An Initial Assessment of Clinical Quantitative Digital Subtraction Angiography (qDSA) Data

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Background

- Digital Subtraction Angiography (DSA) is the standard of care imaging method to evaluate hemodynamics during transarterial embolization.
- Current methods to determine the degree of blood flow reduction rely on subjective visual assessments of injected contrast agent dynamics.
- Quantitative Digital Subtraction Angiography (qDSA) is a method for measuring blood velocity from high frame rate 2D DSA acquisitions.
- Iodinated contrast agent is injected into pulsatile arterial blood flow and oscillations in contrast are tracked as they propagate downstream.[1]
- Previous investigations have shown qDSA velocity estimations are linear with respect to gold-standard ultrasound and MRI velocities in phantoms and swine models.[1][2]
- An interleaved x-ray method has been developed to acquire high frame rate (30 fps) images with reduced radiation dose.[3]
- This study reports the first findings in an IRB-approved study for evaluating the effectiveness of qDSA in human subjects.

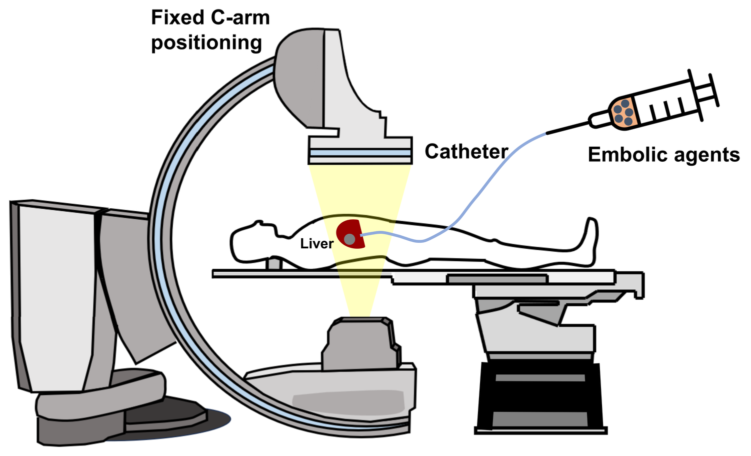


Figure 1: Interventional x-ray system during an embolization procedure. Real-time 2D DSA images are formed during injection of iodinated contrast agent. Microspheres are injected arterially to reduce tumor blood flow.

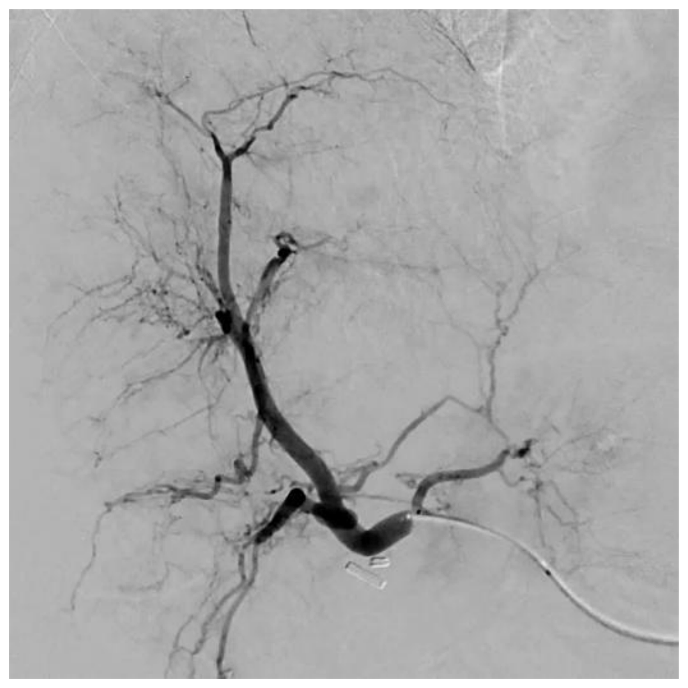


Figure 2: Example DSA image showing a human hepatic artery. The mixing of injected contrast agent with variable blood flow driven by the cardiac cycle leads to contrast oscillations at the point of injection, which propagate downstream with the blood flow.

