from the composite image

As the number of limited projections increases to equal the total number of projections,

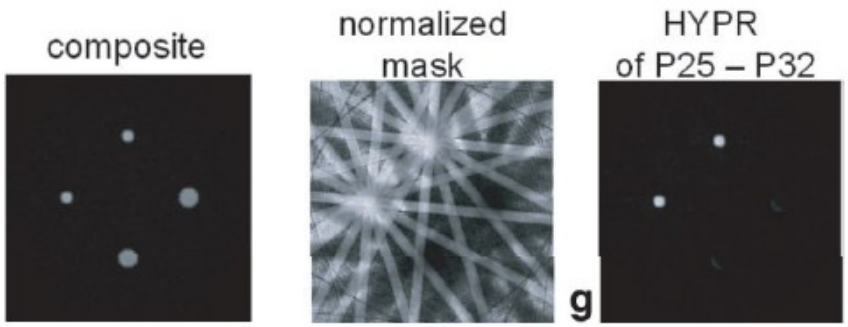
$$\frac{\sum P(r,\theta,\varphi)}{\sum P_c(r,\theta,\varphi)} = 1$$

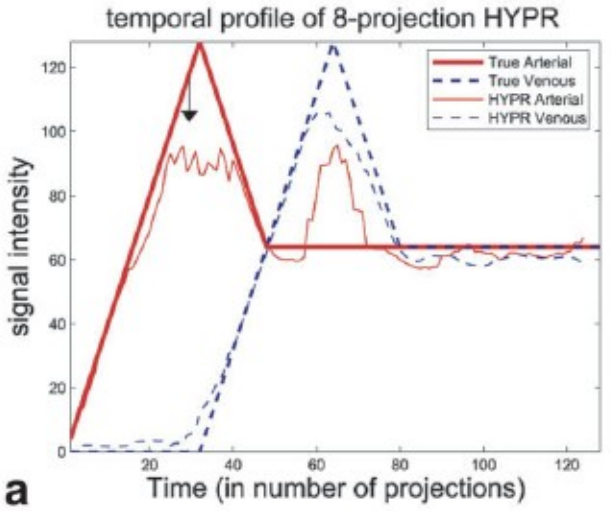
Then $HYPRimage = C(x,y,z)$

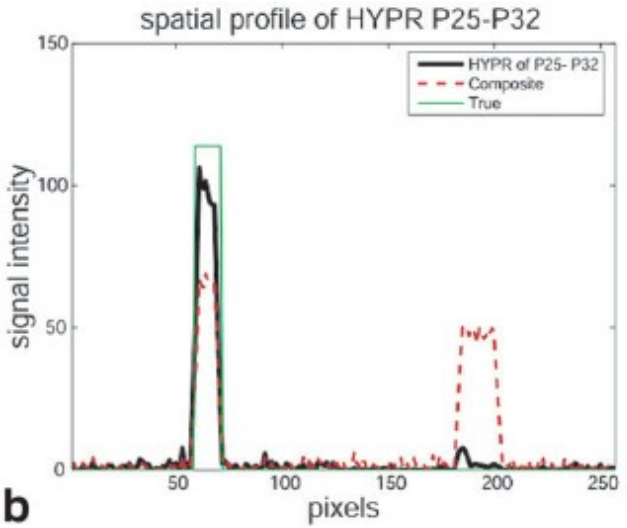
*In other words, as the number of limited projections increases to the number of projections of the composite image, the ratio of the sums is one and the HYPR image is equivalent to the composite image.

Simulation

- 4 object computer model
- Two arteries and two veins a certain distance apart, veins larger than arteries
- Arterial signals increased earlier than venous signals
- HYPR picks up venous intensity early.
- HYPR detects venous intensity for the arterial image, this is called "cross-talk".

