Medical Physics in Diagnostics of Musculoskeletal Diseases

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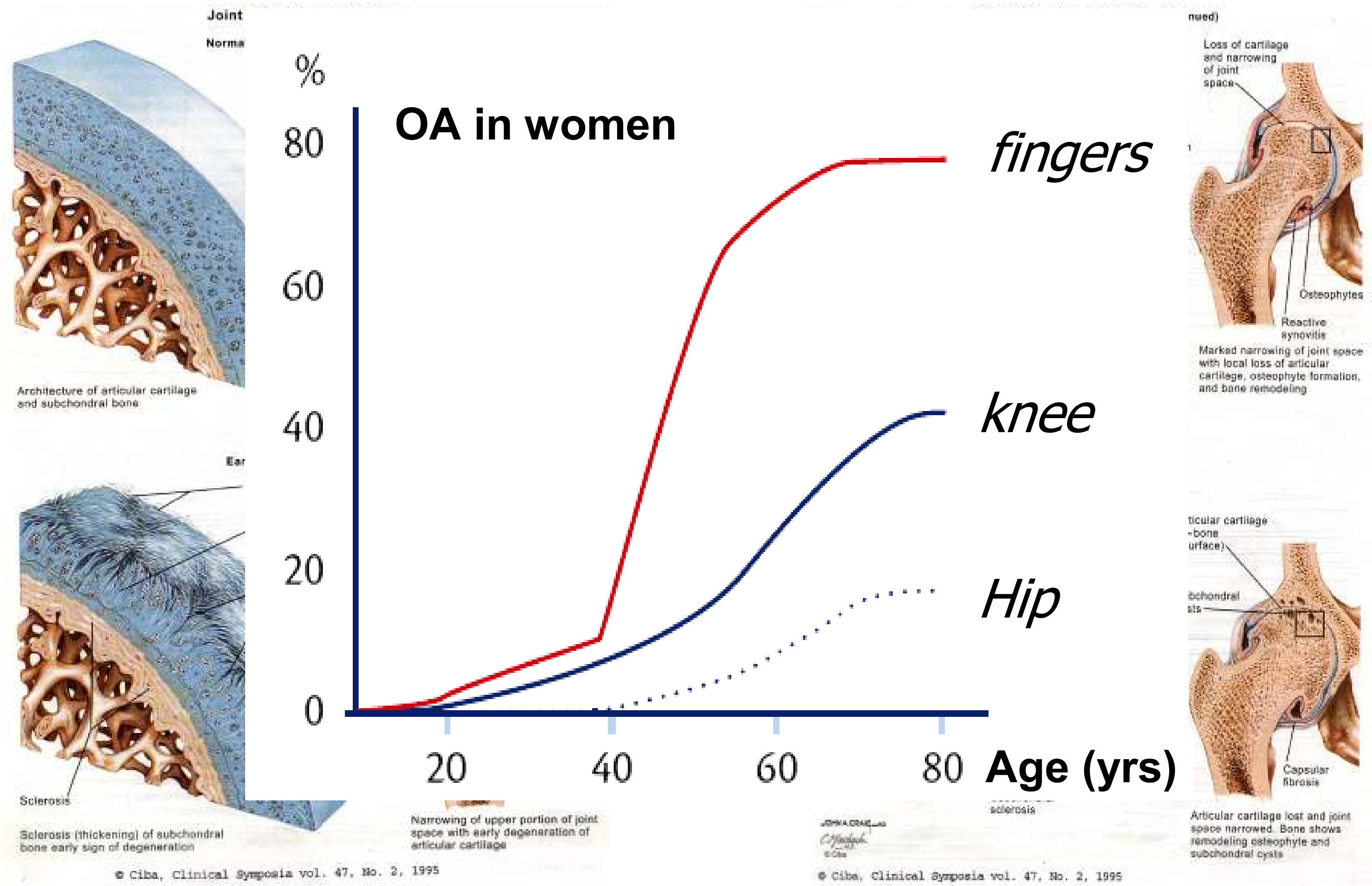
OSTEOARTHRITIS



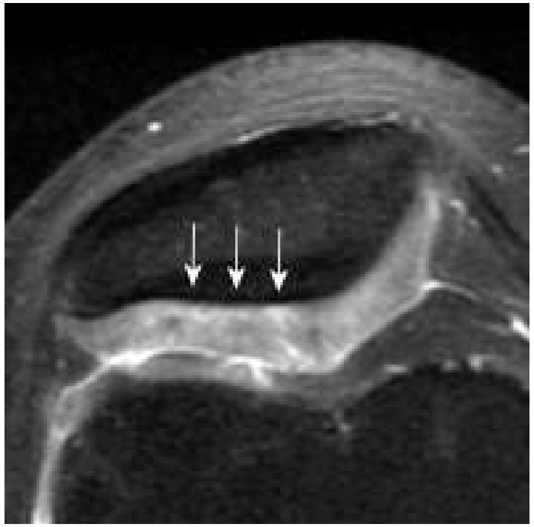
OA Diagnostics

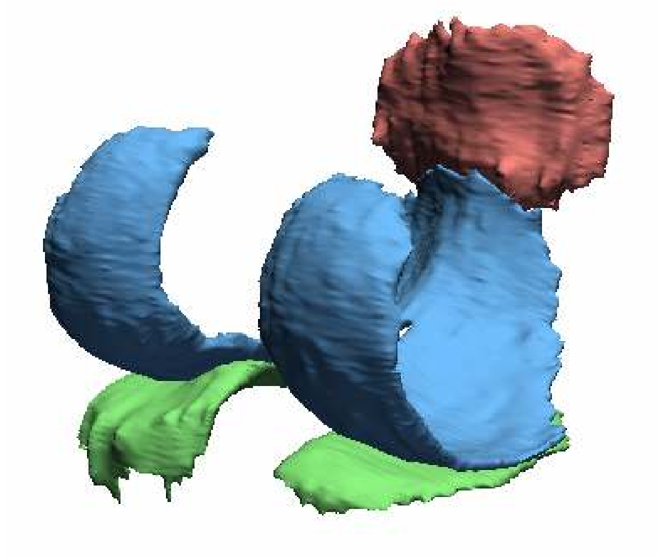
ap X-ray

Healthy joint (Male, 16 years)   **OA joint (Female, 50 years)**

OA Diagnostics

MRI





PD, sagittal,
50 yr, male,
thin, pathological heterogeneity

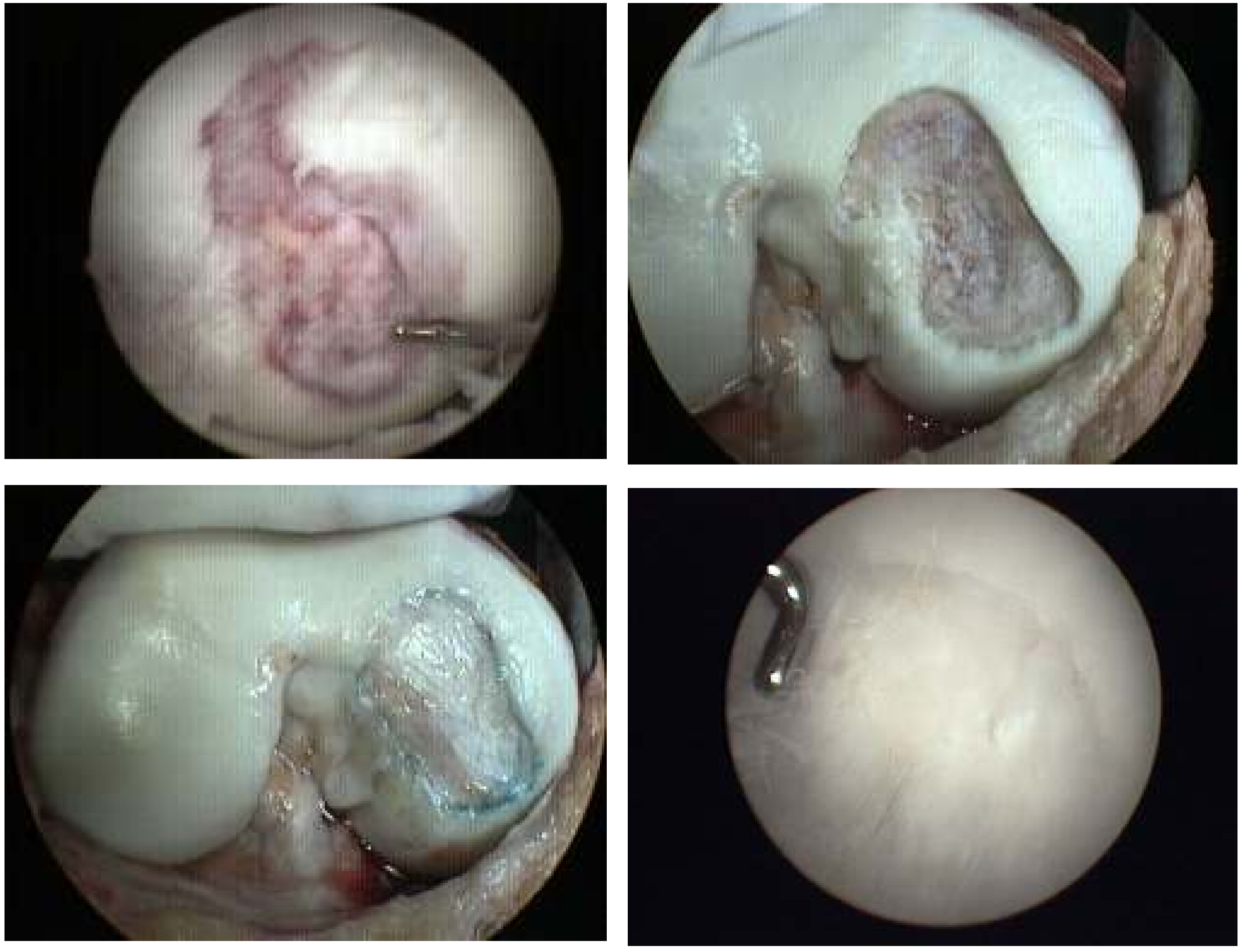
PD, axial,
28 yr, female,
chondromalacia

