초음파 영상을 이용한 혈관 형상 및 유동 계측

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Blood cells

▪ **Compound of blood**

RBC

WBC

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https://www.google.co.kr/

Platelets

AmericasBlood.org

http://www.youtube.com
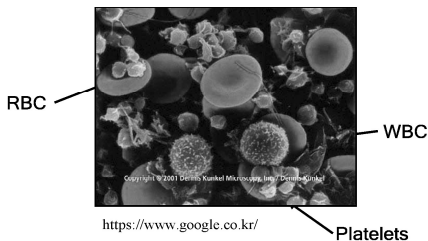
- **Blood is composed of red blood cells (RBCs), white blood cells(WBCs), platelets, and protein macromolecules suspended in plasma.**
- **RBCs are the most important component because of their large proportion in the blood. Primarily, they carry oxygen and collect carbon dioxide through the use of haemoglobin, and have a lifetime of about 120 days.**
- **WBCs are cells of the immune system involved in defending the body against both infectious disease and foreign materials. They live for about 3 to 4 days in the average human body.**
- **Platelets constitute a key component of normal hemostasis and pathological thrombosis. They are very small, irregularly shaped clear cell fragments 2–3 μm in diameter, The average lifespan of a platelet is normally just 5 to 9 days.**
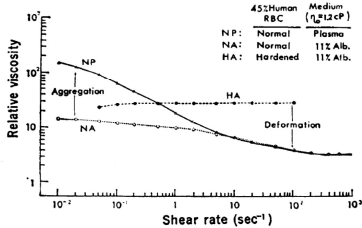
2/15

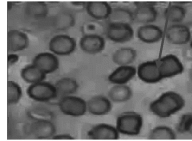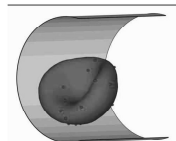# Characteristic of blood

▪ Variation of blood viscosity

Chien, S., *Science*, **168**, 1970

Rouleaux

http://www.youtube.com

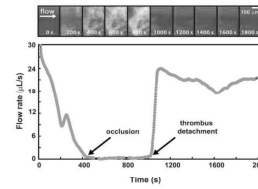Fedosov et al., *Soft Matter* **10**, (2014)

Shear rate (s⁻¹)

High   Moderate   Low

Allard et al., *IEEE Trans. Ultrason. Ferr.* **43**, (1996)
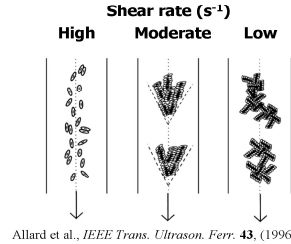
▪ Platelet activation around stenosis

Nesbitt et al., *Nat. Med.* **15**, (2009)

Li et al., *Lab Chip* **12**, (2012)
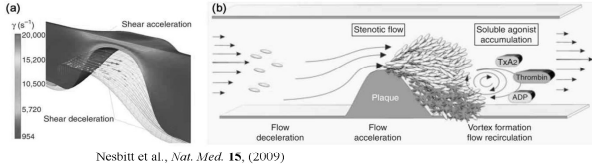
3/15

