Calculation of Energy Loss in the Left Ventricle from Color Doppler Ultrasound

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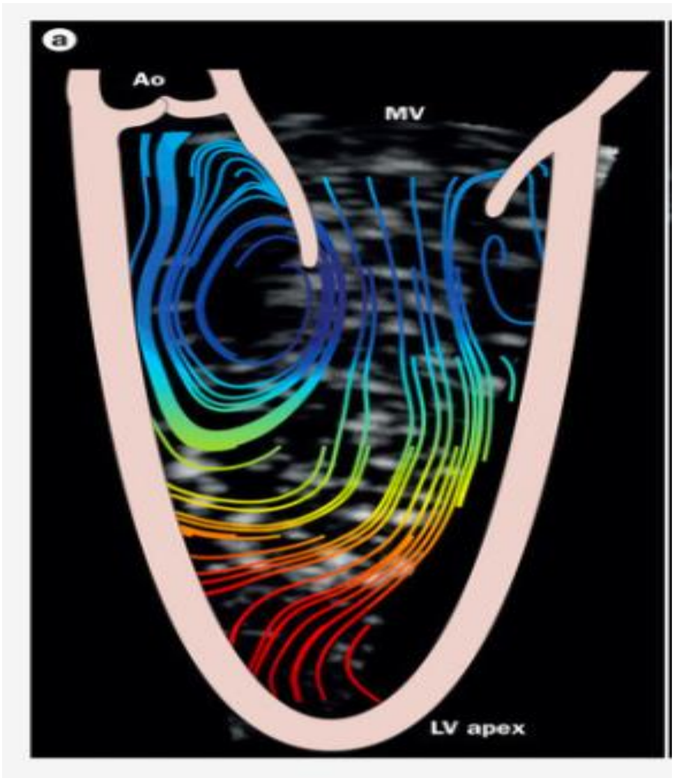
Abstract: Cardiovascular diseases have been associated with blood flow structures in the heart; however, how these flow structures contribute to the progression of these diseases is poorly understood. Here, color-Doppler ultrasound was employed to assess blood flow in the left ventricle by evaluating kinetic energy losses. Color-Doppler ultrasound is a commonly used clinical tool to measure blood flow, but provides limited data, with velocity information only available in a single dimension. This research seeks to assess whether diagnostic values can be calculated directly from color-Doppler ultrasound data or if it is necessary to reconstruct the flow field by investigating energy losses. Energy losses were calculated in synthetic flow fields and ultrasound data. Preliminary results show there is a predictable relationship between the energy losses found using only the radial velocity and those found using reconstructed velocity fields.

1. INTRODUCTION

1. Blood flow in normal and pathological left ventricle

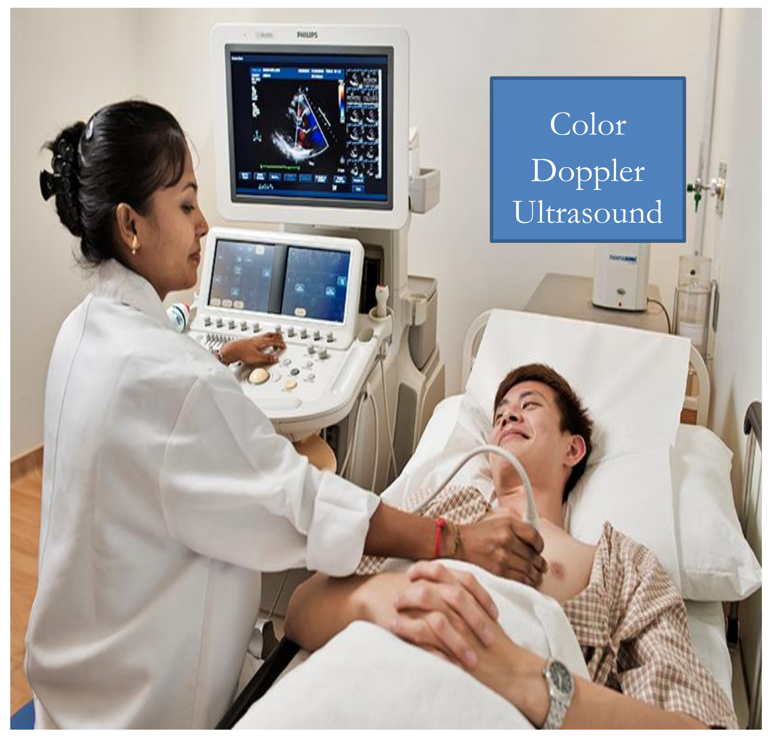
- Cardiovascular disease, such as heart failure, is the leading cause of death worldwide, contributing to 17.5 million deaths annually[1].
- Blood flow structures in the left ventricle are linked with cardiovascular diseases, but it needs to be better understood how these structures contribute to the progression of these diseases.
- The difficulty to image flow in the heart is the main contributor to this lack of understanding.



[2]

2. Imaging of blood flow in the heart

- Phase-Contrast MRI is the current gold standard for imaging flow in the heart, because it provides a full, three-dimensional flow field. However, it is expensive and time-consuming.
- Color-Doppler ultrasound is a much cheaper alternative, but it only provides velocity information in a single dimension.



