Introduction to atherosclerosis

Dorian O. Haskard

Vascular Sciences Section

National Heart and Lung Institute

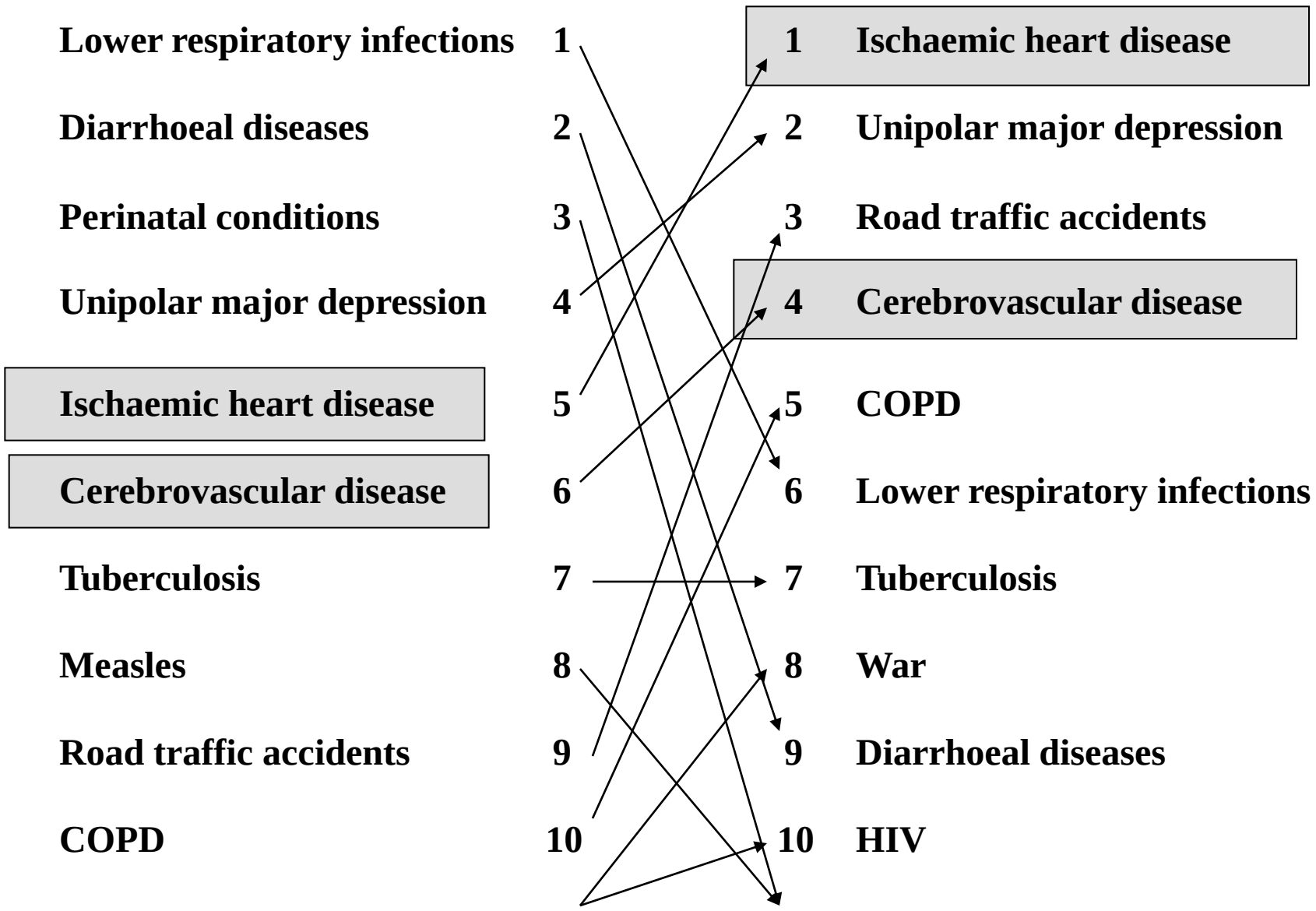
British Heart Foundation

Imperial College London

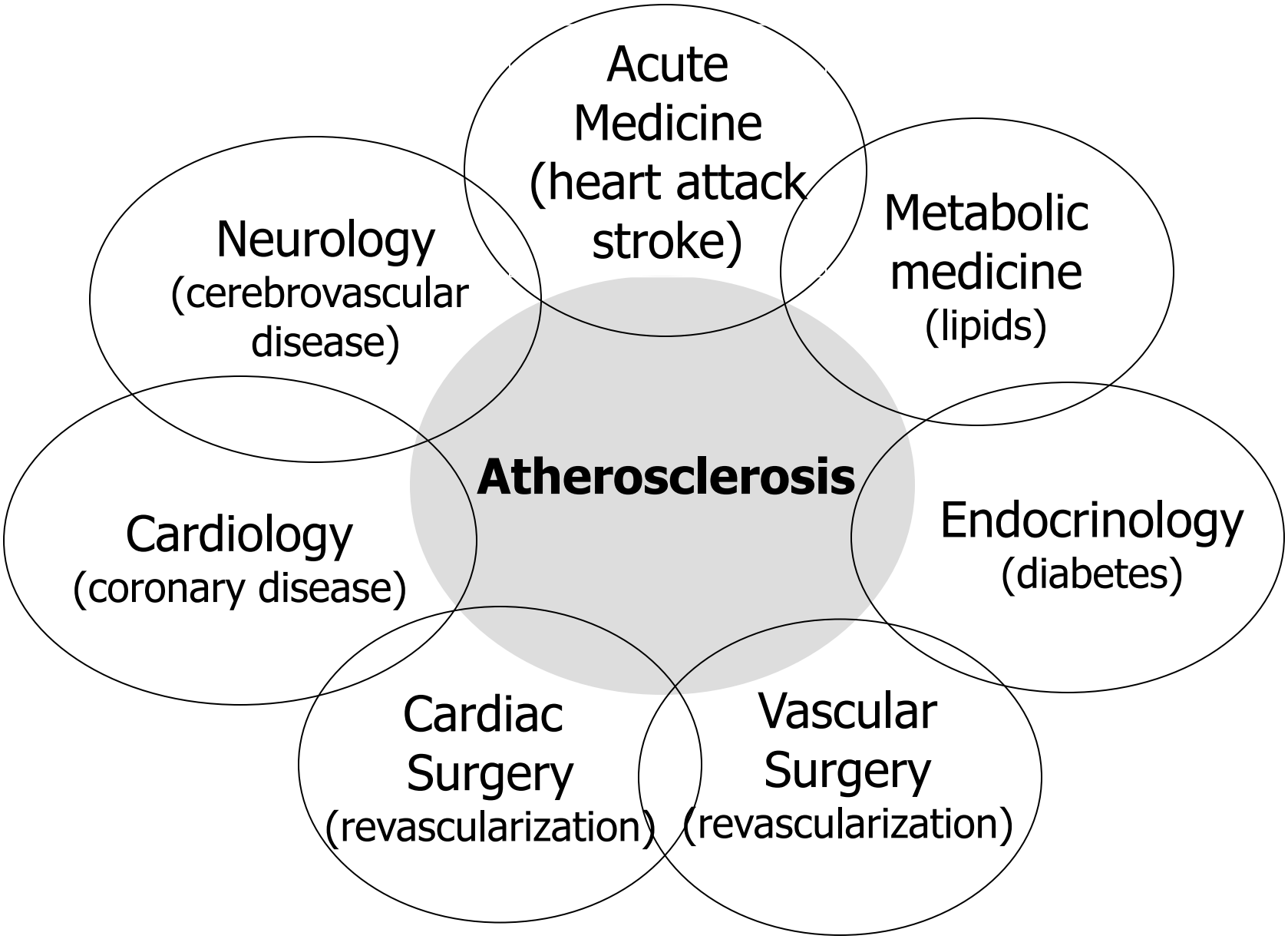
Atherosclerosis

- Introduction
- Pathology
- Cholesterol and inflammation
- Importance of blood flow
- Investigating molecular mechanisms

World disease burden



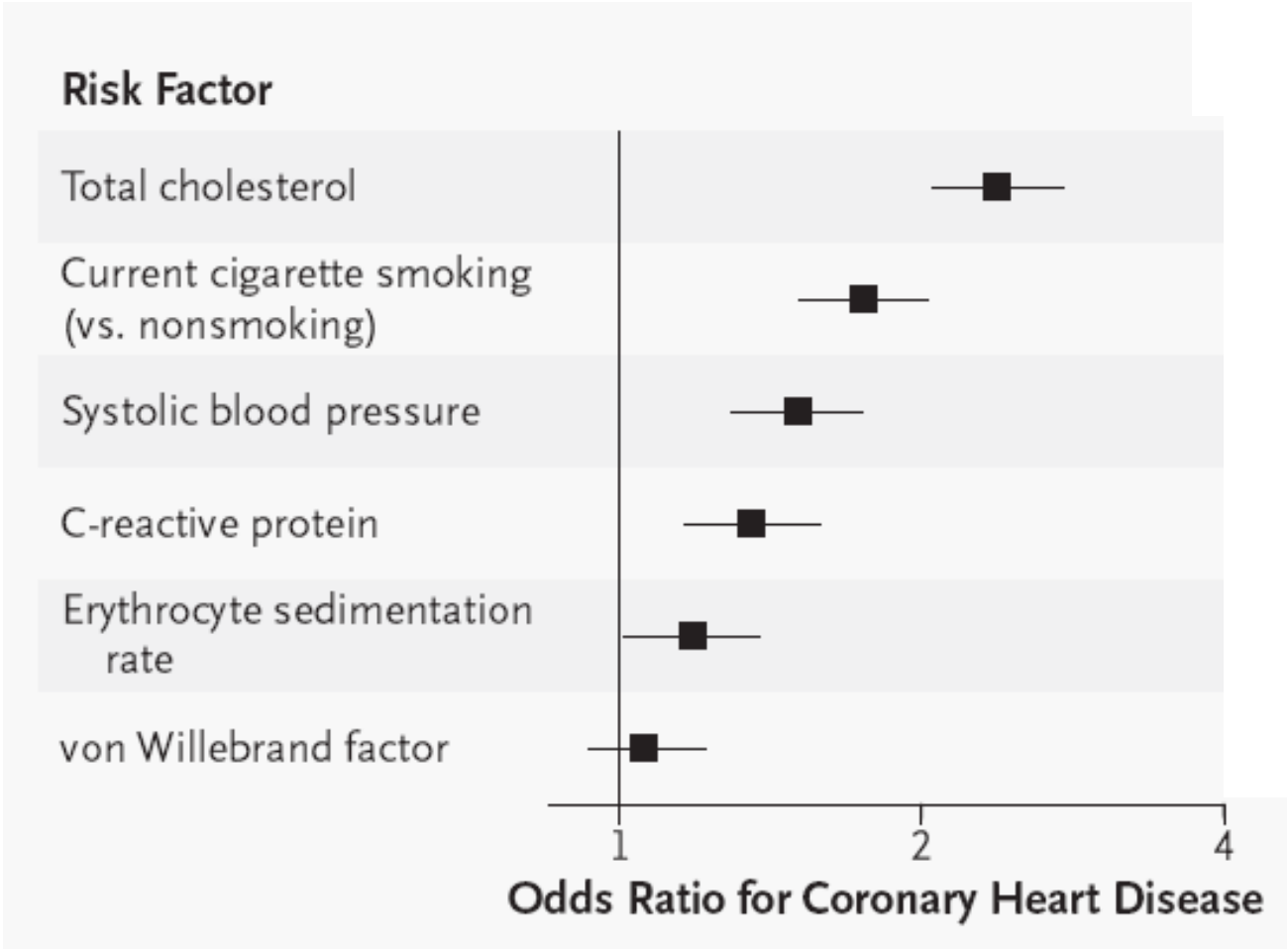
Adapted from Lopez and Murray (1998) Nature Med 4: 1241


Acute Medicine (heart attack stroke)
Neurology (cerebrovascular disease)
Metabolic medicine (lipids)
Atherosclerosis
Cardiology (coronary disease)
Endocrinology (diabetes)
Cardiac Surgery (revascularization)
Vascular Surgery (revascularization)

Risk Factors

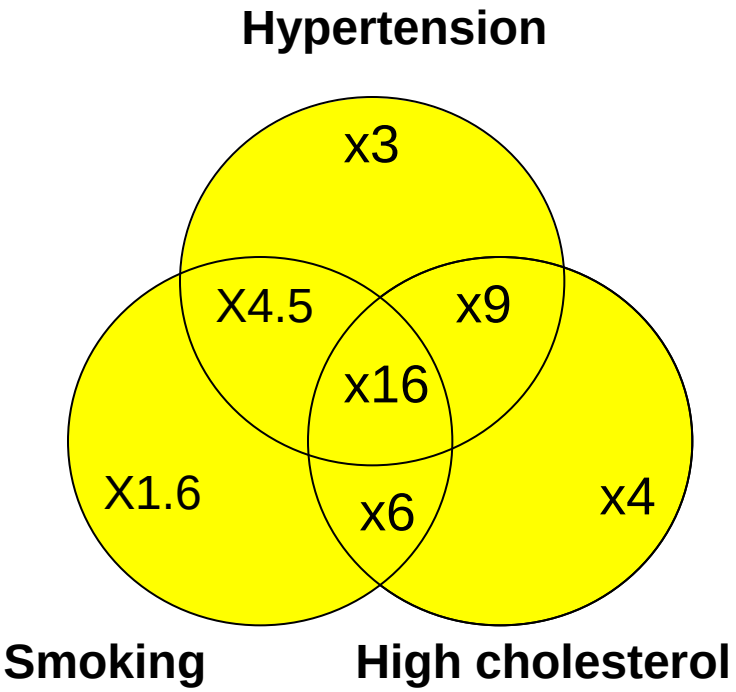
Modifiable	Not modifiable
dyslipidaemia	Age
smoking	Sex
hypertension	Genetics
diabetes mellitus	
visceral obesity	
lack of exercise	
raised homocysteine	