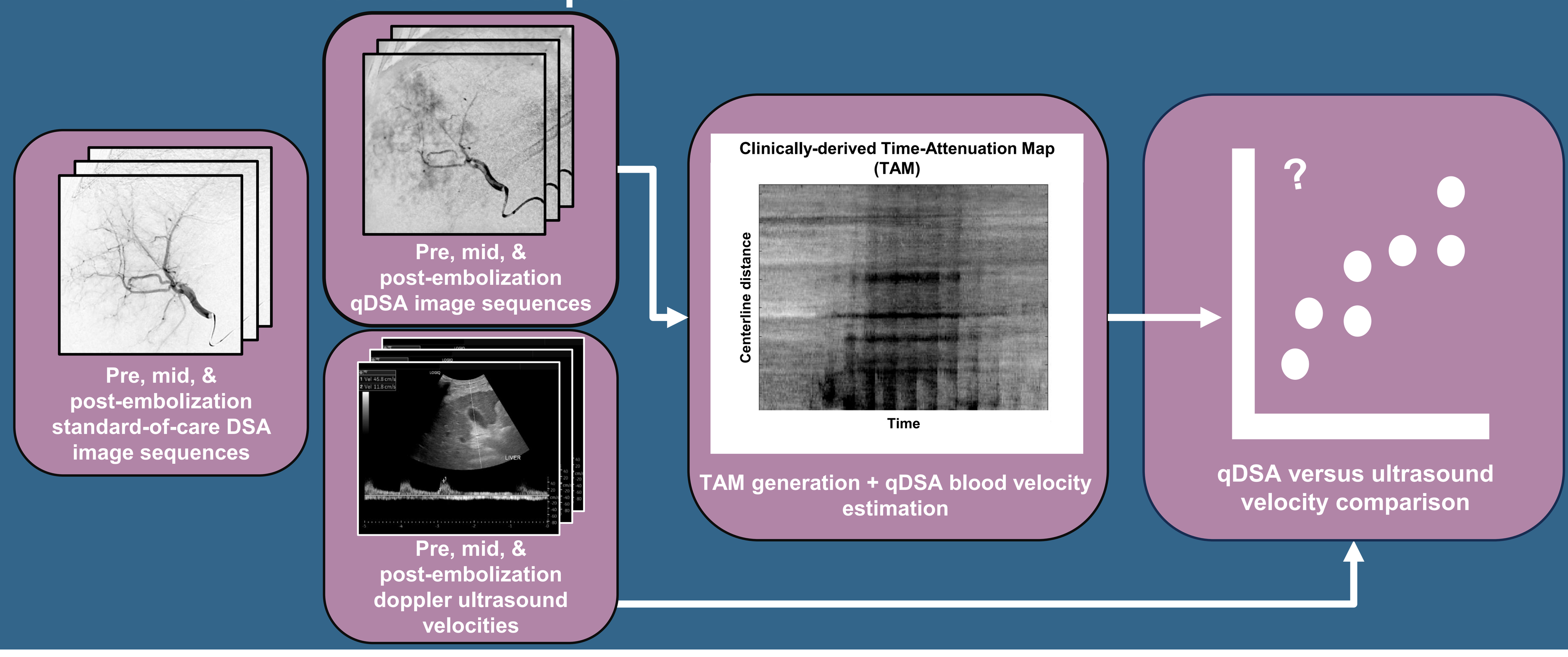
Purpose

The purpose of this study is to report an initial experience of acquiring qDSA data in human subjects.

Methods

Clinical data acquisition

- 6 patients with 9 independent embolized artery branches were enrolled in the study.
- X-ray imaging system: Artis Pheno Robotic C-arm
- Contrast agent: Iohexol 300 mgI/mL
- Pre, mid, and post-embolization sequences acquired in DSA (3-7.5 fps) and qDSA mode (30 fps, fluoro dose).
- Doppler ultrasound captured at each embolization state.