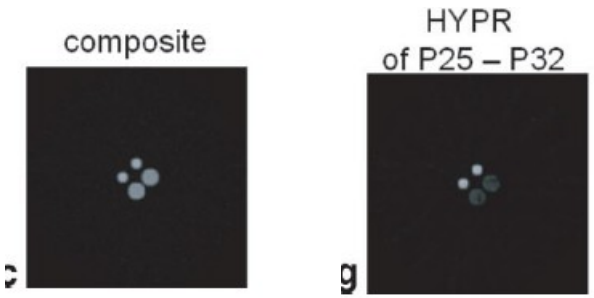


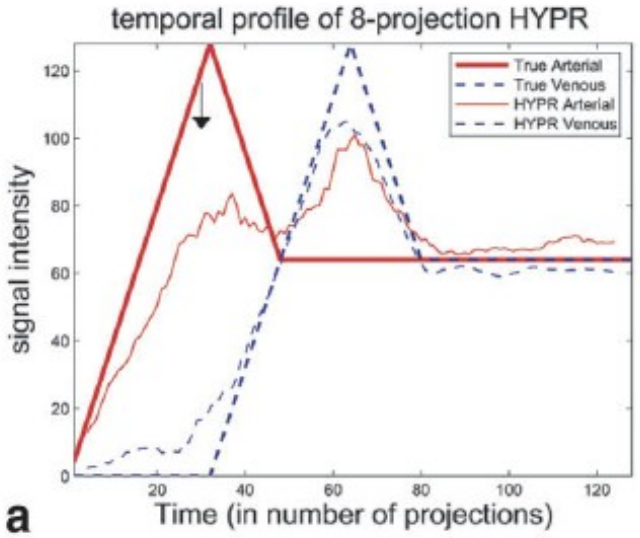


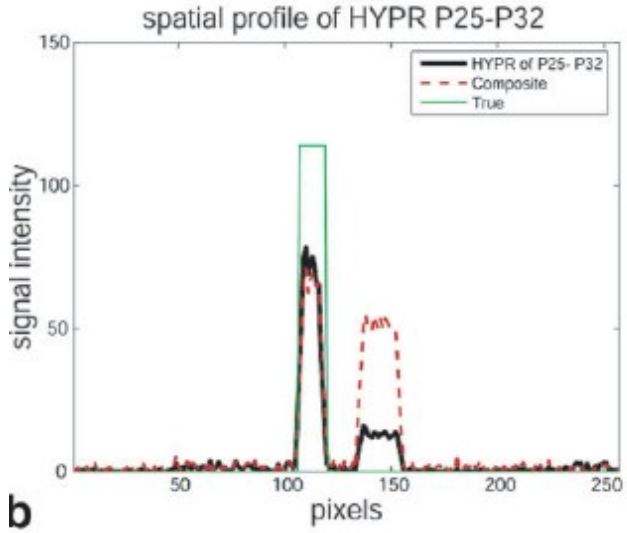


Simulation

- Less sparse than previous simulation.
- Two arteries and two veins closer together than previous simulation, veins larger than arteries.
- Arterial signals increased earlier than venous signals
- HYPR picks up venous intensity early and has a lower arterial intensity.
- HYPR detects venous intensity for the arterial image.