Ultrasound system

▪ Ultrasound Basic Conception

Input Signal

PC

Transducer

Pulse of Sound

Reflected Pulse

$PD = N_c \times T$

Scatter

Focal Zone

Focused Ultrasound Beam

Original Signal

After Rectification

After Smoothing

Brightness Mode Image
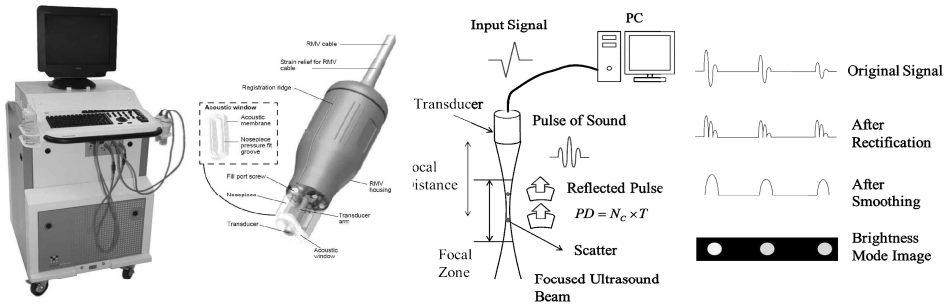
▪ Blood Flow and Wall Motion in abdominal aortas
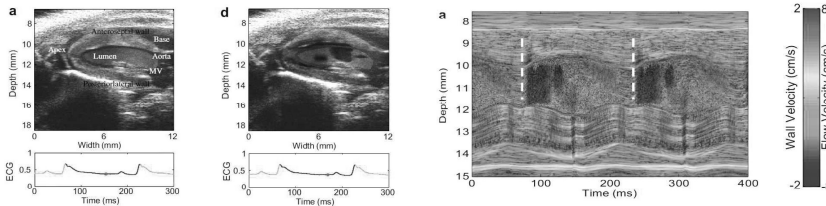
4/15   Luo and Konofagou, *Ultrasound Med Biol*, **37**, (2011)

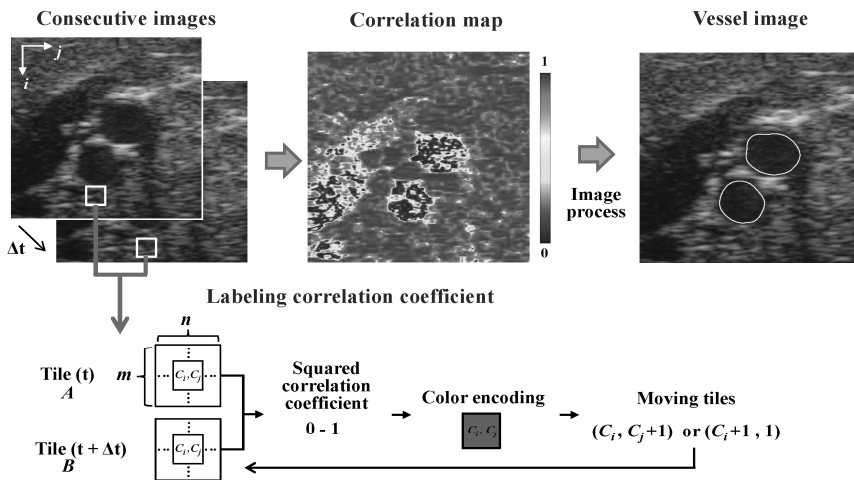# 3D reconstruction from 2D images

- **Schematic diagram**

2D images over time

Electrocardiogram

Aligned 2D images

Probe

Scan direction

Transducer

Carotid artery

Ultrasound beam

Scan direction
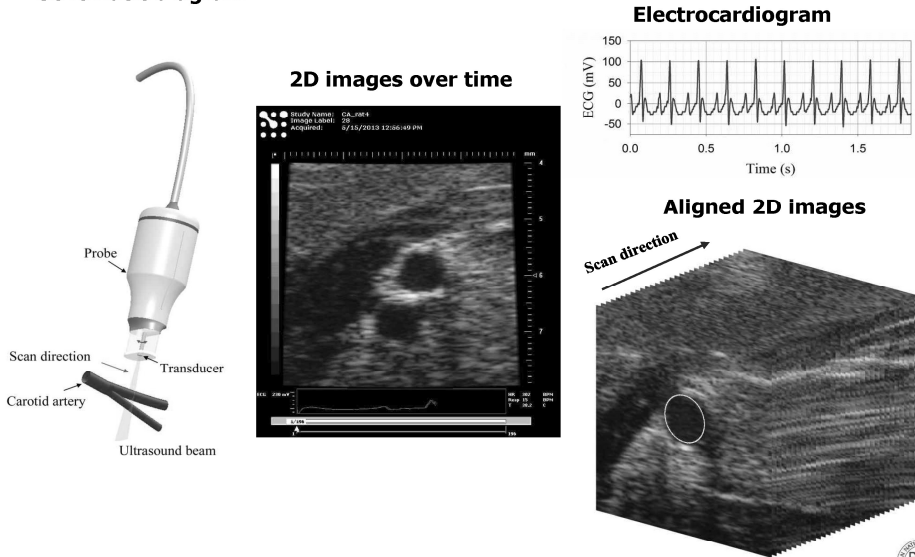
5/15   Yeom et al., *Ultrasonics* **54**, (2014)