3D-reconstruction
56 yr, female,
OA

M. Nieminen, BBC 2005

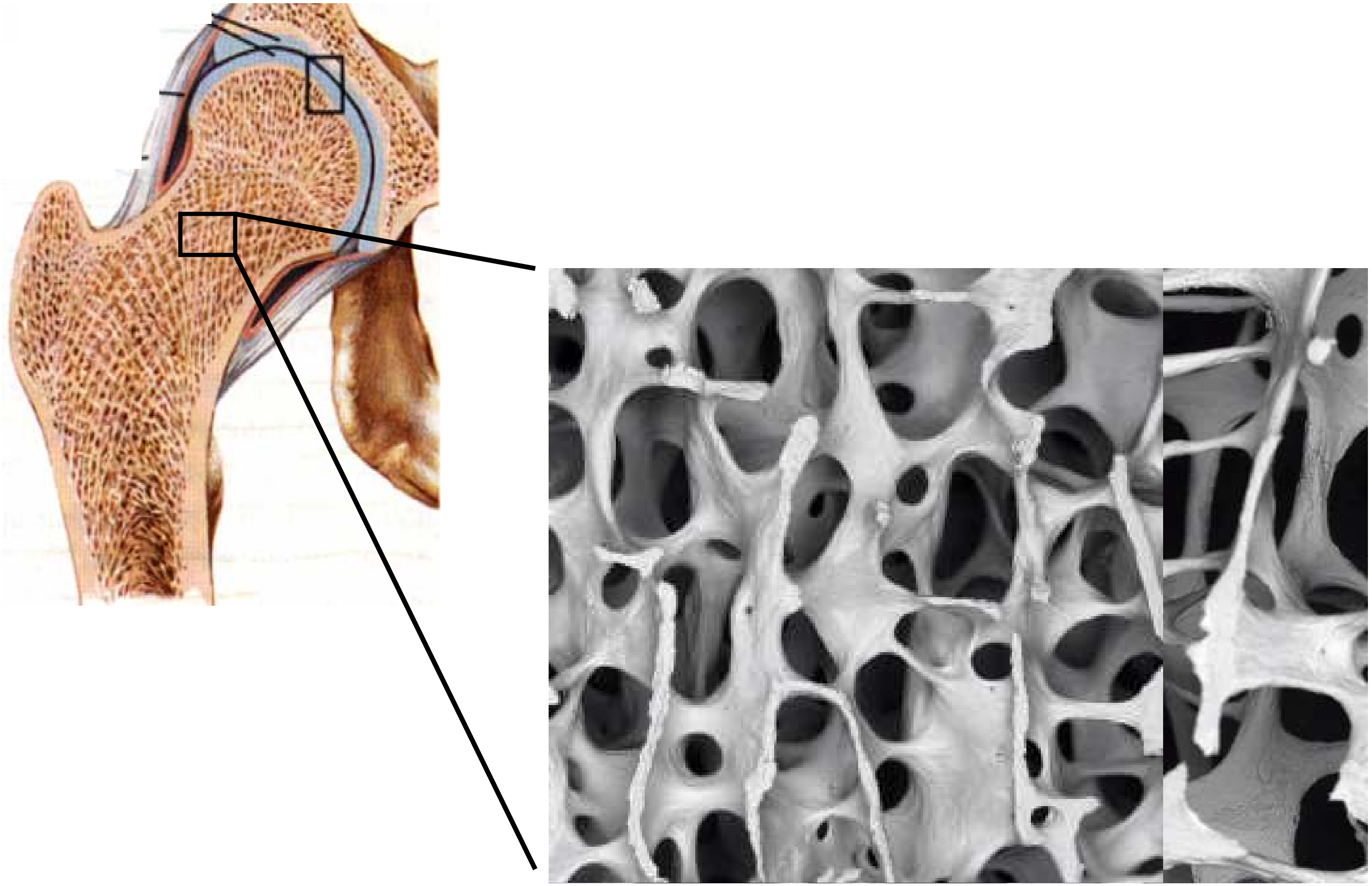
Cartilage Repair

ACT operation, male 34 y, OCD FMC



I. Kiviranta, 2005

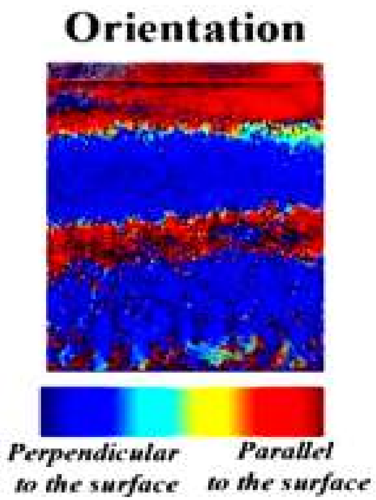
OSTEOPOROSIS

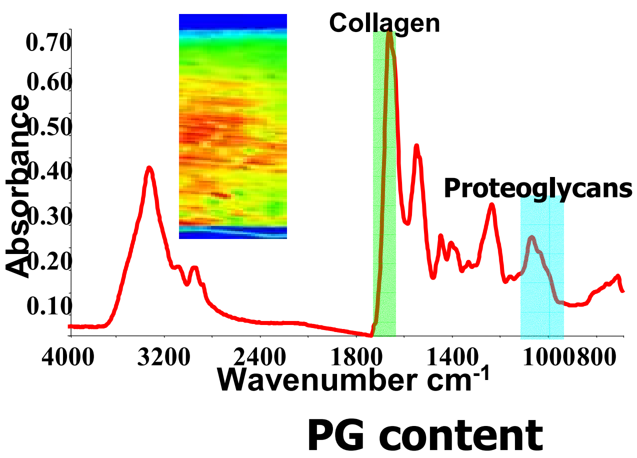


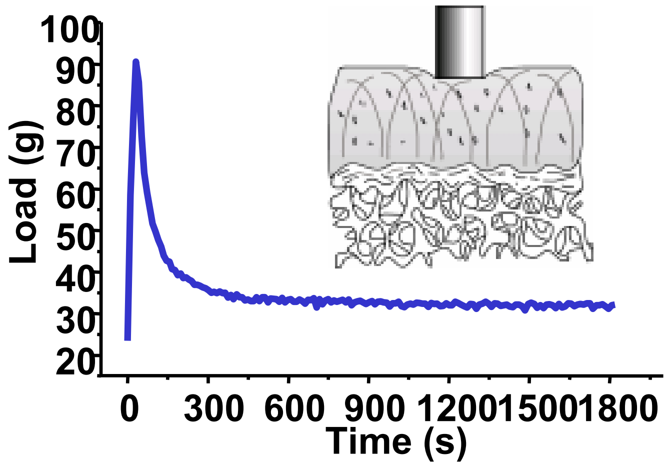
Tissue (e.g. Cartilage) Quality

Integrity of cartilage depends on the tissue

- structure (*e.g.* MRI, ultrasound, optics)
- composition (*e.g.* biochemistry, FTIR)
- mechanical properties (*e.g.* indentation, ultrasound)







REFERENCE METHODS:

Cartilage/bone structure

-QUANTITATIVE MICROSCOPY

Cartilage/bone mechanical properties

- MATERIAL TESTING
- THEORETICAL MODELLING

NEW METHODS:

Cartilage/bone magnetic properties

- MAGNETIC RESONANCE IMAGING

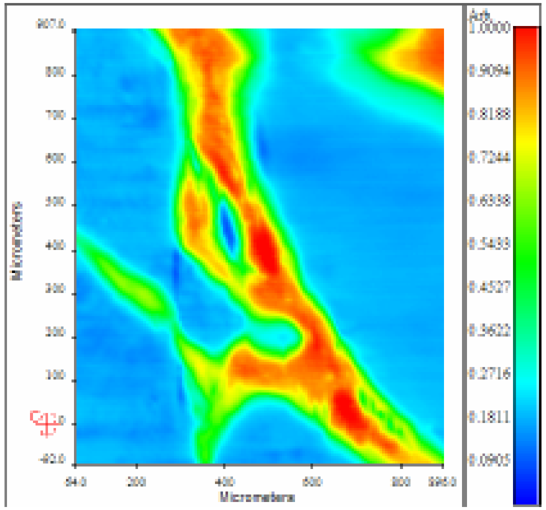
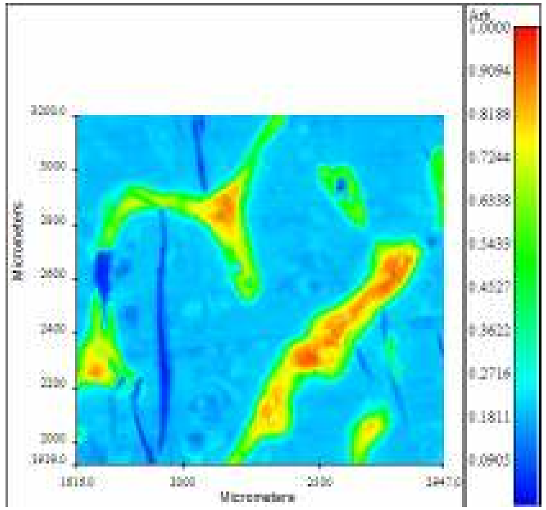
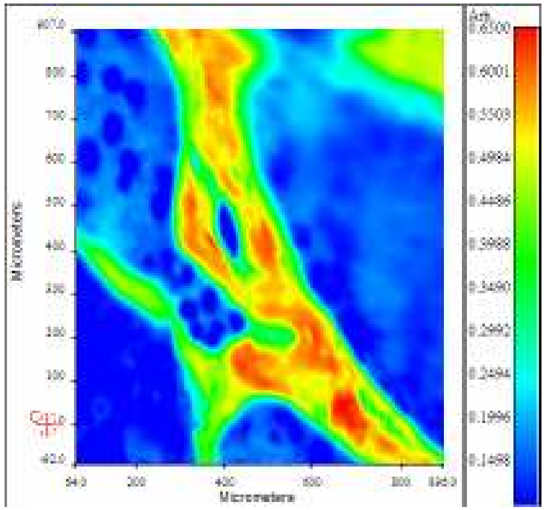
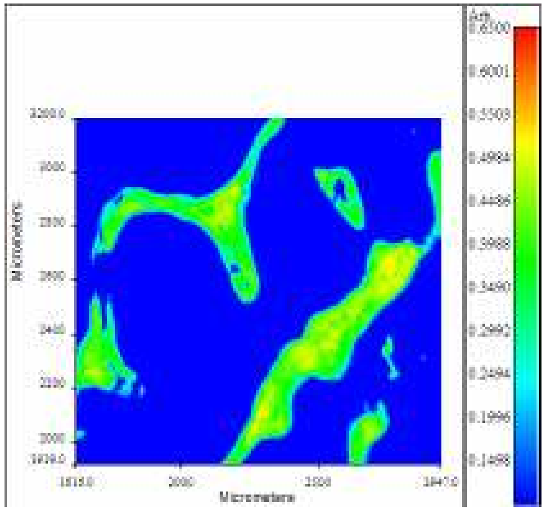
Cartilage/bone acoustic properties

- ULTRASOUND

CHARACTERIZATION OF NORMAL CARTILAGE/BONE PROPERTIES
DIAGNOSIS OF OSTEOARTHROSIS/OSTEOPOROSIS
MONITORING OF CARTILAGE REPAIR