Relative importance of risk factors



Danesh et al 2004 N Engl J Med 350:1387

Risk factor interactions

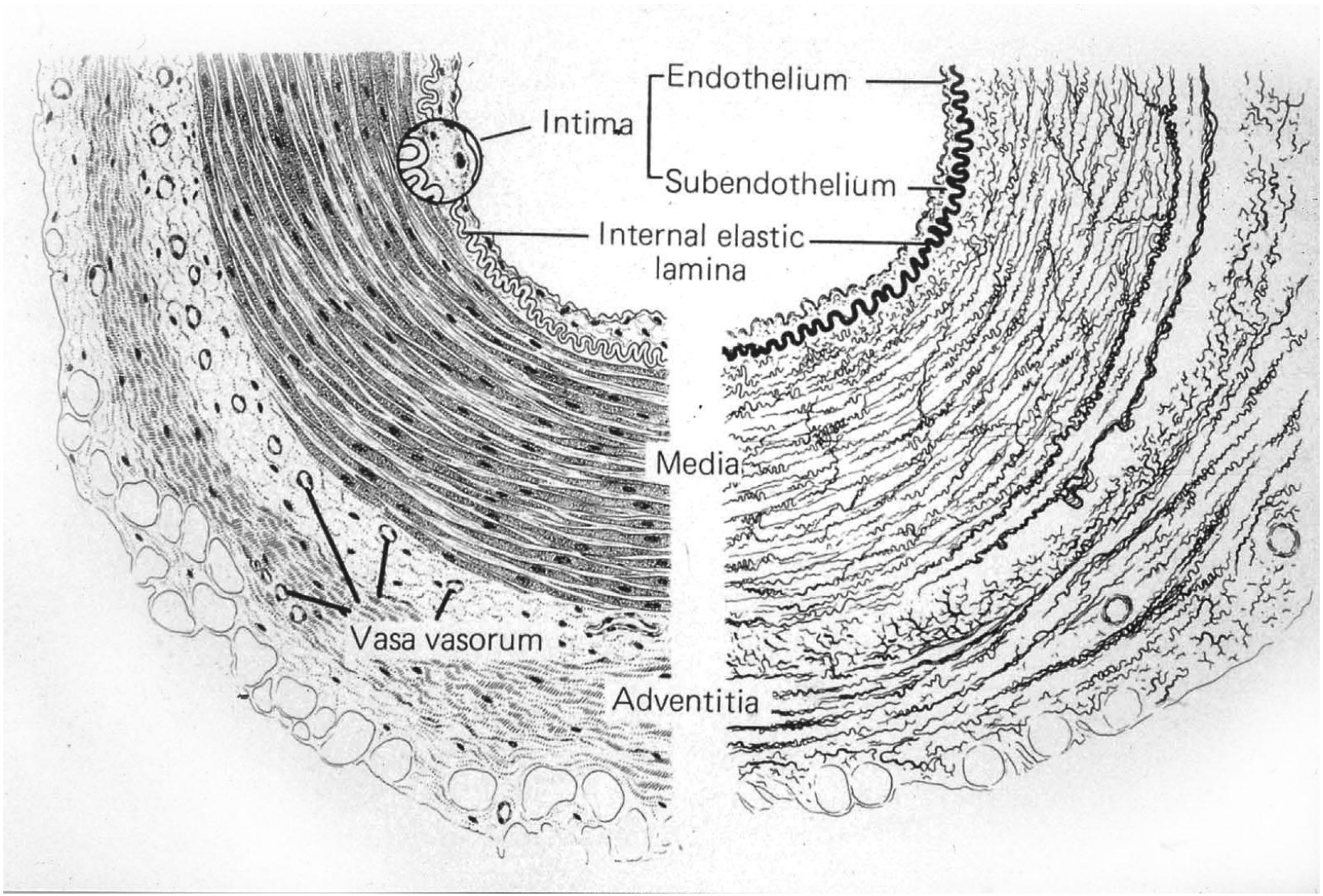


PATHOLOGY

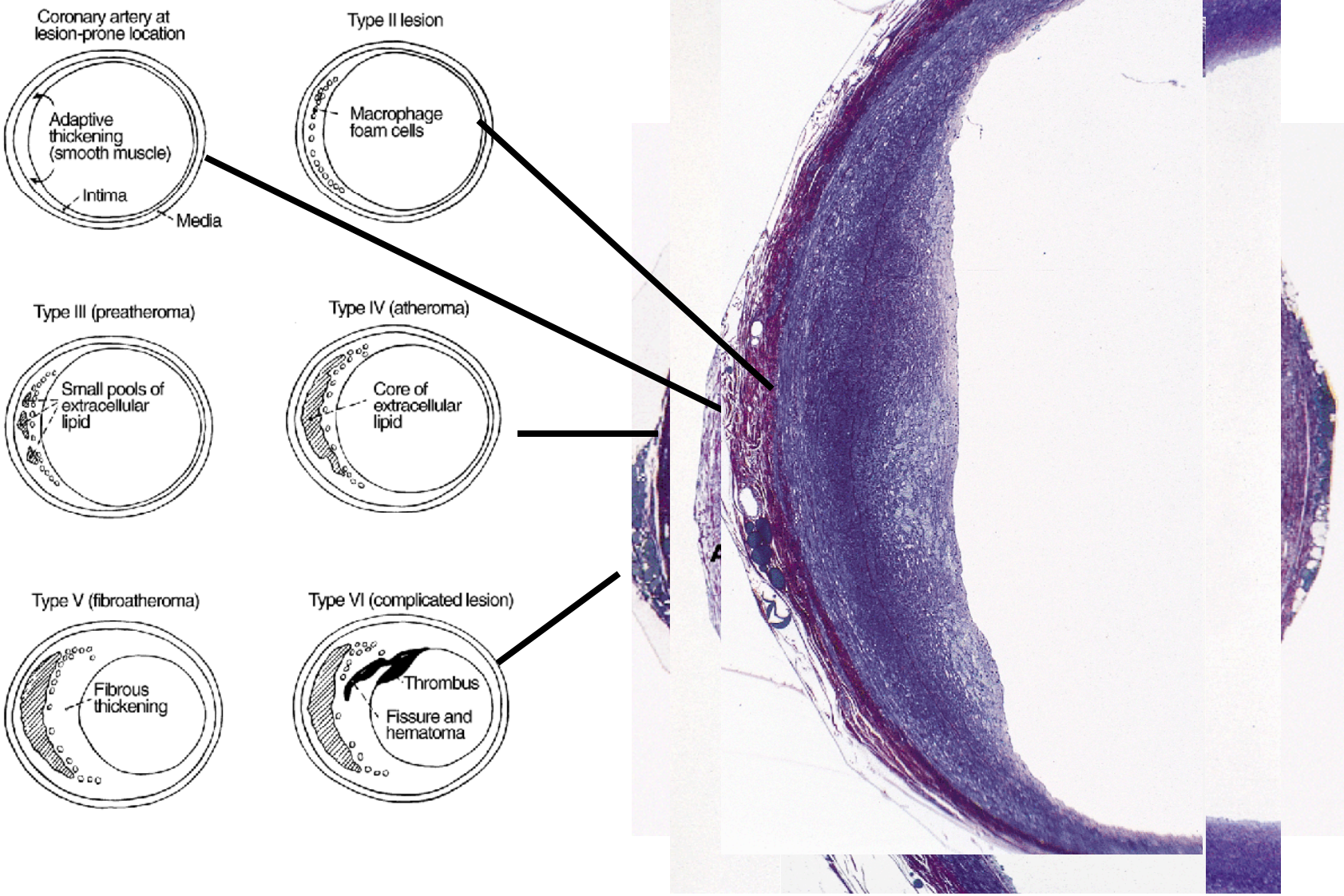
fatty streaks

intermediate lesion

ulcerated plaque


Endothelium
Intima
Subendothelium
Internal elastic lamina
Media
Vasa vasorum
Adventitia

Type II lesion



Debris (eg modified lipoproteins, apoptotic cells)

⇩

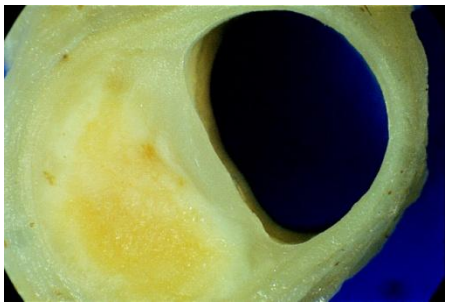
Reversible fatty lesions

⇩

Irreversible remodelling

wound healing ⇙ ⇘ *inflammation/thrombosis*

Stable plaques ⇔ **Unstable plaques**



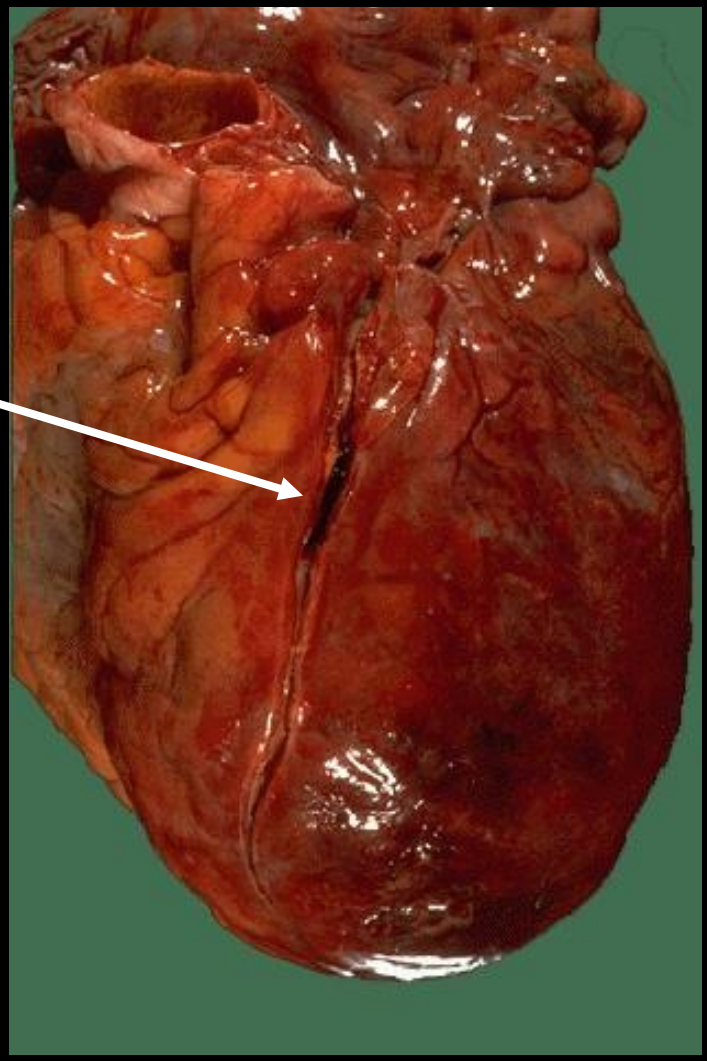
Ischaemia

Thrombosis, embolism

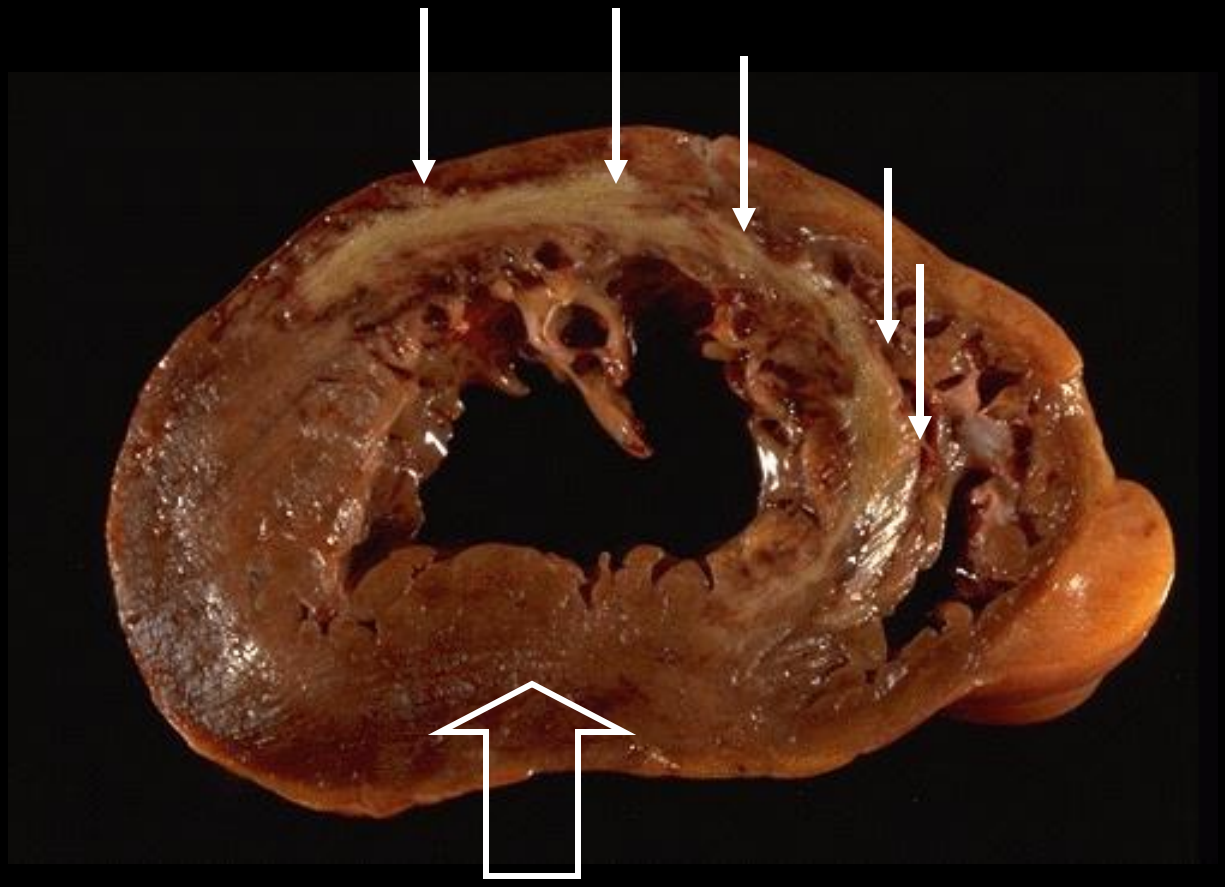
Angina
Intermittant claudication

Acute coronary syndromes
Stroke
Peripheral gangrene

Thrombus occluding left anterior descending coronary artery



Myocardial infarct

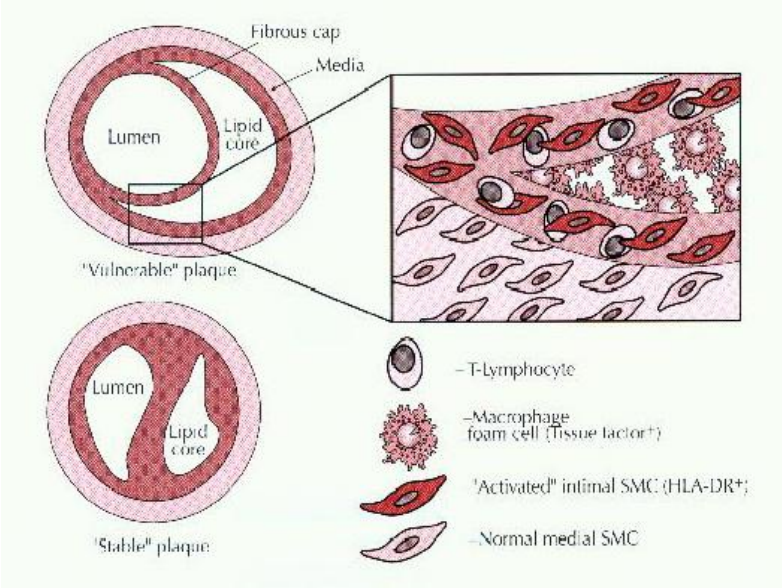


Left ventricle

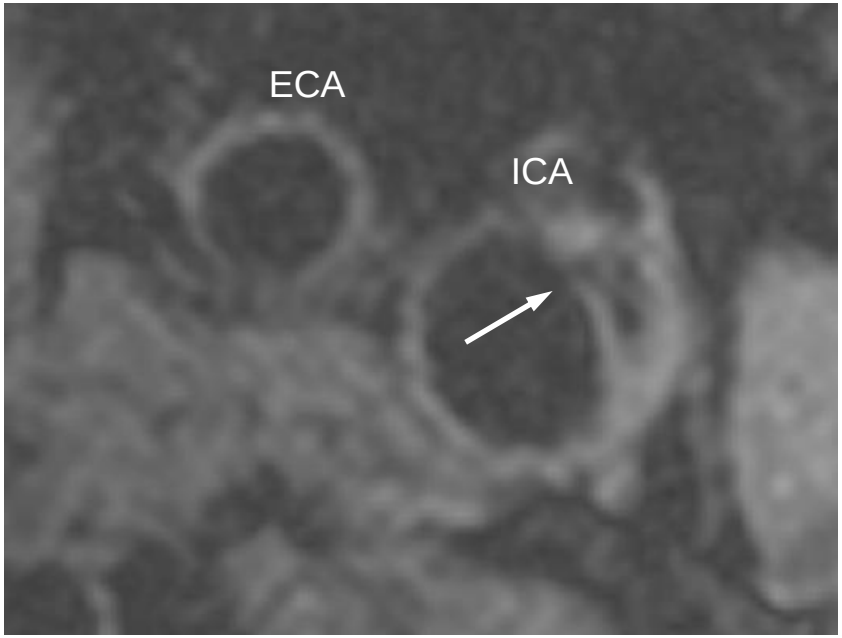
Main cellular players

- **Vascular endothelial cells**
  - Barrier function (eg to lipoproteins)
  - Leukocyte recruitment
- **Platelets**
  - Thrombus generation
  - Cytokine and growth factor release
- **Monocyte-macrophages**
  - Foam cell formation
  - Cytokine and growth factor release
  - Major source of free radicals
  - Metalloproteinases
- **T lymphocytes**
  - Macrophage activation
- **Vascular smooth muscle cells**
  - Migration and proliferation
  - Collagen synthesis
  - Remodelling and fibrous cap formation