3D reconstruction from 2D images
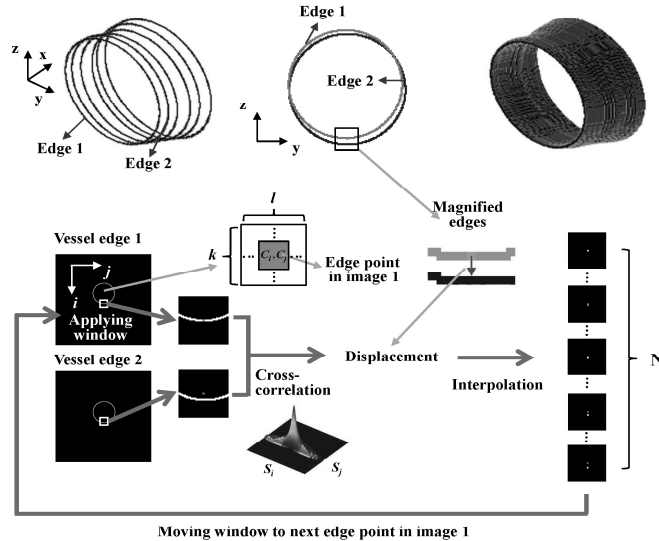
- **Processing procedure for vessel detection**

Consecutive images

Correlation map

Vessel image

j

i

Δt

Image process

Labeling correlation coefficient

n

Tile (t) m — C_i, C_j
A

Tile (t + Δt) C_i, C_j
B

Squared correlation coefficient
$0 - 1$

→

Color encoding
C_i, C_j

→

Moving tiles
(C_i, C_j+1) or $(C_i+1, 1)$

6/15   Yeom et al., *Ultrasonics* **54**, (2014)

3D reconstruction from 2D images

▪ Interpolation procedure

# 3D reconstruction from 2D images

▪ 3D reconstruction
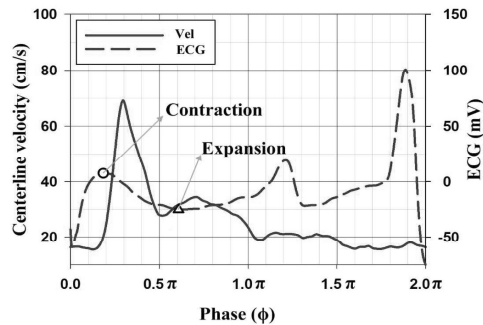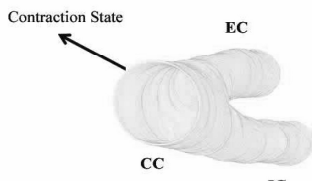
- The **hemodynamic** information at the contraction and expansion states was obtained from measuring the centerline velocity in the CCA by using **PW Doppler.**
- The carotid artery is **fully contracted** before accelerating the centerline velocity of the blood flow.
- However, **full dilatation** does **not** occur at **the peak velocity** (phase angle of $\phi = 0.3\pi$) but at a phase angle of 0.6p. This results from phase shift between velocity and pressure in arteries

SIV (Speckle Image Velocimetry)
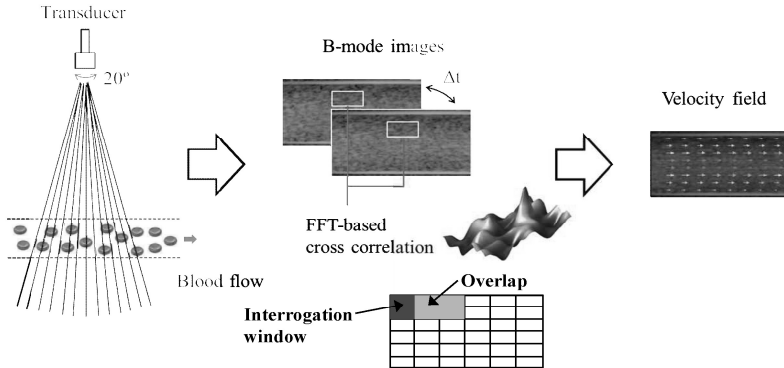
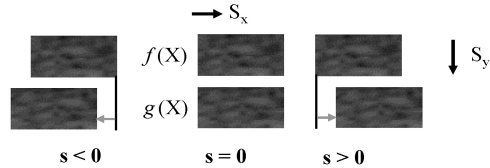- **Cross Correlation**

