Inferior vena cava tracking in spontaneously breathing patients

21st Annual Center for Advanced Signal and Image Sciences Workshop

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Lawrence Livermore National Laboratory

Inferior vena cava tracking in spontaneously breathing patients

Inferior vena cava tracking in spontaneously breathing patients, or

How to tell just how full the Holy Grail of emergency medicine is

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emergency medicine

emergency medicine

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emergency medicine

emergency medicine

burns
stroke
sepsis
trauma
heart disease
catastrophic injuries
multiple organ failure

leading causes of death

emergency medicine

burns

5 **stroke**

sepsis

4 **trauma**

1 **heart disease**

catastrophic injuries

multiple organ failure

multifaceted injuries
emergency medicine
burns
stroke
sepsis
trauma
heart disease
catastrophic injuries
multiple organ failure

multiple echelons of care
emergency medicine
burns
stroke
sepsis
trauma
heart disease
catastrophic injuries
multiple organ failure

$260 billion per year
emergency medicine

Inferior vena cava tracking in spontaneously breathing patients, or

How to tell just how full the Holy Grail of emergency medicine is

the Holy Grail

the Holy Grail

our abc's

the Holy Grail

airway

breathing

circulation

the Holy Grail
airway
breathing
circulation

pH
PaO_2
hematocrit
stroke volume
venous pressure
arterial pressure
heart rate
circulation