Factors predisposing to instability

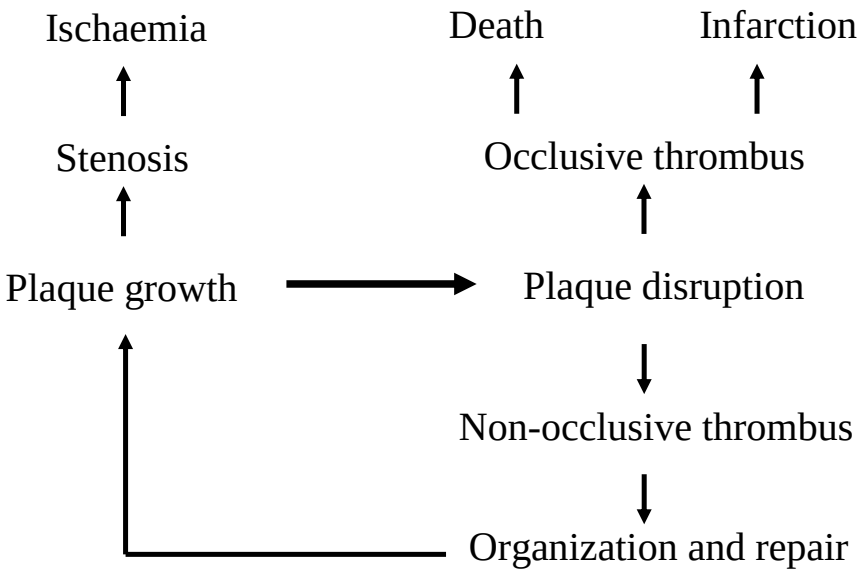


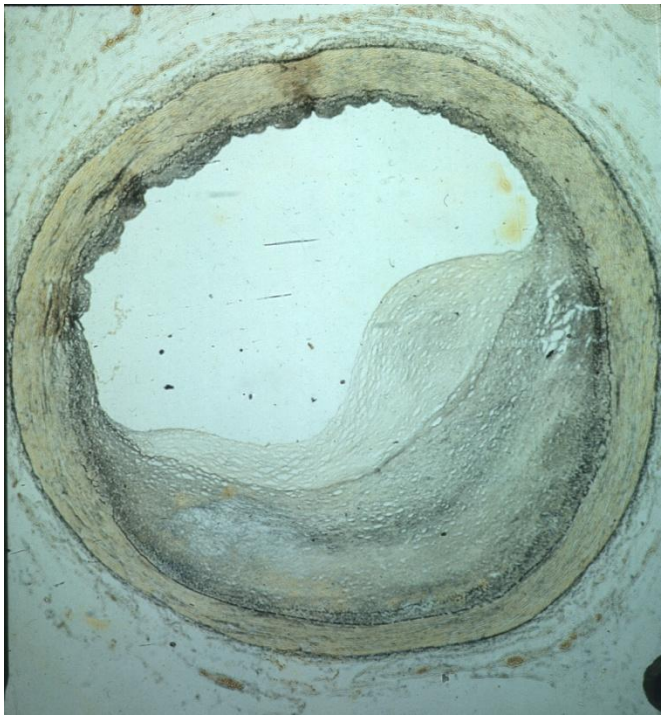
- Large soft eccentric lipid-rich core
- Thin fibrous plaque (< 65 μm)
- Low collagen content / VSMC density
- Infiltrate of activated mo-møs and T cells
- Neovascularization



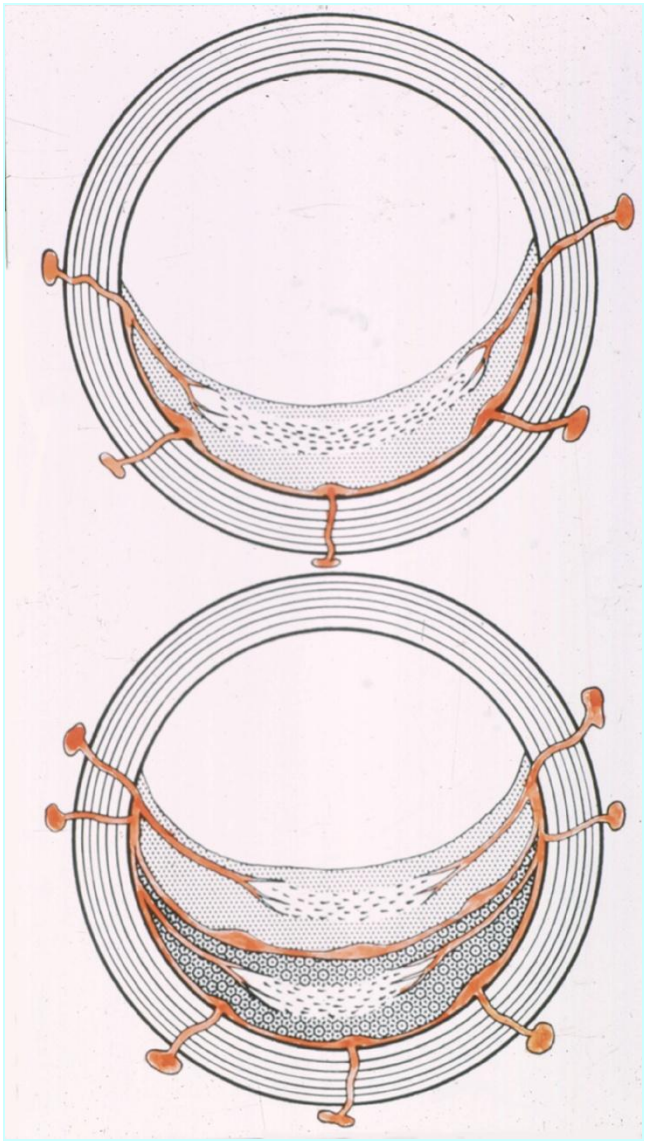
Van der Wal et al 1999
Cardiovascular Research 41:334

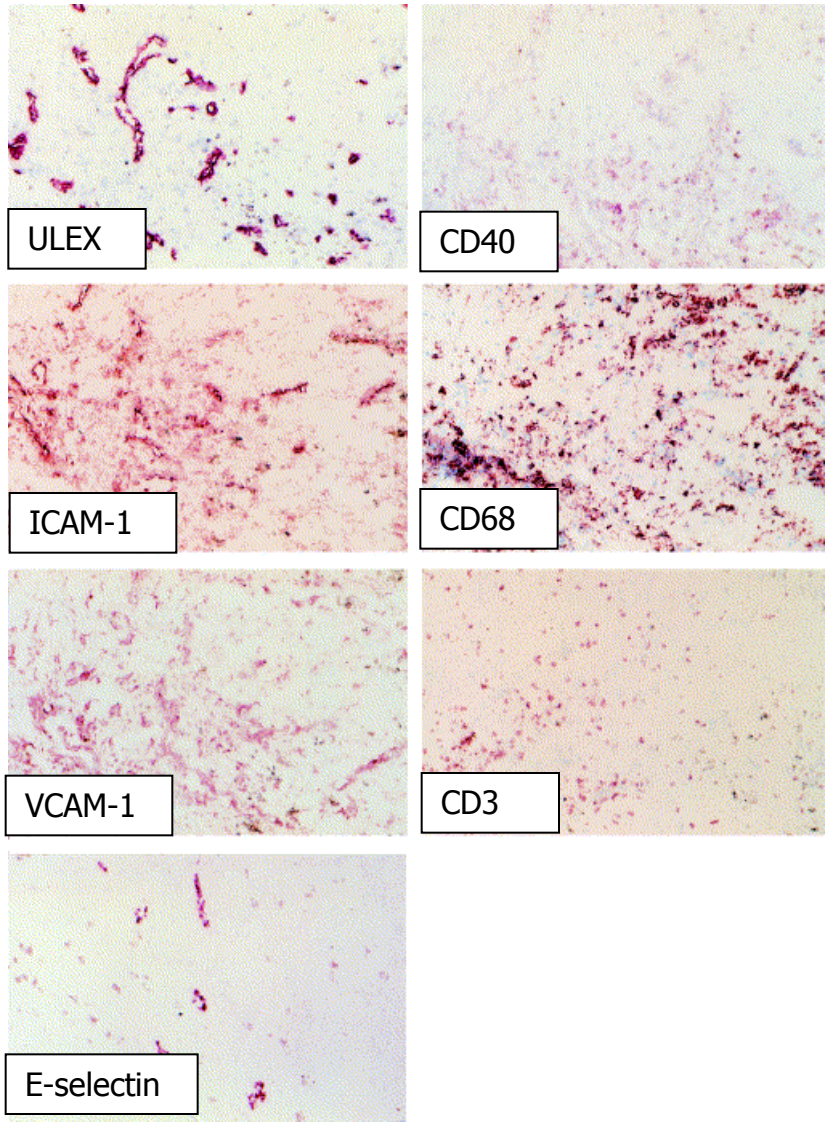
Step-wise progression of atherosclerotic plaques





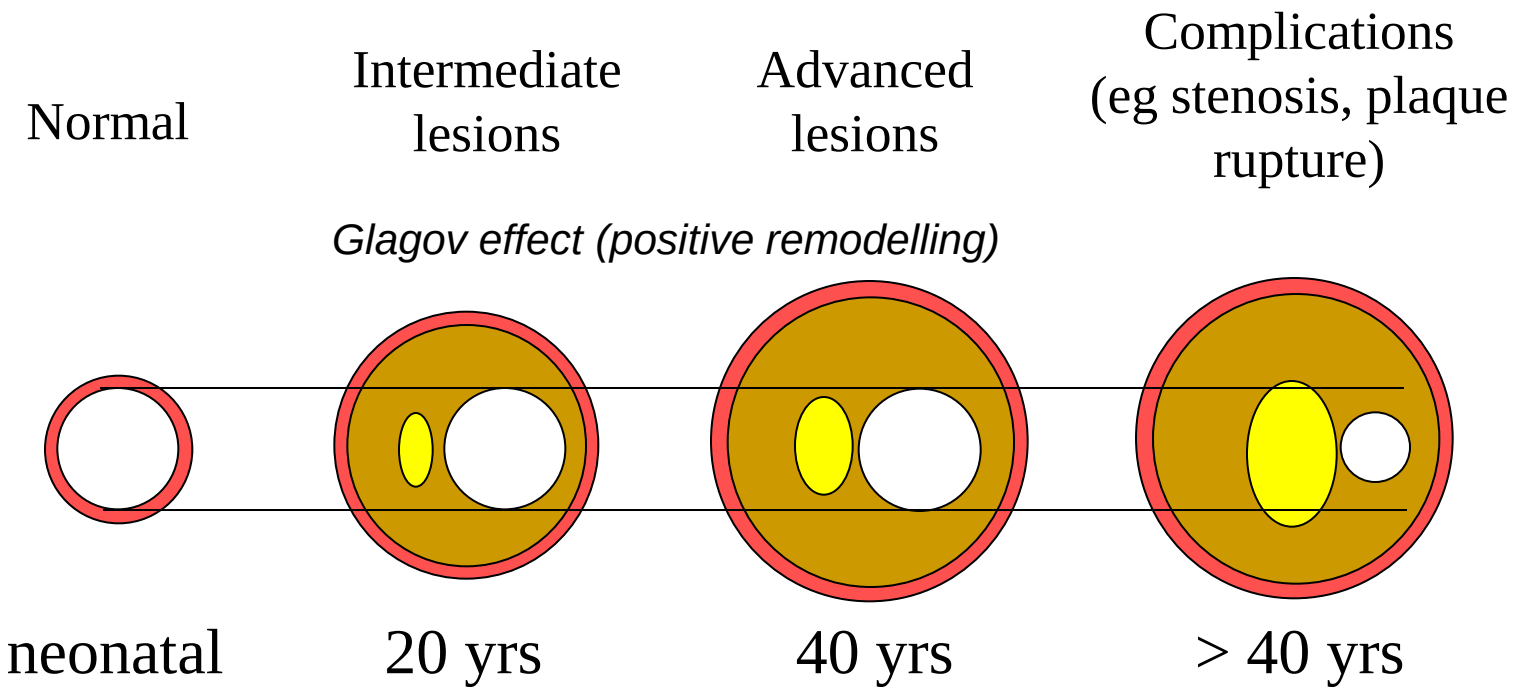
Vasa vasorum are the back-door for leukocyte recru





De Boer et al (1999) Cardiovasc Res 41:443.