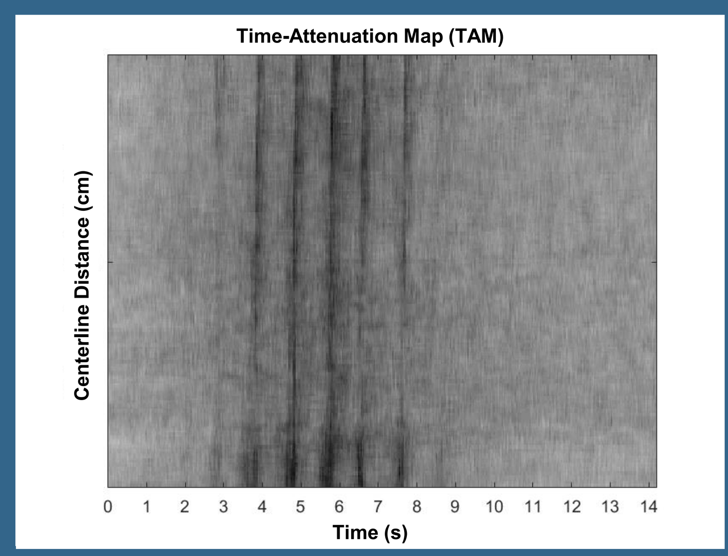


qDSA velocity estimation algorithm

Centerline extraction

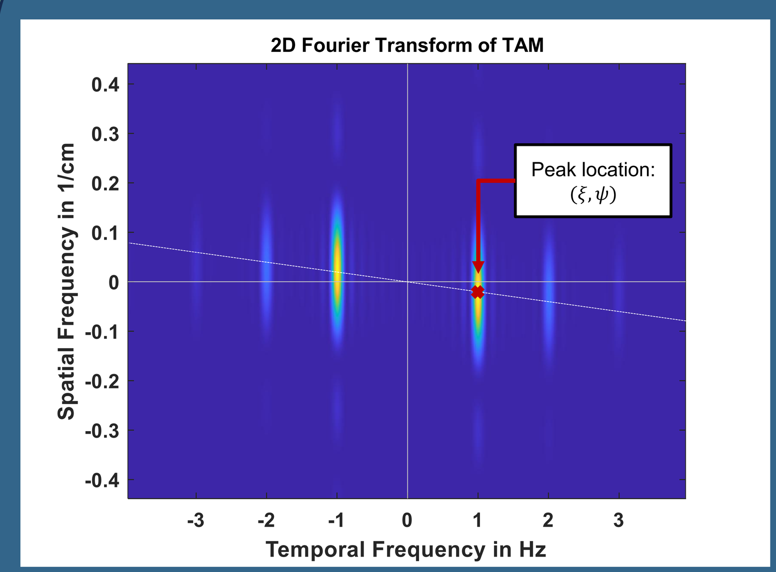
Step 1: Define moving vessel centerlines across qDSA frames.

TAM generation



Step 2: A Time-Attenuation Map (TAM) is generated by plotting qDSA intensity on the vessel centerline along the vertical axis and time along the horizontal axis. The angle of the dark streaks depends on the velocity of contrast oscillations as they propagate downstream.

Fourier-based peak finding



Step 3: The Fourier Transform of the TAM is taken, resulting in a fundamental frequency peak. The location of the peak encodes the velocity: $v = -\xi/\psi$.

