

# 중재적 시술의 공학적 접근

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## **Atherosclerosis**

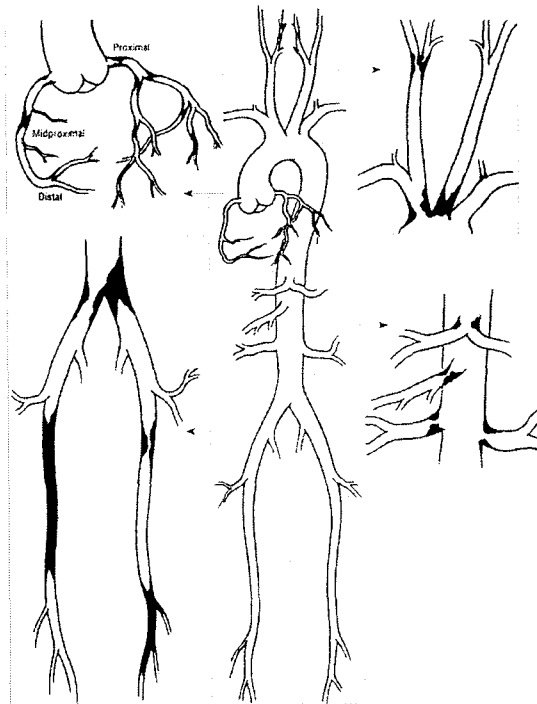
- Generalized degenerative disease process mainly affecting large and medium sized arteries; characterized by the accumulation of cells; matrix fibers, lipids and tissue debris in the intima.
- Susceptible vessel to focal plaque deposition; infrarenal abdominal aorta, carotid bifurcation, coronary artery and superficial femoral artery

## Atherosclerosis

- Hemodynamic forces are localizing factors in atherosclerosis; modification of flow dynamics potentiate plaque deposition at arterial branching, ostia, bifurcations and bends.
- Hemodynamic variables accountable for selective distribution of plaque: shear stress, flow separation and stasis, oscillation of shear stress vectors, turbulence, and hypertension.

## Atherosclerosis

- Arterial branching
- Ostia
- Bifurcations
- Bends.

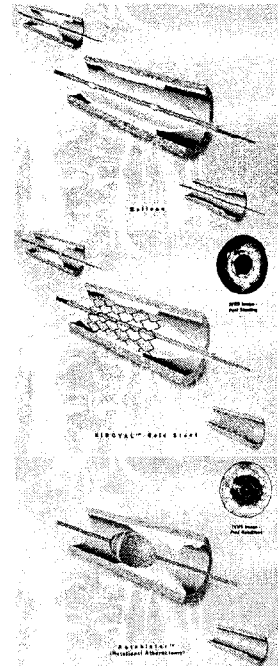


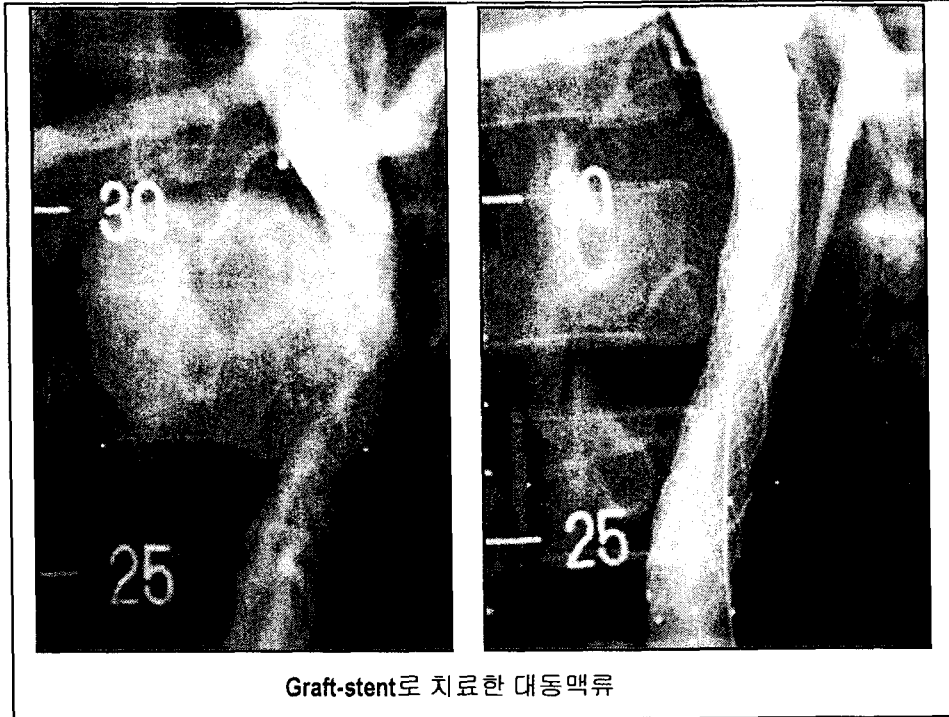
## Clinical Treatment

- Intervention
  - Stent
  - Balloon Angioplasty
  - ....
- Intervention Anastmosis
  - Bypass grafting
  - Sequential bypass
  - Cuff patch