Natural history of atherosclerosis



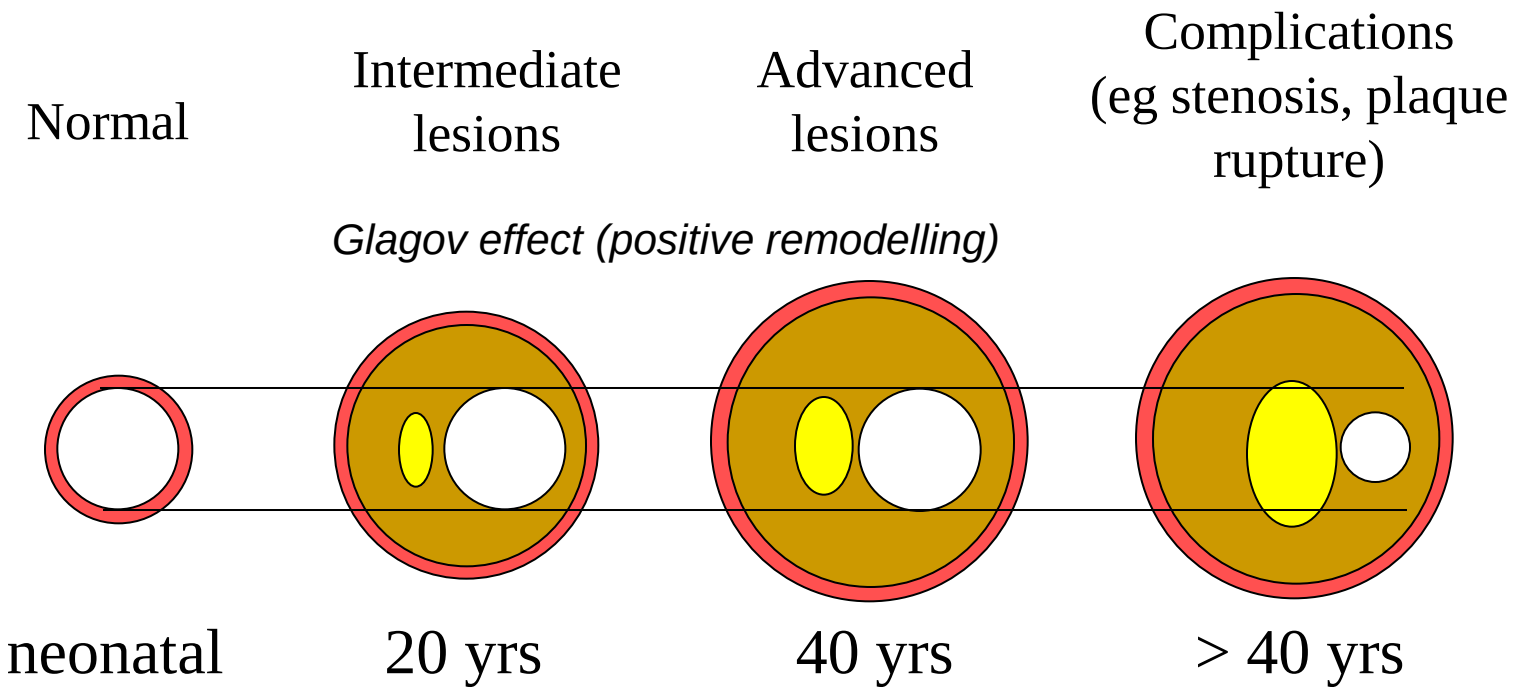
CORONARY DISEASE AMONG UNITED STATES SOLDIERS KILLED IN ACTION IN KOREA

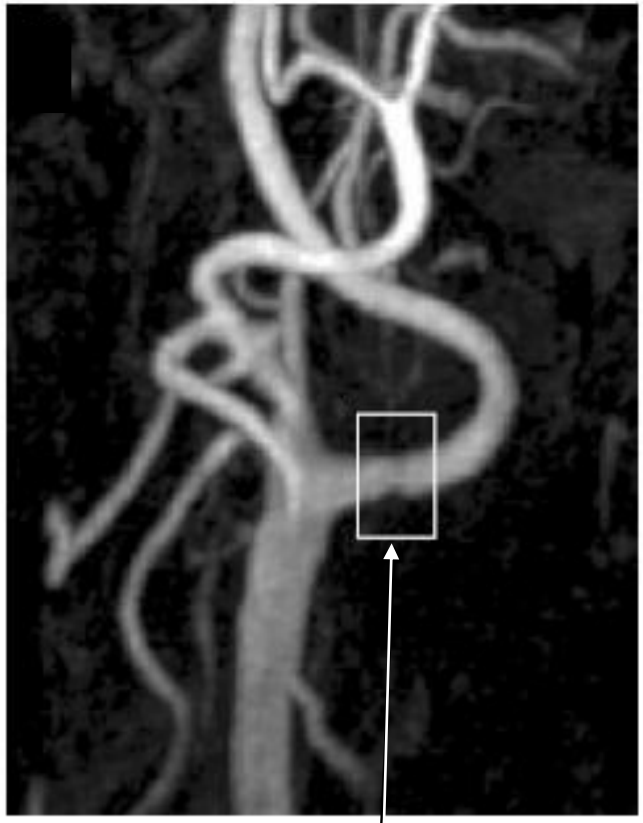
Major William F.Enos, Lieut.Col. Robet H. Holmes (MC), U.S. Army
and
Capt. James Beyer (MC), Army of the U.S.

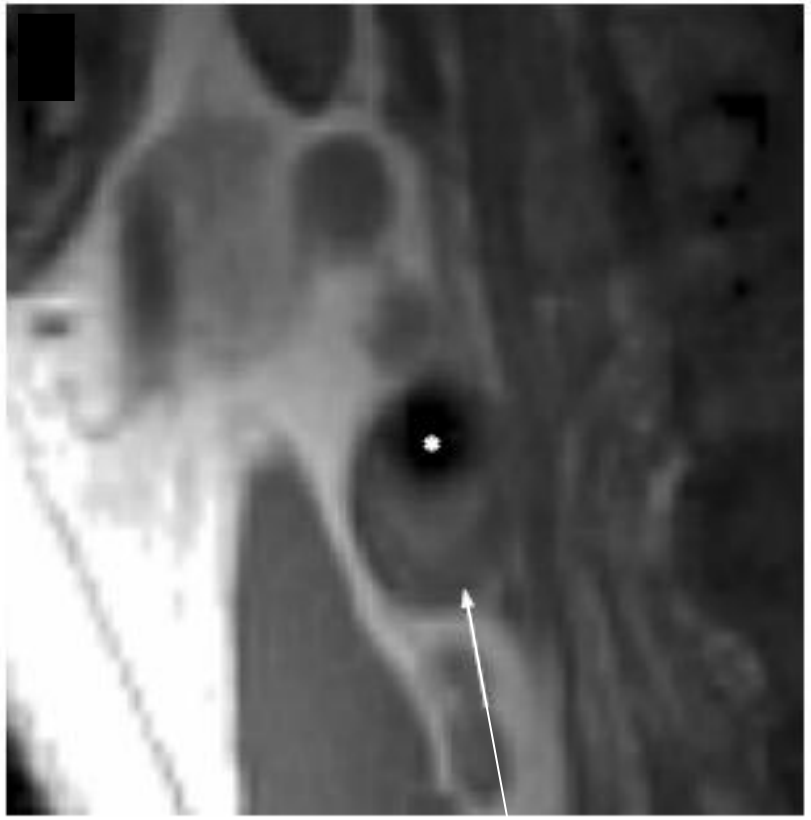
Journal of the American Medical Association July 18th, 1953, p1090

- 300 autopsies performed on United States battle casualties in Korea
- Cases with known coronary disease excluded from study
- Average age 22.1 years – (range 18-48 years)
- 77.3% of hearts showed some gross evidence of coronary disease
- such coronary changes rare in Koreans

Natural history of atherosclerosis







Minor (~30%) stenosis of R internal carotid artery

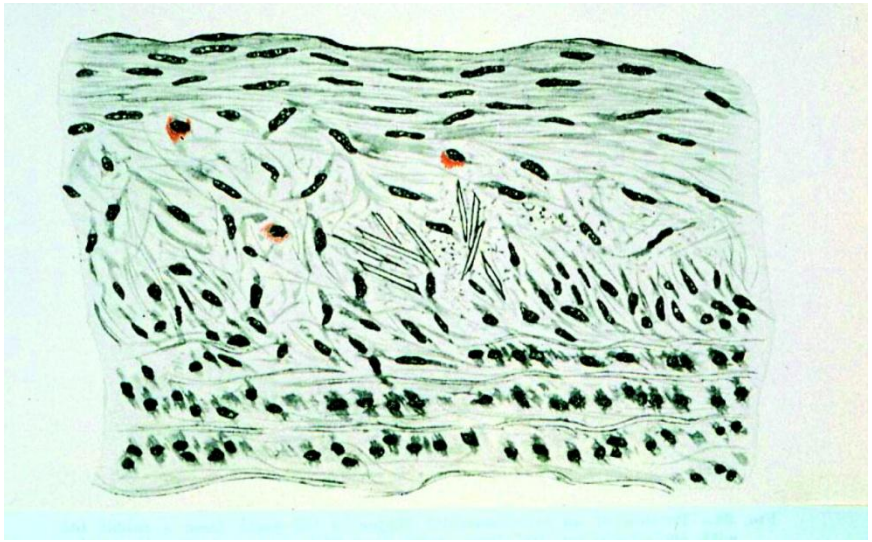
Atherosclerotic plaque occupying ~80% of arterial cross-section

Keenan, N G et al. Heart 2008;94:228

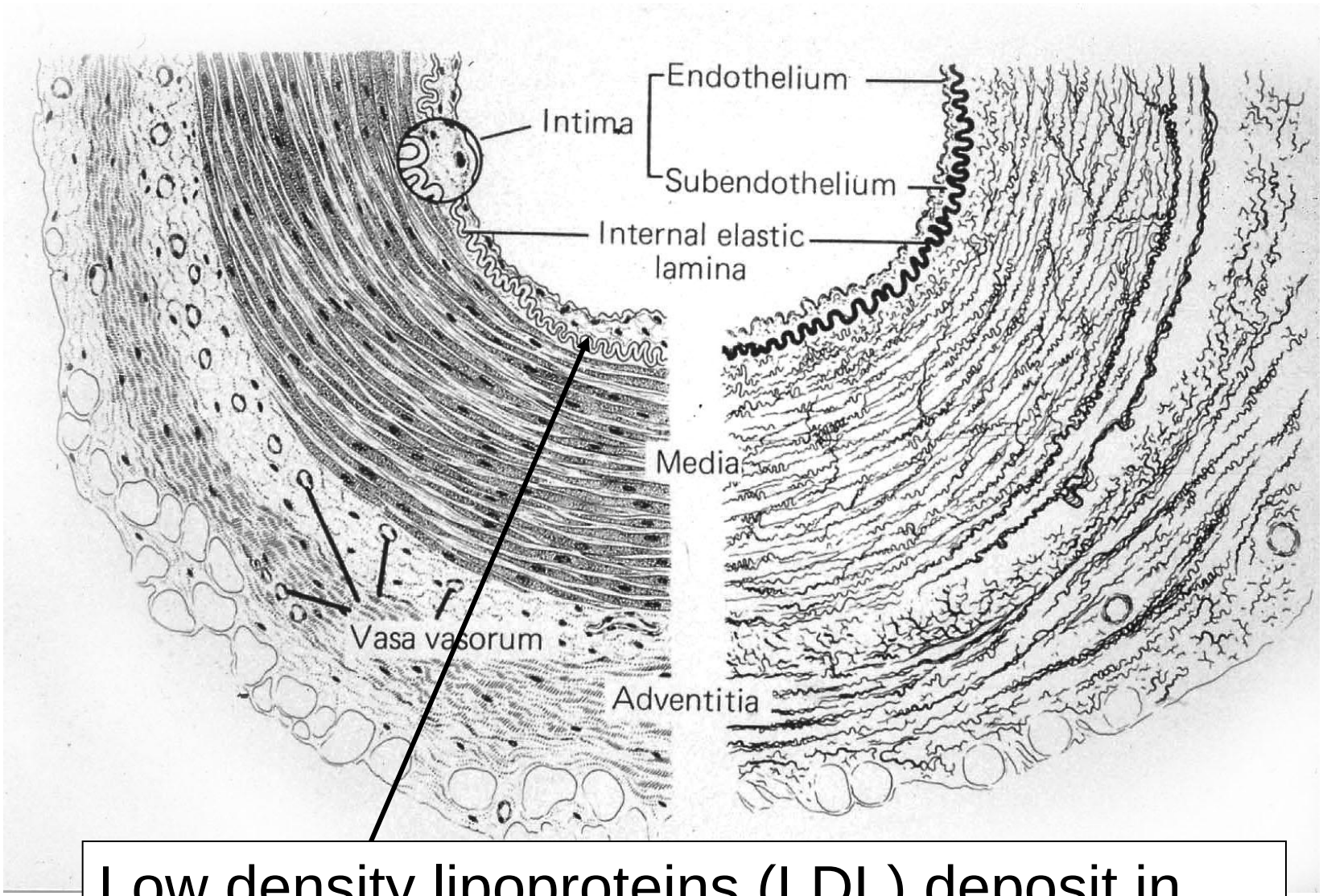
CHOLESTEROL AND INFLAMMATION

History – the cholesterol hypothesis

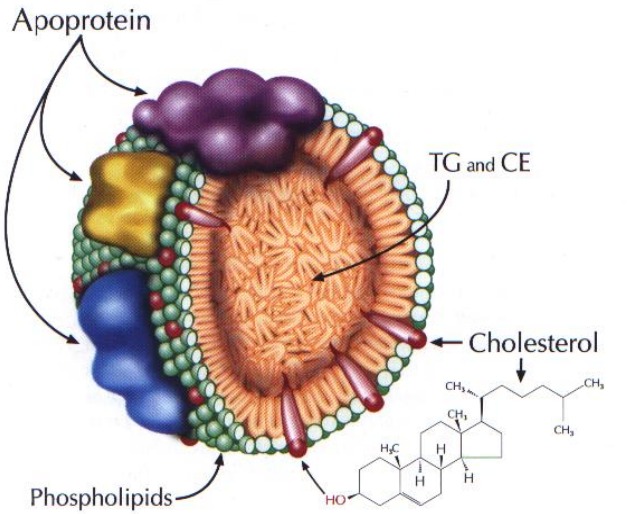
N. N. Anitschkow
Military Medical Academy of St Petersburg
(circa 1904)

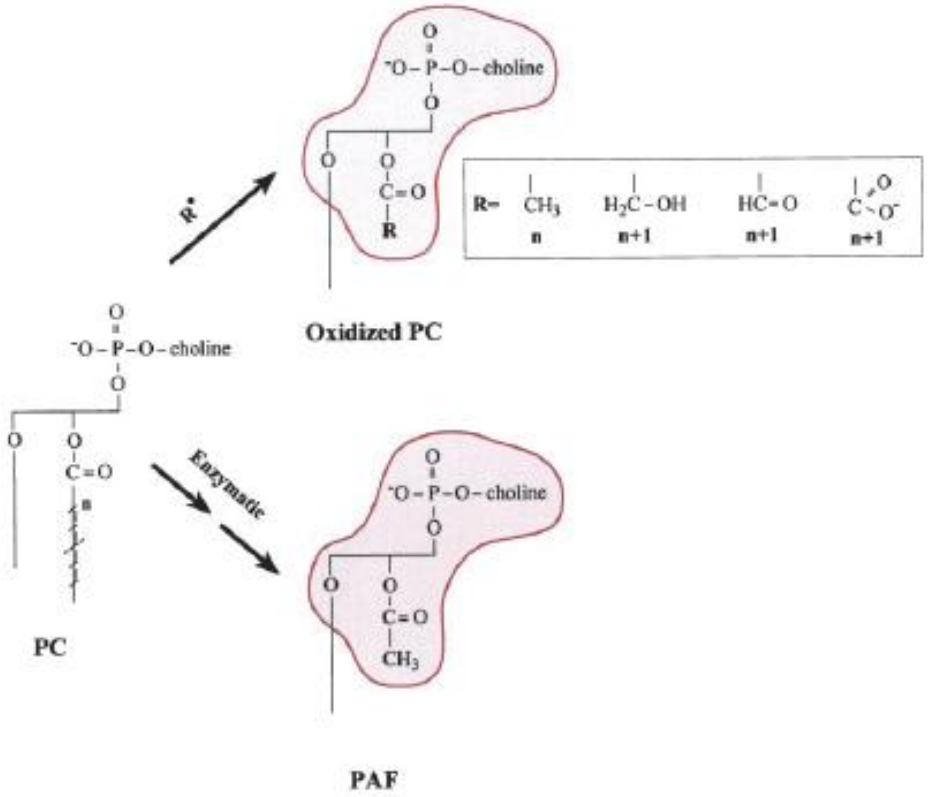


Plaque from a rabbit fed cholesterol for 106 days and then chow for >2 years



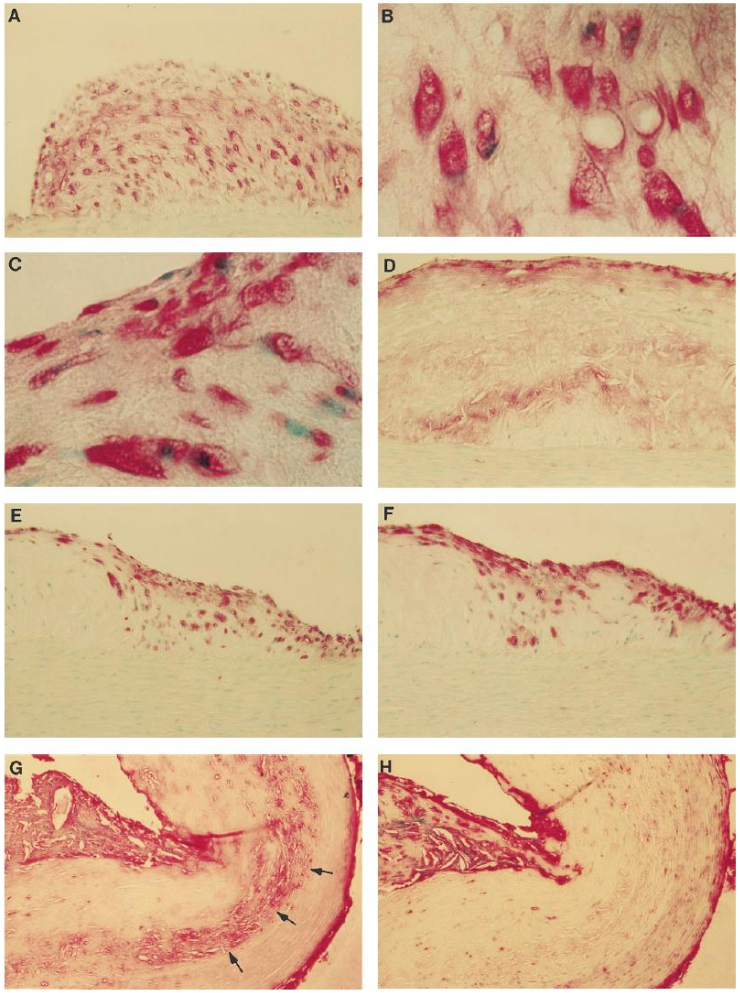
Low density lipoproteins (LDL) deposit in the subintimal space at sites of low/complex flow, and bind to matrix proteoglycans