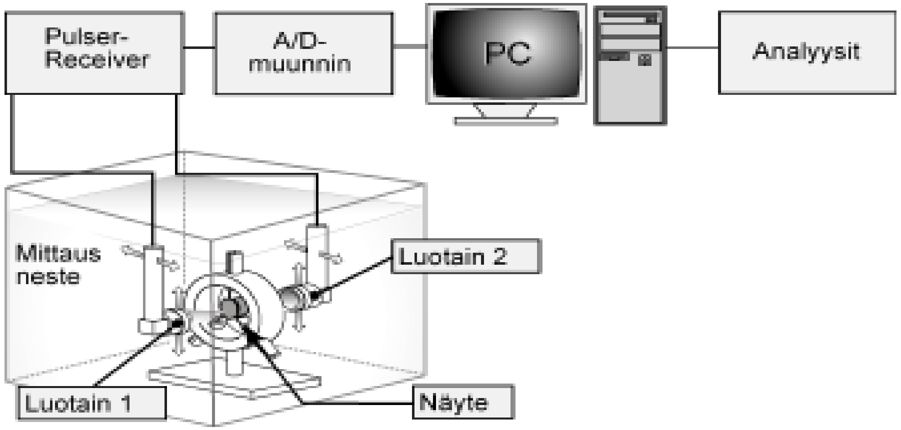
New ultrasound and MRI techniques are developed and applied for the characterization of normal articular cartilage and bone, diagnosis of osteoarthritis and osteoporosis as well as for monitoring of cartilage repair. Microscopic and biomechanical methods provide well-established reference techniques for the validation of ultrasound/MRI techniques

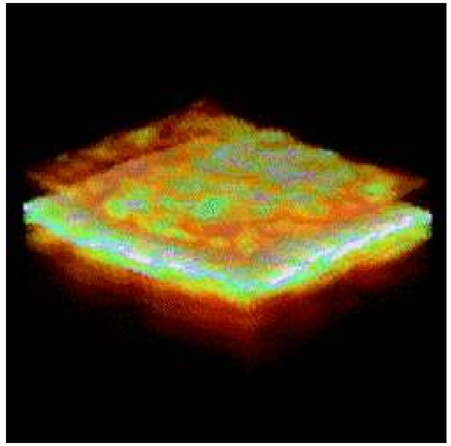
Fourier Transform Infrared Spectroscopy

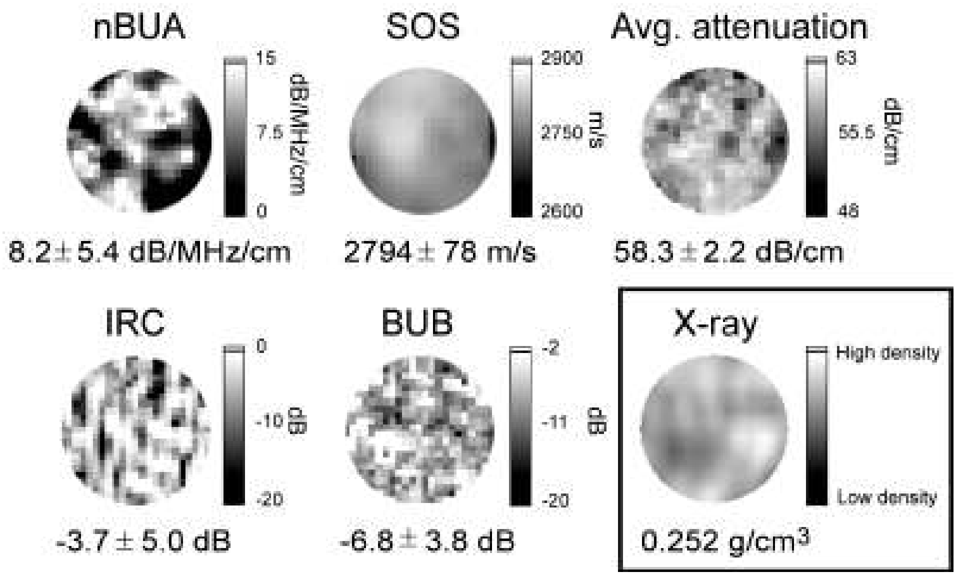
	Normal Bone	Osteoporotic Bone
Mineral content		
Collagen content		

J. Rieppo, BBC 2006

Cartilage and Bone Ultrasound



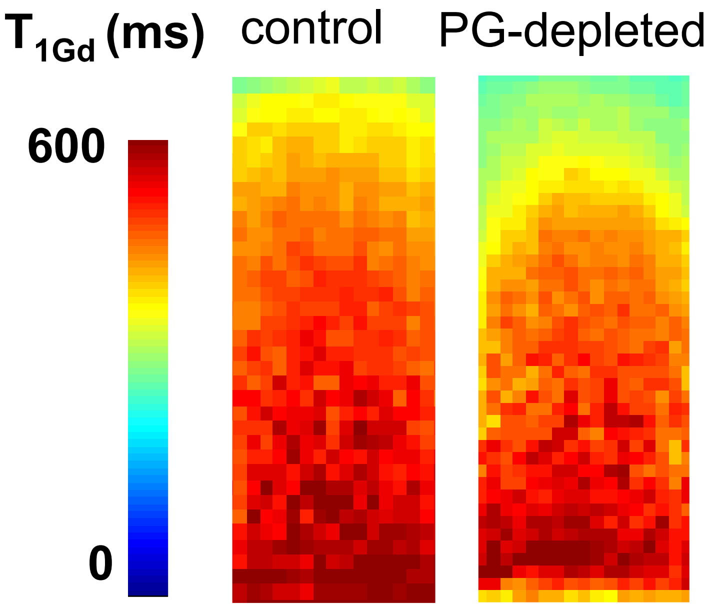


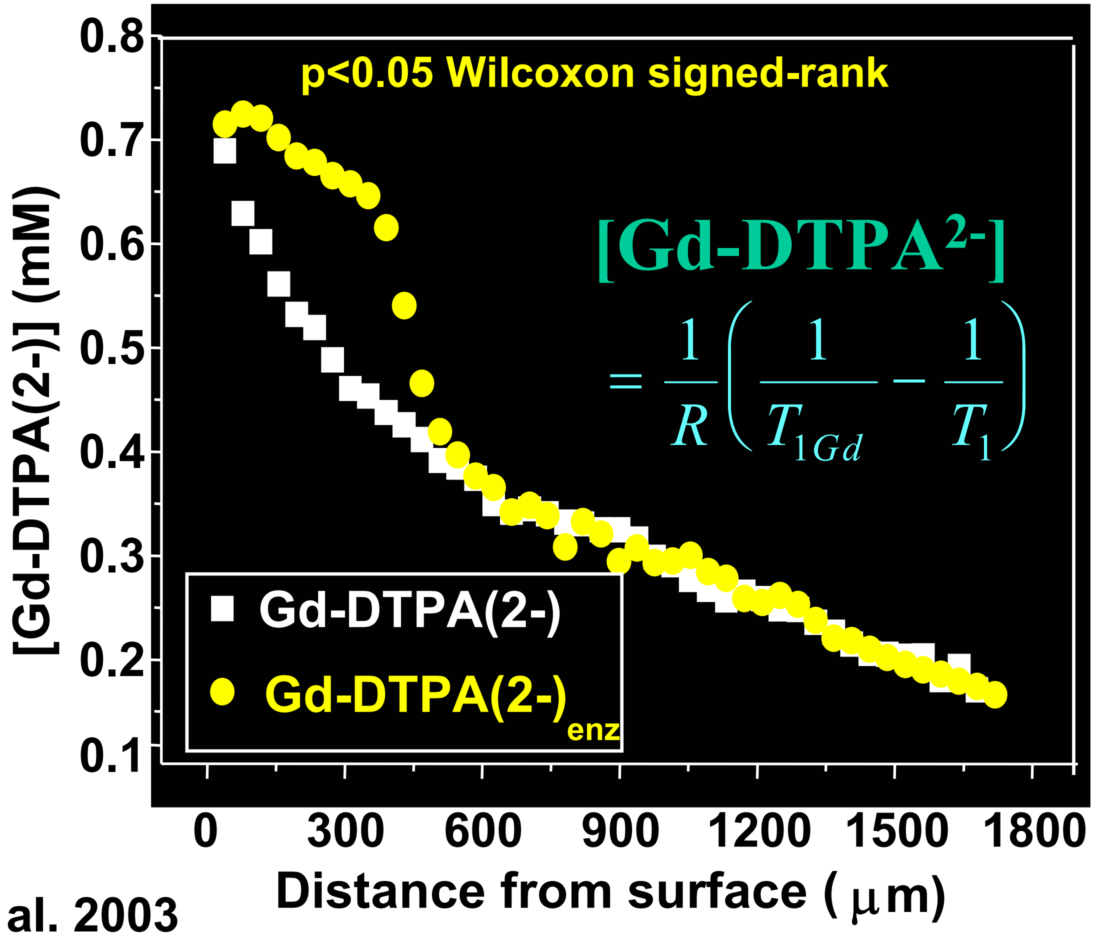


Quantitative MRI of articular cartilage

Gd-DTPA(2-) –ENHANCED T_1 IMAGING[1)]

[GAG] α *T_{1Gd}*





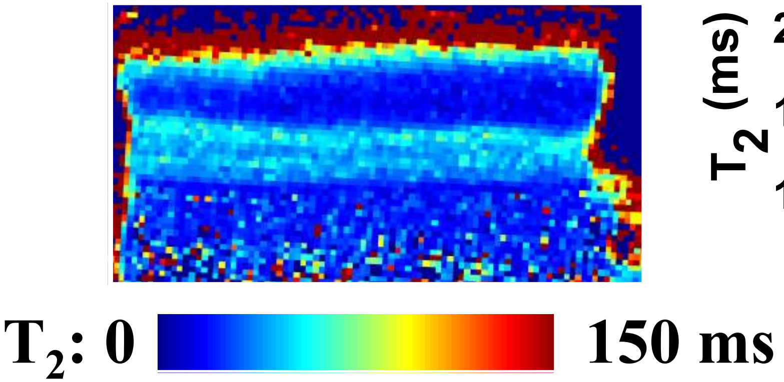
1) Bashir et al. 1999, Nieminen et al. 2003