pH

PaO_2

hematocrit

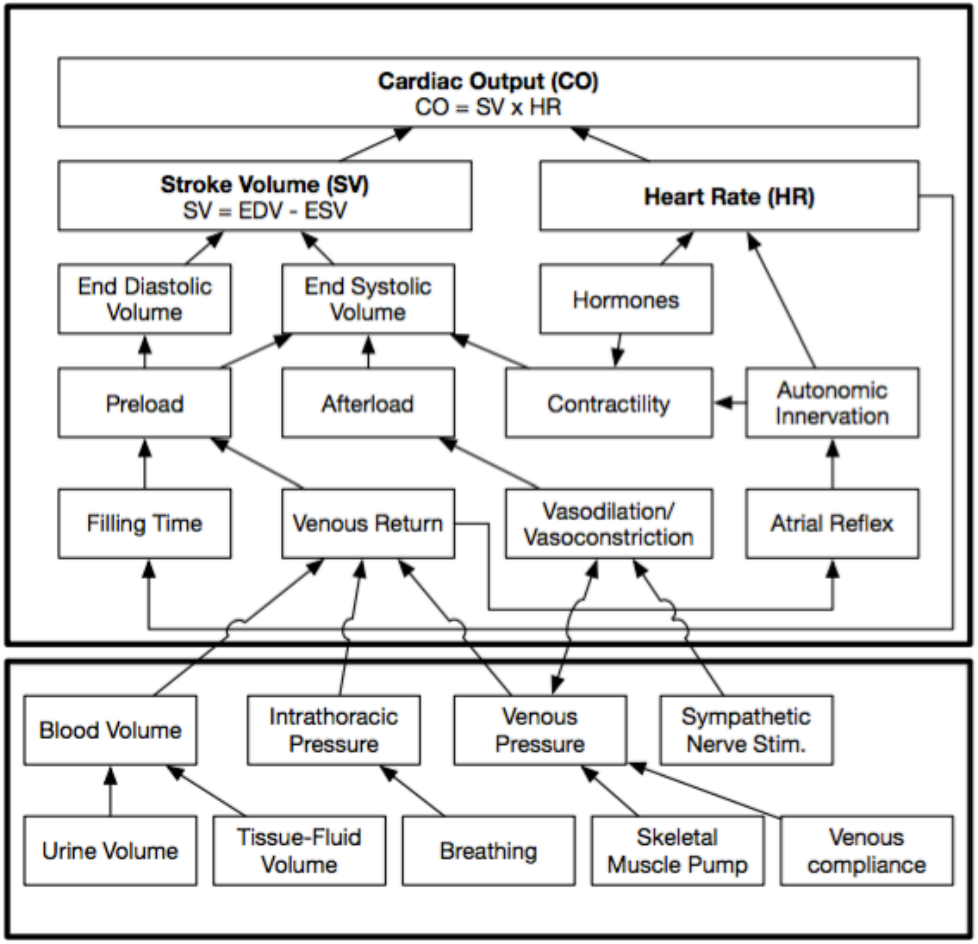
stroke volume

venous pressure

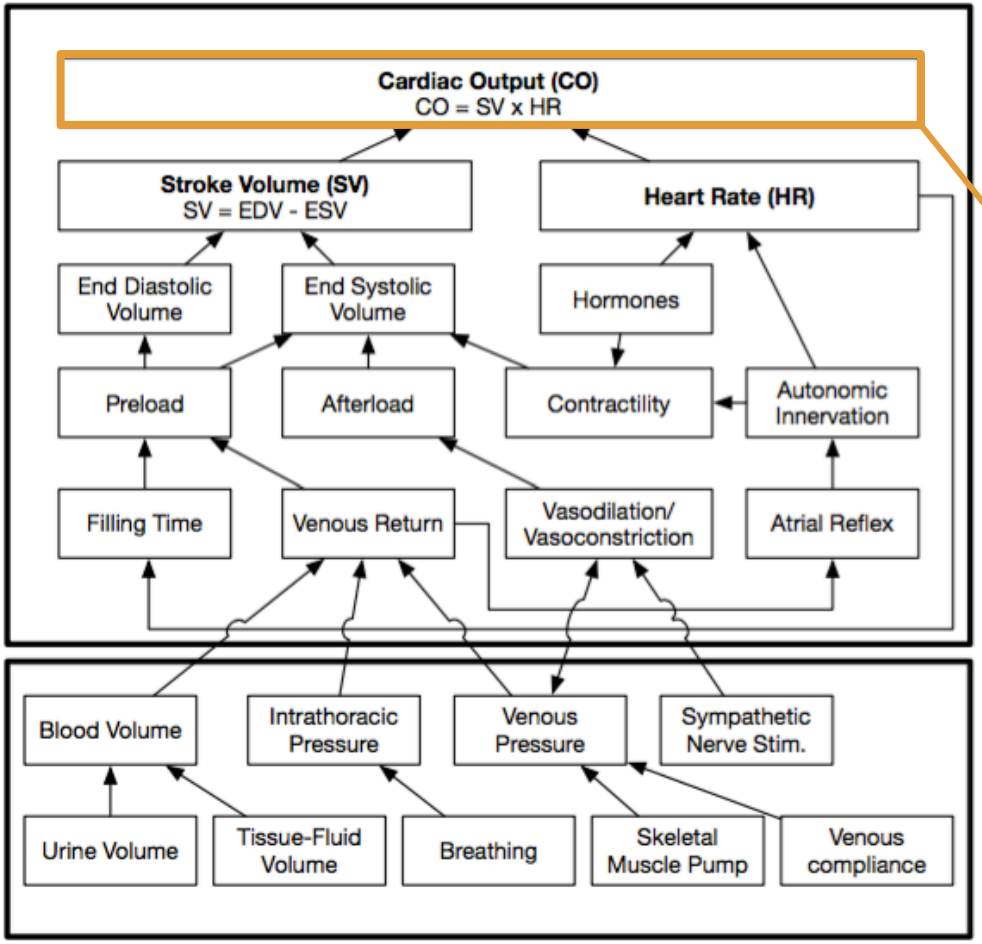
arterial pressure

heart rate

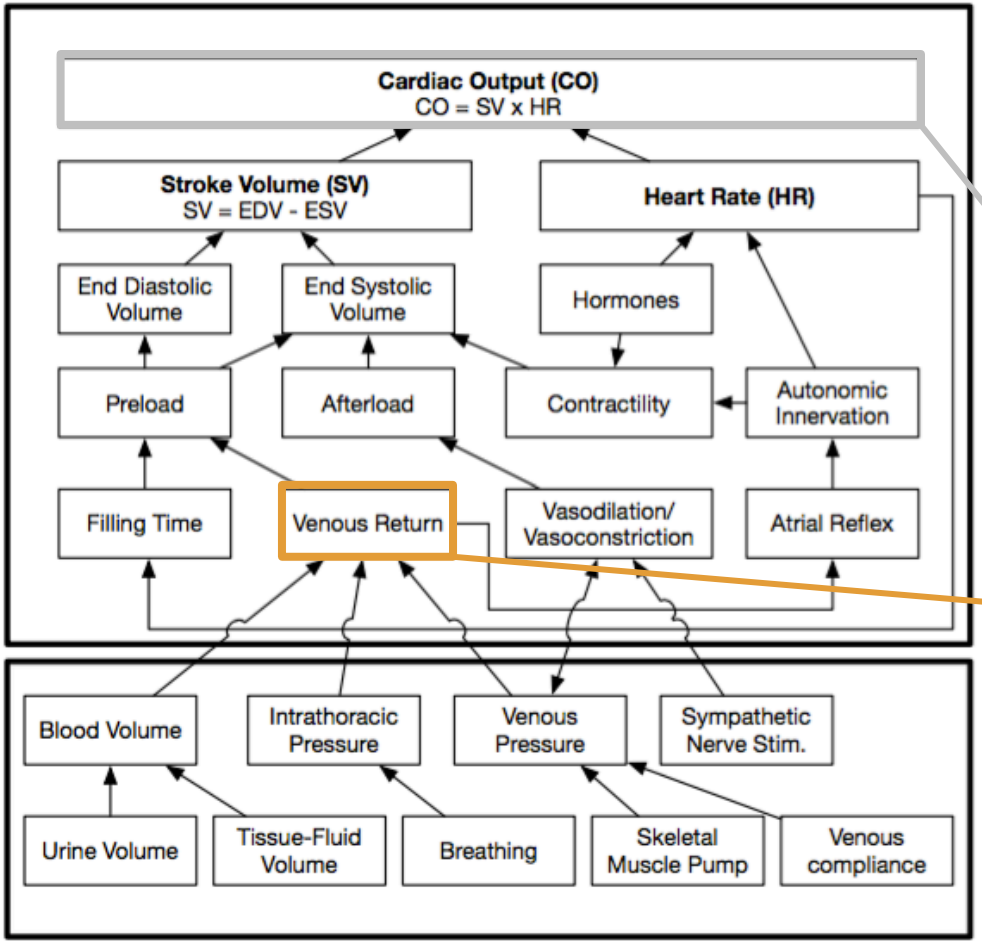
cardiac output



cardiac output

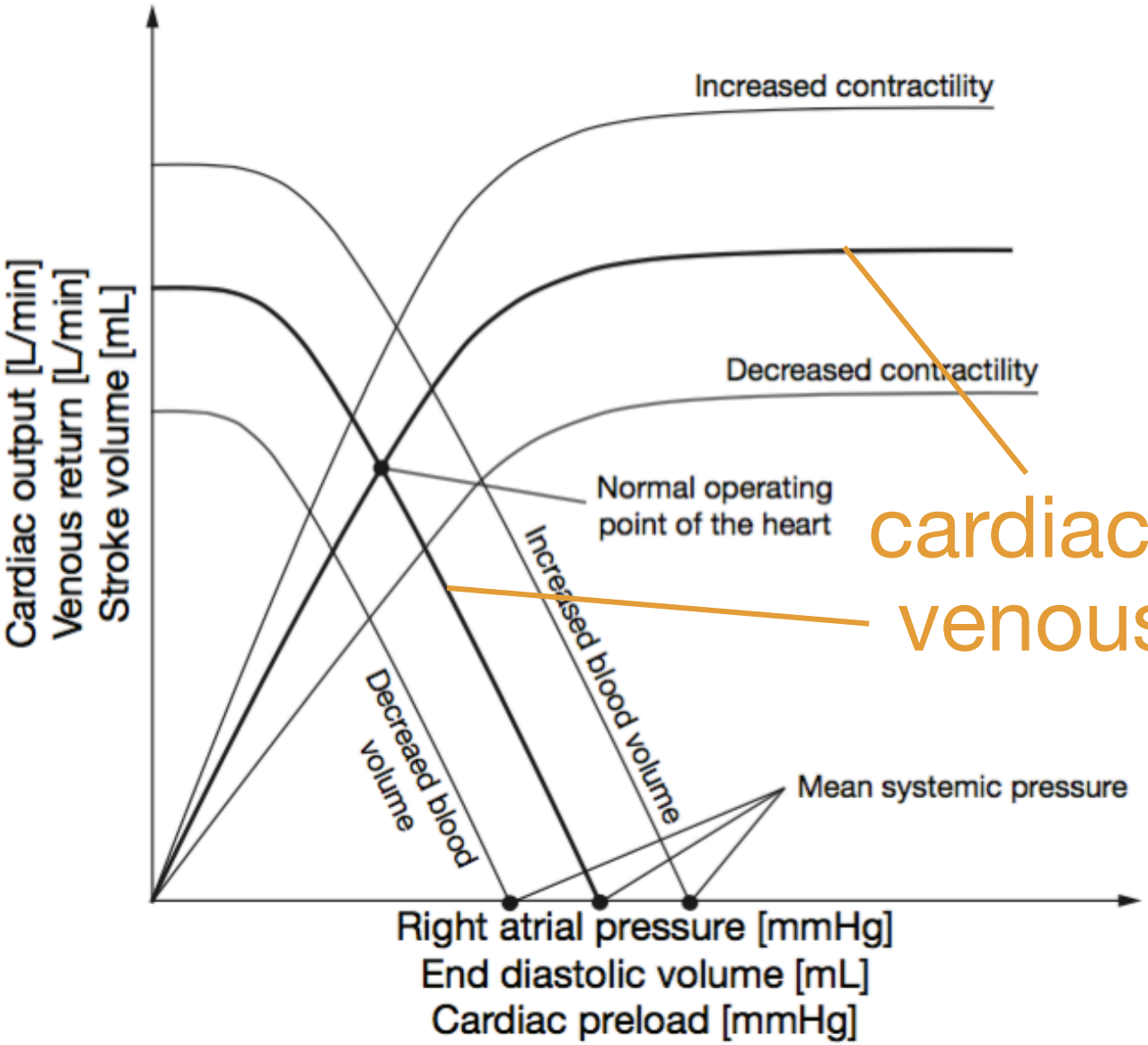


cardiac output



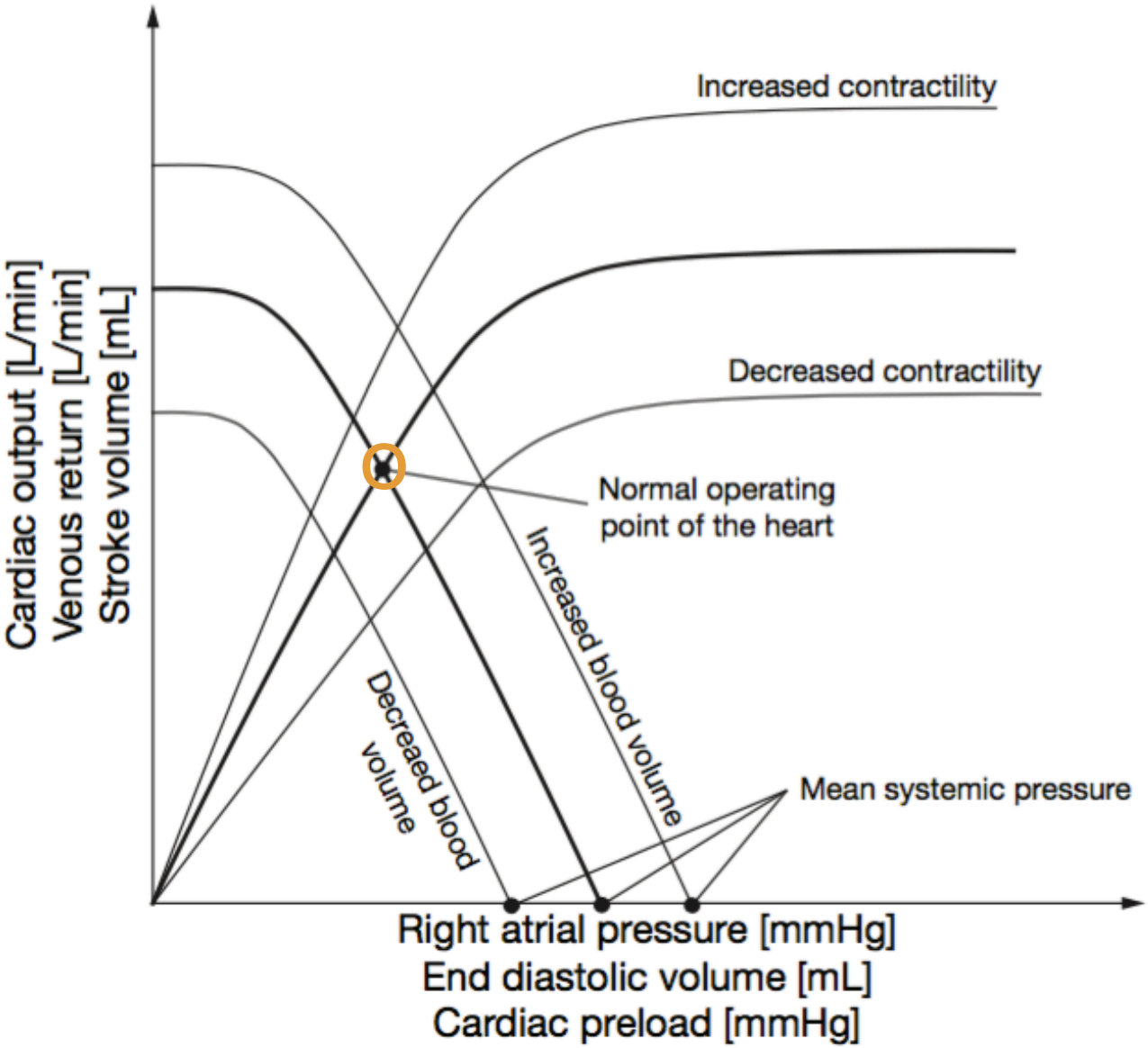
cardiac output

venous return



cardiac output

venous return


Increased contractility
Decreased contractility
Normal operating point of the heart
Increased blood volume
Decreased blood volume
Mean systemic pressure
Cardiac output [L/min]
Venous return [L/min]
Stroke volume [mL]
Right atrial pressure [mmHg]
End diastolic volume [mL]
Cardiac preload [mmHg]

how do we find this?

blood volume

blood volume

intravascular volume status

intravascular volume status

intravascular volume status

hypovolemia:

hemorrahging

dehydration

intravascular volume status

hypervolemia:

congestive heart failure

end stage renal disease

intravascular volume status

how much fluid do you give?

intravascular volume status

how much fluid do you take?

intravascular volume status

how do you measure it?

Inferior vena cava tracking in spontaneously breathing patients, or

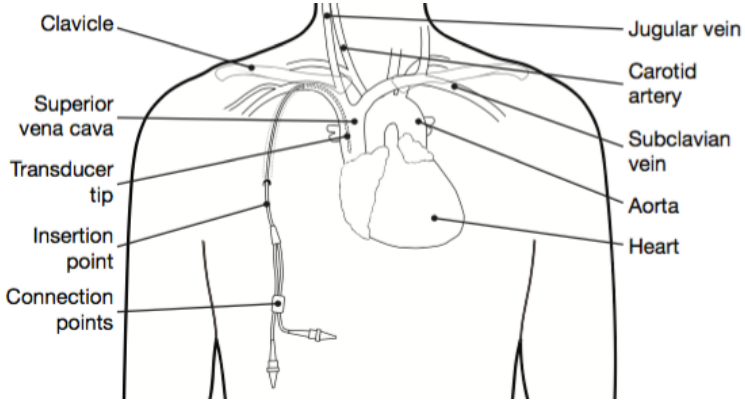
How to tell just how full the Holy Grail of emergency medicine is