McIntyre et al 1999 J Biol Chem 274:25189

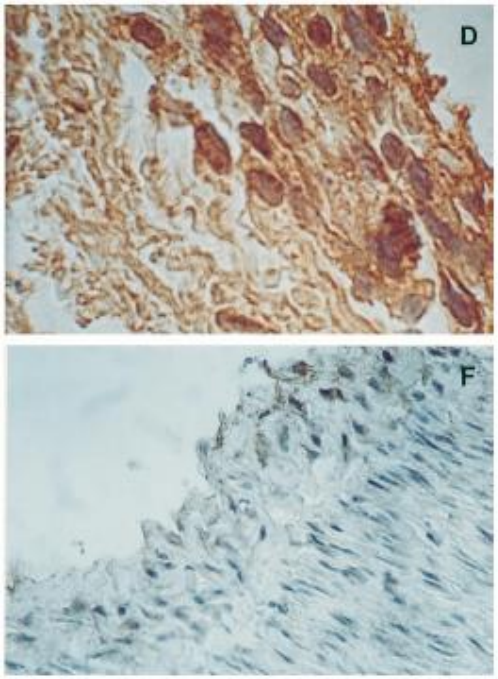
Staining of arteries with antibodies to oxidised phospholipids



Palinski et al 1996 J Clin Invest 98:800

LDL modification in the arterial wall happens before macrophage infiltration

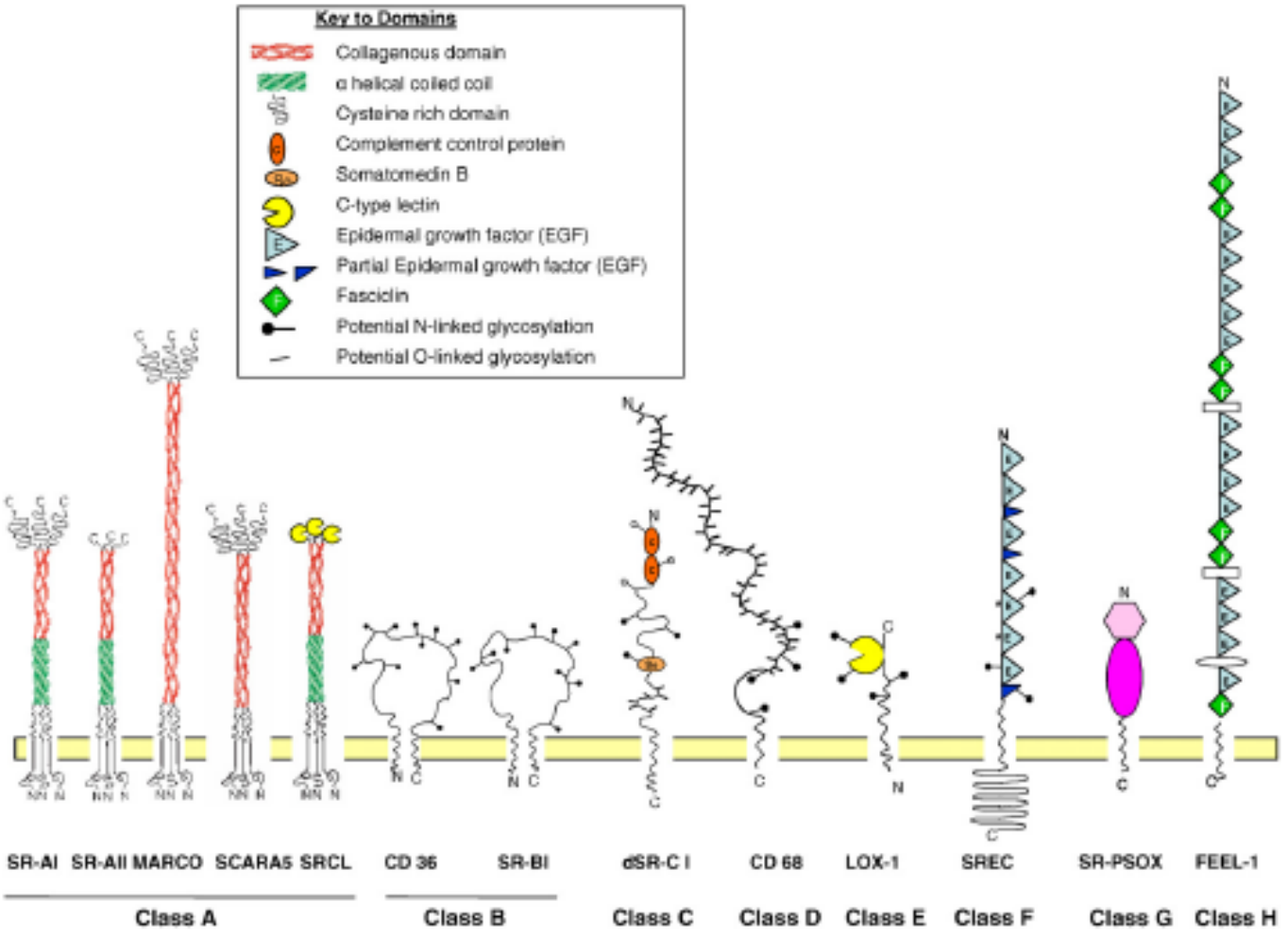
MDA-lysine
(oxidised LDL)



monocyte/møs

Napoli et al 1997 J Clin Invest 100:2680

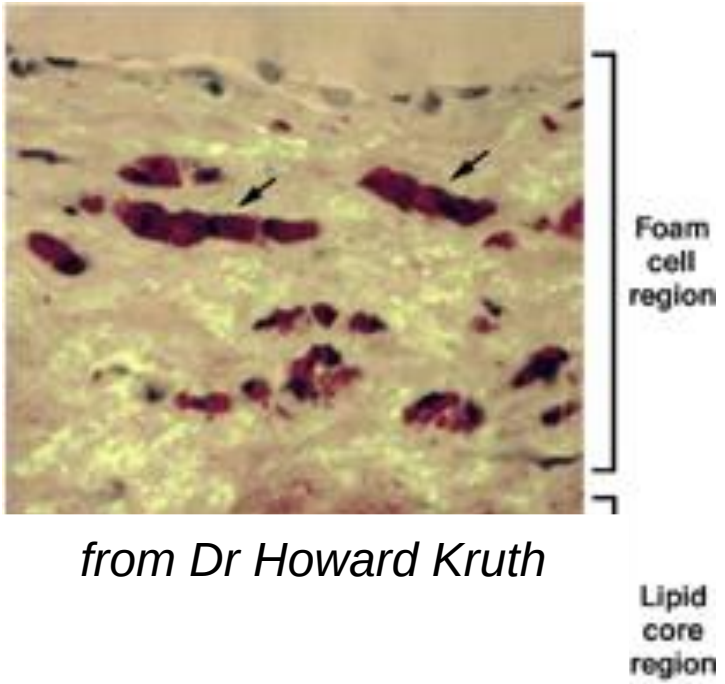
Macrophage scavenger receptors



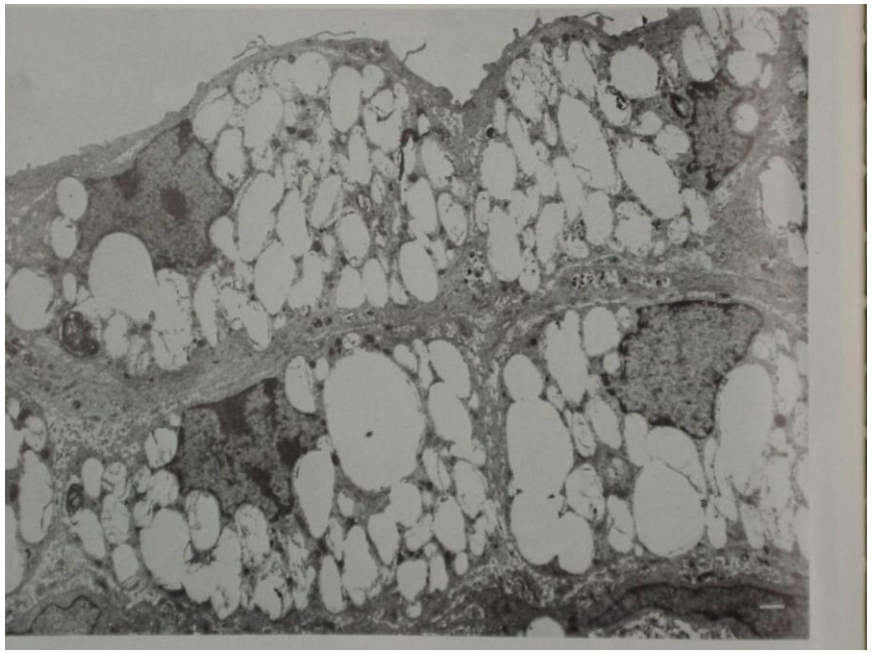
from Pluddemann et al (2007) Methods 43:207

Macrophage uptake of LDL

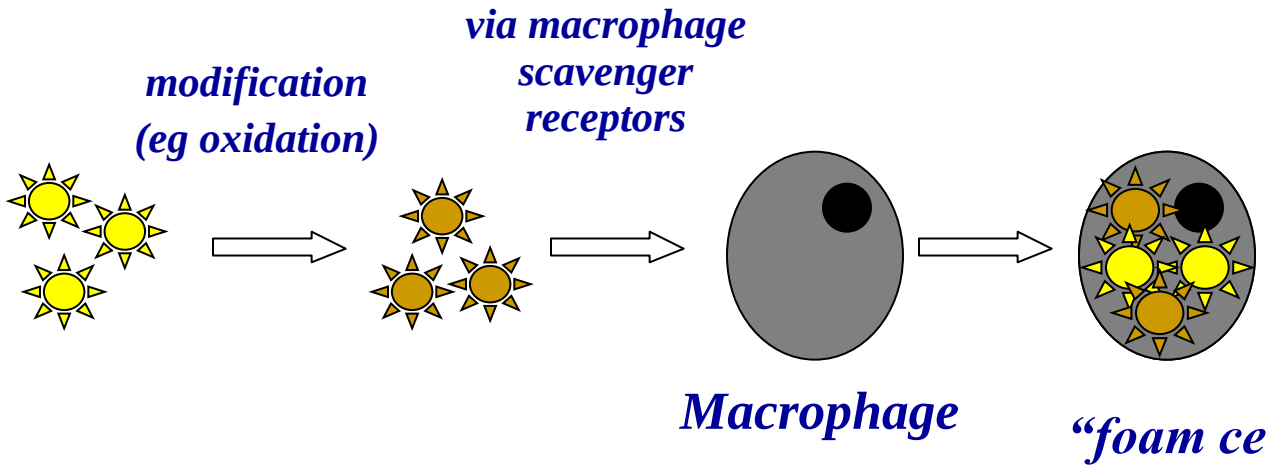
- Physiological uptake of LDL via LDL controlled by receptor down-regulation
- Uptake of oxidised LDL by scavenger receptors is not regulated and results in “foam cell” formation.
- Cholesterol-laden macrophages release cytokines (eg IL-1, TNF) and growth factors (eg PDGF), and die by apoptosis or necrosis



