Echo beyond 2020: Vortex and gradient imaging

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COI

- Research funding: Hitachi, Cannon

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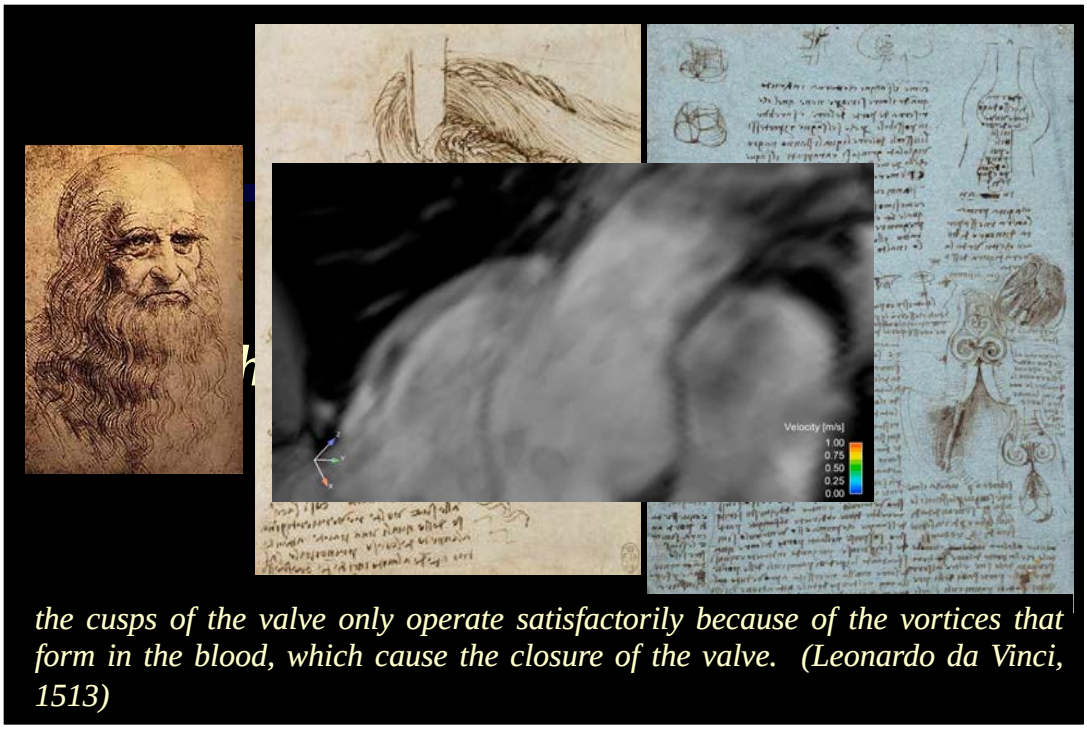

the cusps of the valve only operate satisfactorily because of the vortices that form in the blood, which cause the closure of the valve. (Leonardo da Vinci, 1513)

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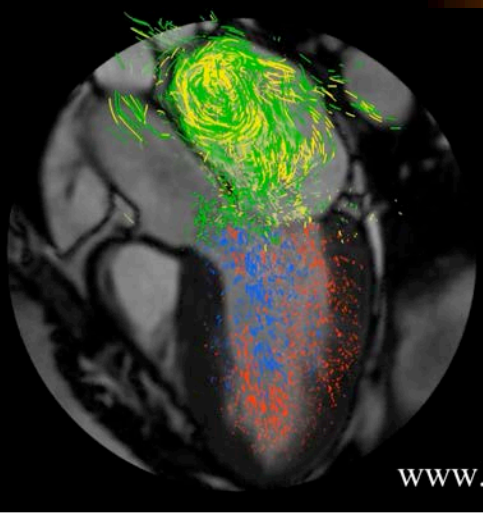
Intracardiac vortex by MRI



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Roles of intracardiac vortex

- To prevent collision of flow
- To avoid excessive turbulence and dissipation of energy
- To redirect blood flow towards LV outflow tract
- To make fluid transport efficient

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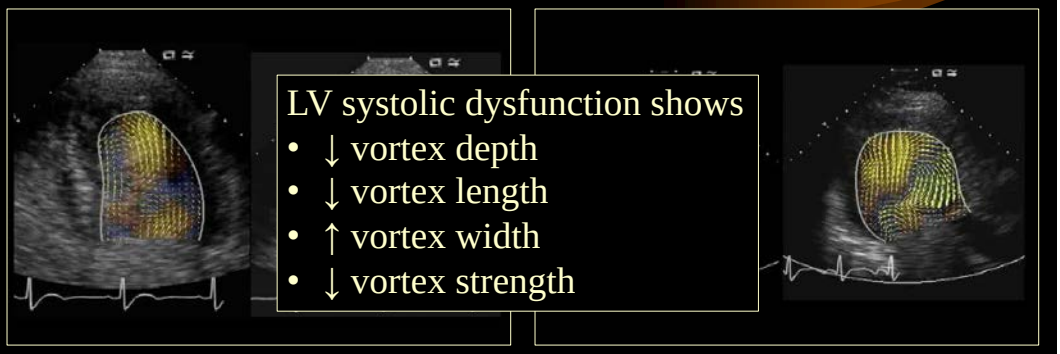
Normal vs. LV systolic dysfunction
Echo Particle Image Velocimetry