How to tell

How to tell: **Physical exam**

2,500 years old…

...still a 50/50 bet

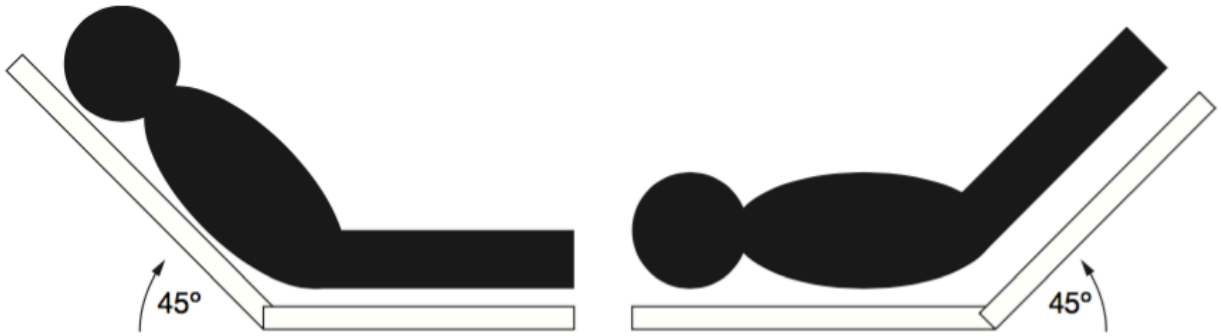


How to tell: **Central line**

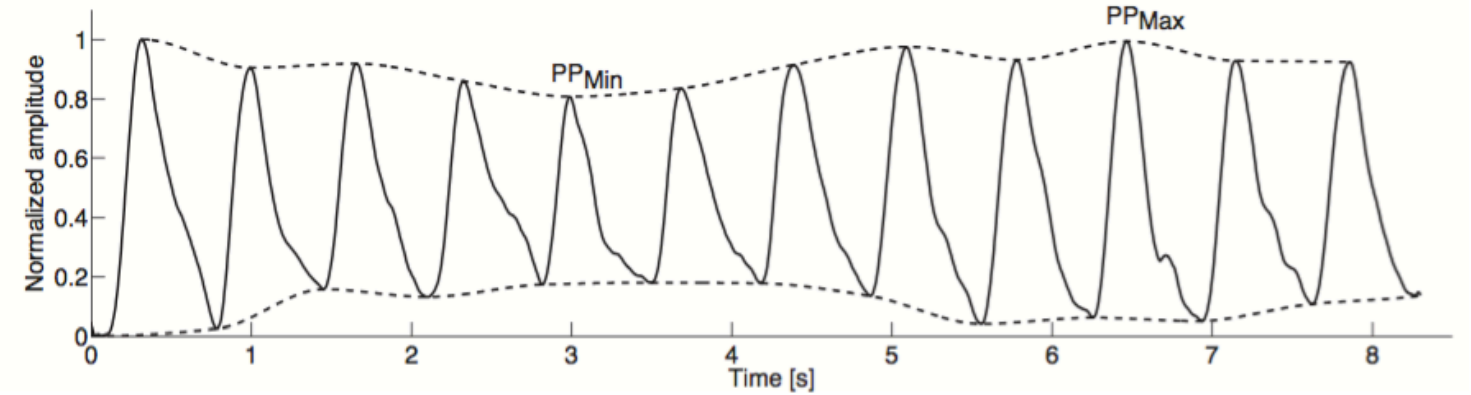
invasive

difficult

tells half the story



How to tell: **Passive leg raise**
a great method
until you're the
one lifting



How to tell: **SVV/PPV**

limited testing in healthy subjects

ideally

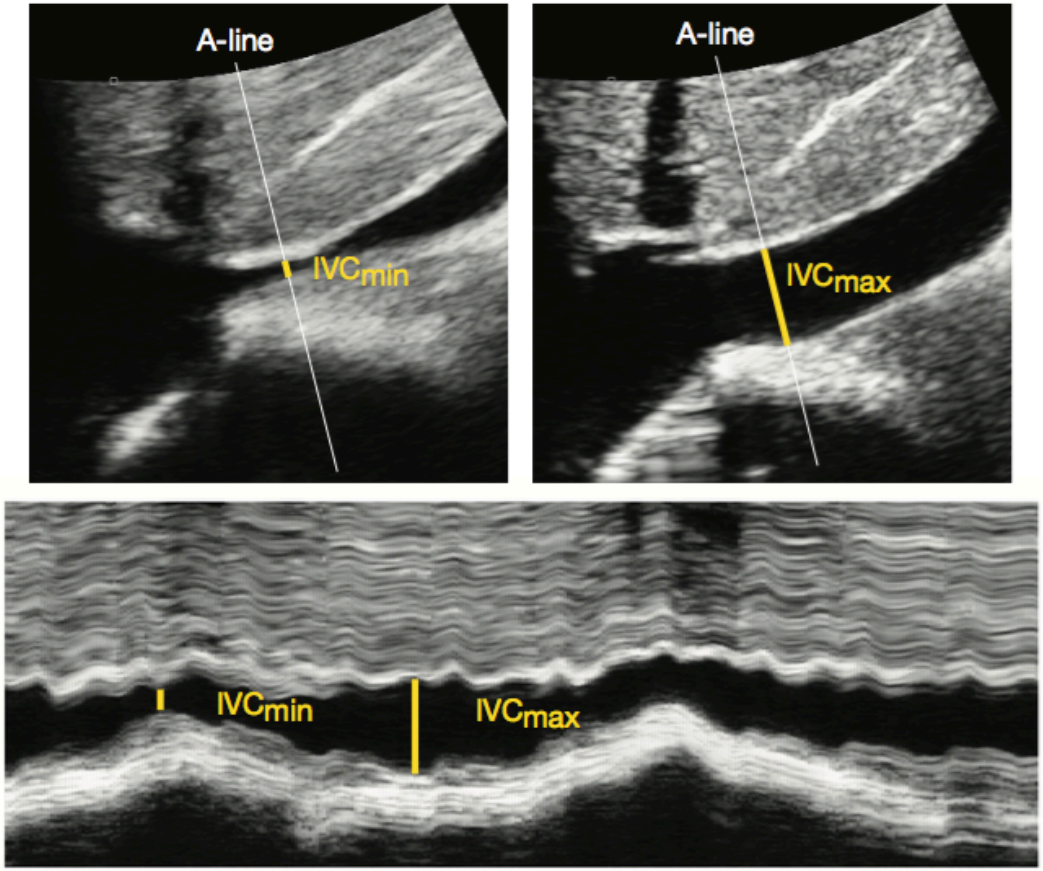
How to tell: non-invasively, dynamically, and in as many environments as possible