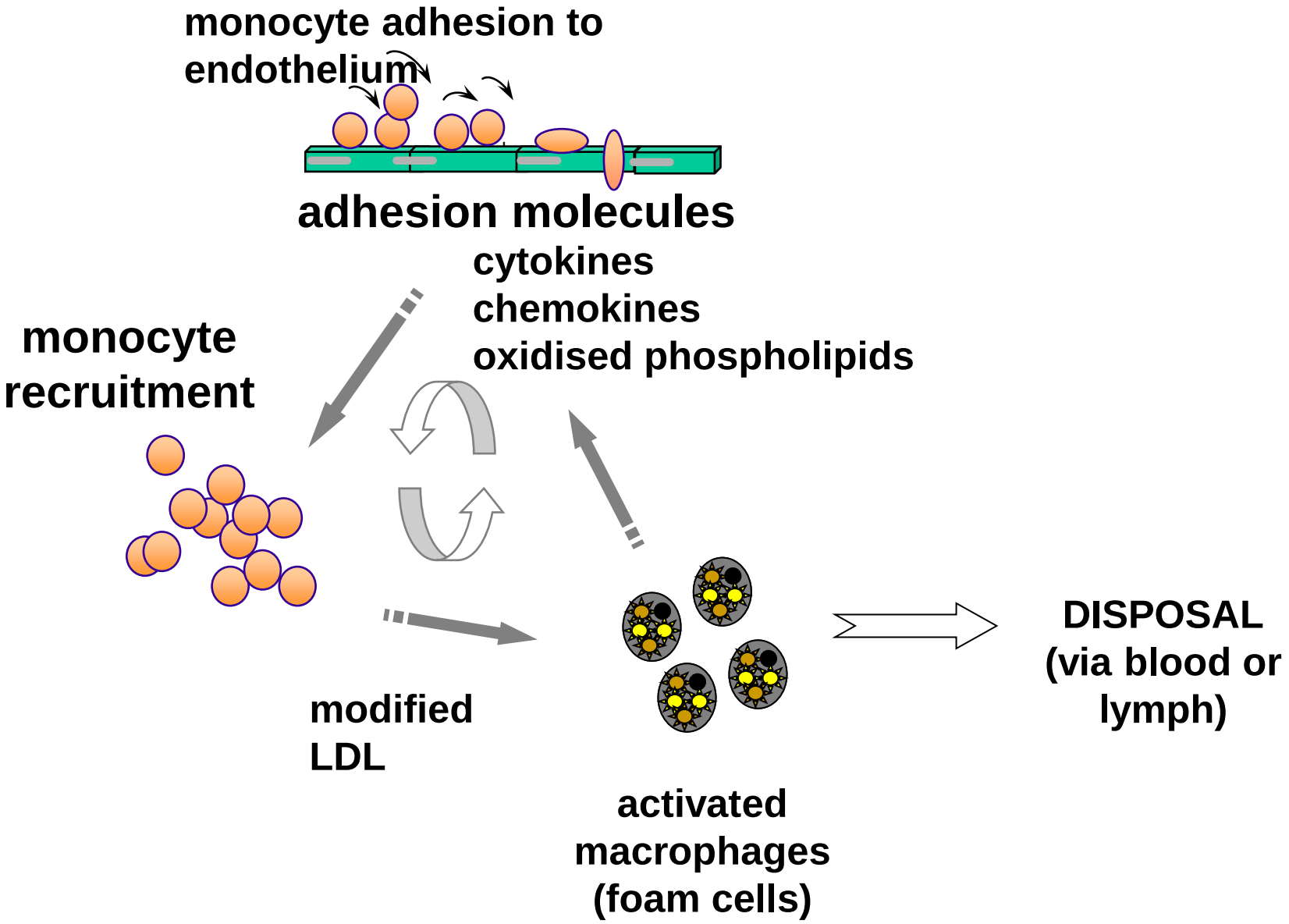
from Dr Howard Kruth



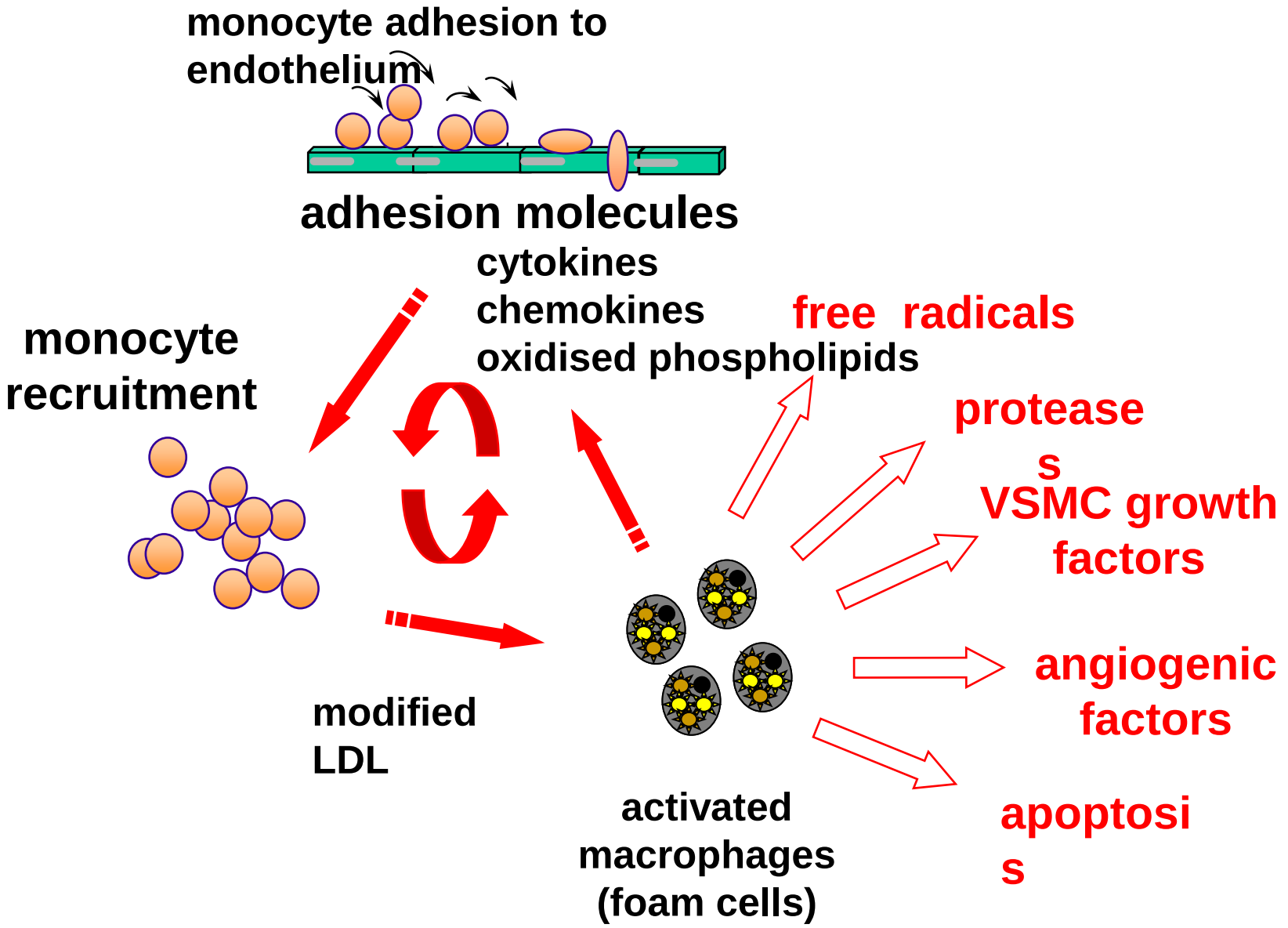
Faggiotto et al 1984 Arteriosclerosis 4:323

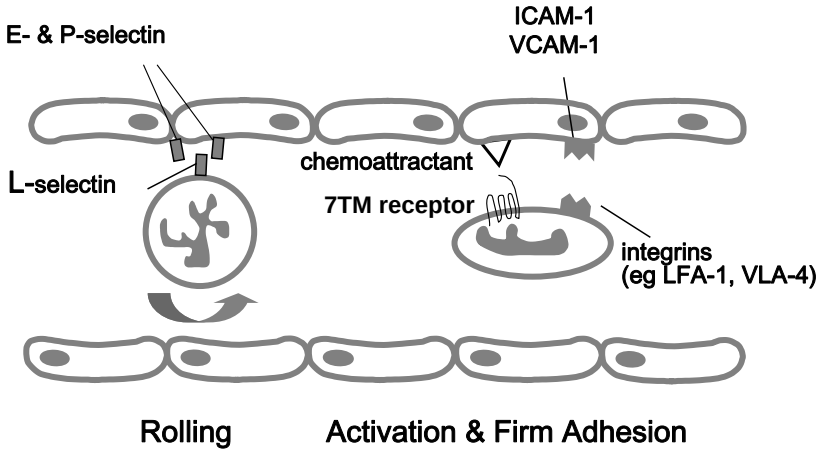


Homeostatic debris disposal

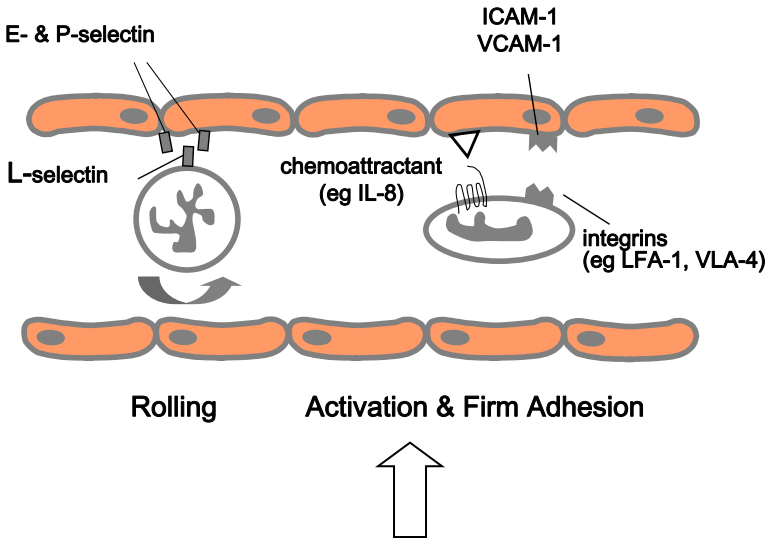


Inflammatory genesis of arterial remodel





Courtesy of Prof Sussan Nourshargh



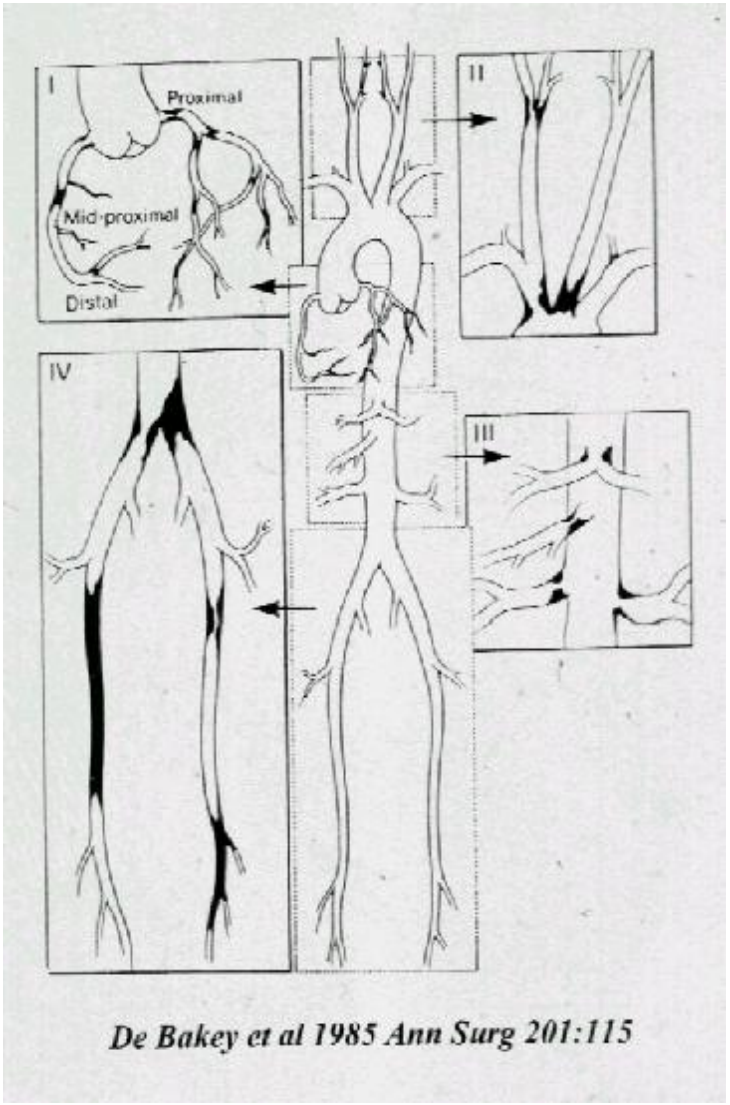
IL-1, TNFα, LPS

137 endothelial cell genes regulated more than 4-fold by IL-1

De Martin et al (2004) ATVB 24:1192

IMPORTANCE OF BLOOD FLOW

Flow-related susceptibility of branch points and curvatures



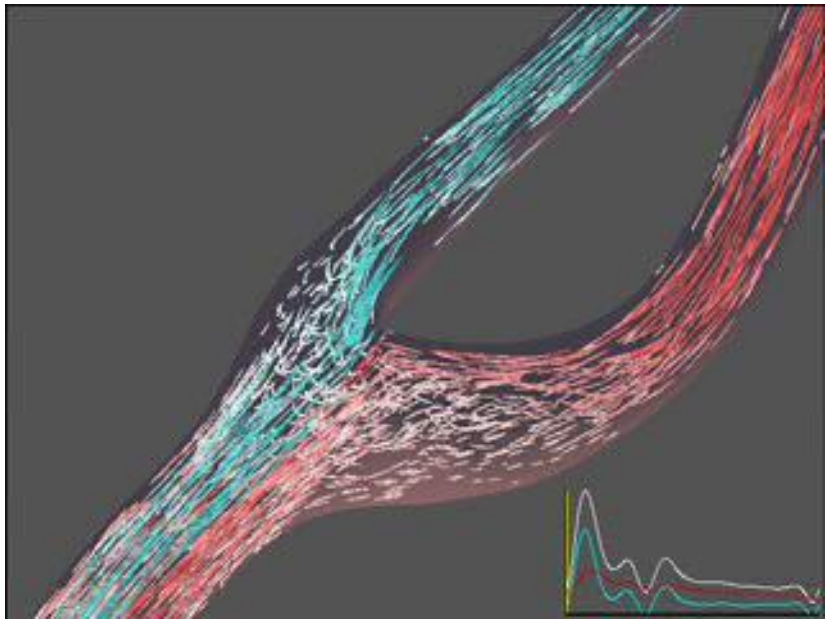
Risk factors are general but atherosclerosis is focal