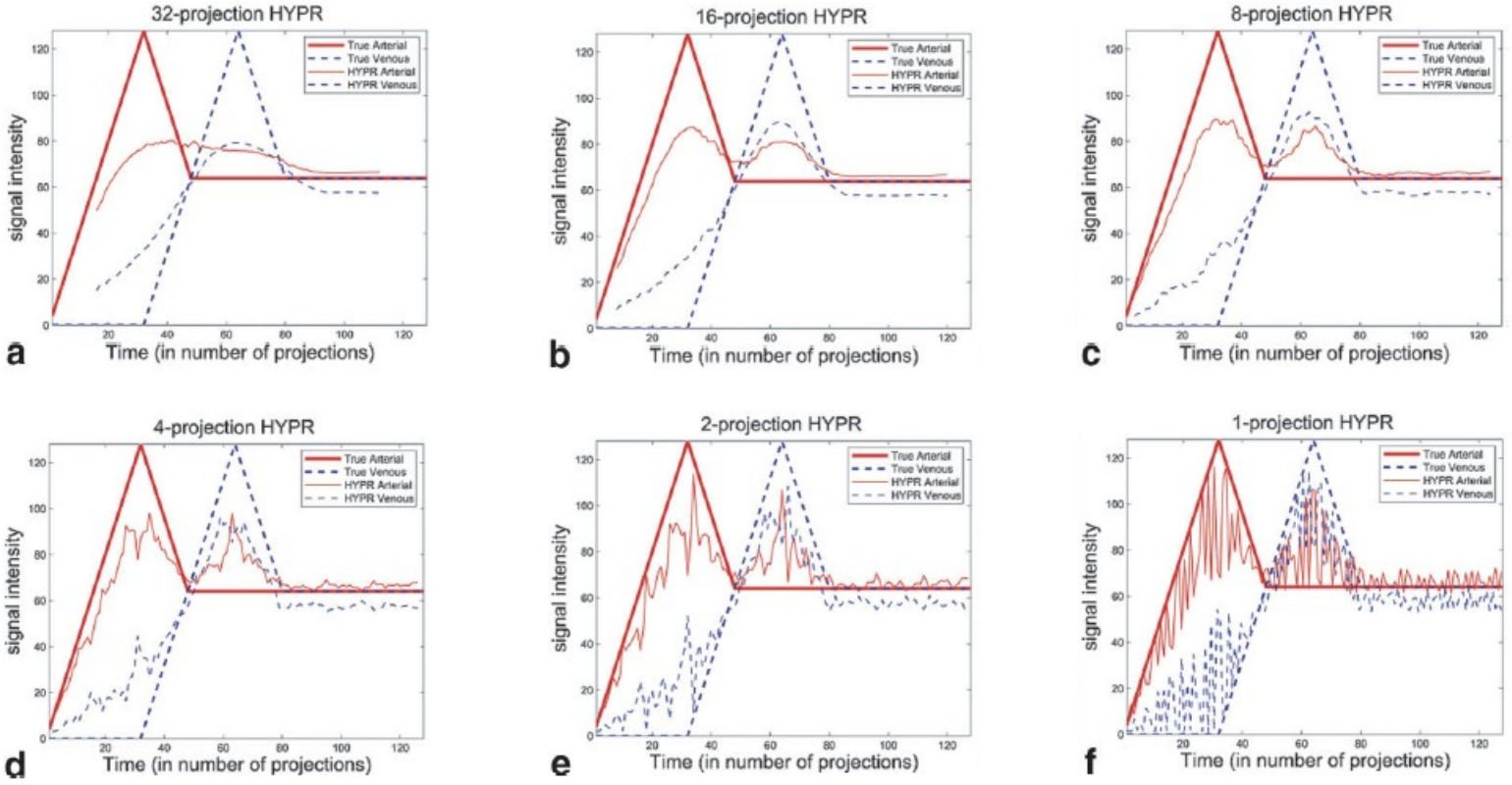






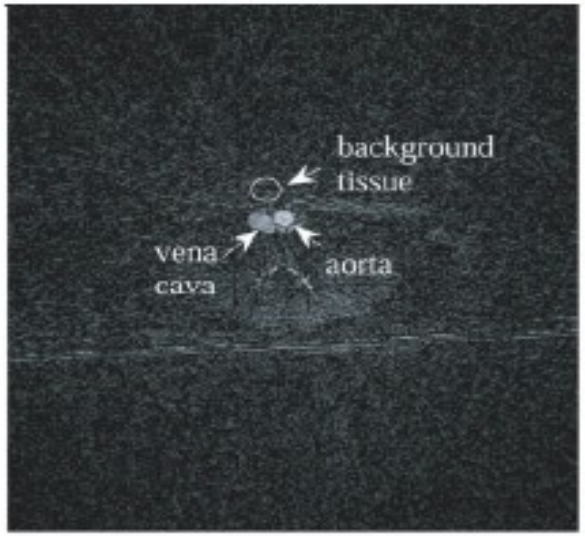
Simulation

- Same dynamics as previous simulation.
- HYPR detects venous intensity for the arterial image.
- Sliding window reconstruction is applied for updating one projection for each HYPR reconstruction.
- As the number of projections is reduces, the greater the fluctuations in intensity.