Inferior vena cava tracking in spontaneously breathing patients, or

How to tell just how full the Holy Grail of emergency medicine is

Inferior vena cava tracking

Inferior vena cava tracking



Inferior vena cava tracking, **the pros**

ultrasound is cheap

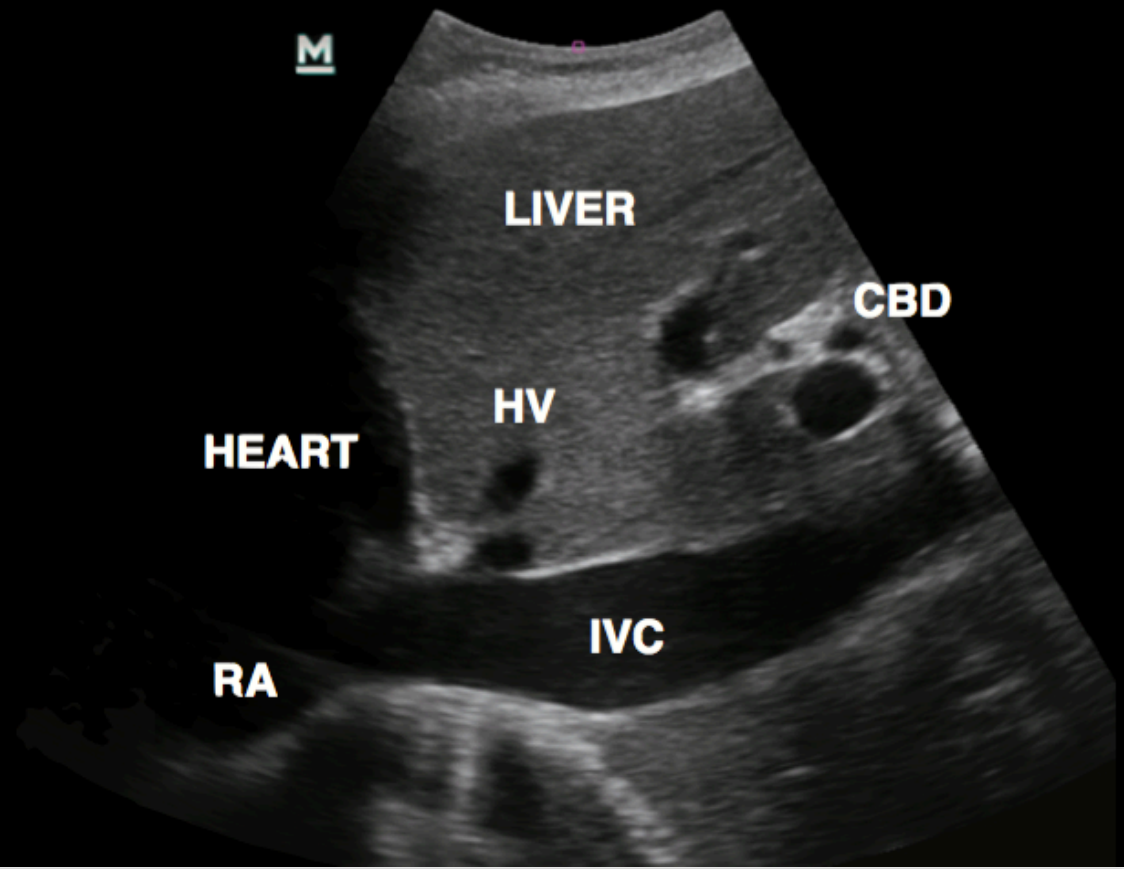
acquisition is quick

rapid POC across environments

Inferior vena cava tracking, **the cons**

operator-dependent
patient-dependent
morbidity-dependent

Inferior vena cava tracking

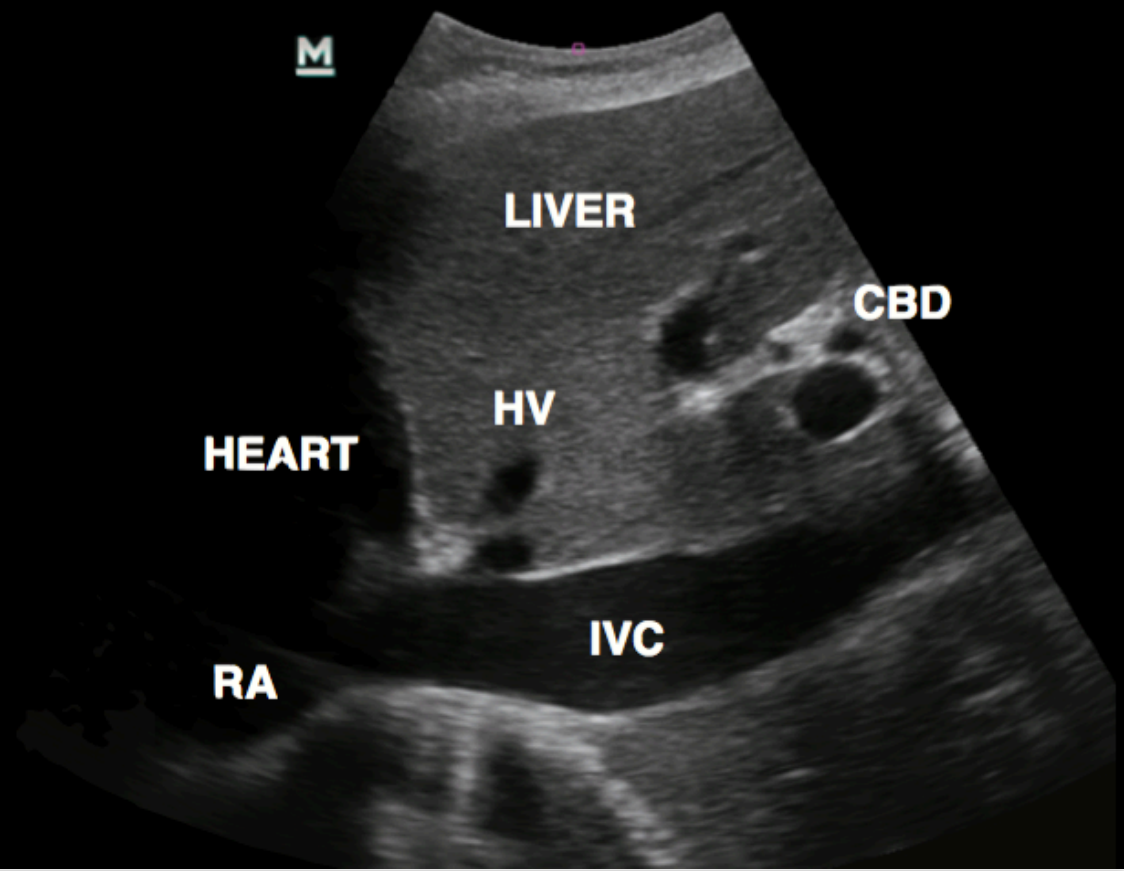


Inferior vena cava tracking

detect

match

track

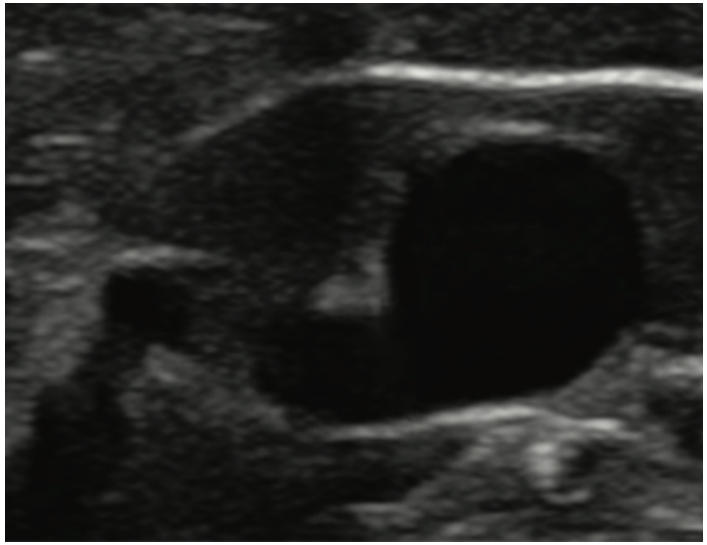


feature detection

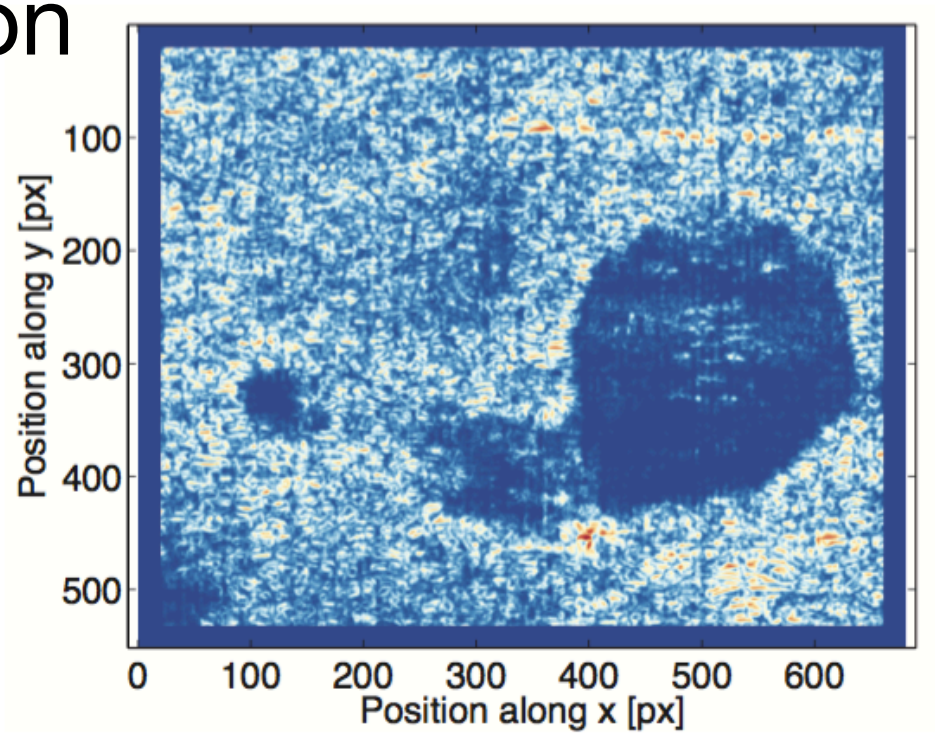
feature detection

skills of the doctor

verification of the engineer



feature detection

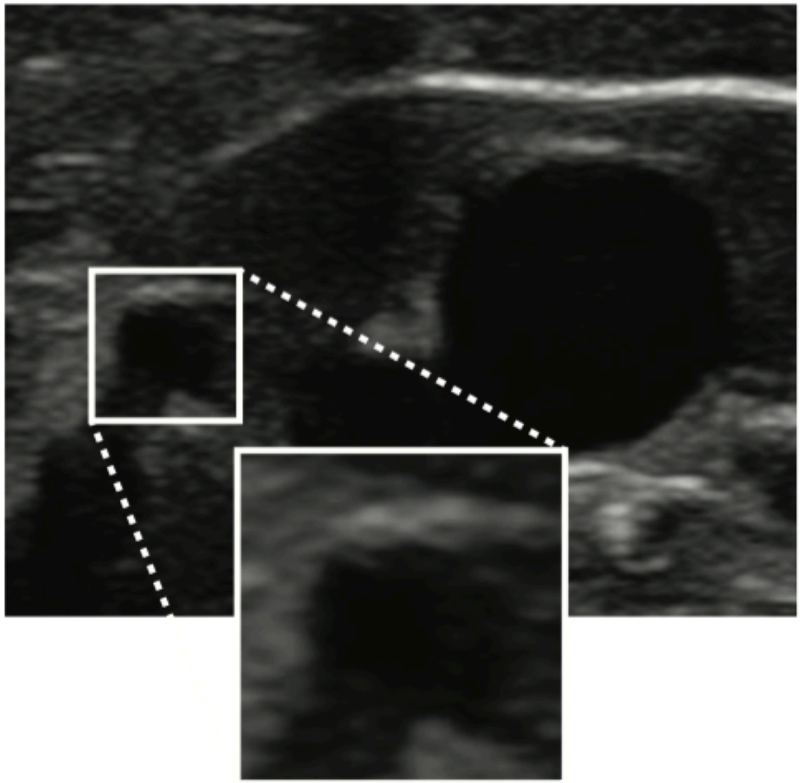


also Harris corners

$$A = \sum_{(i,j)\in W} w(i,j) \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix}$$

feature matching

feature matching



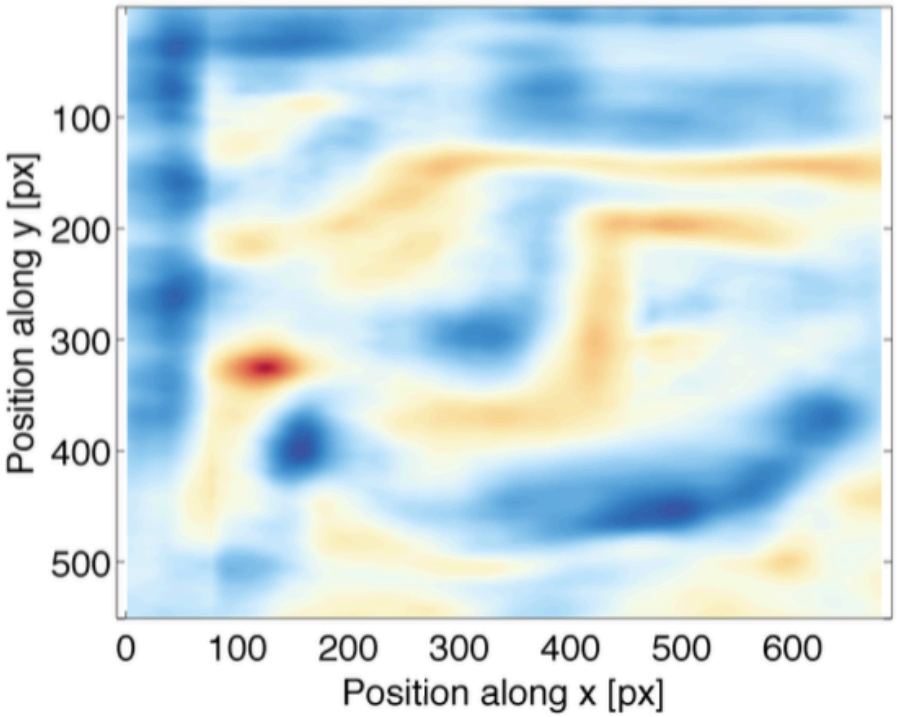
$$I(x,y) * k(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} I(u,v)k(x-u,y-v)$$