Effects of age on lesion localisation

flow

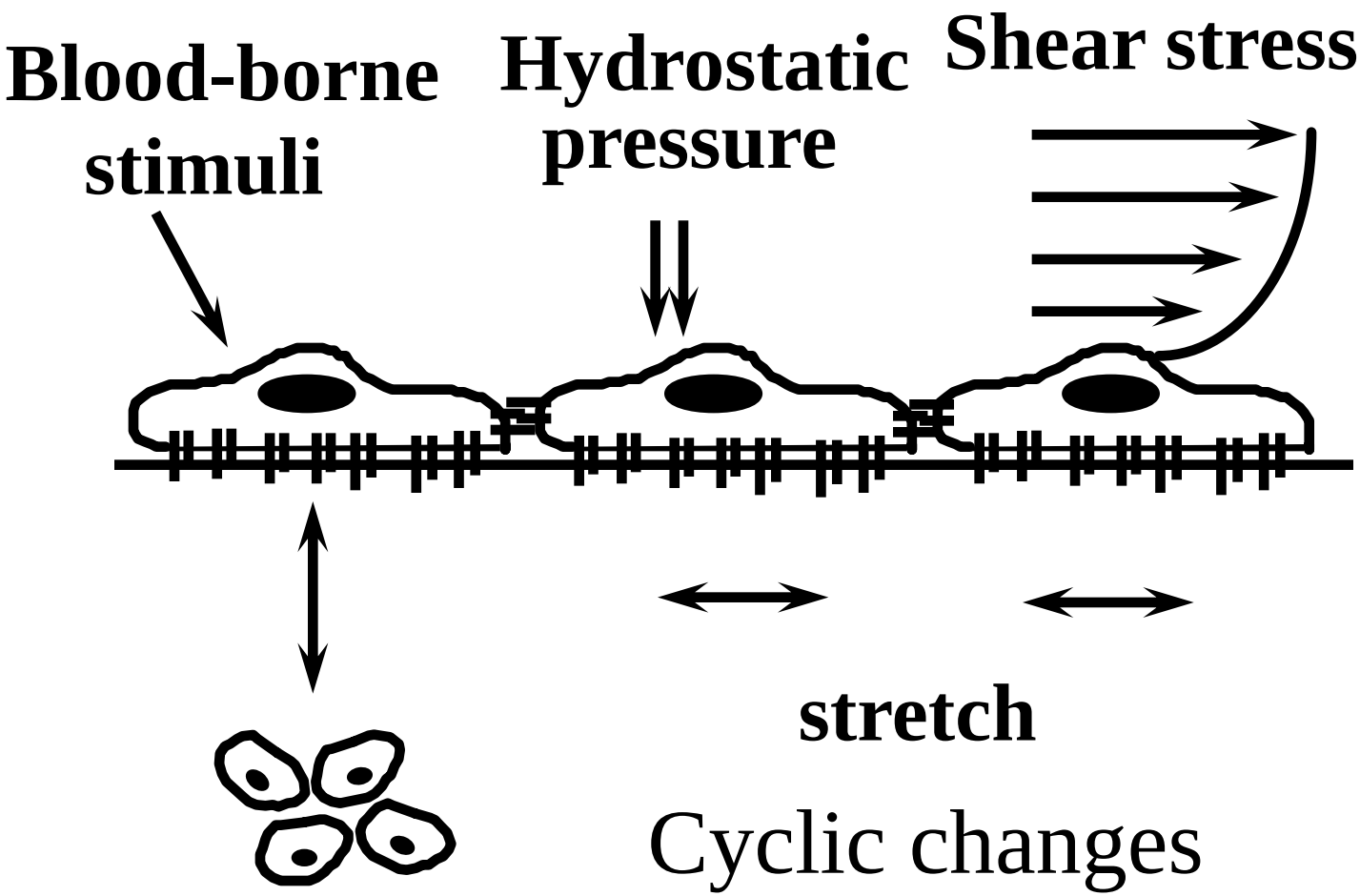
Juvenile rabbit

Courtesy of Peter Weinberg, Imperial College

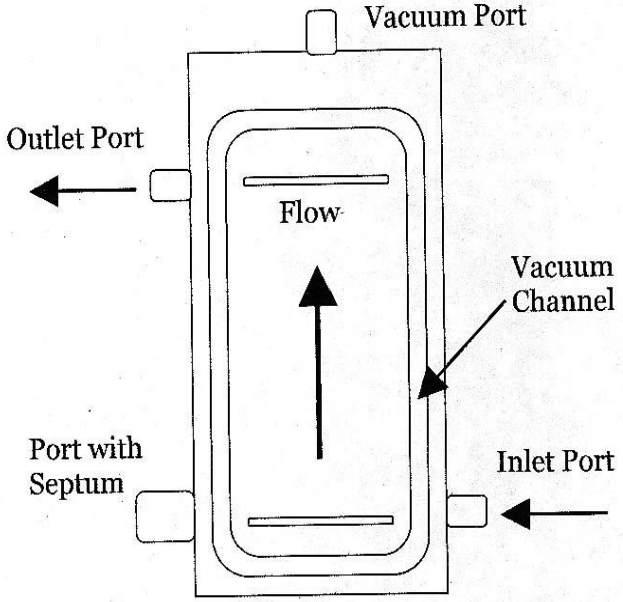


Courtesy of David Steinman
University of Western Ontario

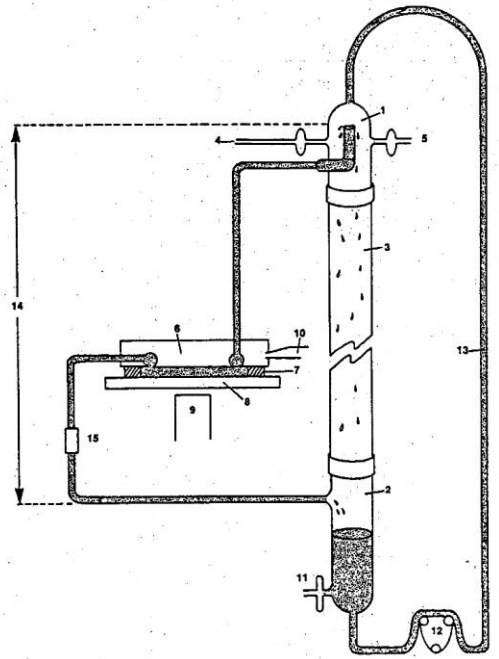
Effects of mechanical forces on endothelial function

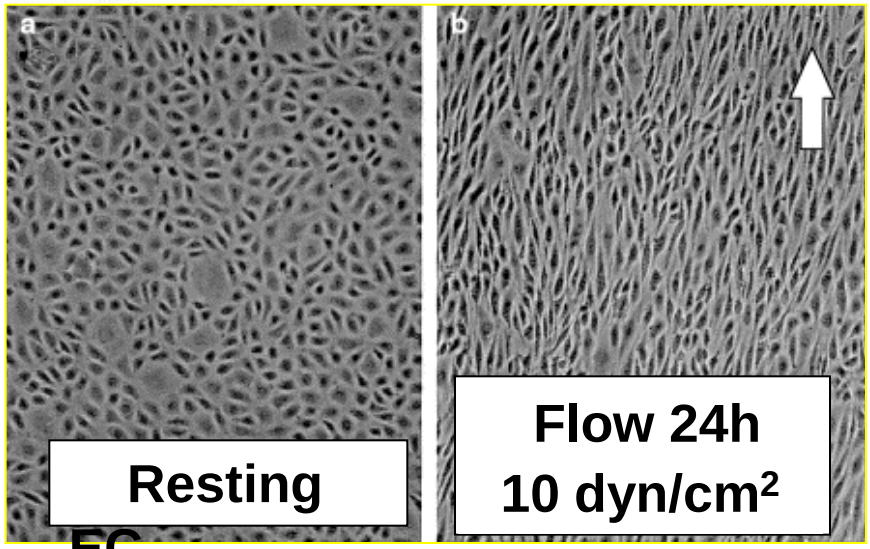


Use of parallel plate flow chamber for studying endothelial cells under flow



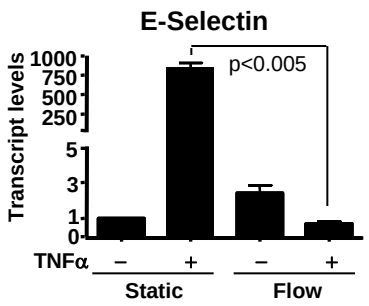
Flow Chamber

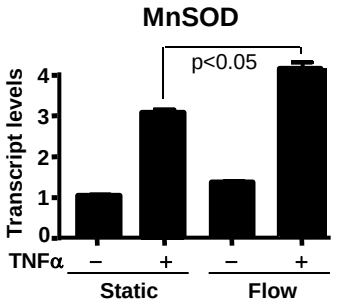


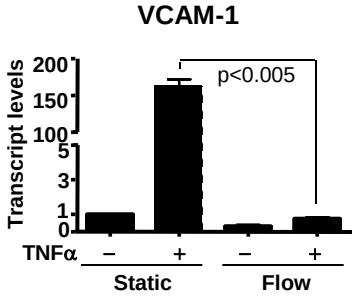


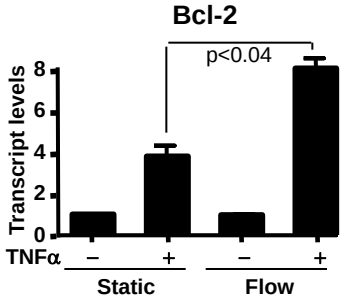
EC

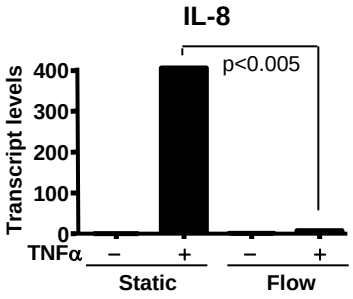
Laminar flow suppresses proinflammatory gene expression but sustains cytoprotective responses in response to TNFα

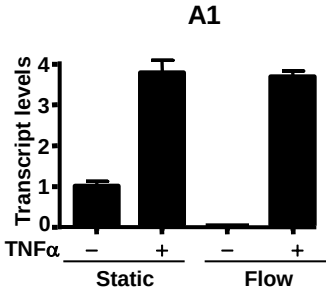








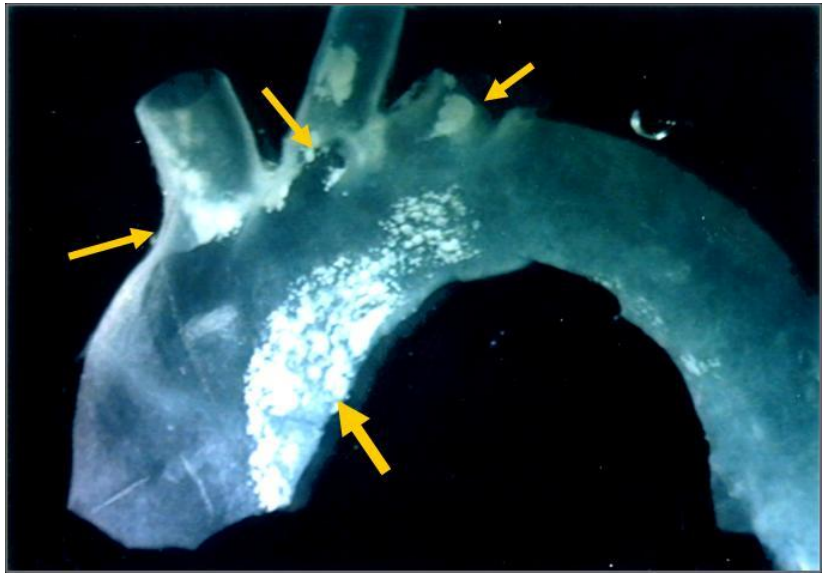




proinflammatory genes

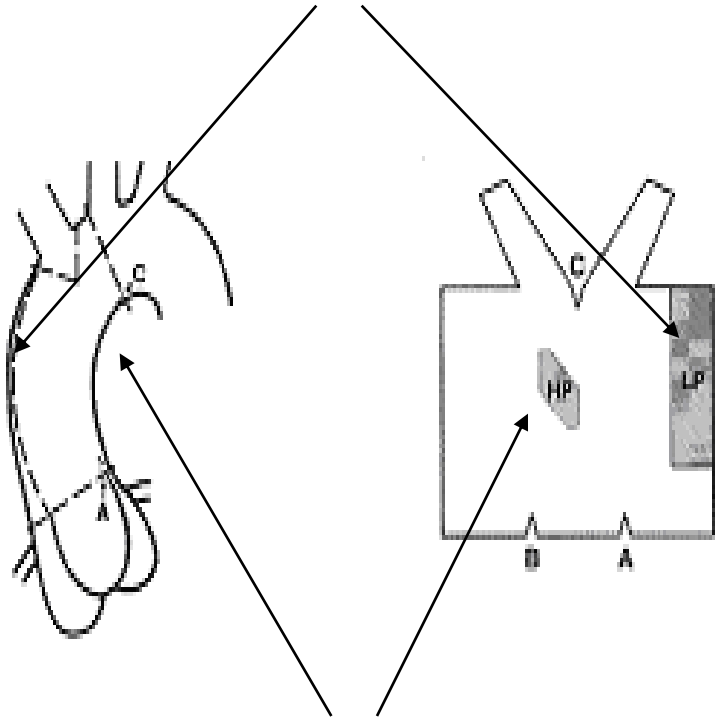
cytoprotective genes

Partridge et al (2007) FASEB J , 21:3553



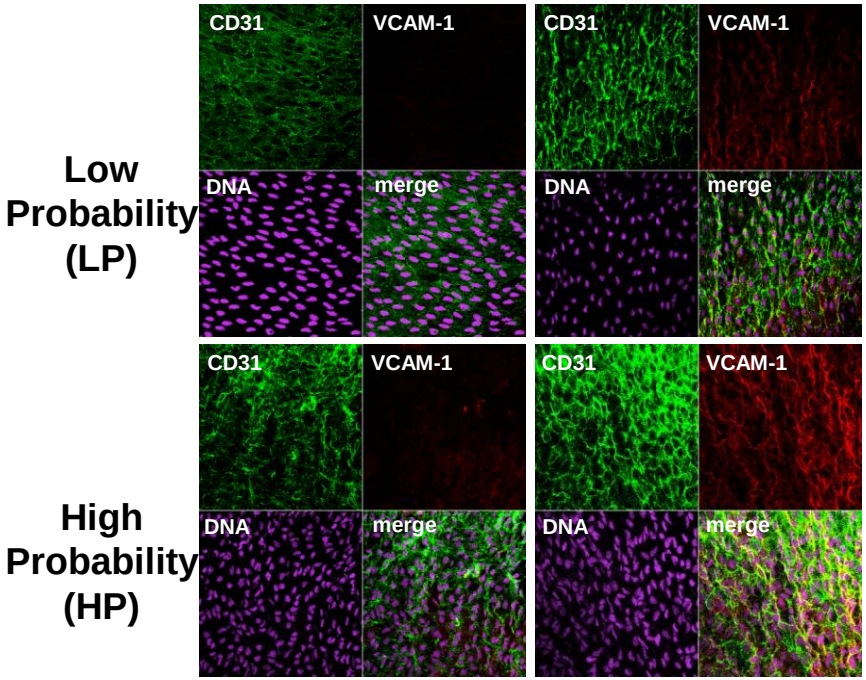
Courtesy of Prof Rob Krams

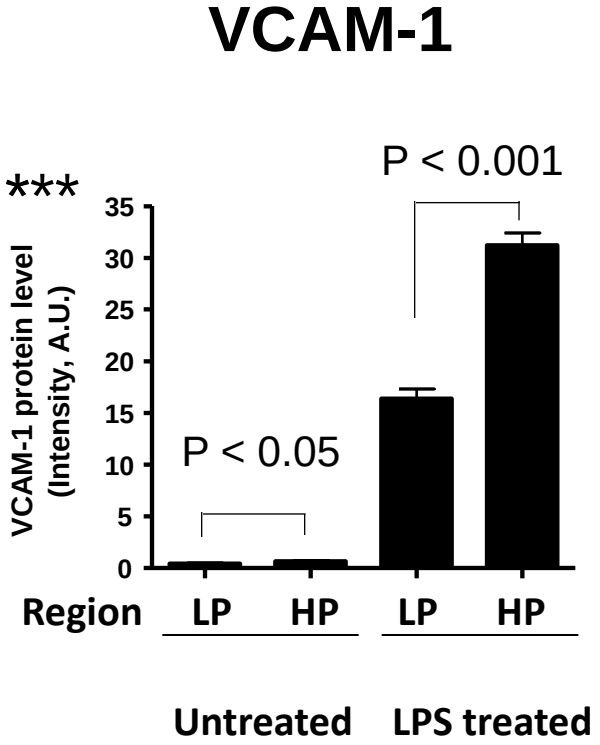
Low probability (HP)



High probability (HP)

Differential adhesion molecule expression in the murine aorta shown by *en face* immunostaining