Normal | LV systolic dysfunction

(Hong GR, JACC Img 2008;1:705)

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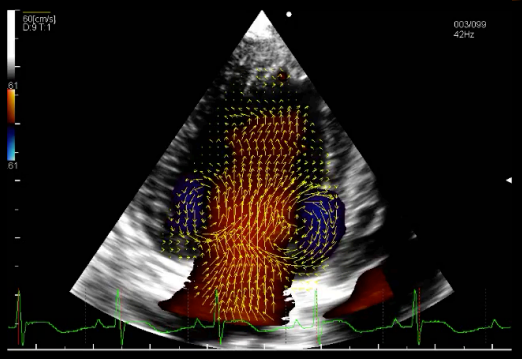
Quantification of intracardiac flow
Vector flow mapping (VFM®)



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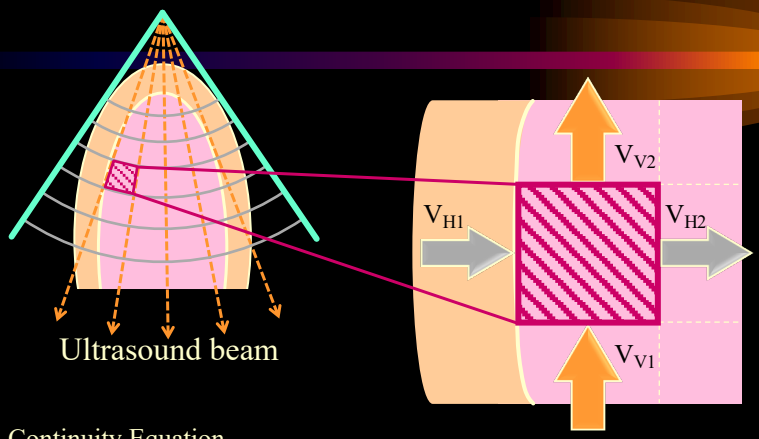
How can we measure horizontal velocity?



Continuity Equation

$$V_{V1} + V_{H1} = V_{V2} + V_{H2}$$

$$V_{H2} = V_{V1} + V_{H1} - V_{V2}$$

V_{V1} , V_{V2}: Doppler
V_{H1} : speckle tracking

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Application of VFM

- Visualization of intracardiac flow
  - Vector mode
  - Pathline imaging
- Flow velocity and direction independent of Doppler beam direction
  - Parameters derived from velocity
    - Shear stress — WSS = μ（dv /dy），μ: blood viscosity
    - Energy loss — EL = $\Sigma ij \int (1/2)\ \mu\ (\partial ui/\partial xj + \partial uj/\partial xi)^2\ dv$
    - Relative pressure difference — Based on Navier-Stokes equation

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Pathline imaging

Pathline: motion of virtual particles

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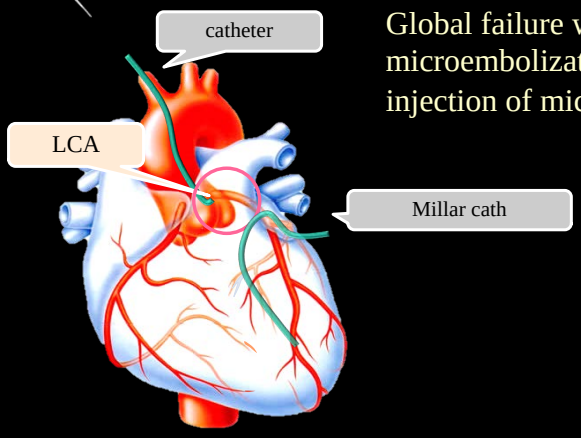
Creation of LV global failure



Global failure was created by coronary microembolization by intracoronary injection of microspheres (85 μm).

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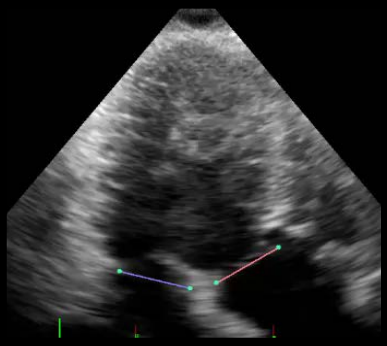
Pathline imaging