$$I(x,y) * k(x,y) = \sum_{i=0}^{W-1}\sum_{j=0}^{H-1} I(i,j)k(x-i,y-j)$$

$$I(x,y) \circ k(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} I(u,v)k(x+u,y+v)$$

$$I(x,y) \circ k(x,y) = \sum_{i=0}^{W-1}\sum_{j=0}^{H-1} I(i,j)k(x_i,y+j)$$

feature matching



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feature tracking

Kanade-Lucas-Tomasi feature tracking

Kanade-Lucas-Tomasi feature tracking

$$\epsilon(\mathbf{d}) = \epsilon(d_x, d_y) = \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} \left(I_1(x,y) - I_2(x+d_x, y+d_y)\right)^2$$

$$\frac{\partial \epsilon(\mathbf{d})}{\partial \mathbf{d}} = 0 = -2 \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} \left(I_1(x,y) - I_2(x+d_x, y+d_y)\right) \begin{bmatrix} \frac{\partial I_2}{\partial x} & \frac{\partial I_2}{\partial y} \end{bmatrix}$$

$$\frac{1}{2}\left[\frac{\partial \epsilon(\mathbf{d})}{\partial \mathbf{d}}\right]^T \approx \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} \left(\mathbf{d}\begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} - \begin{bmatrix} \delta I & I_x \\ \delta I & I_y \end{bmatrix}\right)$$

Kanade-Lucas-Tomasi feature tracking

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define error as a function of displacement

$$\frac{\partial \epsilon(\mathbf{d})}{\partial \mathbf{d}} = 0 = -2 \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} \left(I_1(x,y) - I_2(x+d_x, y+d_y)\right) \begin{bmatrix} \frac{\partial I_2}{\partial x} & \frac{\partial I_2}{\partial y} \end{bmatrix}$$

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find a stable error

$$\frac{1}{2}\left[\frac{\partial \epsilon(\mathbf{d})}{\partial \mathbf{d}}\right]^T \approx \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} \left(\mathbf{d}\begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} - \begin{bmatrix} \delta I & I_x \\ \delta I & I_y \end{bmatrix}\right)$$

Kanade-Lucas-Tomasi feature tracking

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define error as a function of displacement

$$\frac{\partial \epsilon(\mathbf{d})}{\partial \mathbf{d}} = 0 = -2 \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} \left(I_1(x,y) - I_2(x+d_x, y+d_y)\right) \begin{bmatrix} \frac{\partial I_2}{\partial x} & \frac{\partial I_2}{\partial y} \end{bmatrix}$$

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use image gradients to simplify things

$$\frac{1}{2}\left[\frac{\partial \epsilon(\mathbf{d})}{\partial \mathbf{d}}\right]^T \approx \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} \left(\mathbf{d}\begin{bmatrix} I_x^2 & I_xI_y \\ I_xI_y & I_y^2 \end{bmatrix} - \begin{bmatrix} \delta I & I_x \\ \delta I & I_y \end{bmatrix}\right)$$

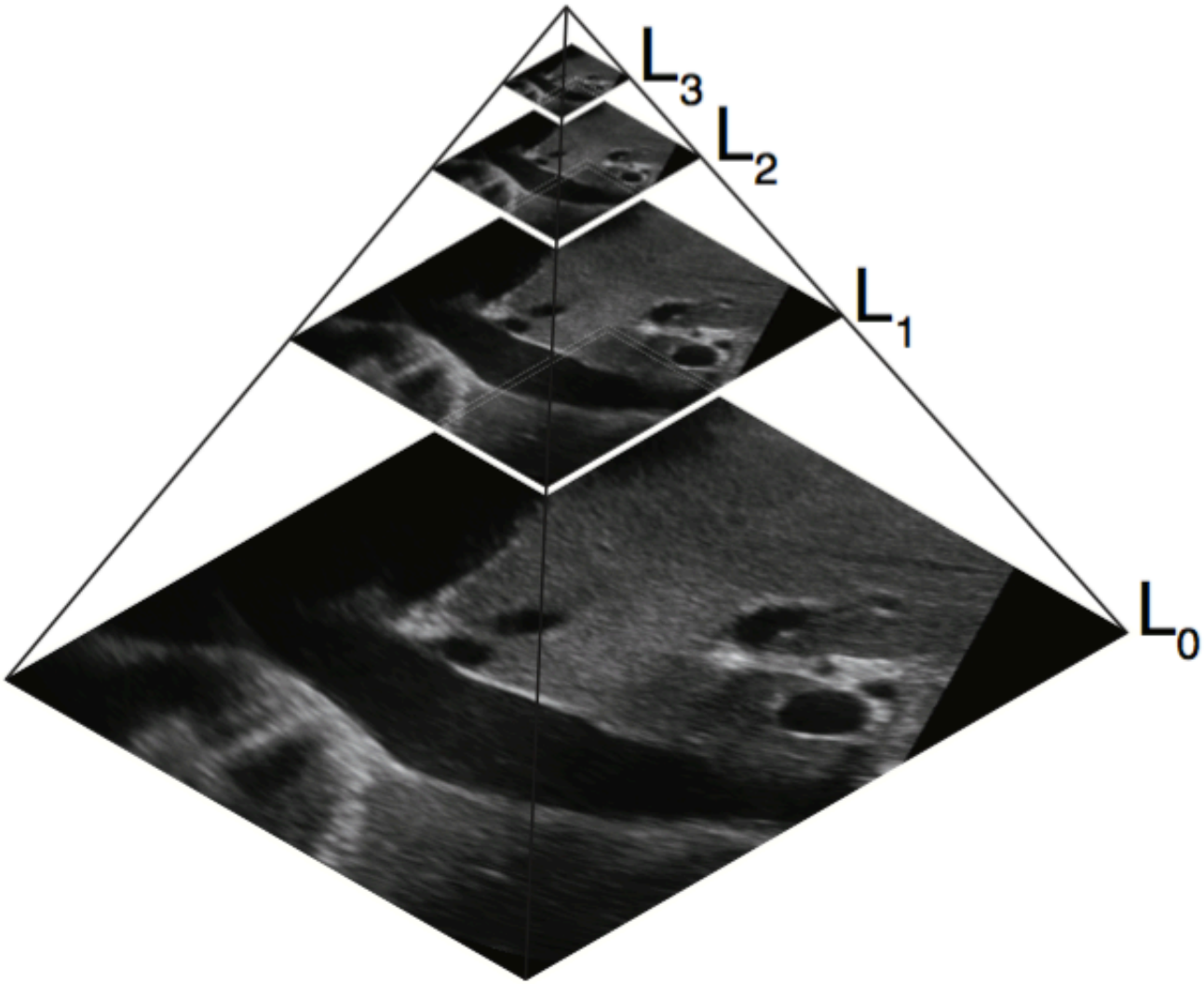
$$b \doteq \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} \begin{bmatrix} \delta I & I_x \\ \delta I & I_y \end{bmatrix}$$

$$G \doteq \sum_{x=u_x-w_x}^{u_x+w_x} \sum_{y=u_y-w_y}^{u_y+w_y} \begin{bmatrix} I_x^2 & I_xI_y \\ I_xI_y & I_y^2 \end{bmatrix}$$