## Interventional approach

- ✓ Balloon
  - Plaque가 단단하지 않은 경우
  - 혈관손상이 비교적 적음
- ✓ Stent
  - 확실하게 혈관확장
  - 혈관손상으로 혈전증 유발
  - 혈관내막증식으로 재협착 발생
- ✓ Rotablator
  - 석회화된 협착부위를 깎아냄
  - 협착부가 편심일 경우 혈관 손상 위험





## Engineering Methodology

### 1. 이론해석

### 2. 컴퓨터 시뮬레이션

- 비용최소 및 계산시간의 단축
- 수학적 모델 필요
- 상세한 유동정보

### 3. 실험

- 신뢰성 있는 정보 측정의 어려움
- 압력측정은 쉬우나 속도, 전단응력의 측정은 어려움

최적의 예측방법-

컴퓨터 시뮬레이션과 실험의 결합

○ Computer simulation

- 속도벡터
- 등속도분포
- 유선과 유맥선

○ Experiment

- *In vivo*

CT, MR Angiogram, Color Doppler Imaging

- *In vitro*

Dye injection method, Birefringence method,  
Photochromic flow visualization,  
Laser light illumination method

## Mathematical Modeling

○ Poiseuille 모델

- 비압축성 뉴턴유체의 정상층류 유동에 대한 Poiseuille 방정식 이용
- Poiseuille 법칙의 생체적용의 한계
  - 뉴턴유체
  - 층류유동
  - 혈관벽에서의 No-slip
  - 정상유동
  - Cylindrical Shape & Rigid wall

○ Womersley 모델

- Navier-Stokes 방정식의 선형화
- Rigid, elastic and viscoelastic wall motion
- Womersley 모델의 생체적용시의 가정
  - 뉴턴유체
  - 층류유동
  - 입구효과의 무시
  - Reflection-free system
  - 지름이 일정한 원형관

○ Other Models

- Modified Navier-Stokes models
- Non-linear models
- Models of vascular beds

## **Computer Simulation**

- 혈액유동의 해석적 연구
  - 혈관의 복잡한 기하학적 형상과 비선형문제로 인한 한계성
- 혈액유동의 컴퓨터 시뮬레이션 연구
  - 기하학적 형상의 복잡성과 지배방정식의 비선형성을 극복하기 위한 대안으로 컴퓨터 시뮬레이션 방법의 이용이 늘어 나고 있는 추세
  - 오늘날 크게 향상되고 있는 컴퓨터의 하드웨어능력 뿐만 아니라 유동현상을 예측 가능하게 하는 수학적 모델과 해석알고리즘의 개발 등으로 만족할 만한성과
- 장점 : 경비가 저렴, 짧은 시간내 해석가능
- 단점 : 실험적 연구와 비교하여 수치해석결과의 타당성 검증 요구

## Governing Equations

***3D, Pulsatile, Incompressible Blood Flow***

$$\frac{\partial u_j}{\partial x_j} = 0$$

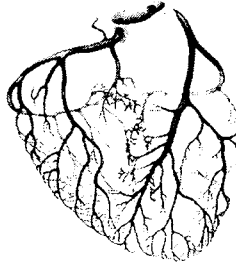
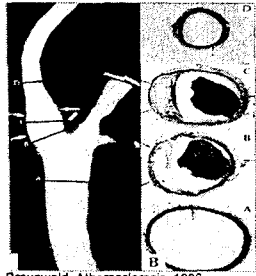
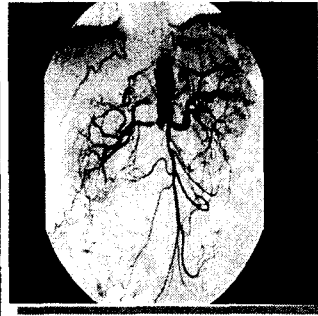
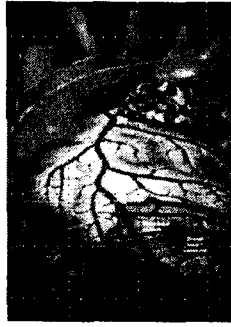
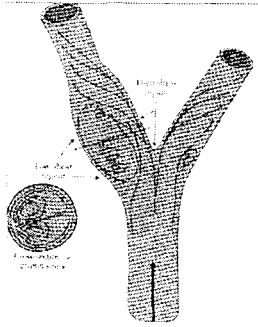
$$\rho \left( \frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} \right) = - \frac{\partial p}{\partial x_i} + \eta \frac{\partial}{\partial x_j} \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right)$$