Control



Heart failure

Ejection rate = # outflow particles / # inflow particles

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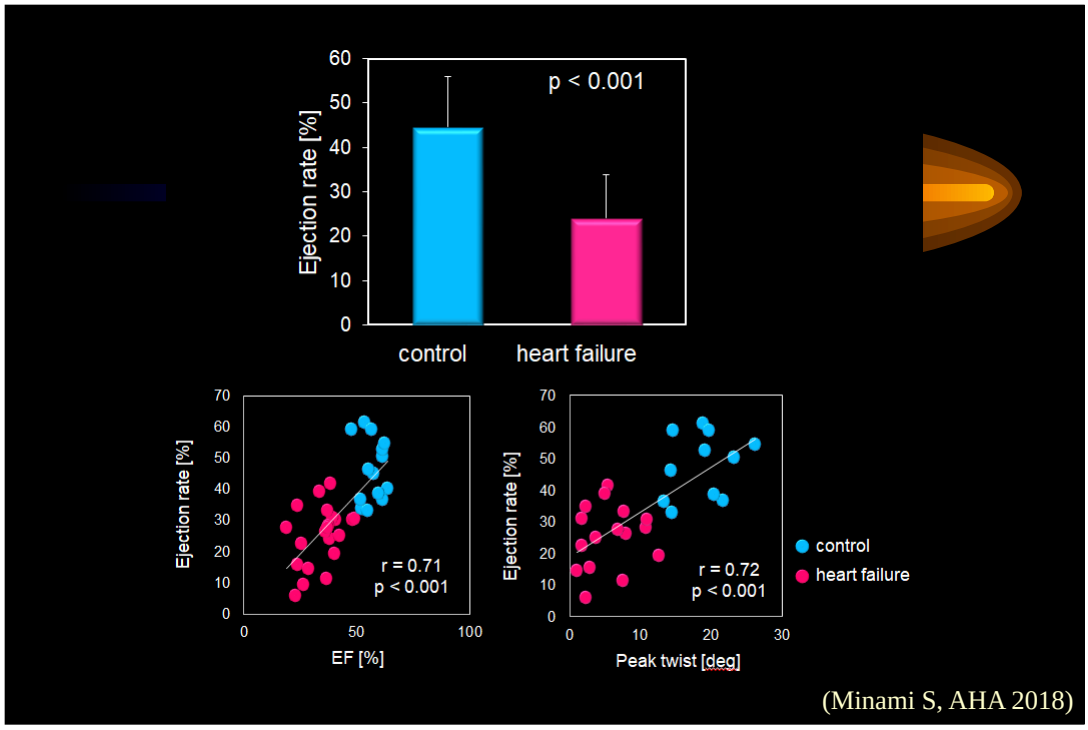
p < 0.001
Ejection rate [%]
60
50
40
30
20
10
0
control
heart failure
Ejection rate [%]
EF [%]
r = 0.71
p < 0.001
Peak twist [deg]
r = 0.72
p < 0.001
control
heart failure
(Minami S, AHA 2018)

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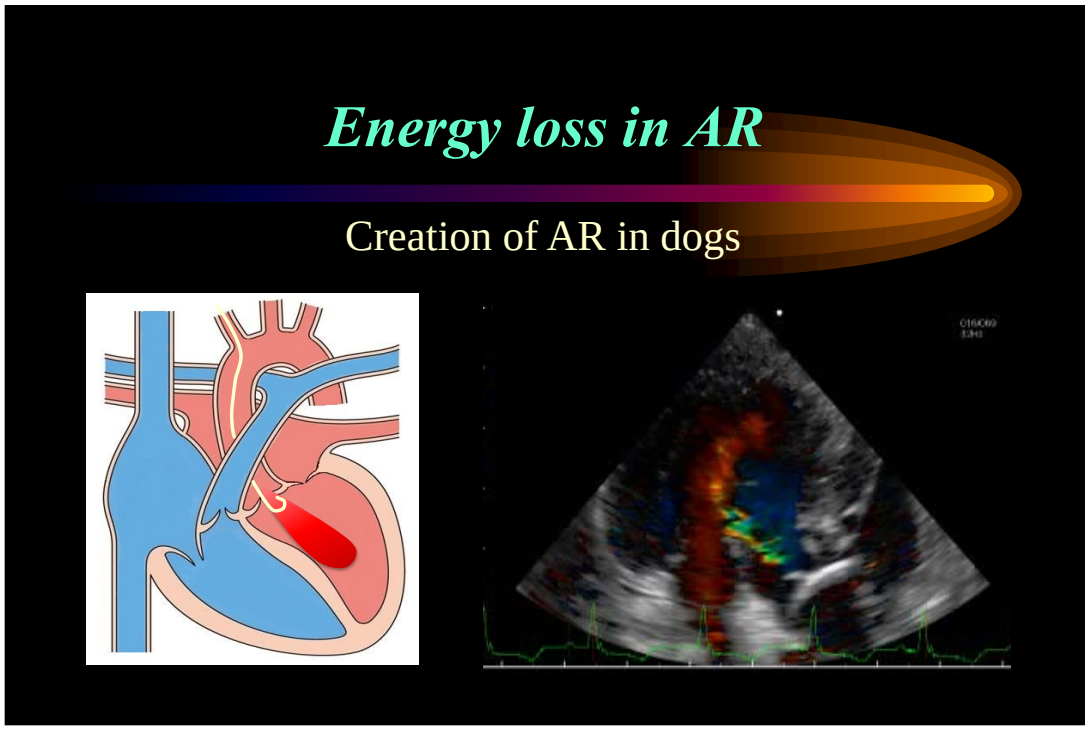
Energy loss in AR
Creation of AR in dogs