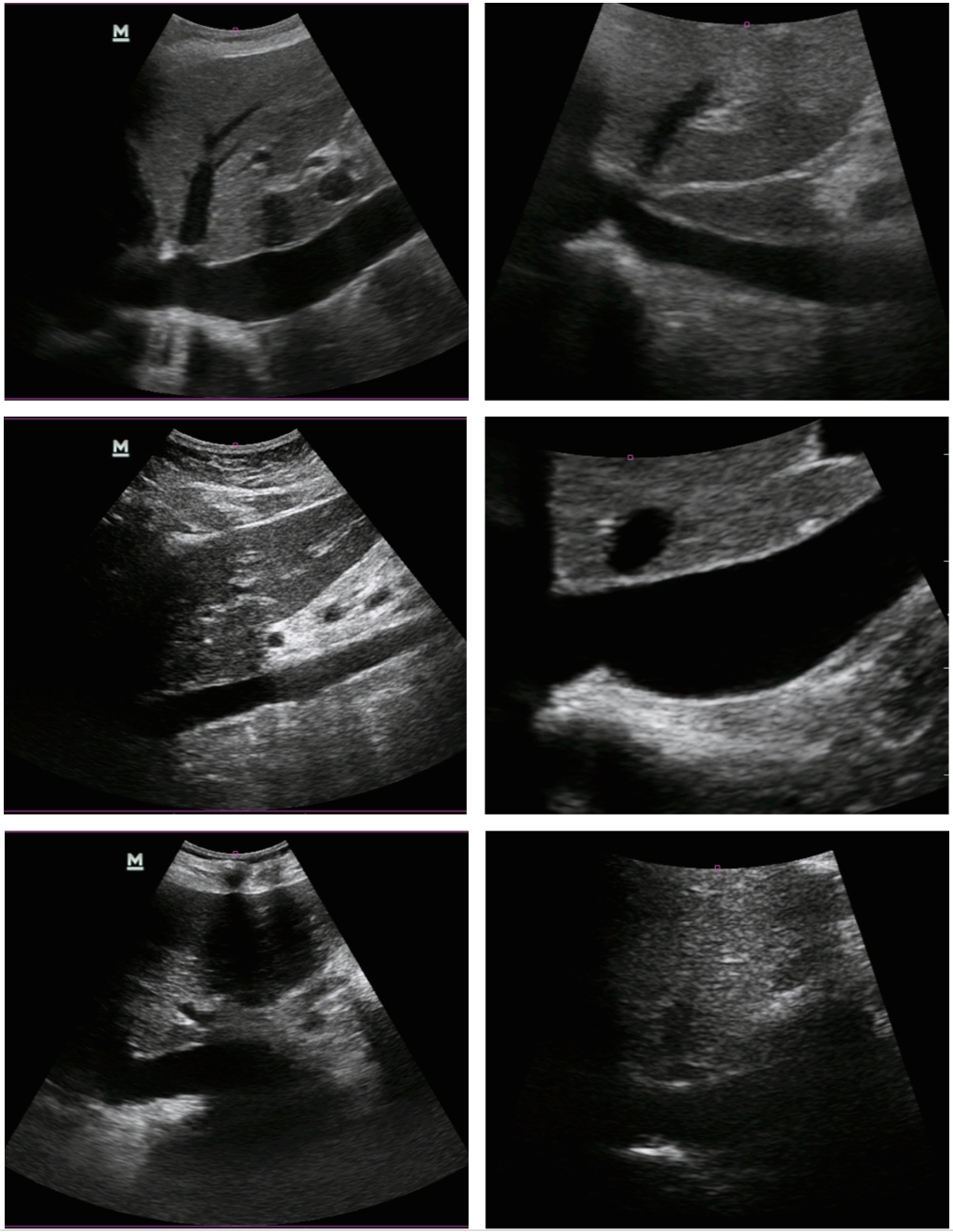
$$\mathbf{d}_{opt} = G^{-1}b$$

simplify things

$$\mathbf{d}_{opt} = G^{-1}b$$ **simplify things**

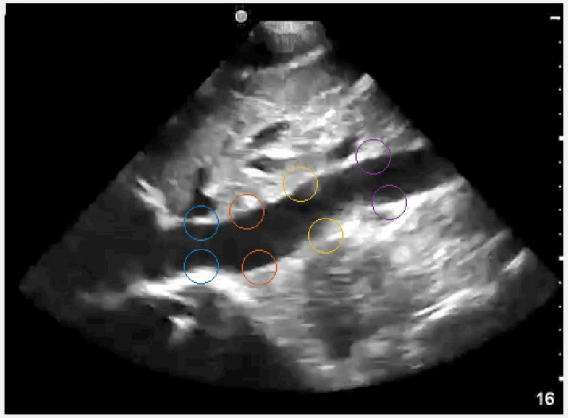


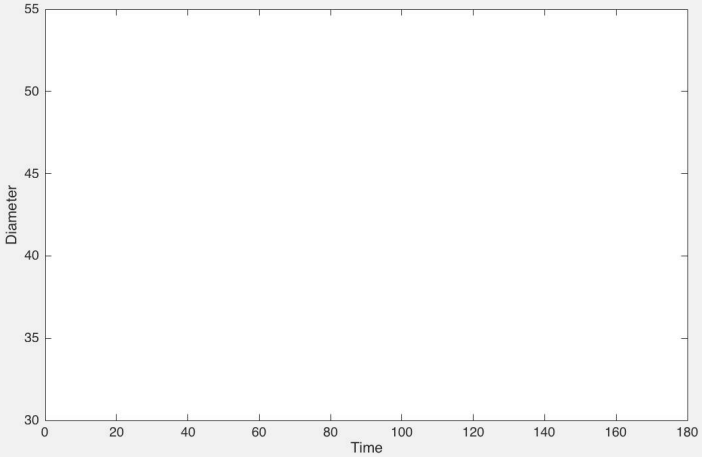
$$\mathbf{d} = \sum_{n=0}^{m} 2^{L_n} \mathbf{d}^{L_n}$$


M
M
M

Inferior vena cava tracking in **spontaneously breathing patients**, or How to tell just how full the Holy Grail of emergency medicine is

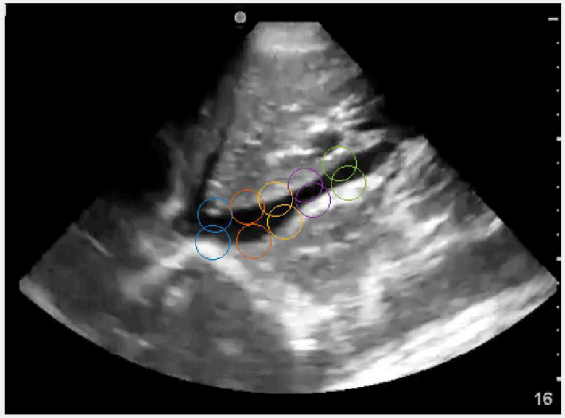
spontaneously breathing patients

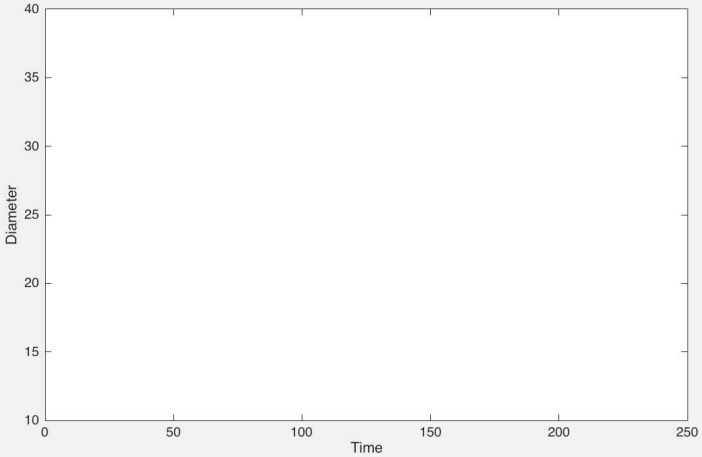




euvolemic

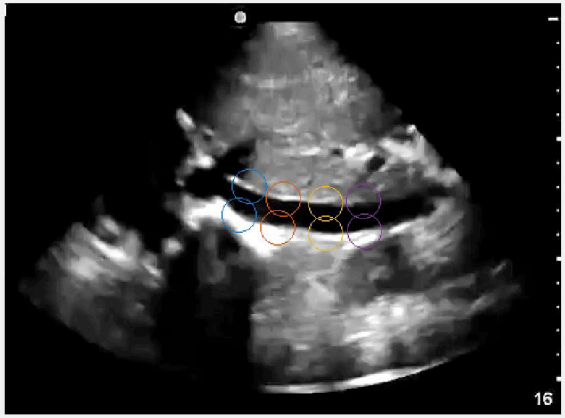
spontaneously breathing patients

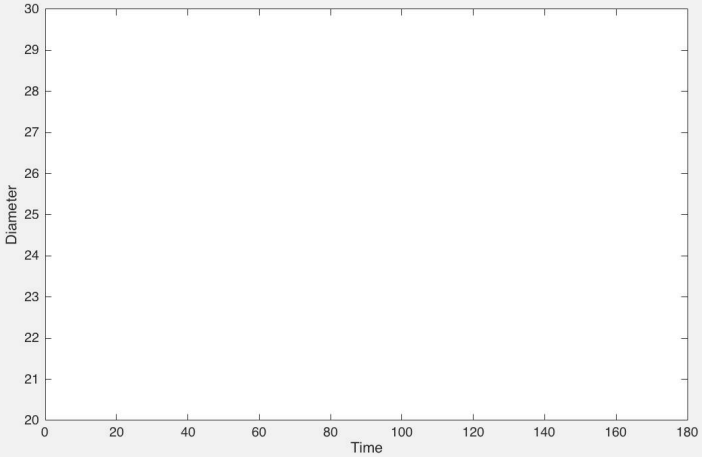




hypovolemic

spontaneously breathing patients





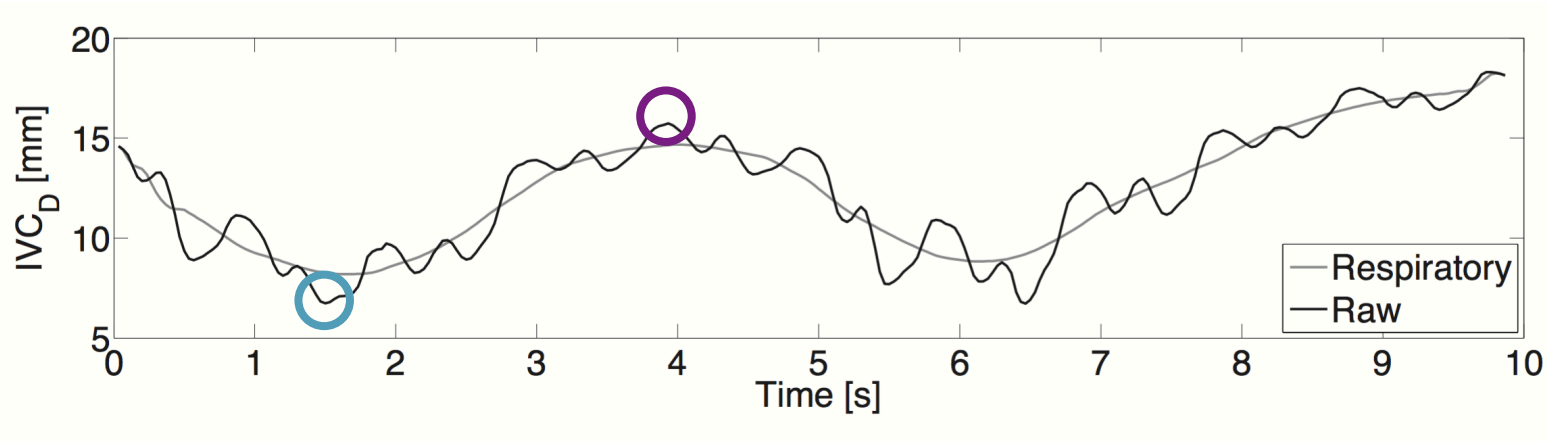
hypervolemic

47 patients

mildly ill (in ER)