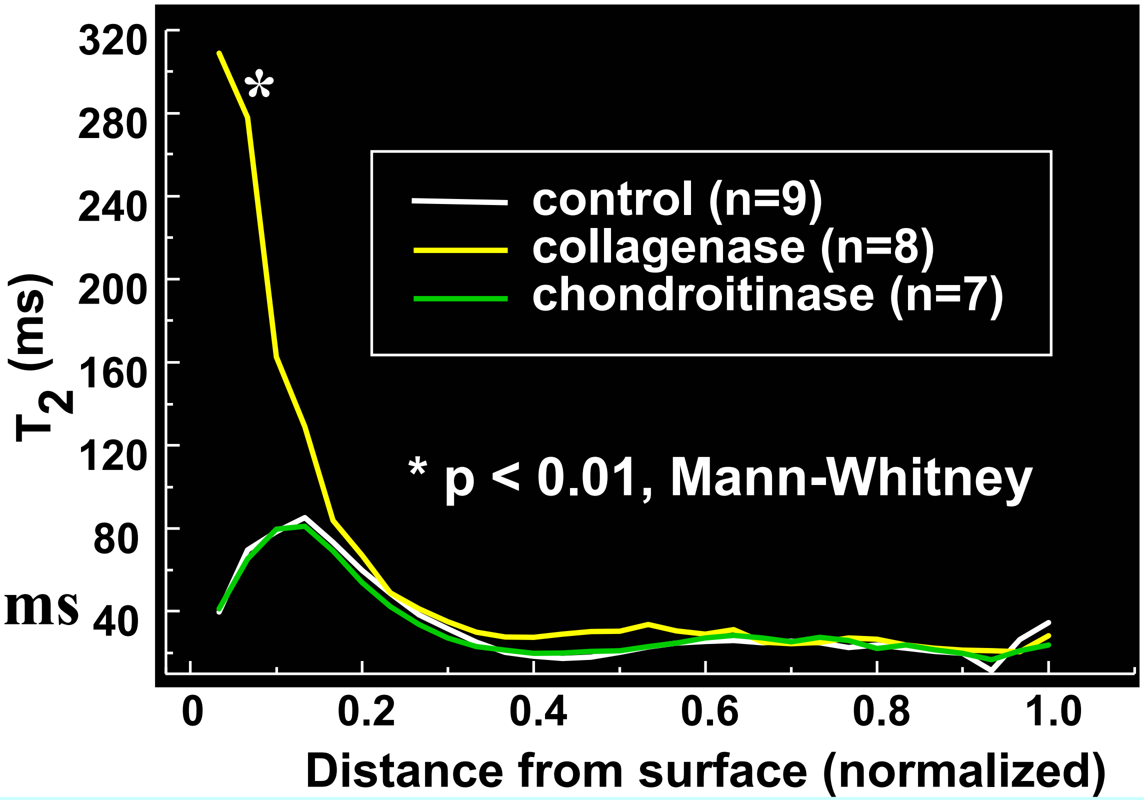
Quantitative MRI of articular cartilage

T2 mapping

- **Cartilage water strongly interacts with collagen directly/indirectly → T_2 relaxation time of tissue water may be reflective of collagen integrity[1)]**

collagenase





1) Nieminen et al. 2000, 2001

Cartilage Mechanics
Modelling

Continuity equation:

$$\nabla \cdot (\phi^s \mathbf{v}^s + \phi^f \mathbf{v}^f) = 0$$

Momentum equations:

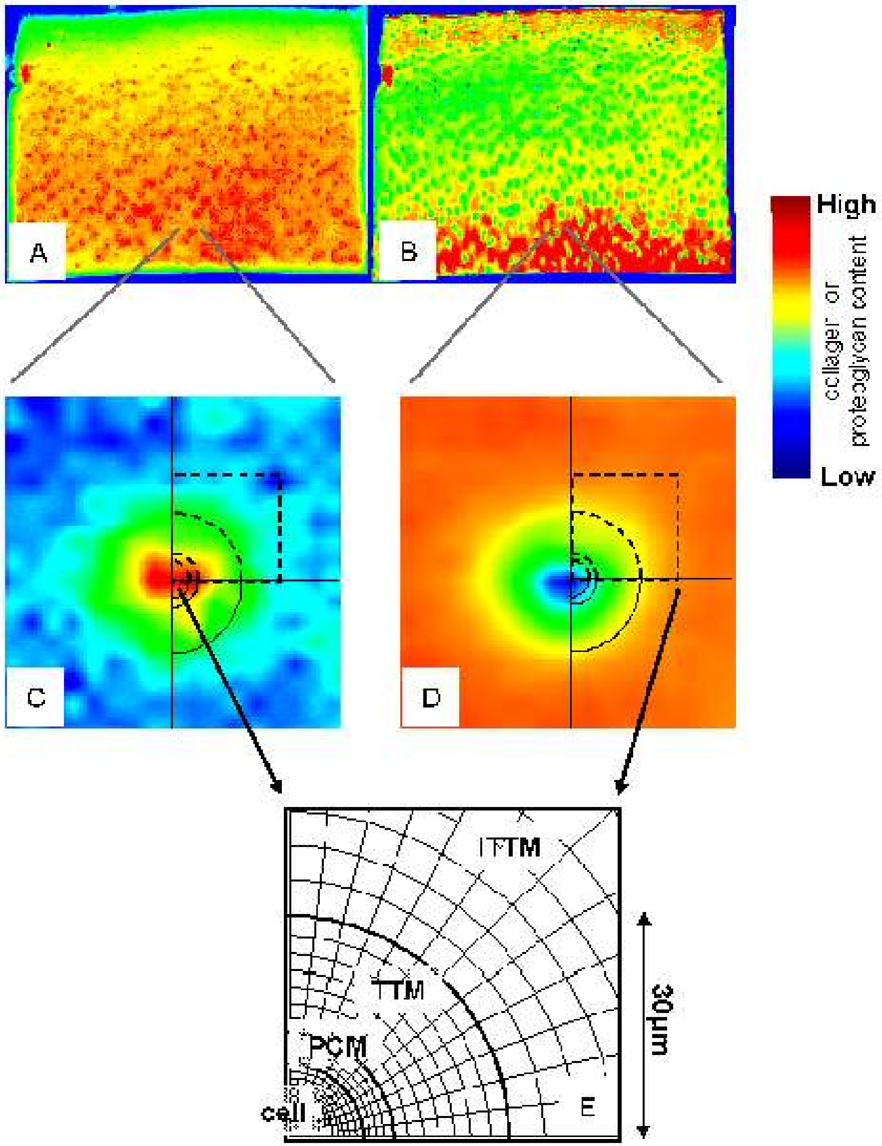
$$\nabla \cdot (\sigma^\alpha + \pi^\alpha) = 0 \quad \alpha = s, f$$

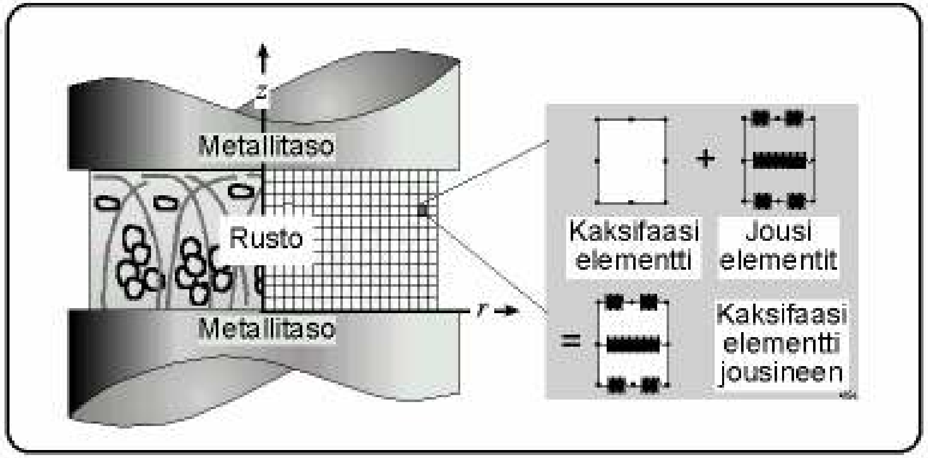
Constitutive equation:

$$\sigma^f = -\sigma^f p \mathbf{I}$$

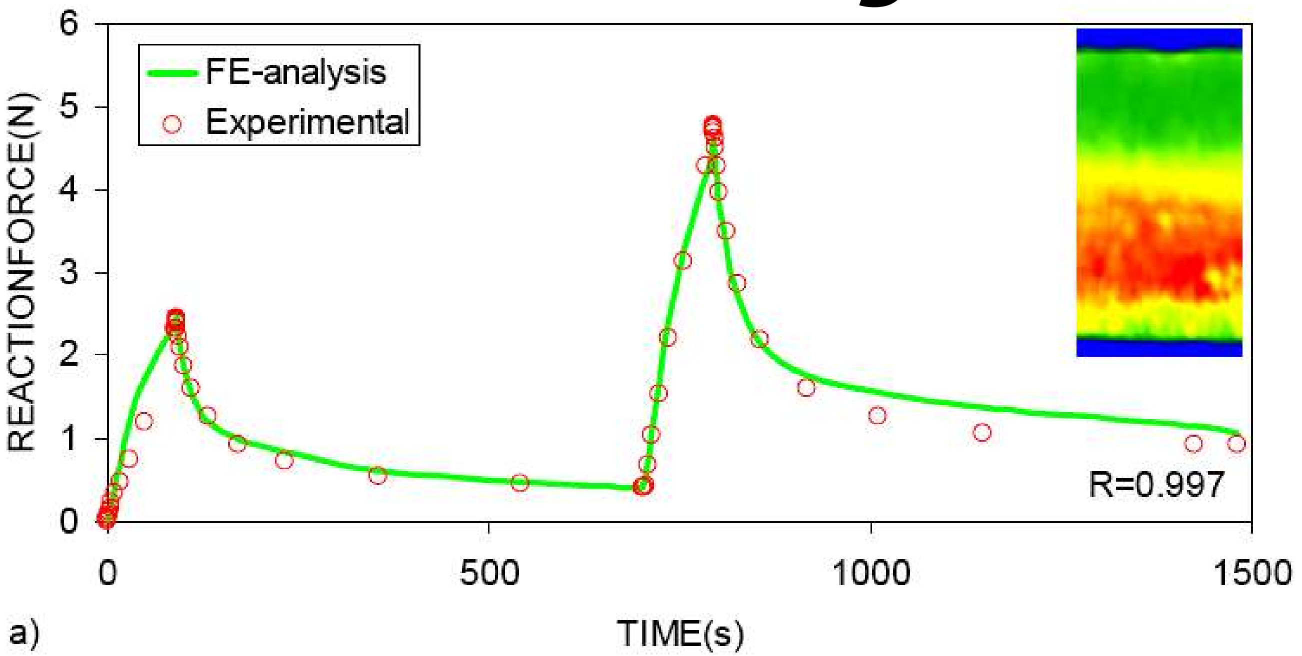
$$\sigma^s = -\phi^s p \mathbf{I} + \bar{\sigma}^s$$

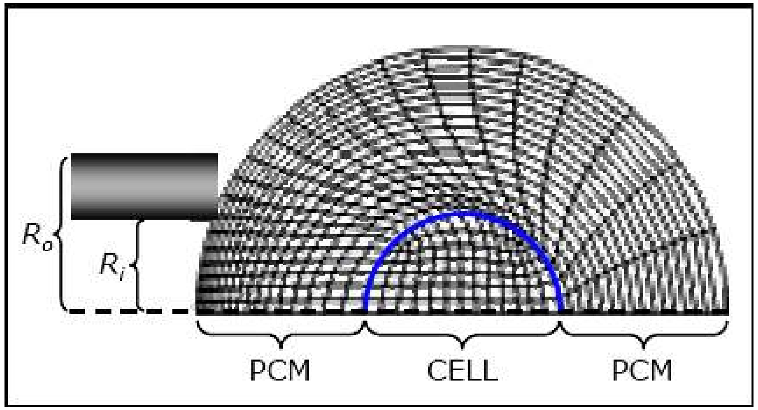
$$\pi^s = -\pi^f = K(\mathbf{v}^f - \mathbf{v}^s)$$