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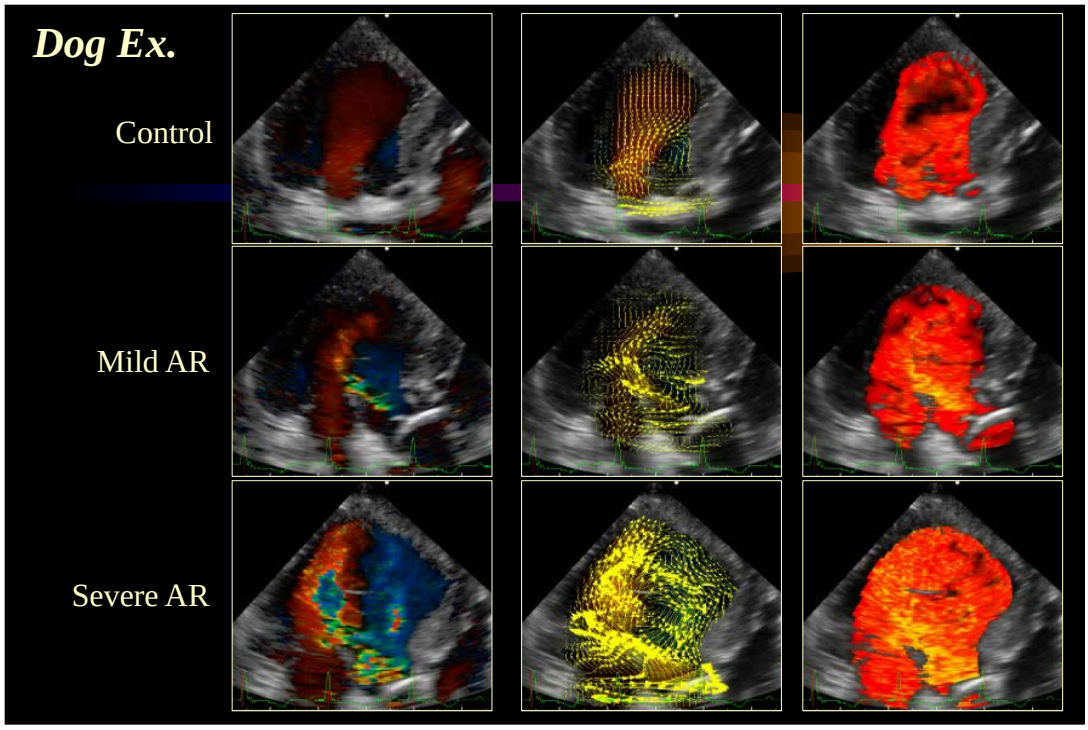
Dog Ex.
Control
Mild AR
Severe AR

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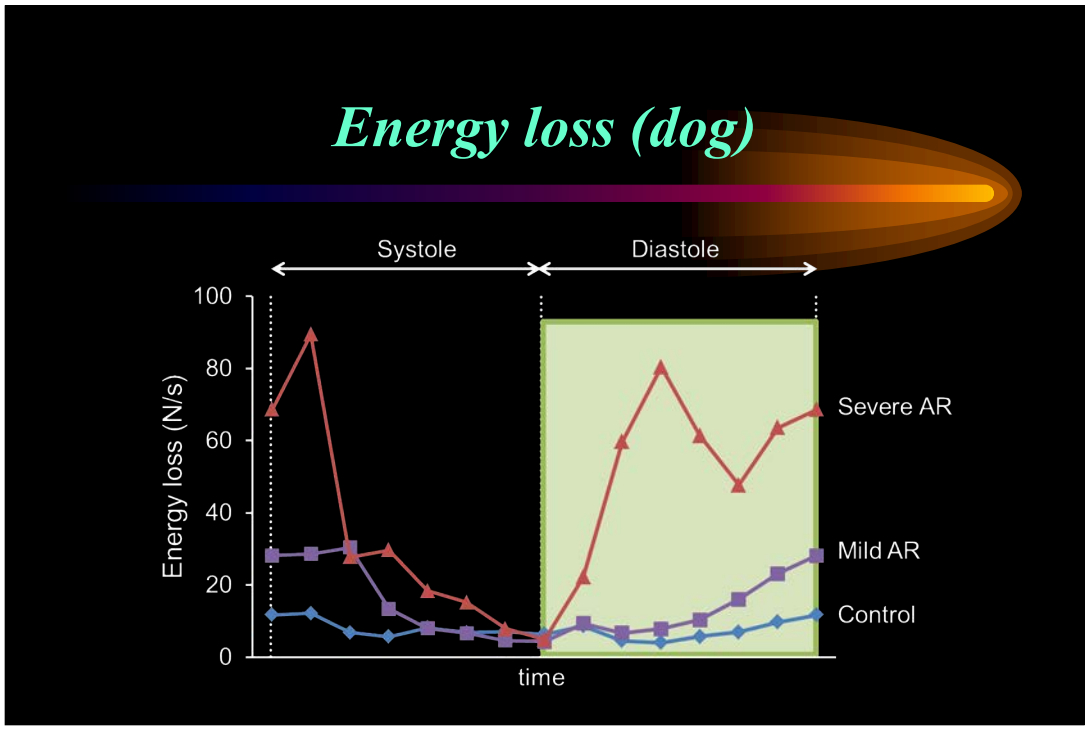
Energy loss (dog)
Systole
Diastole
Energy loss (N/s)
100
80
60
40
20
0
time
Severe AR
Mild AR
Control