$$R_{f_n g_n}(s) = \int f_n(X) g_n(X+s) dX$$

- **Displacement**

$$dx_n = \max(R_{f_n g_n}(s))$$

- **Gaussian peak fit**
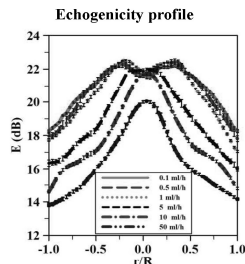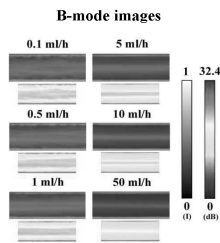
$$\varepsilon = \frac{1}{2} \frac{\ln R(\xi-1) - \ln R(\xi+1)}{\ln R(\xi-1) + \ln R(\xi+1) - 2\ln R(\xi)}$$
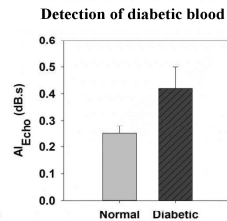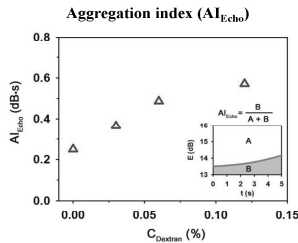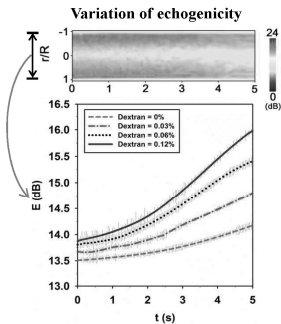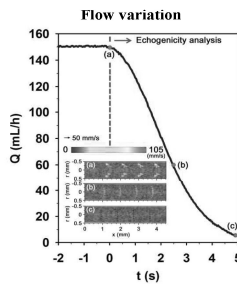
9/15

Measurement of RBC aggregation

- **Variation of rat blood image**
- **Quantification of echogenicity**

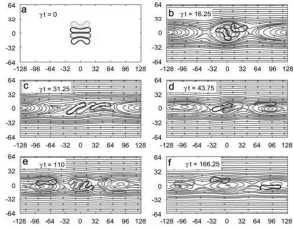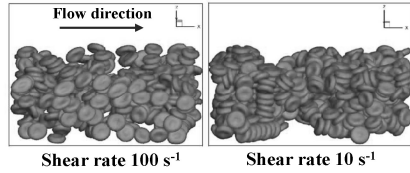

10/15

Estimation of RBC dissociation

▪ **RBC aggregates dissociation**
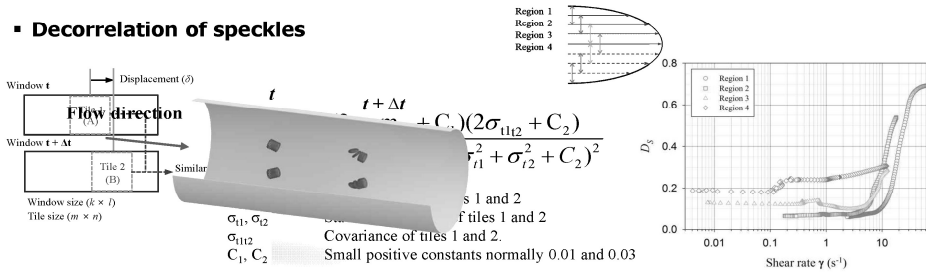

Intercellular force
$D_e = 5.2 \times 10^{-8}$ μJ

Shear rate
$\gamma = 20$ s^{-1}

Zhang et al., J Biomech, **41**, 2008

Shear rate 100 s^{-1} Shear rate 10 s^{-1}

Xu et al., J Biomech, **46**, 2013

▪ **Decorrelation of speckles**

$$\frac{\cdots + C_1)(2\sigma_{t1t2} + C_2)}{\cdots \sigma_{t1}^2 + \sigma_{t2}^2 + C_2)^2}$$