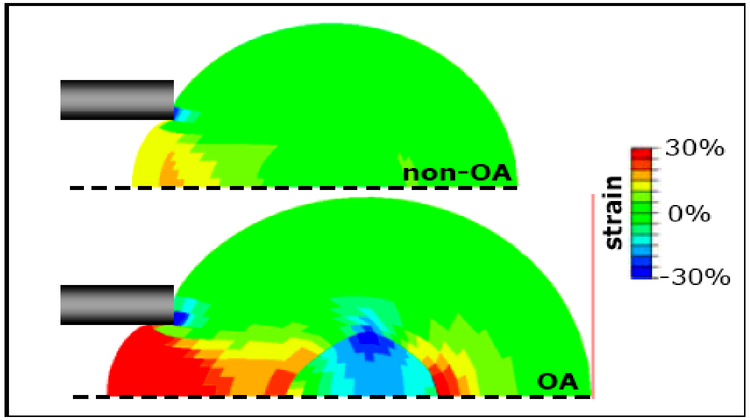




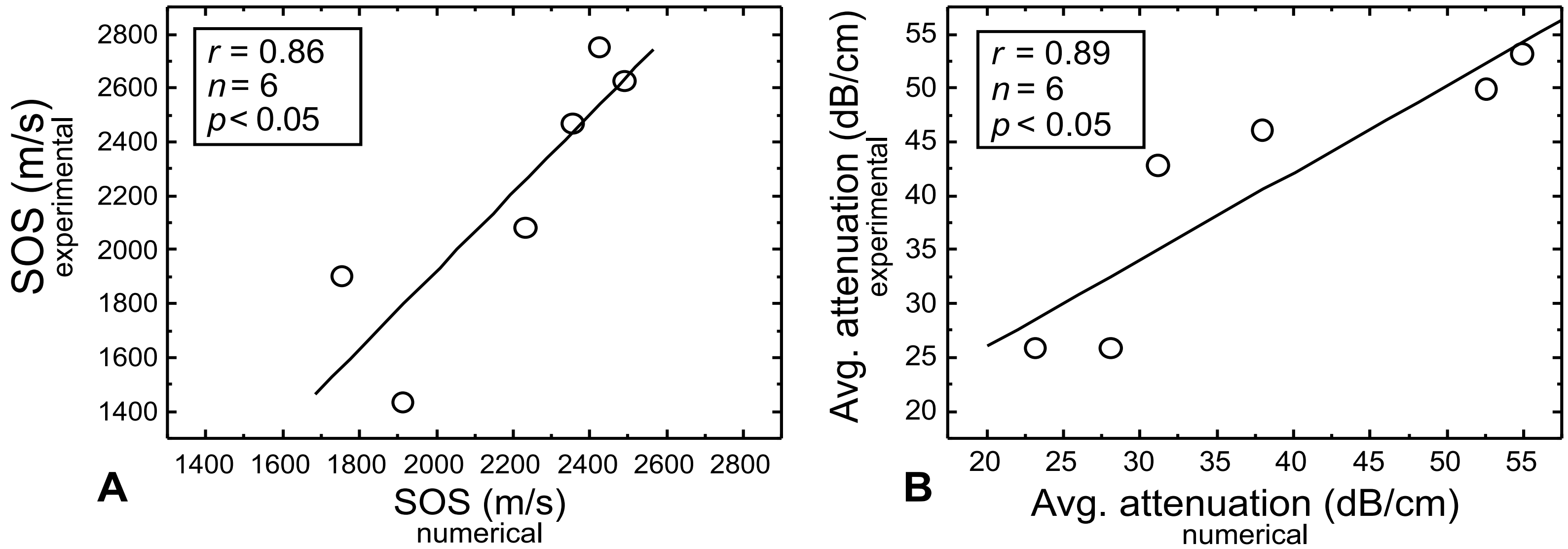
Cartilage Mechanics
Modelling

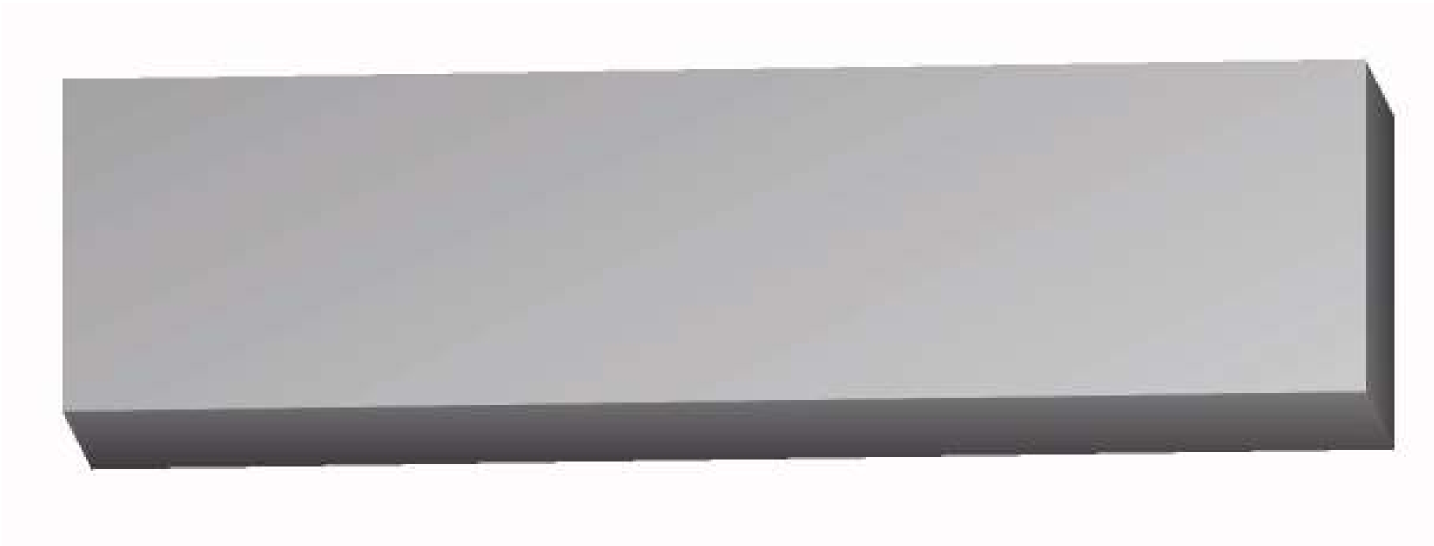






Bone Ultrasound
Modelling

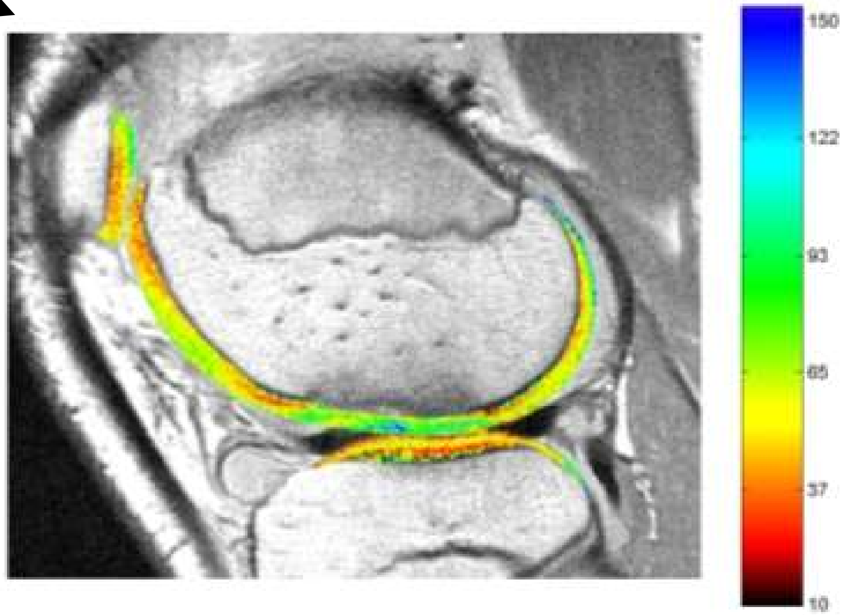




In Vivo Diagnostics

Qualitative technique

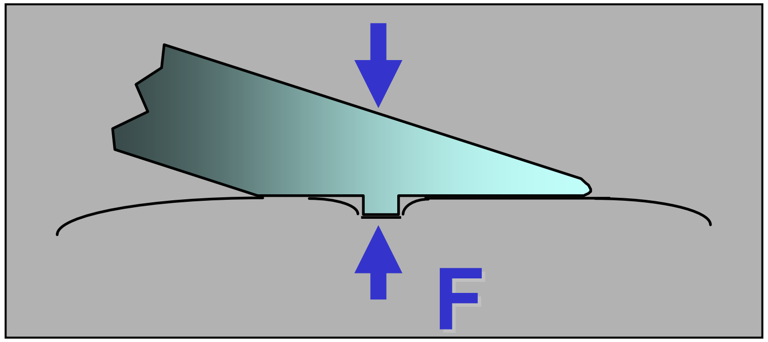
Quantitative technique (non-invasive?)