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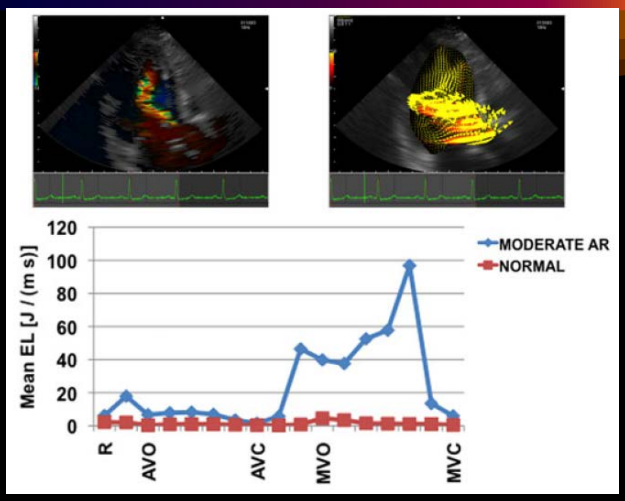
Energy loss in patients with AR



(Stugaard M, EHJ-CVI 2015;16:723)

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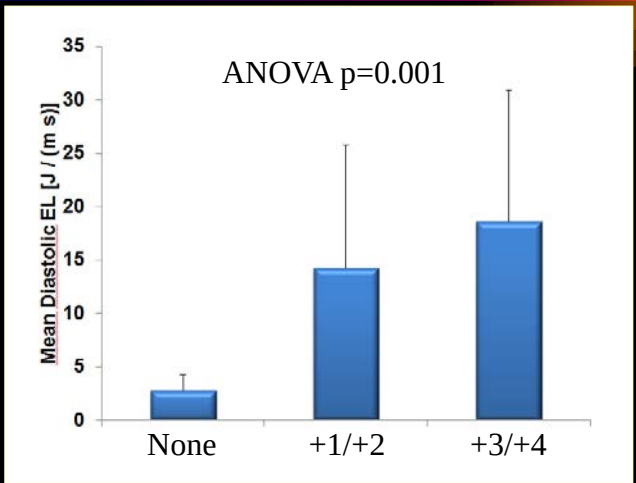
AR severity and energy loss clinical cases



(Stugaard M, EHJ-CVI 2015)

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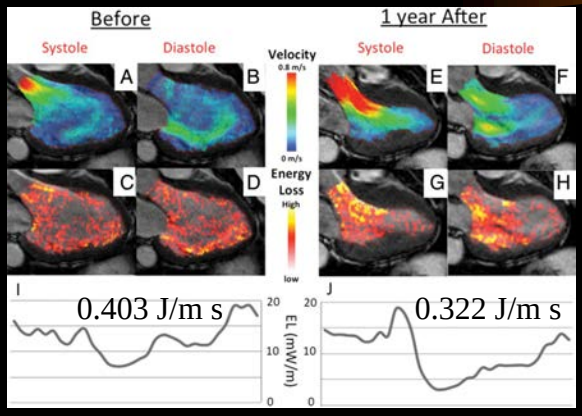
Energy loss may be a novel parameter

Energy loss reflects therapeutic effect in DCM.



(Nabeta T, Itatani K, et al. EHJ 2015;36:637)

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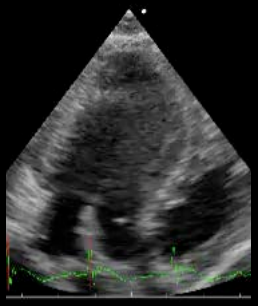
From vector to pressure