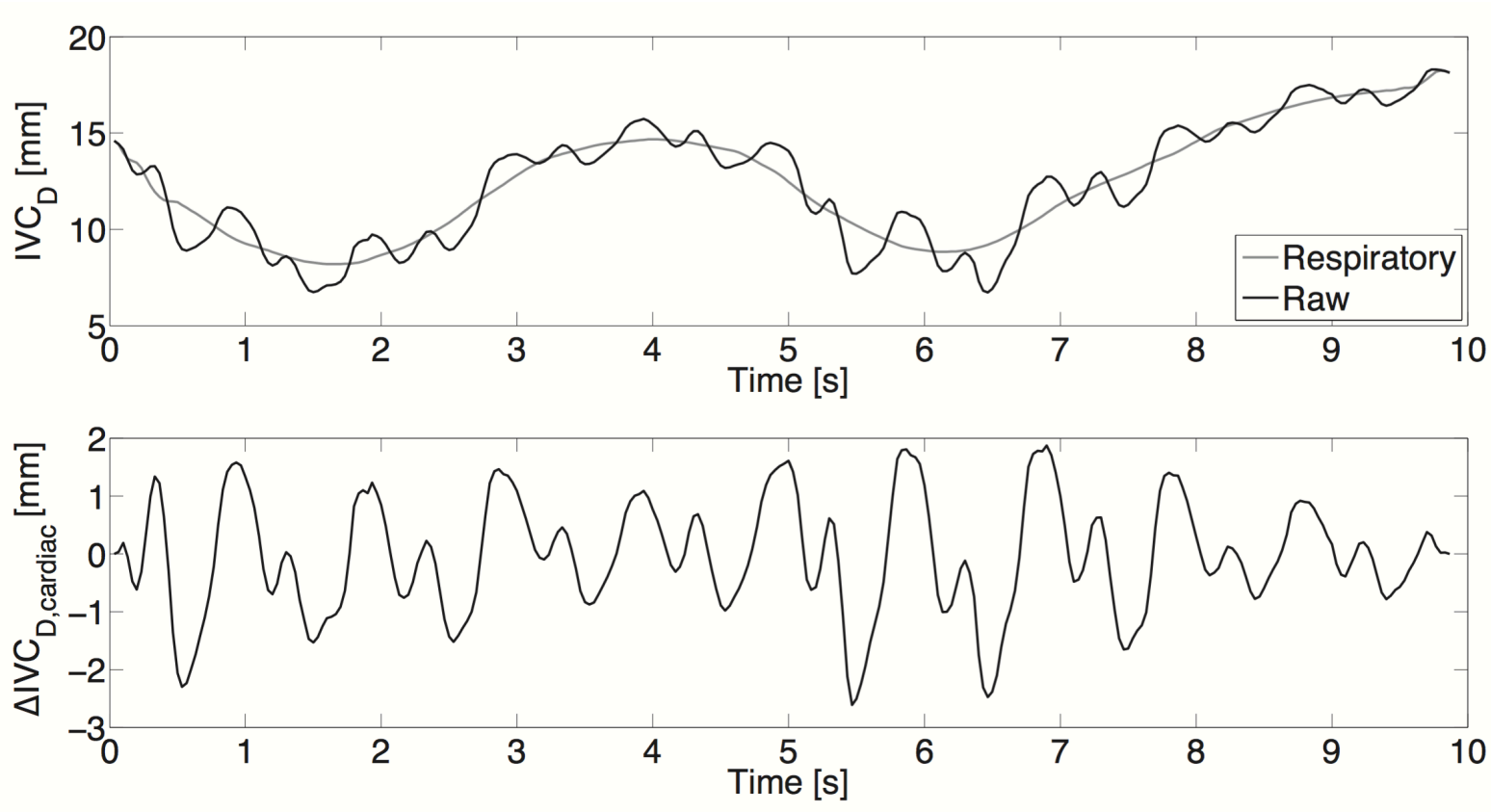
subcostal US

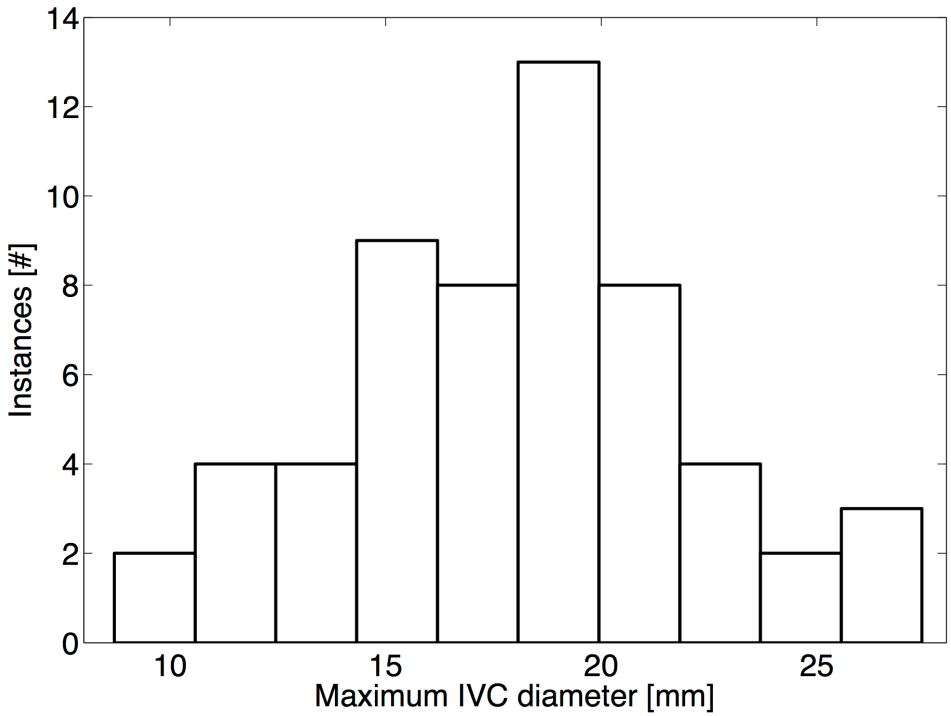
measurements made by certified sonologists