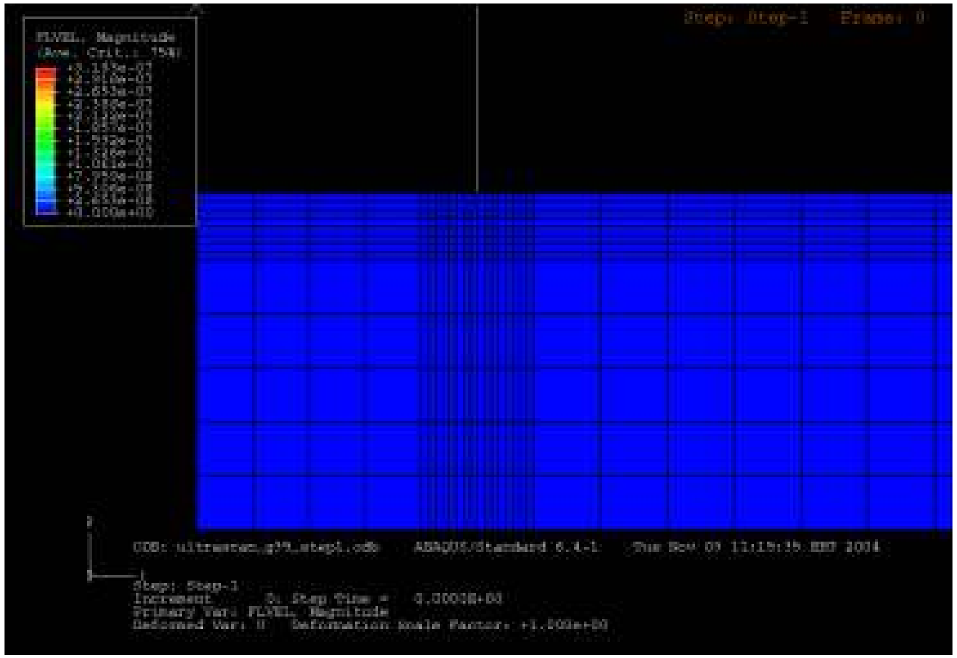
In Vivo Diagnostics

Mechanical Indentation

Lyyra et al.; Med. Eng. Phys. 17:395-399, 1995

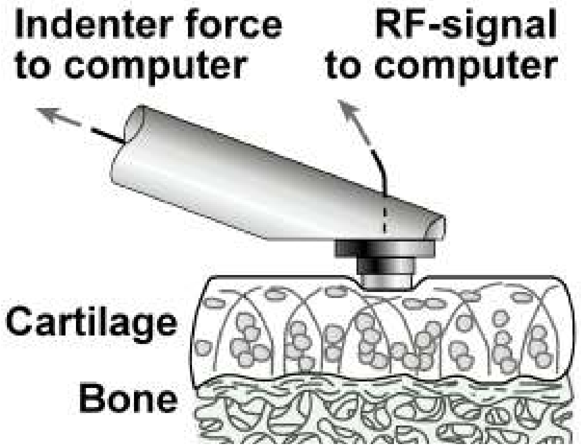


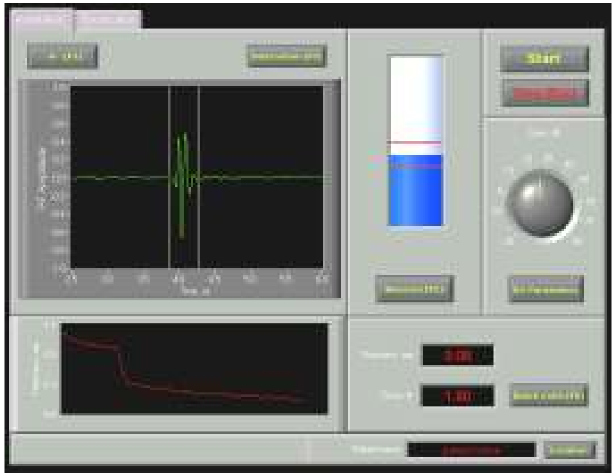
INDENTER FORCE (F) INDICATES CARTILAGE STIFFNESS

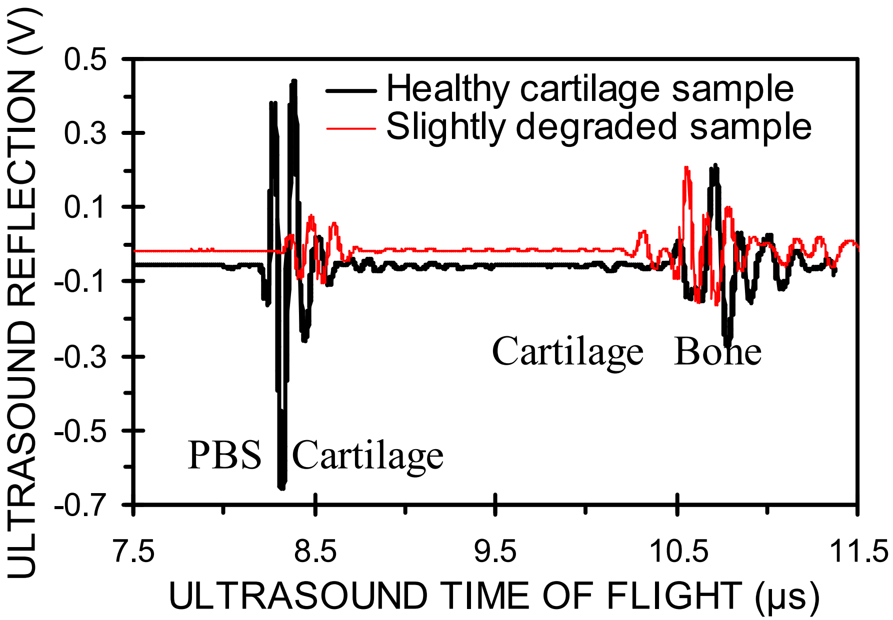


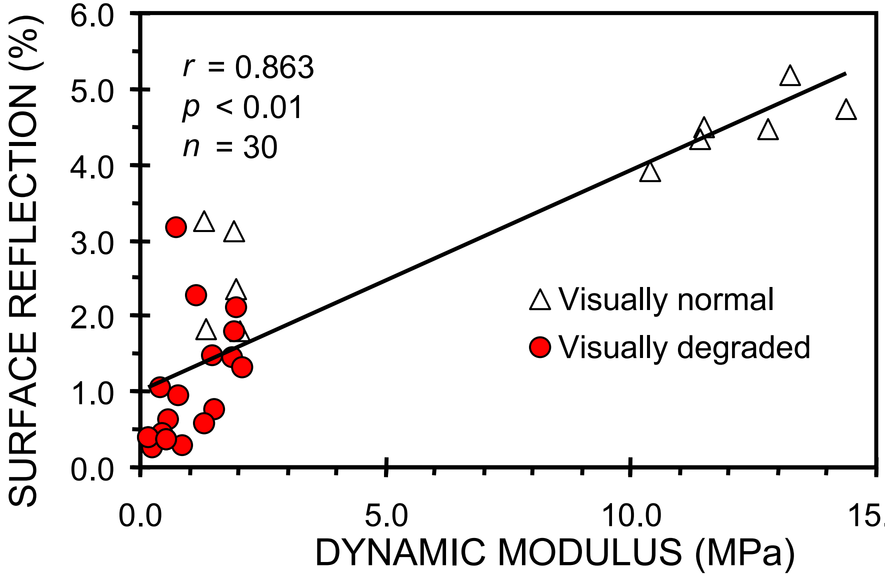
In Vivo Diagnostics

Ultrasound Indentation

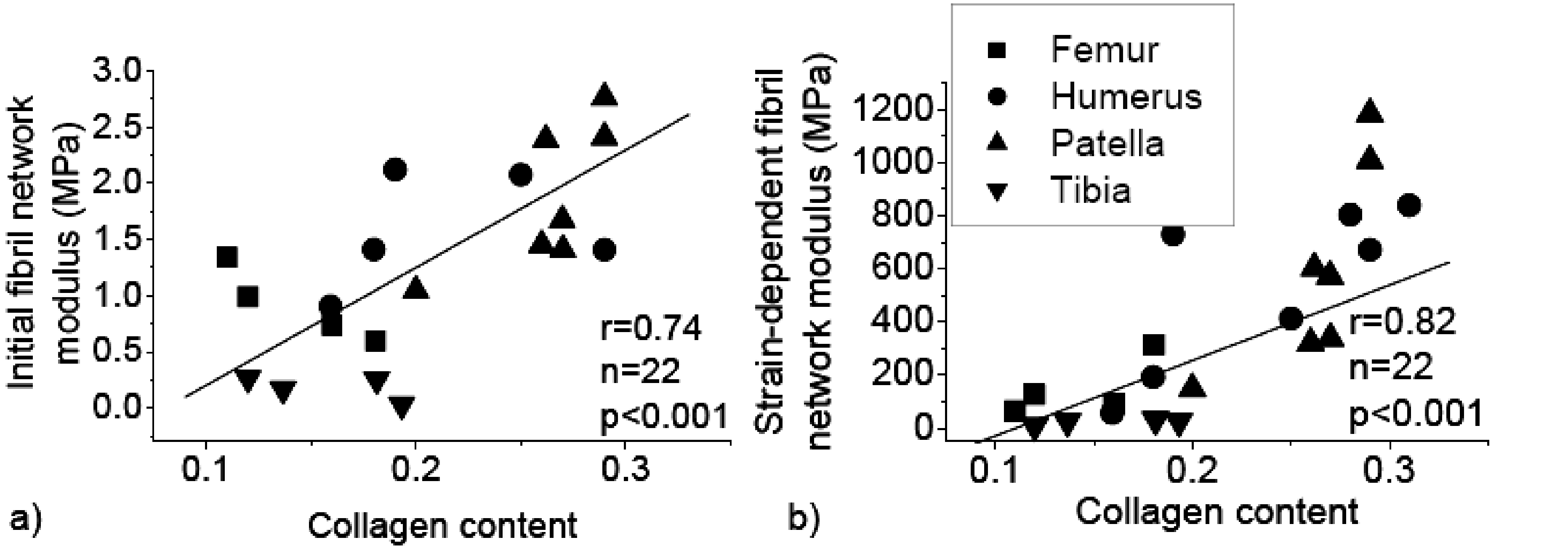






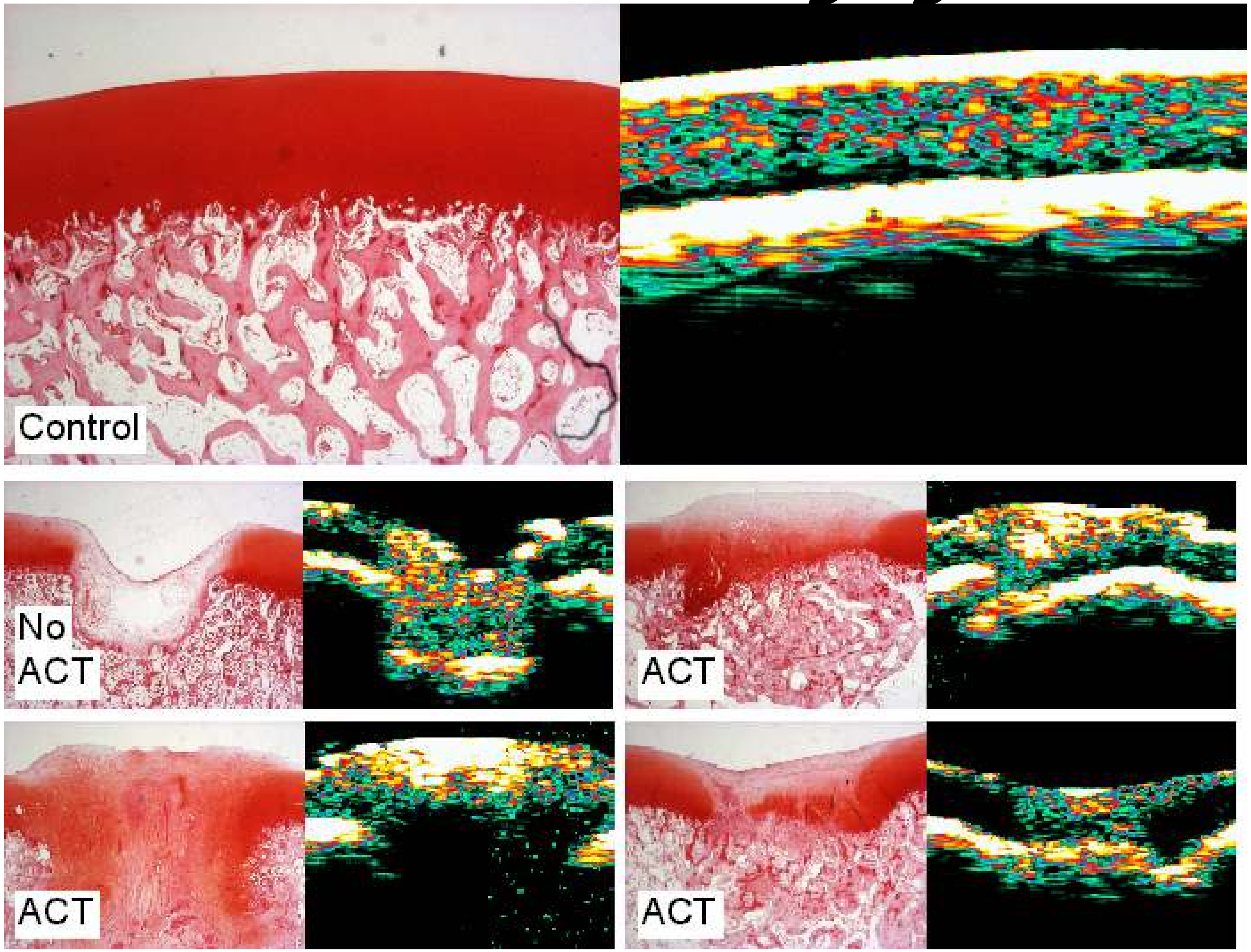


Cartilage Mechanics
Modelling



In Vivo Diagnostics

Ultrasound Imaging



Quantitative Ultrasound Analysis