Navier-Stokes equation

Vector mode

Relative pressure imaging

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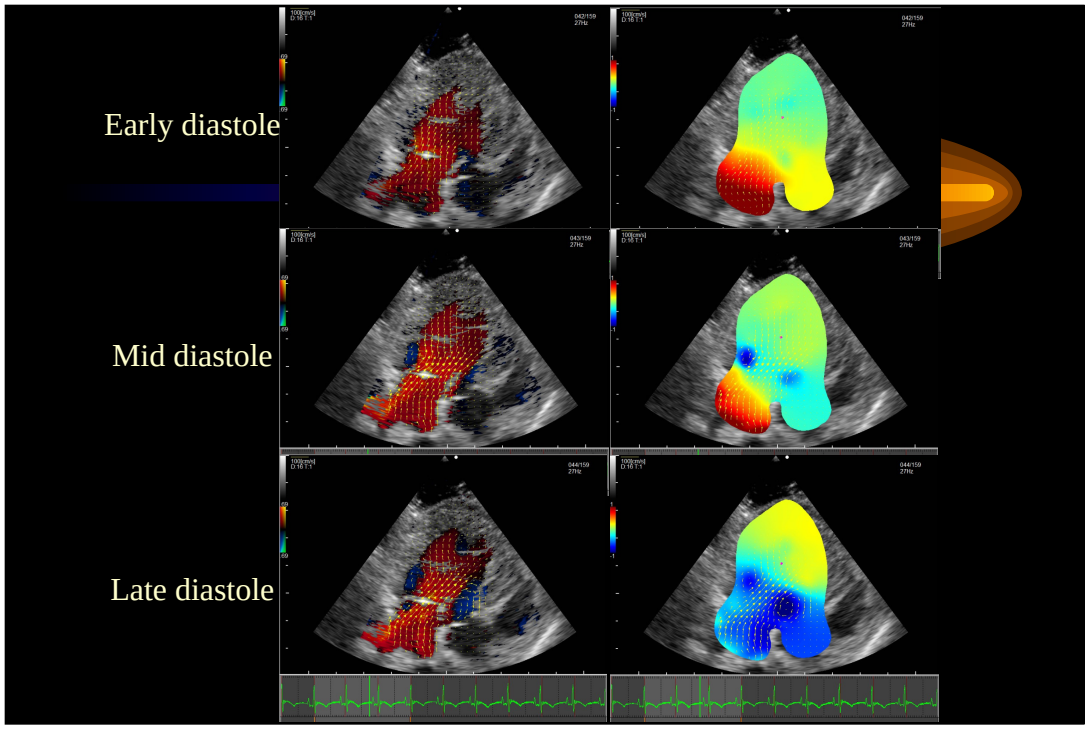

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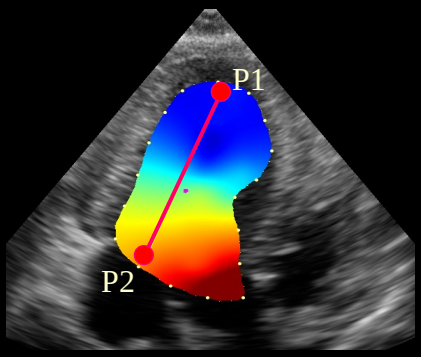
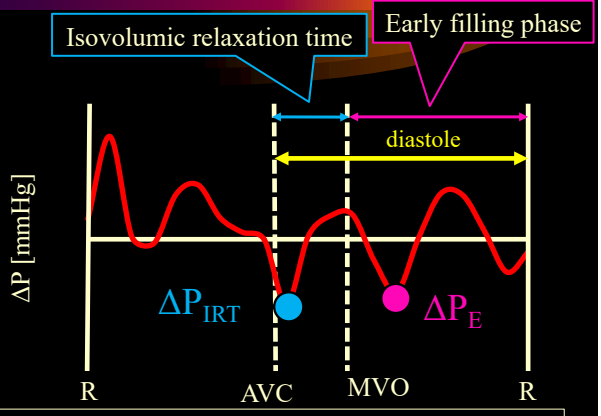
Intraventricular pressure difference





ΔP_{IRT} = IVPD during IRT = diastolic suction

ΔP_{E} = IVPD during early diastole = suction from LV + pushing from LA

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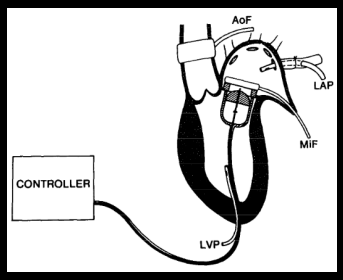
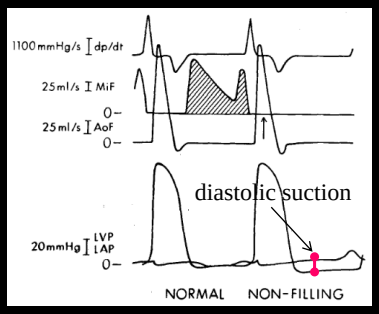
Diastolic suction

The capacity of the LV to generate a subatmospheric pressure during early diastole in nonfilling beats.





LVP becomes negative when MV is closed at end-systole.→ *diastolic suction*

(Yellin EL, Prog Cardiovasc Dis 1990;32:247)