**Constitutive Eq. : Carreau Model**

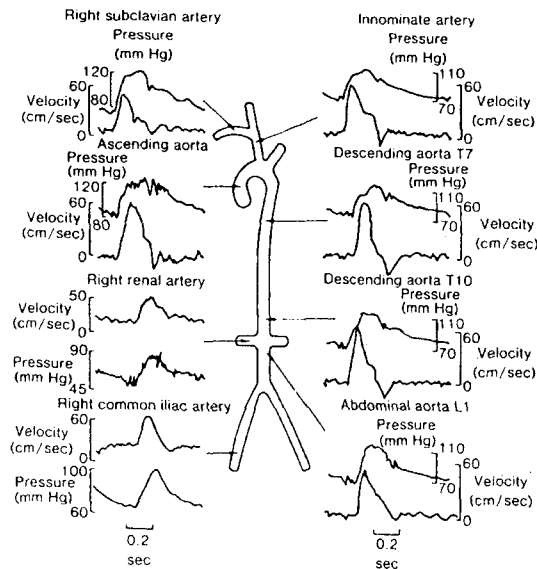
## Consideration Parameters

- Blood flow features in the human vessel
  - 3-D arterial geometry
  - Physiological flow(Pulsatile flow)
  - Non-Newtonian behavior
  - Elastic vessel wall compliance

### 3-D arterial geometry



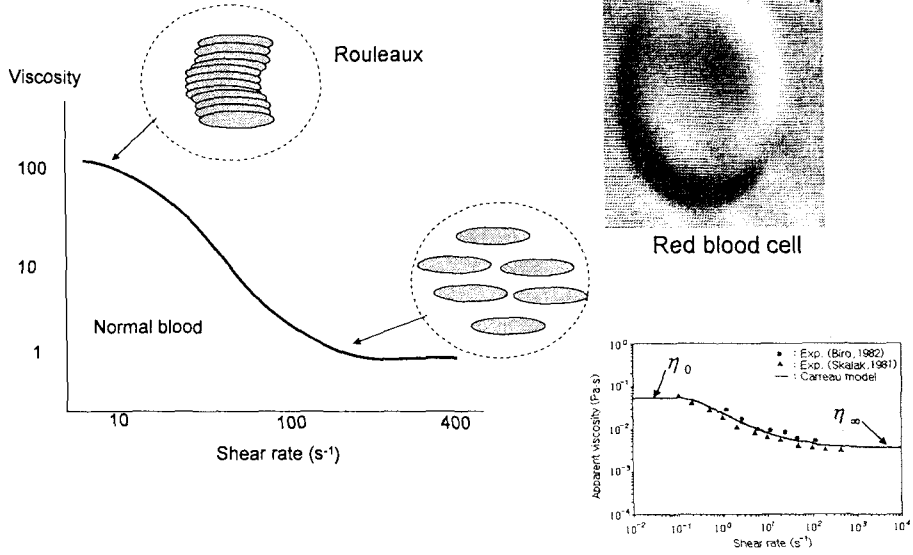
Braunwald, Atherosclerosis, 1996



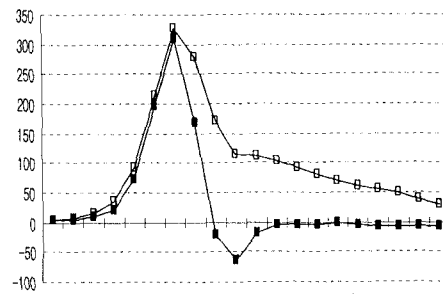
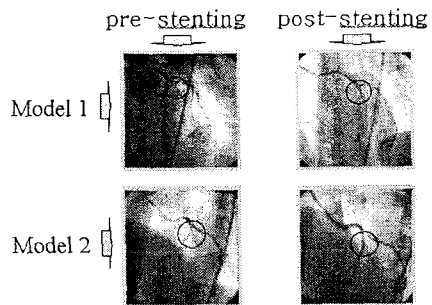
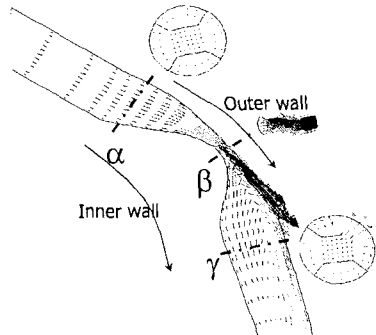
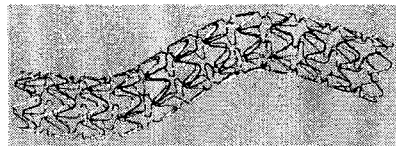
Pressure and velocity waveforms in different arteries recorded in a human