Results

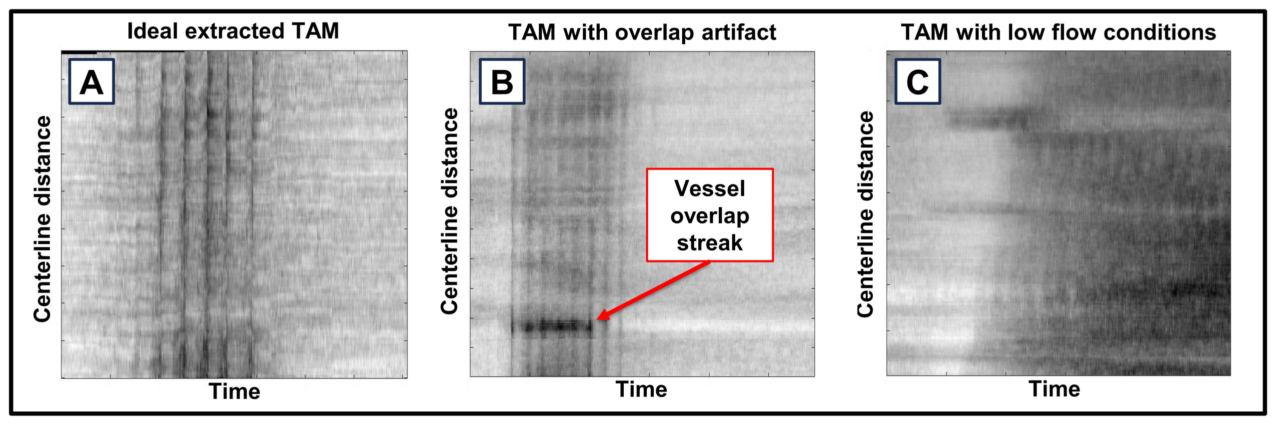


Figure 3: TAMs from images obtained from human subjects. Image A shows an artifact-free TAM, with dark streaks of contrast at an angle. Image B shows a TAM with dark enhancement towards the bottom due to vessel overlap. Image C shows a TAM obtained with a relatively high rate of injection (1.5 mL/s) during low blood flow conditions (post-embolization).

qDSA velocity analysis

- TAM artifacts included broad spatial and temporal changes in intensity due to contrast stagnation and localized contrast due to vessel overlap (Figure 3).
- From **pre-embolization to mid-embolization endpoints**, 12/14 (85.7%) of qDSA velocities exhibit median velocity reduction. For doppler ultrasound measurements, 6/8 (75.0%) of ultrasound velocities exhibit mean velocity reduction.
- From **mid-embolization to post-embolization endpoints**, 10/15 (66.7%) of qDSA velocities exhibit median velocity reduction. For doppler ultrasound measurements, 5/8 (62.5%) of ultrasound velocities exhibit mean velocity reduction.
- From **pre-embolization to post-embolization endpoints**, 12/15 (80.0%) of qDSA velocities exhibit median velocity reductions. For doppler ultrasound measurements, 8/9 (88.9%) of ultrasound velocities exhibit mean velocity reduction.

Data acquisition

- Contrast injection techniques for qDSA were adjusted downwards in rate and volume (range 0.5 – 5 mL/s, 2.0-6.0 s) relative to typical DSA to maintain visible contrast oscillations.
- Small detector modes resulted in less noisy images and larger vessels, which were more suitable for qDSA analysis.
- Sources of error for ultrasound acquisition included respiratory motion, small vessel sizes, and ultrasound measurement location differing from vessel analysis region.