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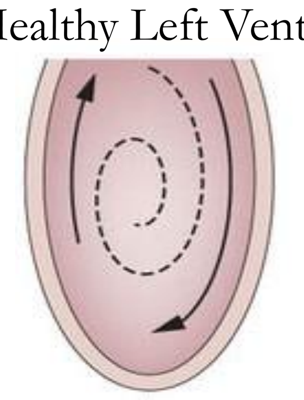
3. Kinetic energy as a potential diagnostic measure

Healthy Left Ventricle



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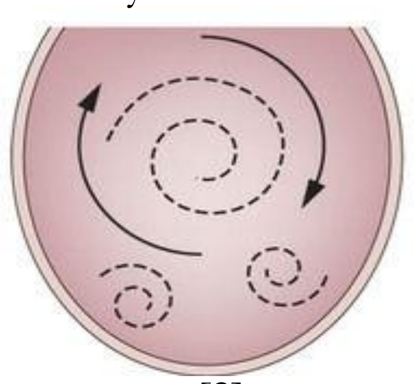
Unhealthy Left Ventricle



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Recent studies show that blood flow in normal and pathological flow is linked with kinetic energy loss (i.e. Energy loss is higher in unhealthy left ventricles).

2. METHOD

1st Method: Energy loss is calculated from only the radial velocity, which is measured directly from color-Doppler ultrasound.

Input: Radial velocity from Color-Doppler Ultrasound data

↓

Flow Energy Loss

$$\mu \int_{\Omega} \left[\left(\frac{\partial u_r}{\partial r} \right)^2 + \left(\frac{u_r}{r} \right)^2 \right] d\Omega$$

↓

Energy Loss as a result

2nd Method: Energy loss is calculated from both the radial velocity and reconstructed velocity.

Input: Radial velocity from Color-Doppler Ultrasound data

↓

Polar Continuity Equation: used to reconstruct in-plane component of velocity [3]

$$\frac{\partial u_\theta}{\partial \theta} + r \frac{\partial u_r}{\partial r} + u_r = 0$$

↓

Flow Energy Loss

$$\mu \int_{\Omega} \left[\left(\frac{\partial u_r}{\partial r} \right)^2 + \left(\frac{1}{r} \frac{\partial u_\theta}{\partial \theta} + \frac{u_r}{r} \right)^2 + \left(r \frac{\partial}{\partial r} \left(\frac{u_\theta}{r} \right) + \frac{1}{r} \frac{\partial u_r}{\partial \theta} \right)^2 \right]$$