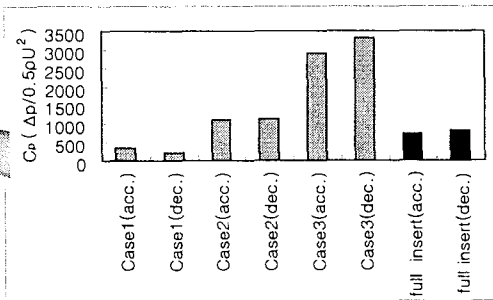
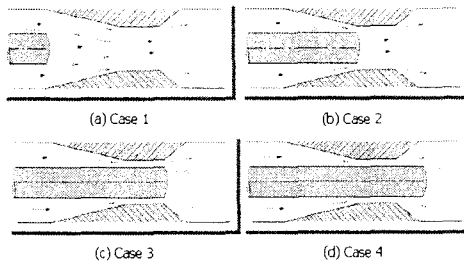
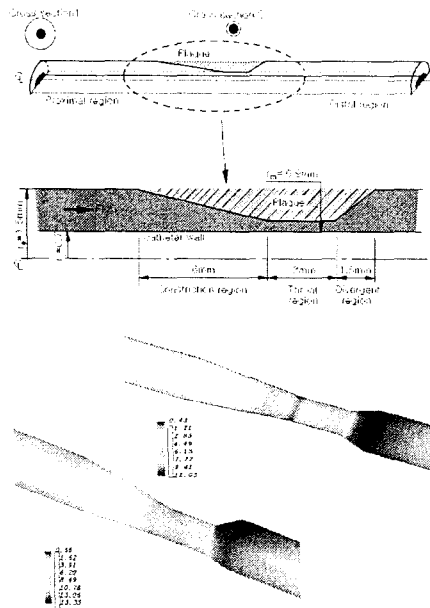
### Why non-Newtonian?



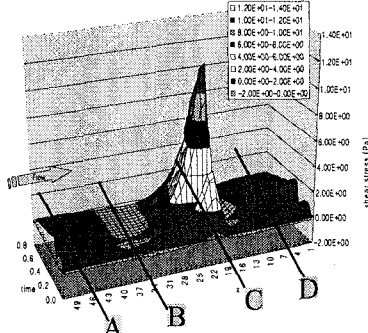
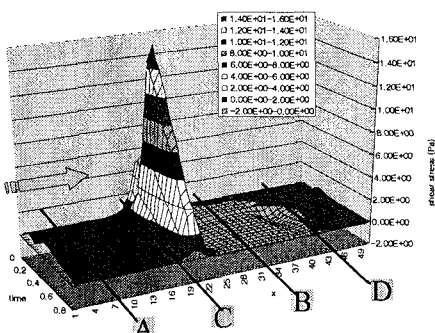
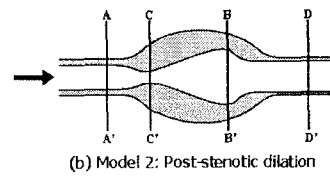
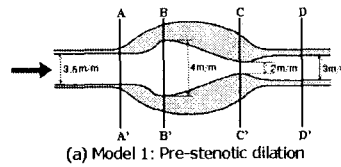
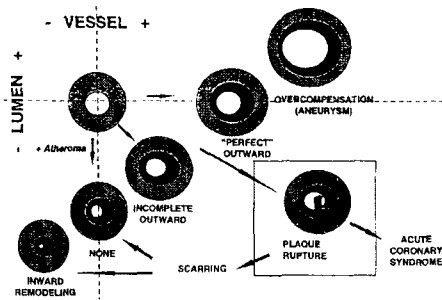
### Stent 관련 연구



# Catheter 관련 연구



# Remodeling 관련 연구



Anastomosis 관련 연구