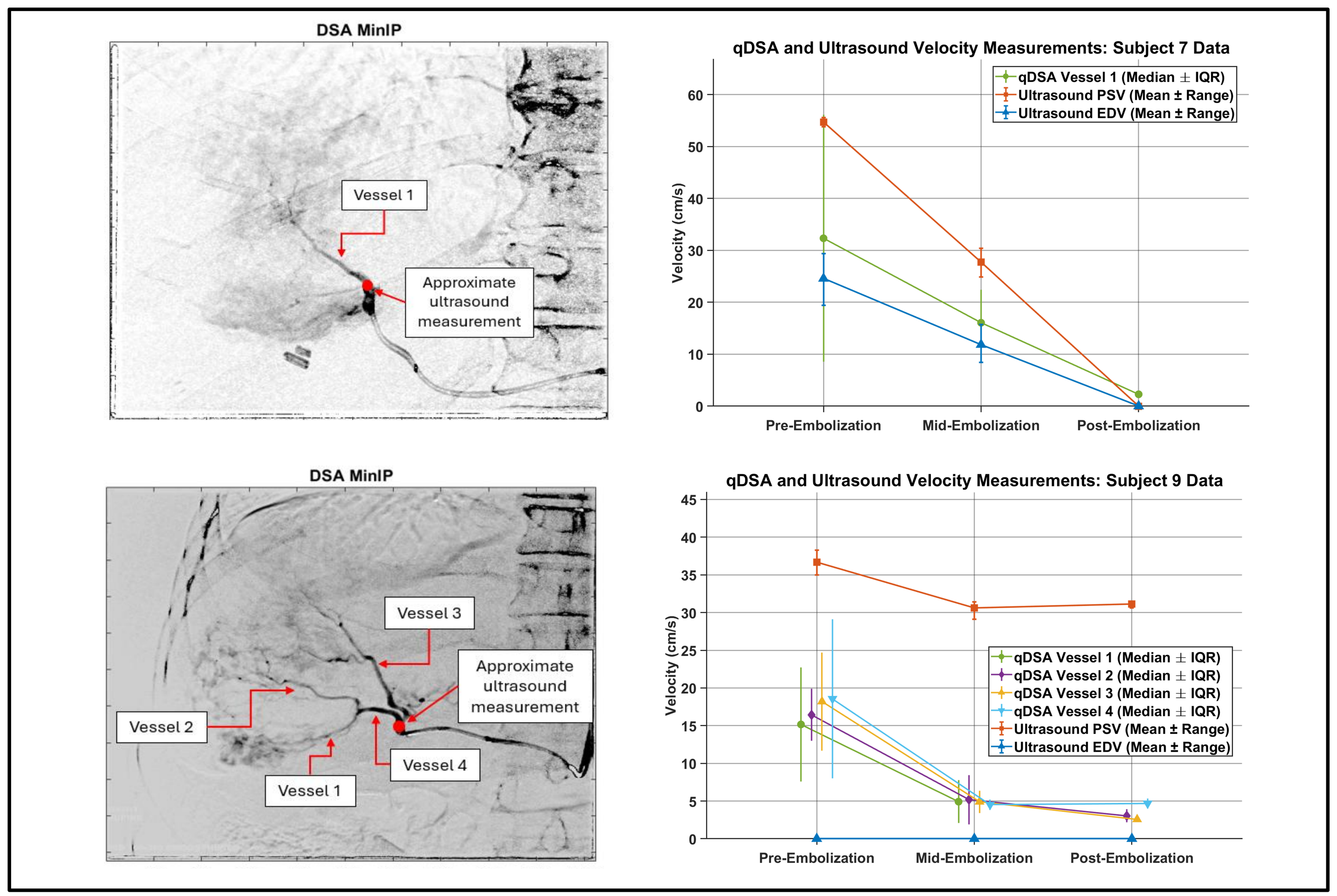


Figure 4: DSA acquisition minimum intensity projections (MinIPs, left column) showing the vessel with qDSA blood velocity estimation locations and the approximate location of the doppler ultrasound velocity measurements. The plot on the right shows qDSA velocities (median and interquartile range (IQR)) along with ultrasound peak systolic velocities (PSV) and end diastolic velocities (EDV).

Conclusions

- Proper C-arm positioning, small detector modes, respiratory management, and optimized contrast delivery allowed for data acquisition suitable for qDSA analysis.
- Blood velocity was reduced following embolization in 80.0% of the cases as measured by qDSA and in 88.9% of the same cases as measured by doppler ultrasound.
- If multiple arterial branches are visible in qDSA imaging, it may be possible to utilize velocity estimations in multiple independent vessel branches to inform more personalized embolization treatments.
- Future studies will identify optimal contrast injection rates based on background blood flow and analyze the accuracy of qDSA versus doppler ultrasound velocities in additional patients undergoing embolization procedures.

Acknowledgements

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References

[1] Wagner MG, Whitehead JF, Periyasamy S, Laeseke PF, Speidel MA, Spatiotemporal frequency domain analysis for blood velocity measurement during embolization procedures. Med Phys. 2024 Mar;51(3):1726-1737. doi: 10.1002/mp.16715.

[2] Whitehead, JF, Hoffman CA, Wagner MG, Periyasamy S, Meram E, Keller ME, Speidel MA, Laeseke PF. Quantitative Digital Subtraction Angiography Measurement of Arterial Velocity at Low Radiation Dose Rates. CardioVasc Interven Radiol. 2024 July;47:1119-1126. doi: 10.1007/s00270-024-03809-7

[3] Whitehead JF, Hoffman CA, Wagner MG, Minesinger G, Nikolau E, Laeseke P, Speidel MA, Interleaved x-ray imaging: A method for simultaneous acquisition of quantitative and diagnostic digital subtraction angiography. Med Phys. 2023 Oct; 51(4):2468-2478 doi: 10.1002/mp.16794