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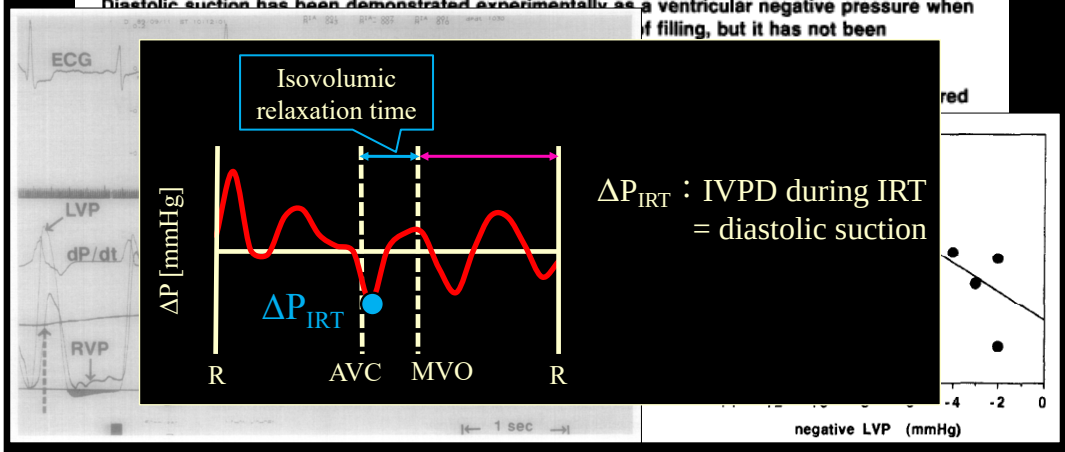
Diastolic suction in the human ventricle: Observation during balloon mitral valvuloplasty with a single balloon

Diastolic suction has been demonstrated experimentally as a ventricular negative pressure when ... filling, but it has not been ... red



(Nakatani S, AHJ 1994;127:143)

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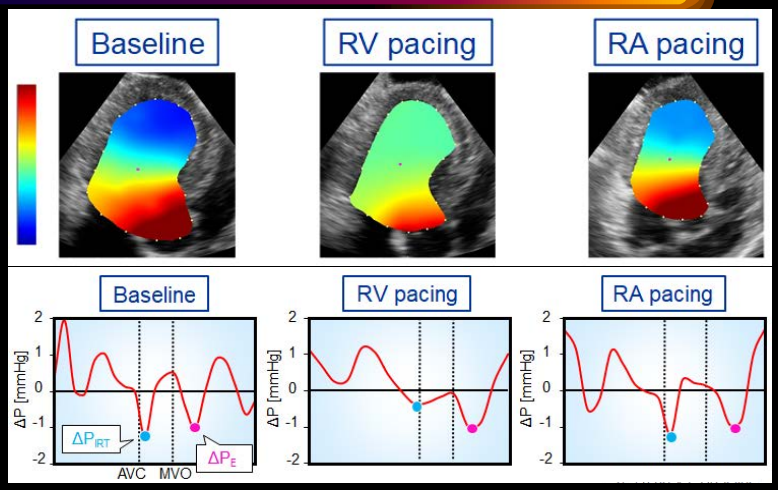
IVPD during dyssynchrony

20 dogs
RV pacing（n=10）
RA pacing（n=10）

LV dyssynchrony
↓
↓ diastolic suction
↓
Heart failure



(Minami S, AHA 2017)

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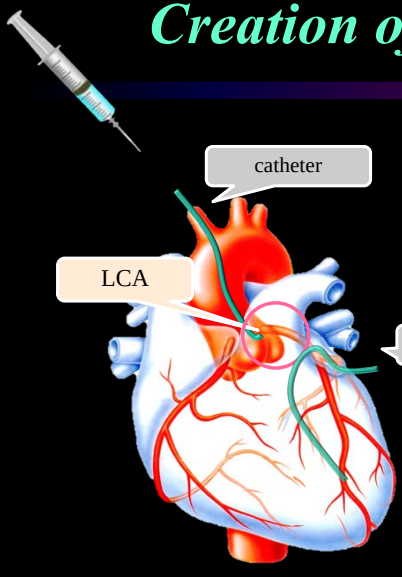
Creation of LV global failure



Global failure was created by coronary microembolization by intracoronary injection of microspheres (85 μm).

LVEDP < 15　mild failure (n=6)
LVEDP≧15　moderate failure (n=11)