- Ultrasound Reflection coefficient (*R*) and Integrated Reflection Coefficient (*IRC*)[1] can be calculated for both *cartilage surface* and *cartilage-bone interface*

$$R = \frac{1}{m}\sum_{i=1}^{m}\frac{A_i}{A_i^{ref}}$$

$$IRC = \frac{1}{\Delta f}\int_{\Delta f} R_c^{dB}(f)\,df$$

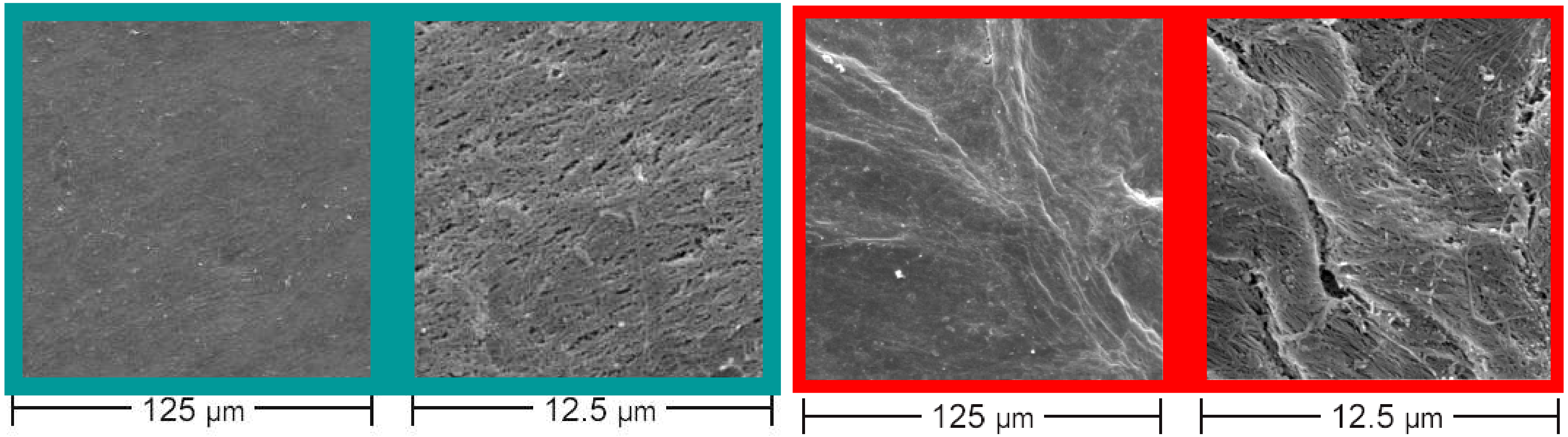
m = number of scan lines
A_i = amplitude from the interface
A_{iref} = reference amplitude from PBS-air interface

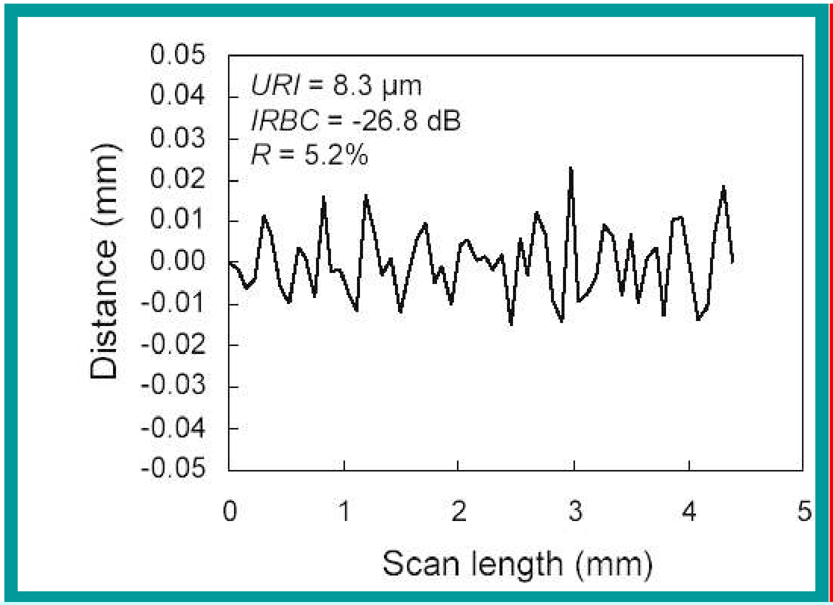
$R_c^{dB}(f)$ = energy reflection coefficient of the interface (dB scale)
Δf = frequency range

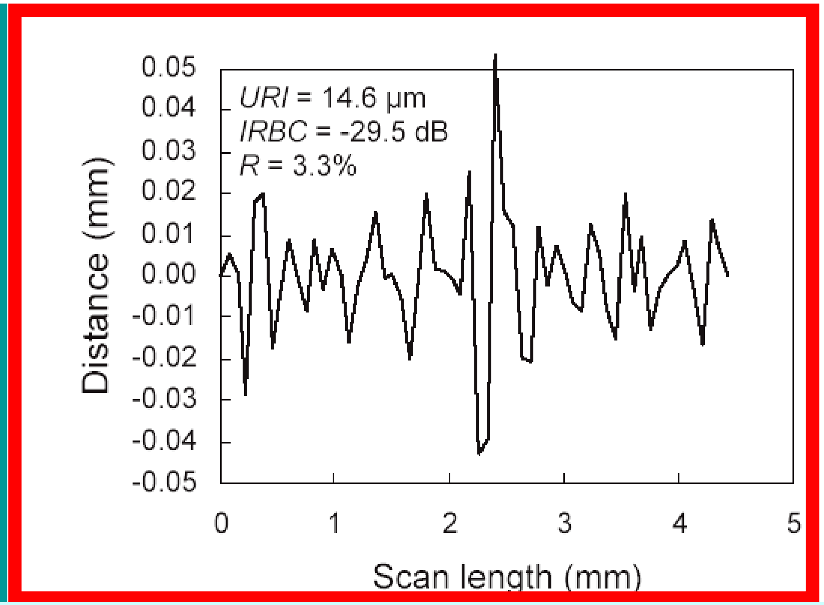
[1] Cherin *et al.*. Ultrasound Med Biol 24:341-354, 1998