s 1 and 2
σ_{t1}, σ_{t2} ... of tiles 1 and 2
σ_{t1t2} Covariance of tiles 1 and 2.
C_1, C_2 Small positive constants normally 0.01 and 0.03

11/15   Yeom et al., *Ultrasonics*. **54(6)**, (2014)

Verification and application of SIV

▪ **Verification of SIV technique**

SIV Doppler   Window size: 0.96 mm   Range gate: 1 mm

Bland-Altman analysis

95% limits of agreement

Mean value of difference
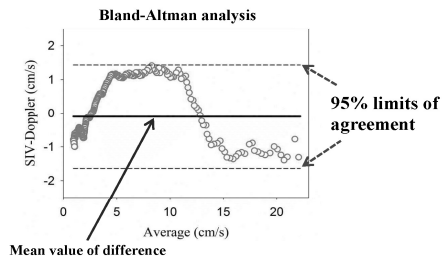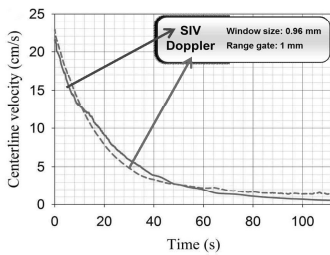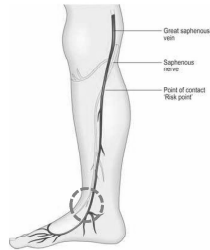
▪ **Measurement of blood flow in human vein**
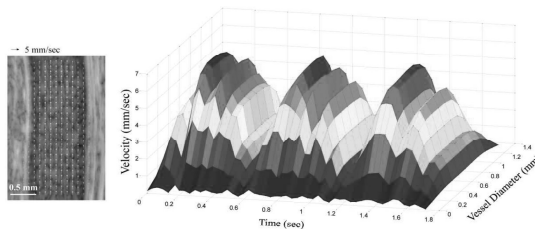
• An anterior superficial thigh vein
• Image size: 280 × 440 pixels
• Diameter: 1.2 mm
• Velocity range: 0.3-6.1 mm/s
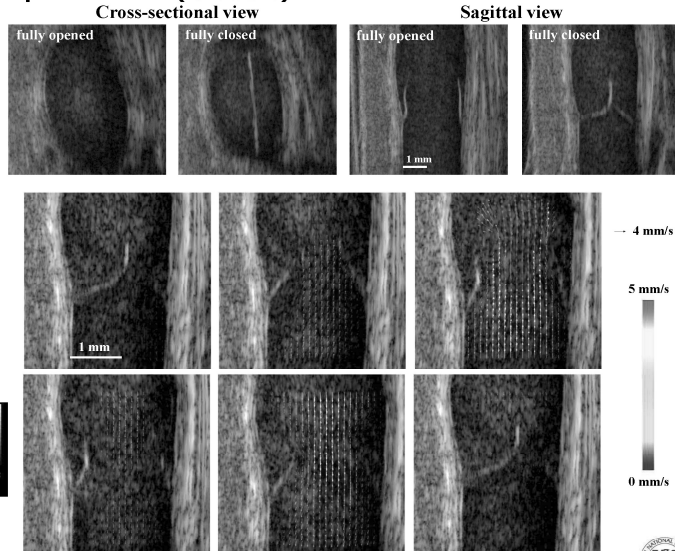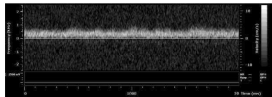
12/15   Yeom et al., *Ultrasonics*. **54(6)**, (2014)