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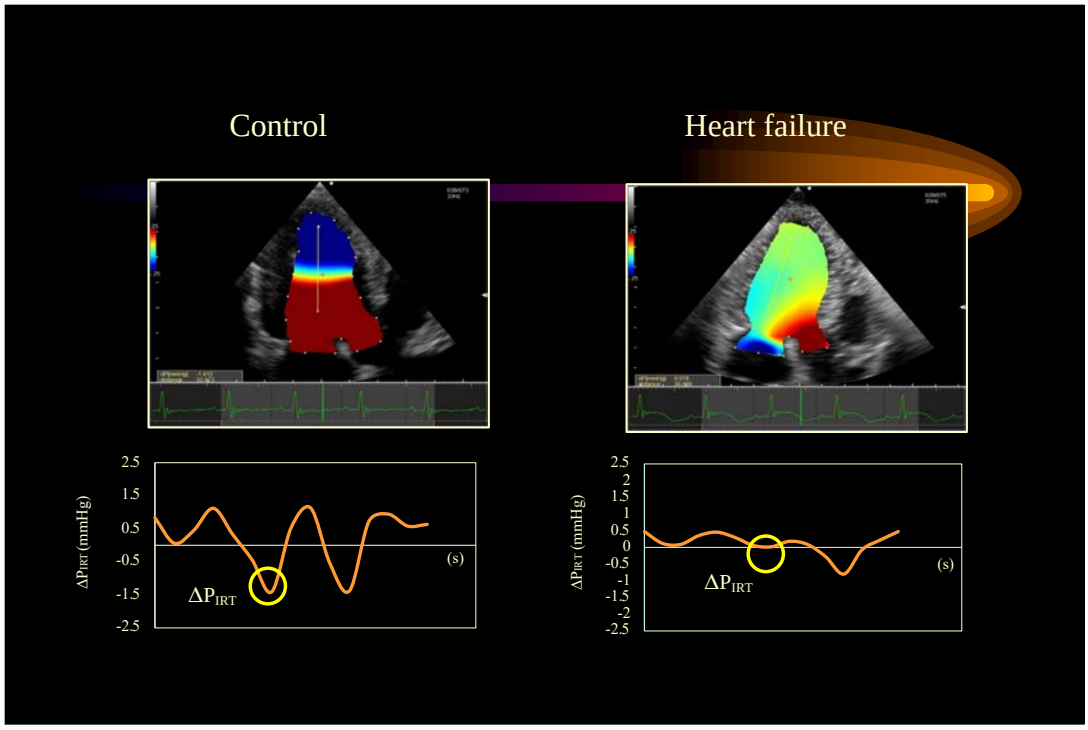
Control
Heart failure
ΔPIRT (mmHg)
2.5
1.5
0.5
-0.5
-1.5
-2.5
ΔPIRT
(s)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
ΔPIRT (mmHg)
ΔPIRT
(s)

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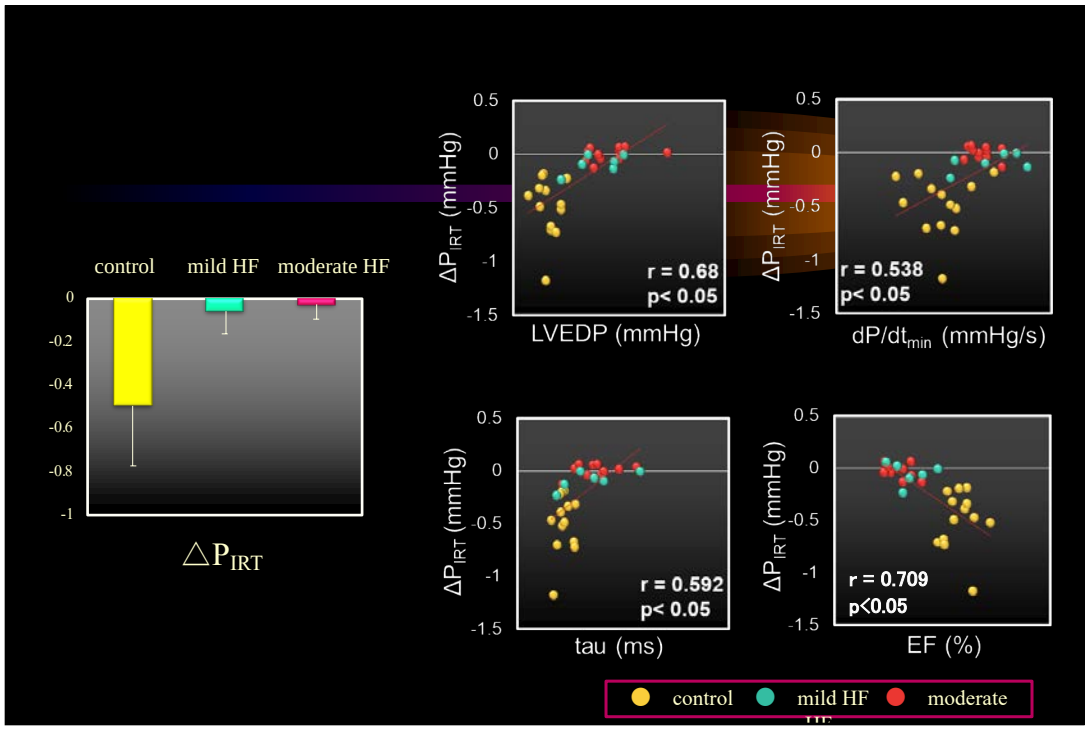
control
mild HF
moderate HF
0
-0.2
-0.4
-0.6
-0.8
-1
△PIRT
ΔPIRT (mmHg)
0.5
0
-0.5
-1
-1.5
r = 0.68
p< 0.05
LVEDP (mmHg)
r = 0.538
p< 0.05
dP/dtmin (mmHg/s)
r = 0.592
p< 0.05
tau (ms)
r = 0.709
p<0.05
EF (%)
control
mild HF
moderate

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Conclusions

- VFM (vector flow mapping) provides us information on intracardiac flow velocity and vortex independent of Doppler beam direction.
- Ejection rate, shear stress, energy loss and intraventricular relative pressure distribution derived from VFM may be useful to assess pathophysiology of various cardiac conditions.
- IVPD during IRT may be useful as a new index of diastolic function (diastolic suction).

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Echo beyond 2020: Vortex and gradient imaging

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