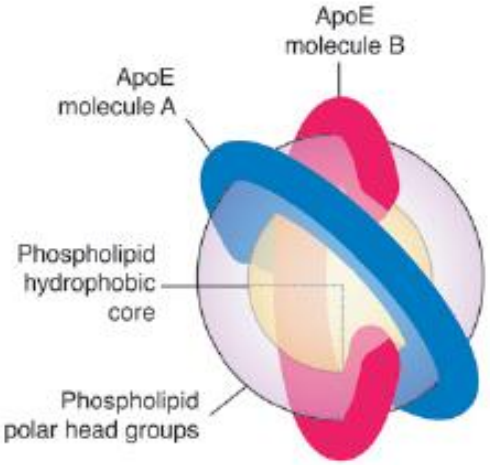




INVESTIGATING MOLECULAR MECHANISMS

Mouse models of atherosclerosis

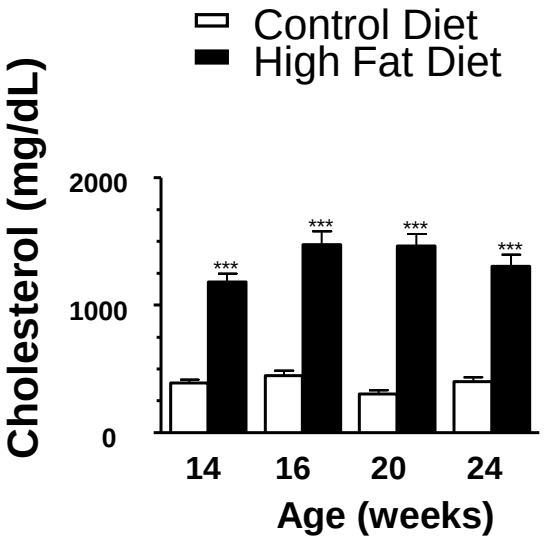
- **ApoE-/-**
  - 34kd component of VLDL and chylomicrons
  - ligand for LDL receptor

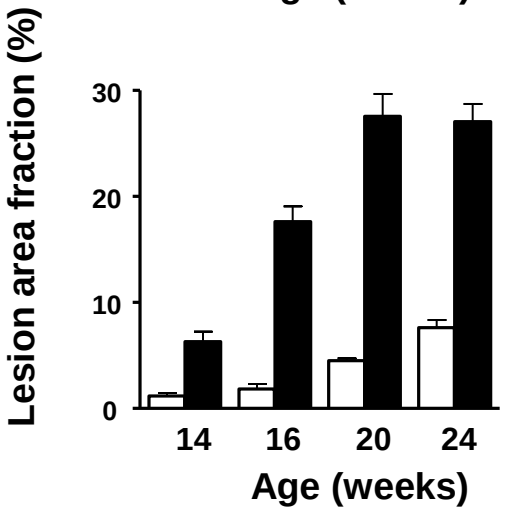


- **LDL receptor -/-**
  - Mutations in familial hypercholesterolaemia

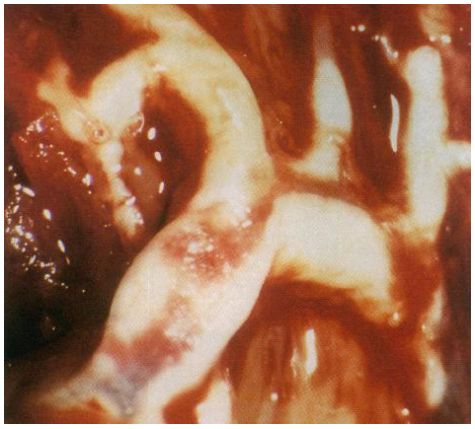
xanthoma

Atherosclerosis in *Ldlr*$^{-/-}$ mice



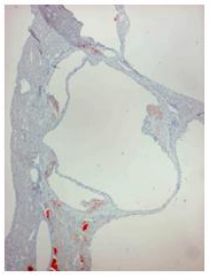
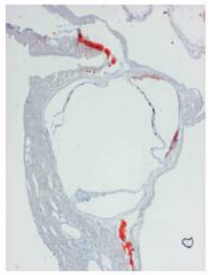
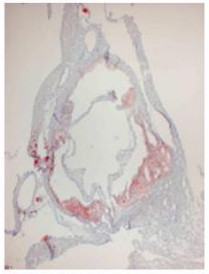
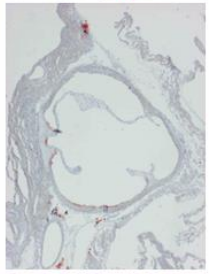
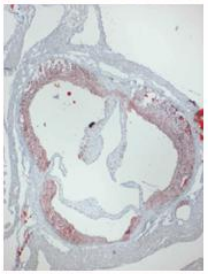
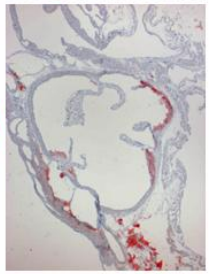
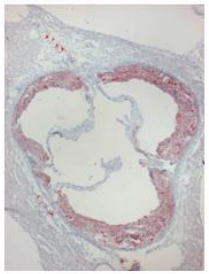
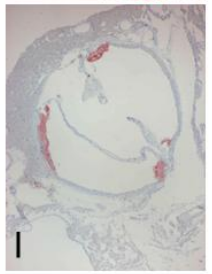


wild-type



Ldlr-/- high fat 13 mo

Ishibashi et al 1994 JCI 93:1885

	high fat	chow
14		
16		
20		
24		

weeks

Aortic valve

Influence of adhesion molecules, chemokines and cytokines on mouse atherosclerosis

Accelerators

Adhesion molecules
P-selectin
E-selectin
ICAM-1
VCAM-1

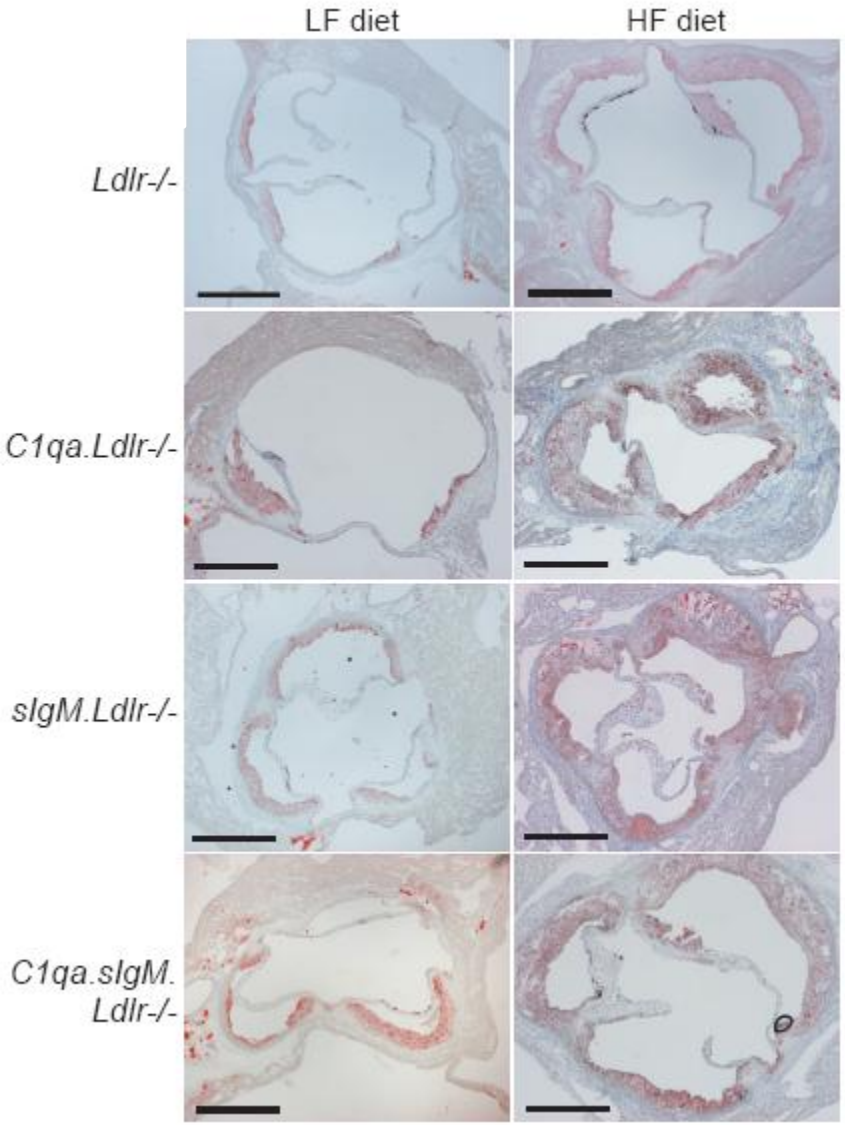
Chemokines & receptors
MCP-1
CCR2
CXCR2
CX3CR1

Cytokines
IL-1
TNFa
IL-4
IL-6
IL-12
IL-18
IFNg

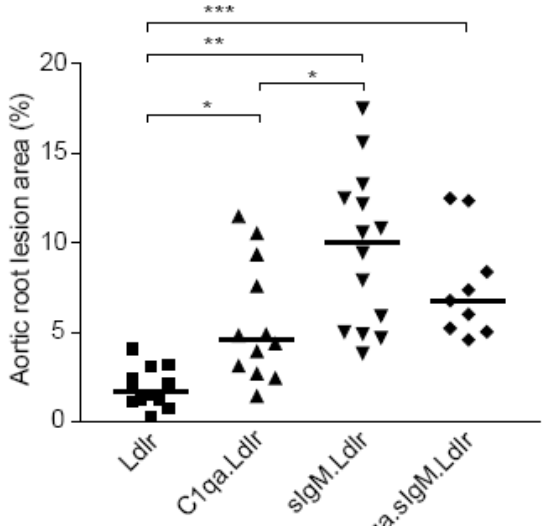
Decelerators

IL1RA
TGFb
IL-10

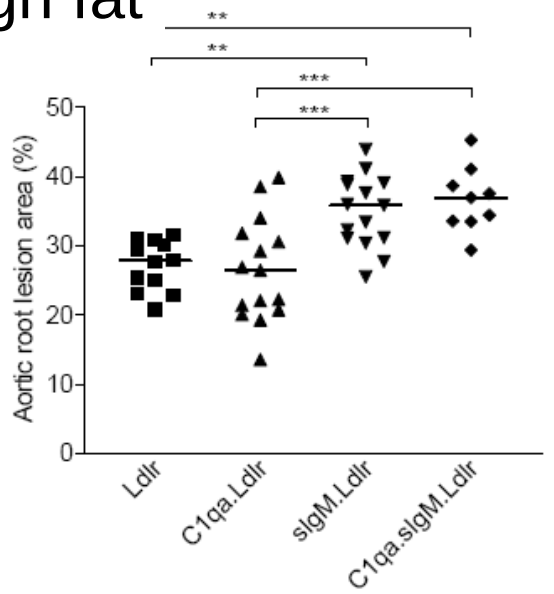
IgM deficiency accelerates atherosclerosis



Low fat

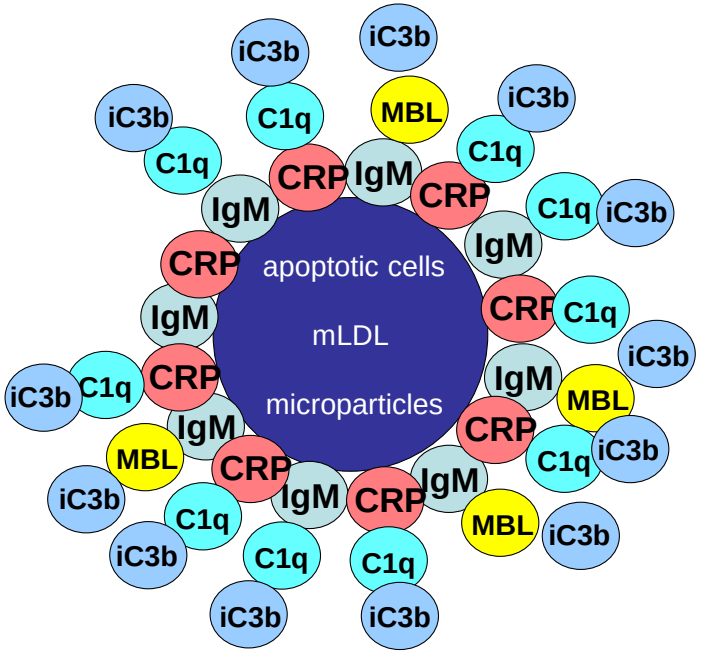


High fat



Lewis et al 2009 Circulation 120:417

Hypothetical model of the role of complement and IgM natural antibodies in atherosclerosis



Homeostatic clearance

Role of T lymphocytes in atherosclerosis

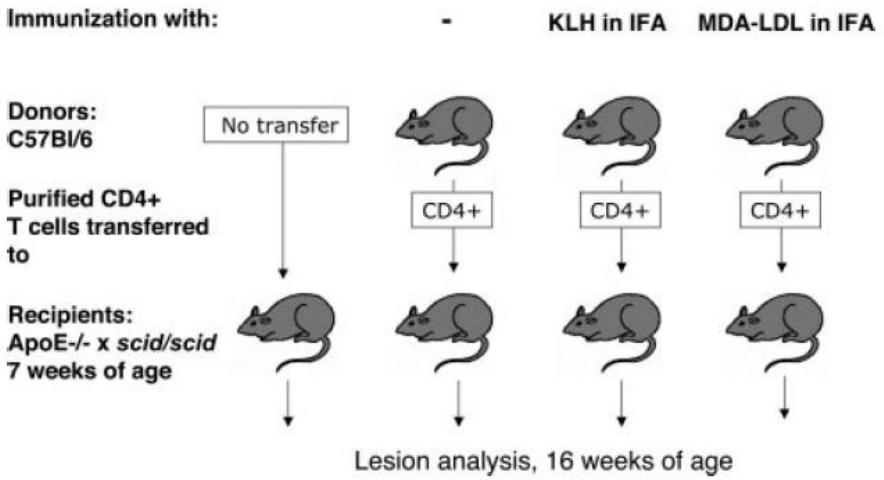
- Atherosclerotic plaques contain MHC Class II positive dendritic cells and T lymphocytes at all stages

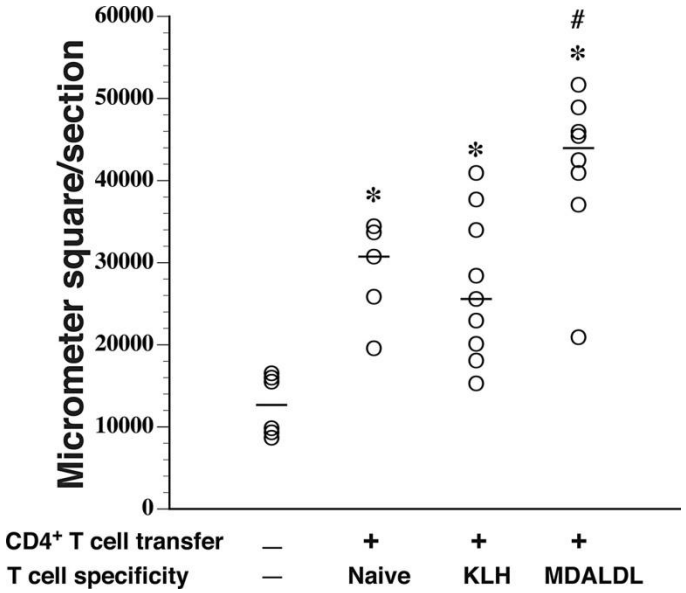
- Plaque T cells show evidence of activation (eg HLA-DR, IFNγ)

- Plaque T cells are oligoclonal and ~10% react with oxidised LDL

- T cells may activate macrophages and VSMC (eg via CD40L-CD40 contact interactions)

Effects of CD4 T cell transfer





Zhou et al (2006) ATVB 26:864

Summary

- Atherosclerosis can be viewed as a dynamic chronic inflammatory disease of arteries
- The innate immune system regulates the safe disposal of lipoproteins and other debris from the arterial wall and is intrinsically protective
- Overdrive of the innate immune system leads to irreversible remodelling, and this may be accelerated by adaptive immune mechanisms
- The interplay between proinflammatory and wound healing pathways governs plaque stability