In Vivo Diagnostics

High resolution ultrasound imaging



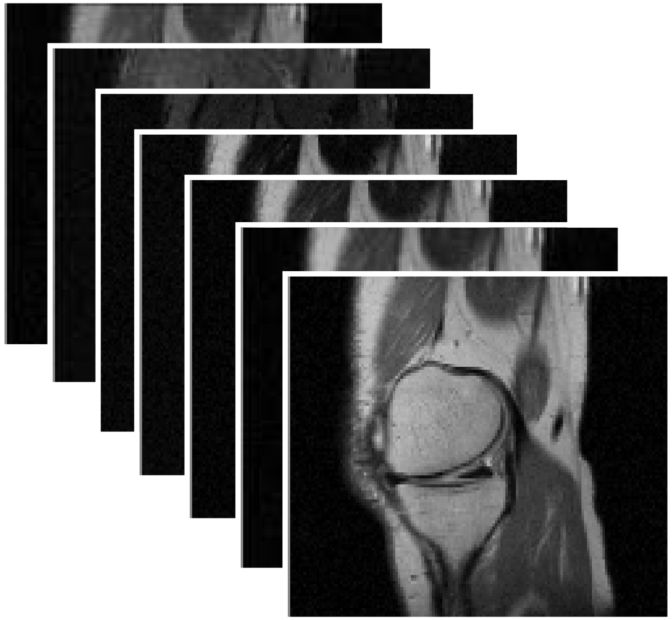




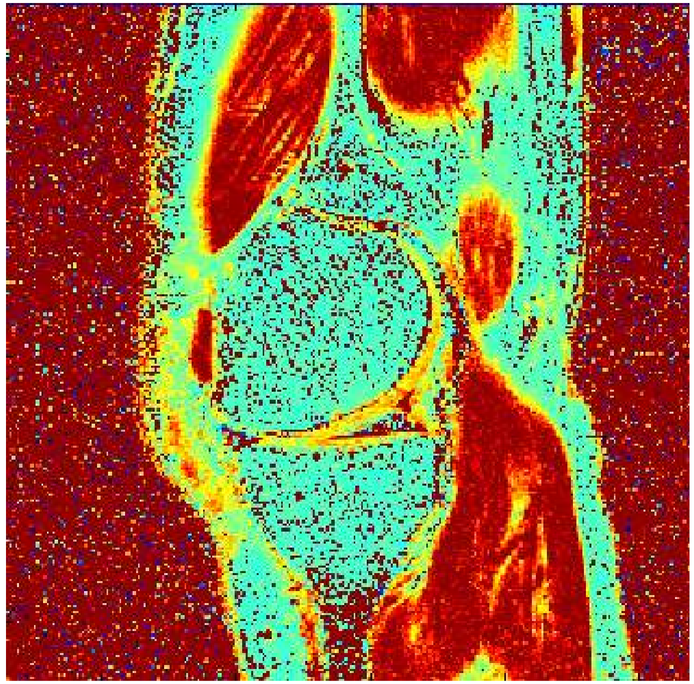
In Vivo Diagnostics

Quantitative MRI

T_1-imaging

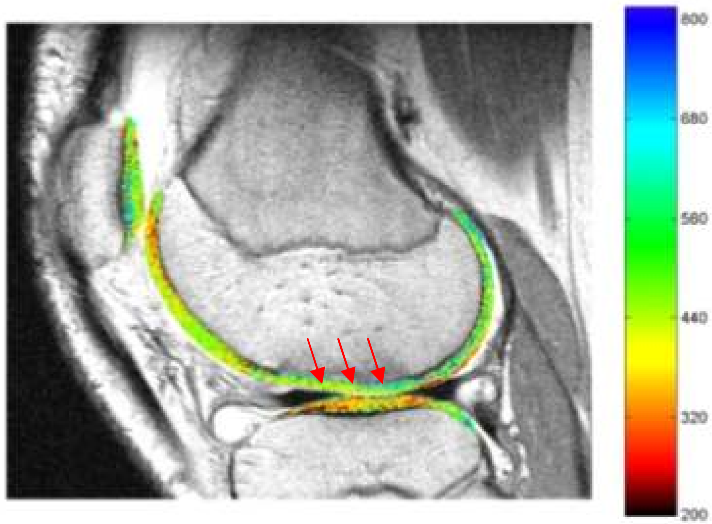


T_1-map

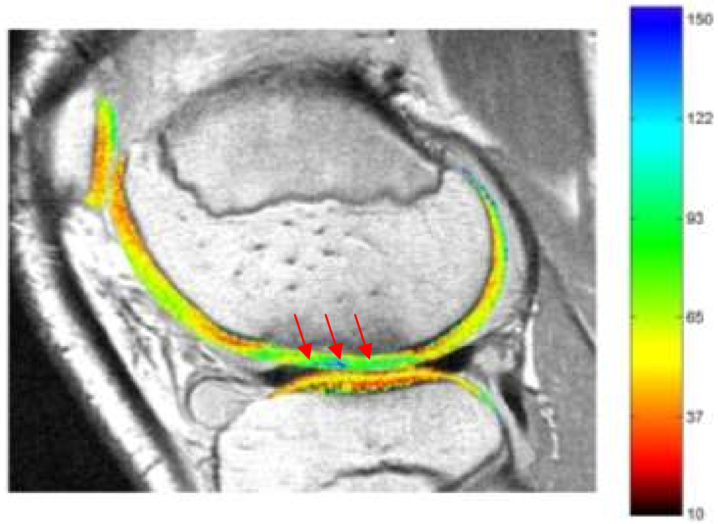


dGEMRIC and T2 in ACT patient

dGEMRIC

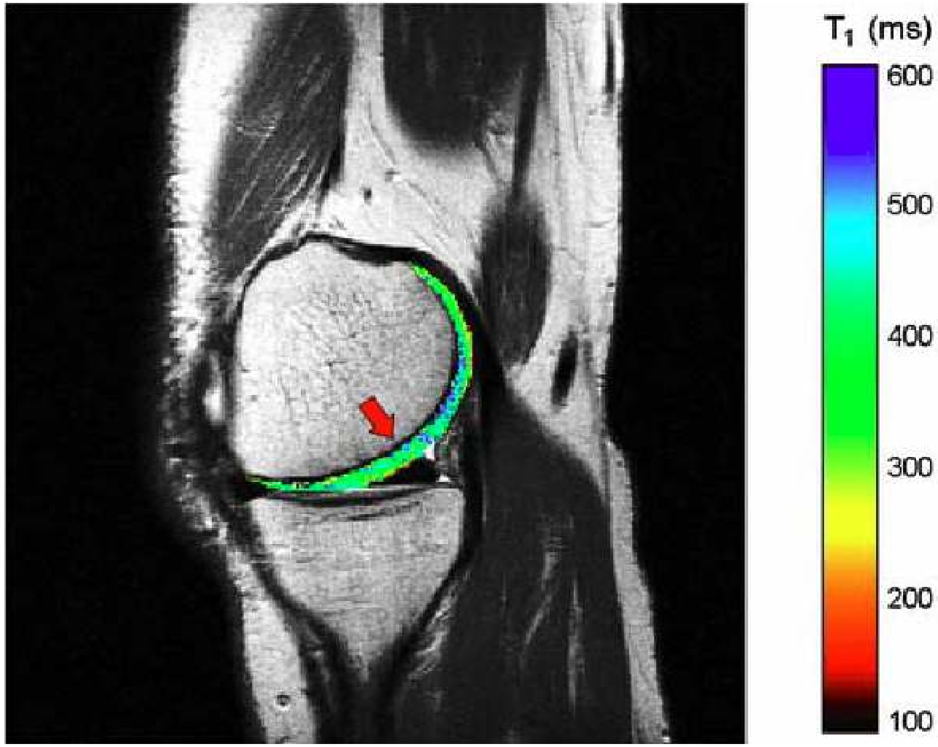


T2



- in ACT graft dGEMRIC shows PG concentrations comparable to adjacent hyaline cartilage
- T2 in graft has higher T2 as compared to surrounding tissue. This is anticipated to relate to a collagen network different from normal cartilage

ACT repair in human knee



Patient	Arthroscopic finding	INDENTATION FORCE			T1 RELAXATION TIME		
Nro	ICRS grade	graft (N)	control (N)	ratio (% of control)	graft (ms) mean ± SD	control (ms) mean ± SD	ratio (% of control)
27	11	1.8	5.7	31	388 ± 54	426 ± 44	91
26	11	1.2	2.1[a]	59	421 ± 52	366 ± 55	115
19	9	1.3	3.3	38	381 ± 60	422 ± 64	90
28	10	0.9	3.2	27	470 ± 44	339 ± 67	139

Osteoporotic Fracture Risk (OFR) Study

OFR

Quadriceps Oy

eximia SOFTWARE CONSULTING

MSD

PARACELSUS MEDIZINISCHE PRIVATUNIVERSITÄT

OULUN DIAKONISSALAITOS

Image analysis system

LMU Ludwig-Maximilians-Universität München

UNIVERSITY of OULU

ENERIS SOLUTIONS

INTOPII

INNSBRUCK MEDICAL UNIVERSITY

Ultrasound prototype testing

Validation of risk assessment tools

JYVÄSKYLÄN YLIOPISTO University of Jyväskylä

Ultrasound technology

KUOPION YLIOPISTO

Ultrasound devices for diagnosis and therapy

THE UNIVERSITY OF HULL

UNIVERSITE PIERRE & MARIE CURIE

Imperial College London

NEXT WAVE®

FinnWell

TEKES

TU/e technische universiteit eindhoven

Ultrasound technology

Bone biophysics

Erasmus Universiteit Rotterdam

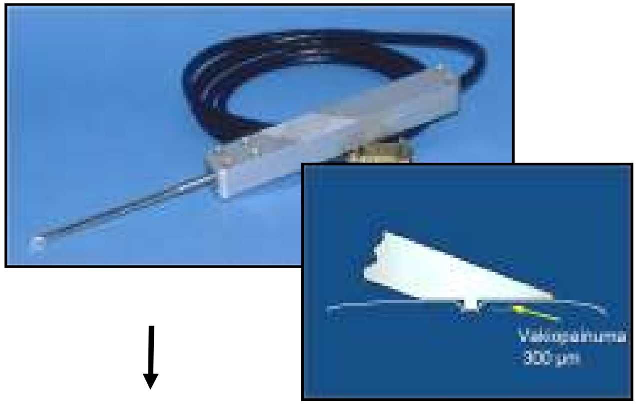
Artscan Oy

Satucon Osaava erikoislääkäriyhteisö

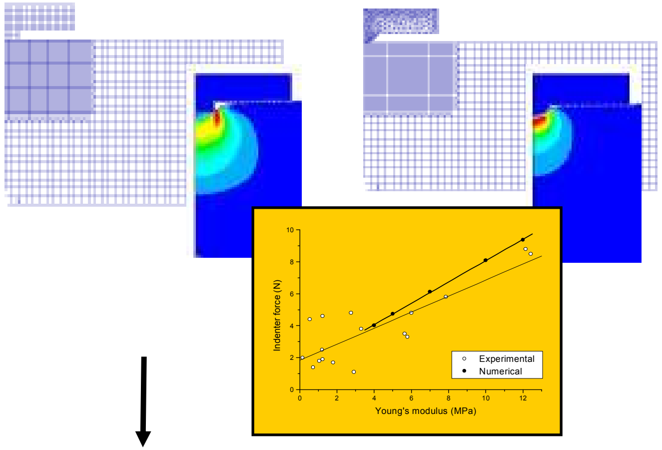
Quadriceps Oy

MSD

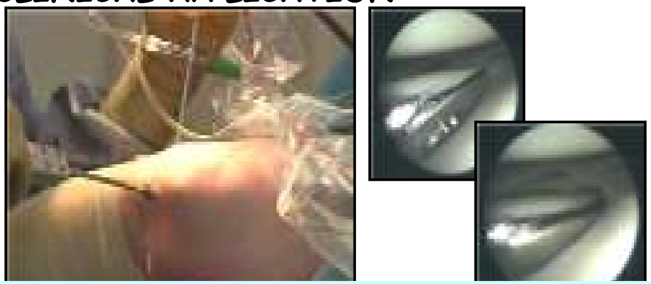
BASIC SCIENCE RESEARCH ->
NEW IDEA AND MEASUREMENT PRINCIPLE



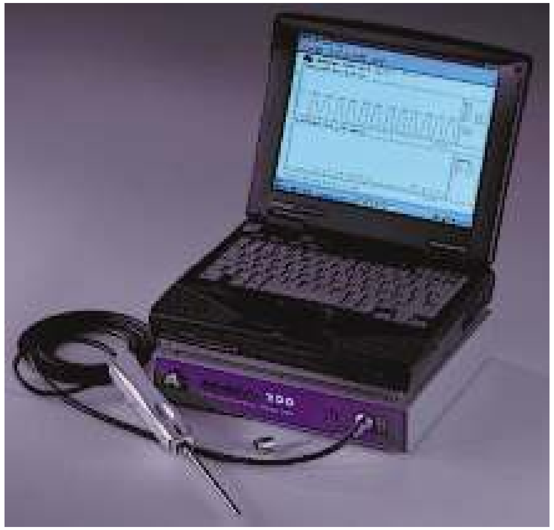
THEORETICAL/COMPUTATIONAL AND
EXPERIMENTAL VALIDATION



CLINICAL APPLICATION



From innovation to FDA approved product...



BIOPHYSICS
BONE AND CARTILAGE

Acknowledgements

BBC-group

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Academy of Finland
TEKES