↓

Energy Loss as a result

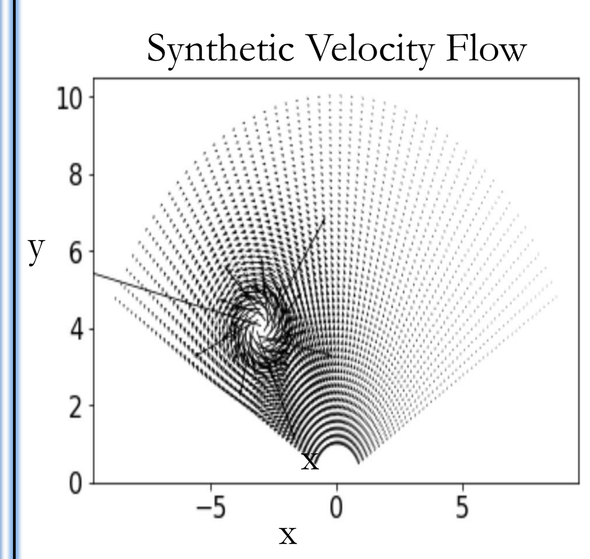
↓

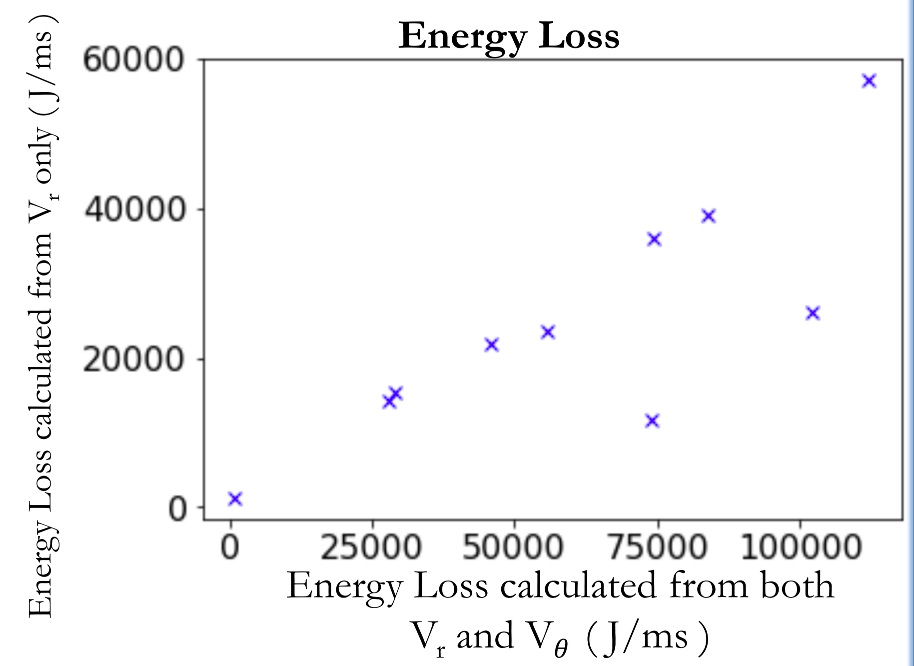
1st Method and 2nd Method were compared

3. RESULTS

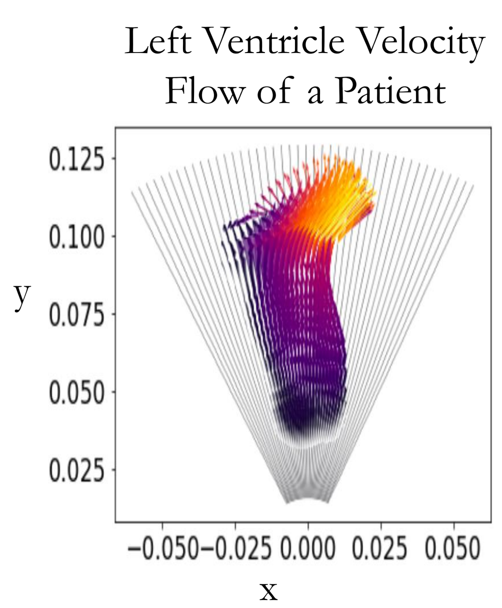
- A predictable relationship exists between the energy loss calculated from only the radial velocity and energy loss calculated from both the radial and reconstructed velocity.

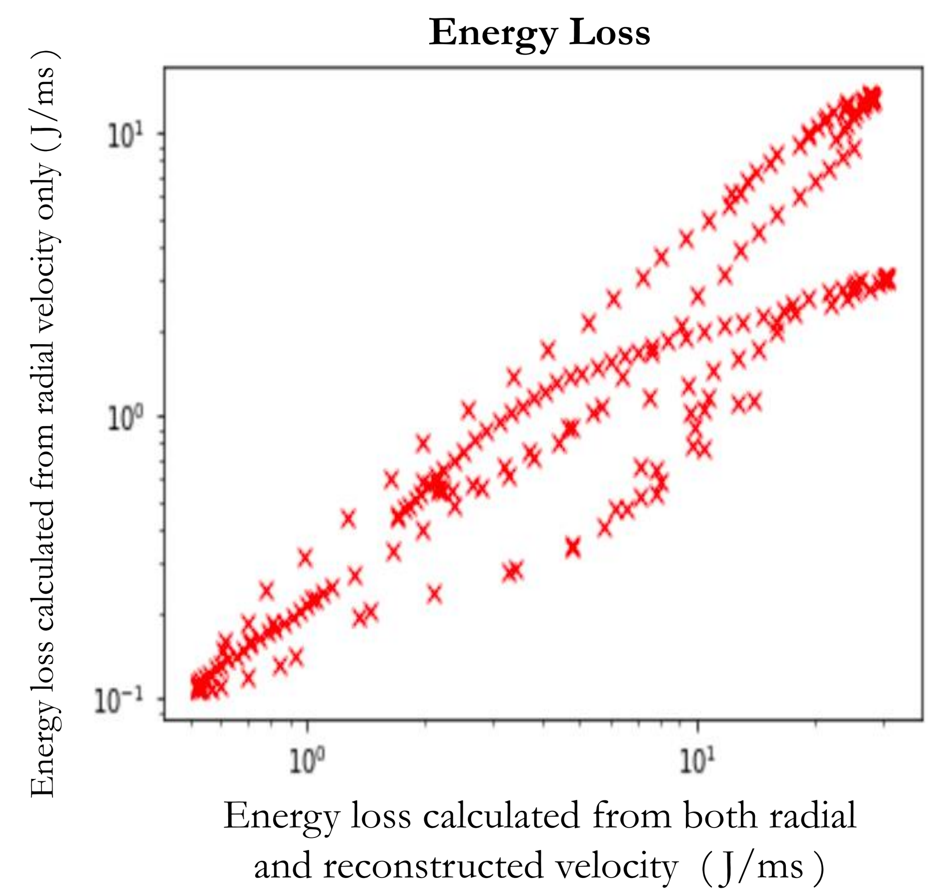
Synthetic Result





Patient Result





4. DISCUSSION AND CONCLUSION

There is no need to reconstruct the velocity field in determining energy loss if there is a predictable relationship between the energy loss using radial velocity only and energy loss with both the reconstructed and radial velocity field.

5. FUTURE PLANS

- Compare kinetic energy losses in healthy and diseased patients.
- Determine the relationship between the energy loss calculated with both the reconstructed and radial velocity and the energy loss calculated with radial velocity only.

6. REFERENCES

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