Application of SIV

▪ **Valve in the greater saphenous vein (대복재정맥) at the ankle**

https://www.google.co.kr/

Doppler results

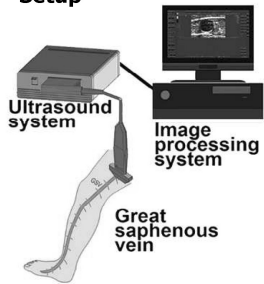**Cross-sectional view**   **Sagittal view**

13/15   Nam & Yeom et al, *Int J Cardiovasc Imaging* **59**, (2015)

Helical flow behind valve

▪ **Setup**   ▪ **SIV measurement**
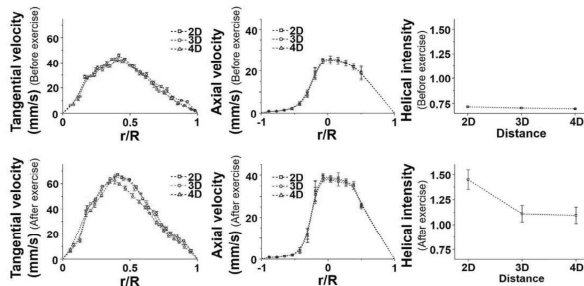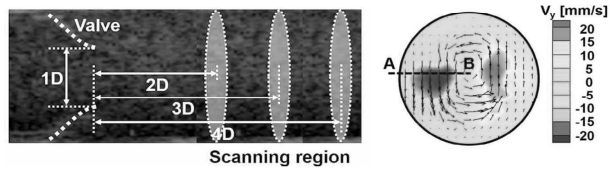

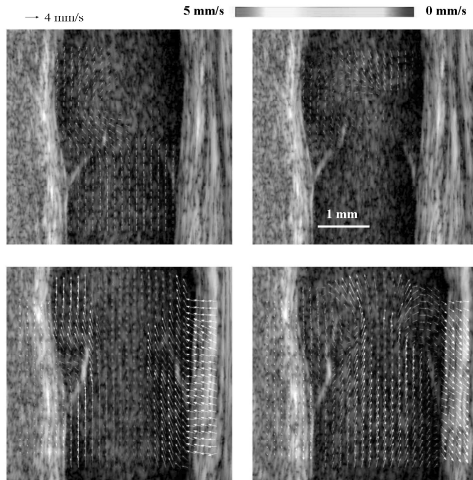Secondary abnormal flows are closely associated with venous diseases.
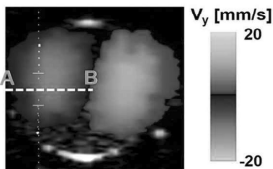
Exercise: lift and put their heels down for 10 min

14/15   Lee & Yeom et al., *Ultrasound Med. Biol.* **44**, (2018)
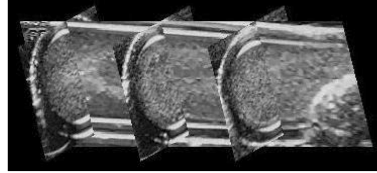
Simultaneous measurement

▪ Wall motion and blood flows

→ 4 mm/s   5 mm/s   0 mm/s

1 mm

15/15   Nam & Yeom et al, *Int J Cardiovasc Imaging* **59**, (2015)

▪ RBC aggregation and blood flows

Echogenicity variation at upstream of stenosis

Nam et al., *Ultrasound Med Biol*, **34**, (2008)

Effect of smoking for echogenicity variation

Variable	Category	
	Cluster 1 Heavy smoker group ($n = 17$)	Cluster 2 Mild smoker group ($n = 11$)
ΔA_{cve}	4.98 ± 4.26	-0.31 ± 3.91*
DCC	18.1 ± 6.0	4.0 ± 4.1**
SY	8.5 ± 5.2	7.5 ± 7.1
Age	26.8 ± 4.9	28.6 ± 5.2
WEH	4.4 ± 4.7	5.2 ± 4.0
ΔHR	3.3 ± 5.8	2.9 ± 4.1

ΔA_{cve} = change of amplitude of cyclic variation of echogenicity
DCC = daily consumption of cigarettes
SY = smoking years
WEH = weekly exercise hours
ΔHR = change of heart rate
Li et al., *Ultrasound Med. Biol.* **37**, (2011)