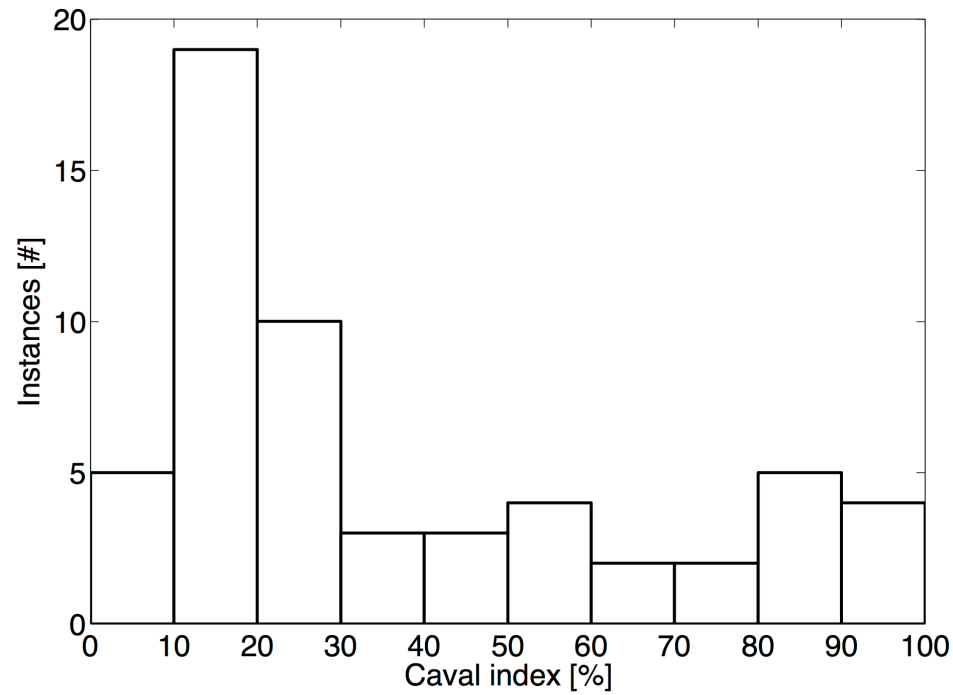


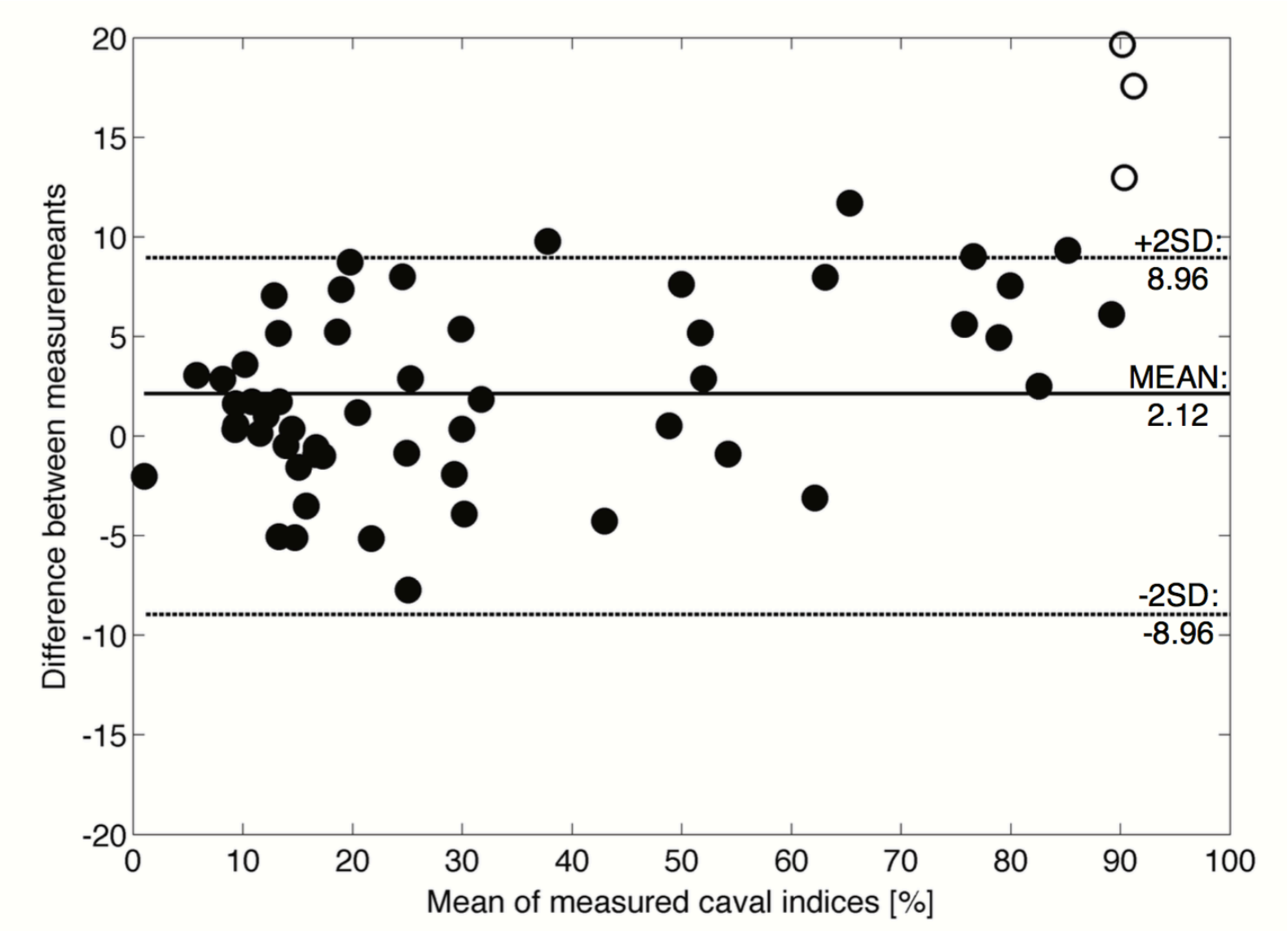
measurements

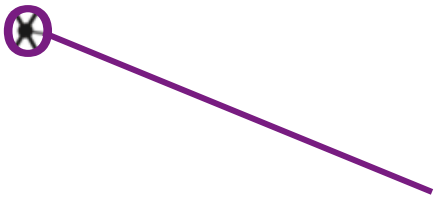
$$C.I. = \frac{\boxed{D_{max}} - \boxed{D_{min}}}{\boxed{D_{max}}}$$


20
15
10
5
IVC_D [mm]
0
1
2
3
4
5
6
7
8
9
10
Time [s]
Respiratory
Raw
2
1
0
−1
−2
−3
ΔIVC_D,cardiac [mm]
0
1
2
3
4
5
6
7
8
9
10
Time [s]

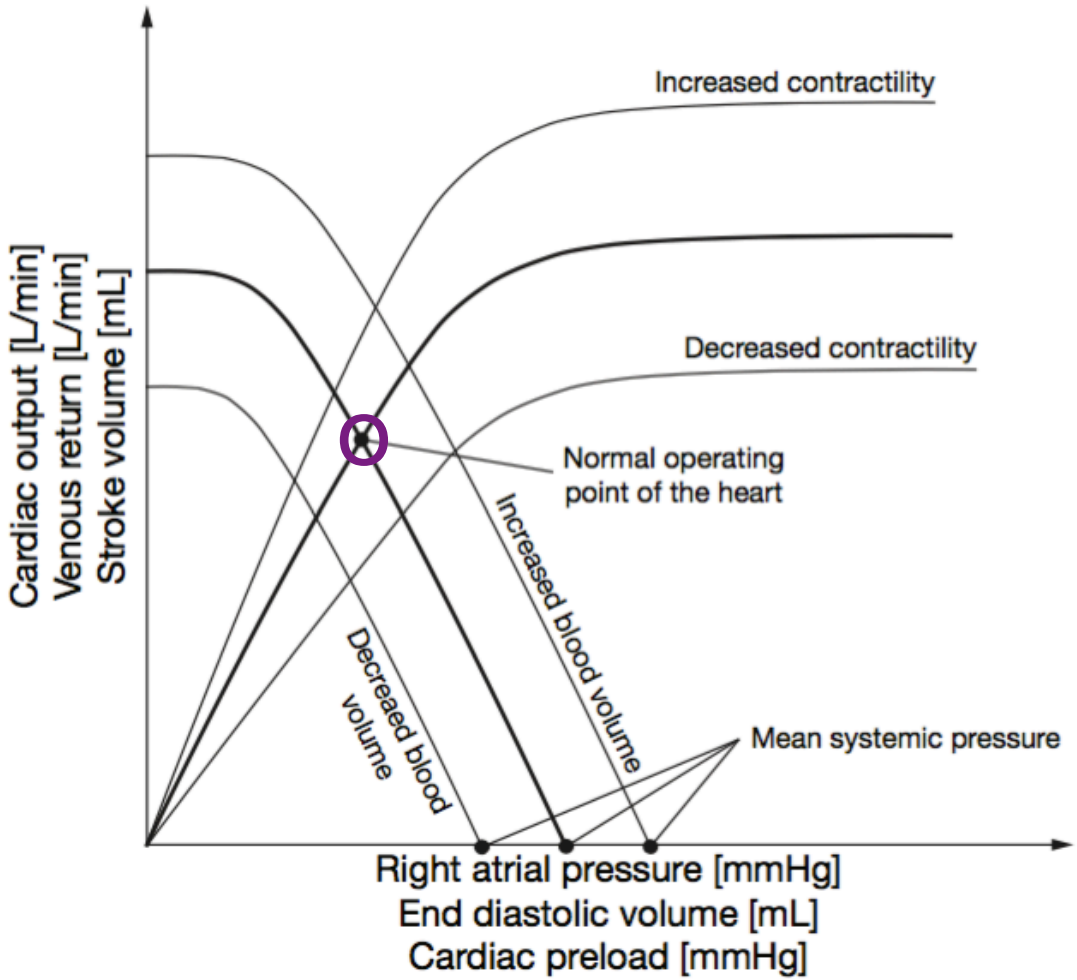

Instances [#]
Maximum IVC diameter [mm]
0
2
4
6
8
10
12
14
10
15
20
25

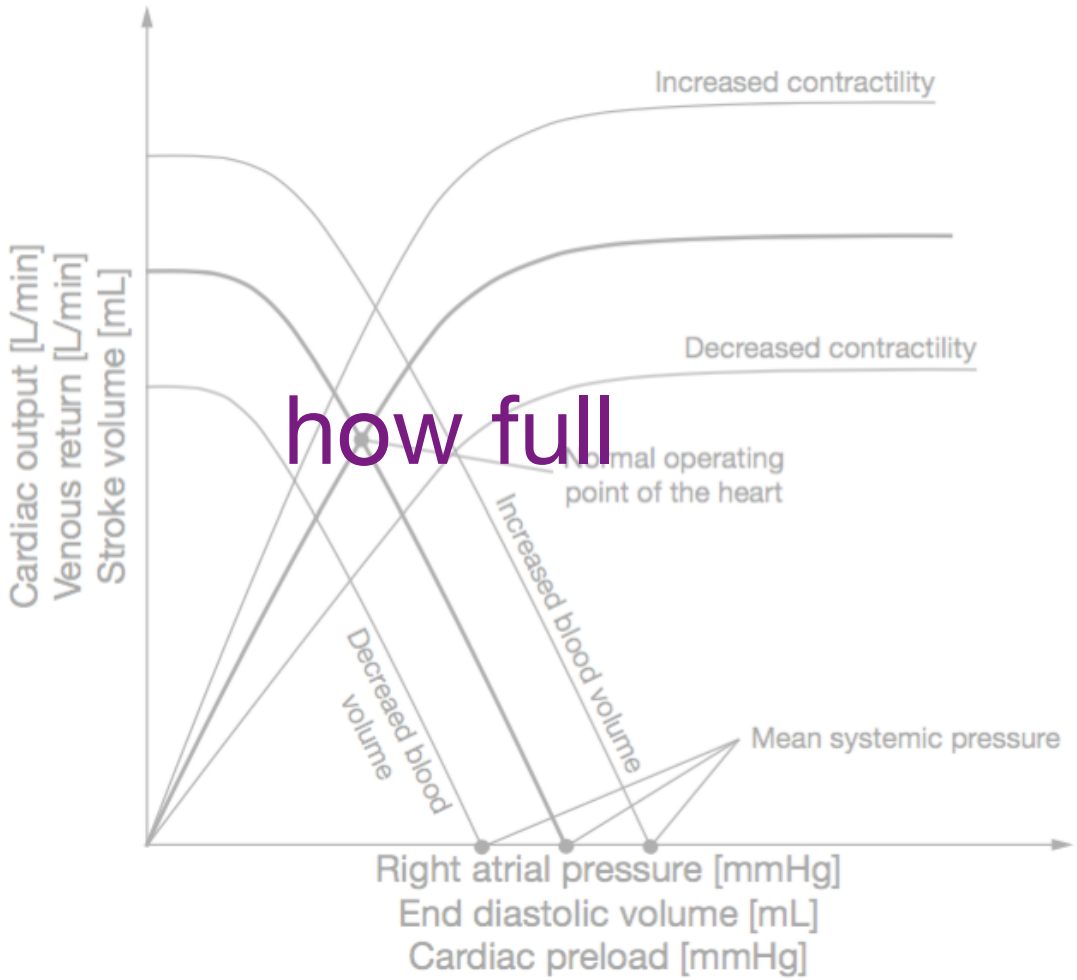

Instances [#]
Caval index [%]
0
5
10
15
20
0
10
20
30
40
50
60
70
80
90
100


20
15
10
5
0
-5
-10
-15
-20
0
10
20
30
40
50
60
70
80
90
100
Difference between measuremeants
Mean of measured caval indices [%]
+2SD:
8.96
MEAN:
2.12
-2SD:
-8.96



can now
find this


Increased contractility
Decreased contractility
Normal operating point of the heart
Increased blood volume
Decreased blood volume
Mean systemic pressure
Cardiac output [L/min]
Venous return [L/min]
Stroke volume [mL]
Right atrial pressure [mmHg]
End diastolic volume [mL]
Cardiac preload [mmHg]


Increased contractility
Decreased contractility
Normal operating point of the heart
Increased blood volume
Decreased blood volume
Mean systemic pressure
Cardiac output [L/min]
Venous return [L/min]
Stroke volume [mL]
Right atrial pressure [mmHg]
End diastolic volume [mL]
Cardiac preload [mmHg]

how full

Inferior vena cava tracking in spontaneously breathing patients, or

How to tell just how full the Holy Grail of emergency medicine is

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Inferior vena cava tracking in **spontaneously breathing patients**, or

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