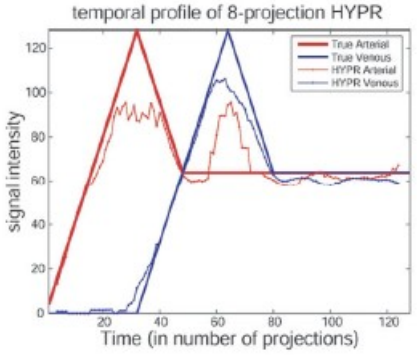


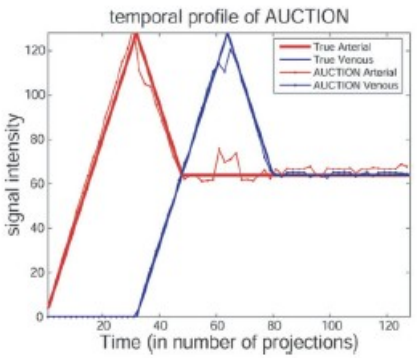
Background Tissue Signals

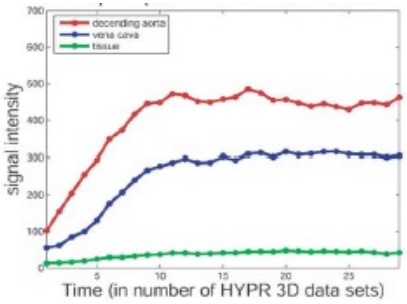
- Comparison of HYPR and AUCTION
- Arterial signal is less intense
- Background tissue is reconstructed more accurately than other signals.

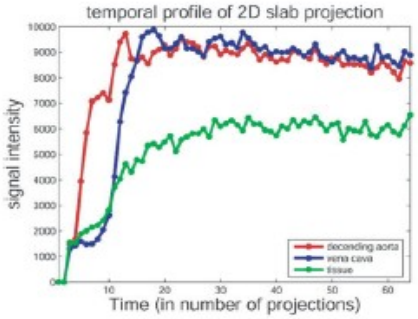


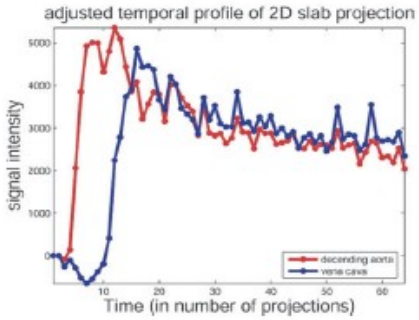
temporal profile of HYPR 3D data sets











Signal-to-Noise Ratio

- Filtered backprojection applied to limited-projection images produces a SNR that is significantly lower than that of the composite image.
- Unfiltered backprojection produces a higher SNR than filtered backprojection.
- The SNR of a HYPR image is dominated by the low SNR of the limited projection image.

Ex) Assume we have a circular shaped object that we are projecting,

SNR_c – SNR of the composite image

N_v – diameter of the object in pixels=5

N_{pix} – matrix size of the composite image in pixels=256

N_p – number of projections per HYPR group=16

$$SNR = SNR_c \frac{N_v}{\sqrt{N_{pix}}} \sqrt{N_p} = SNR_c \frac{5}{\sqrt{256}} \sqrt{16} = SNR_c (1.25)$$

Findings

- In Original HYPR, there is need to avoid the pixels that are zero (or near zero), these cause artifacts (spikes) in the HYPR image when the projections are normalized.
- In Wright HYPR, this is avoided since the denominator is the sum of a number of projections. The likelihood of zeros in the denominator is reduced.
- The number of acquisitions taken using bit-reversed ordering must be a power of 2.
- Large vessels cause signal interference to small vessels in HYPR, especially when the vessels are close to each other.
- Since this is a sparse data set, the interference of the nonuniform dynamics is relatively minor in terms of the overall image contrast.