Osteoporosis: Imaging-based fracture risk prediction

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Osteoporosis Research Group and Collaborators

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**Collaborators:**
- CT Image Reconstruction Group, Department of Radiology (Peter Noël, PhD)
- MRI Research Group, Department of Radiology (Dimitrios Karampinos, PhD)
- Biomechanical Lab, Department of Orthopedic Surgery (Rainer Burgkart, MD)

**Collaborators:**
- Biomedical Physics, E17 (Prof. Franz Pfeiffer, PhD)
- Computation in Engineering (Prof. Ernst Rank, PhD)
- MPE (Christoph Räth, PhD)
- MQIR Group, UCSF (Prof. Thomas Link, MD)

**Funding Sources:**
Osteoporosis

is defined as a skeletal disorder characterized by compromised bone strength predisposing an individual to an increased risk of fracture.
Economic Burden of Osteoporotic Fractures

Germany:
The health burden and costs of osteoporotic fractures from 2010 to 2050 are estimated up to 88.5 billion Euros.

→ increased morbidity and mortality

Bleibler et al. Osteoporosis International 2013
Clinical Goal

• To identify patients with osteoporotic fractures
• To identify patients at high risk of osteoporotic fractures

to initiate appropriate therapy.
Clinical Goal

- To identify patients with osteoporotic fractures
- To identify patients at high risk of osteoporotic fractures
to initiate appropriate therapy.
Diagnosis of Osteoporotic Vertebral Fractures

→ underreported by radiologists in routine exams
Automatic Detection of Osteoporotic Fractures

Automatic detection, identification, and segmentation of the vertebrae in MDCT images:

Baum et al. European Radiology 2014
Automatic Detection of Osteoporotic Fractures

Baum et al. European Radiology 2014
Clinical Goal

- To identify patients with osteoporotic fractures
- To identify patients at high risk of osteoporotic fractures
to initiate appropriate therapy.
## Prediction of Bone Strength

Based on BMD measurements at the spine/hip using DXA

<table>
<thead>
<tr>
<th>Status</th>
<th>BMD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>T-score of -1 or above</td>
</tr>
<tr>
<td>Osteopenia</td>
<td>T-score lower than -1 and greater than -2.5</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>T-score of -2.5 or lower</td>
</tr>
</tbody>
</table>
Prediction of Bone Strength

T-scores and BMD values of patients with and without osteoporotic fractures overlap:

Schuit et al. Bone 2004
Prediction of Bone Strength beyond BMD

Bone strength primarily reflects the integration of BMD and bone quality.

Bone quality includes:
• Bone microstructure
• Bone composition
Prediction of Bone Strength beyond BMD

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Bone quality includes:
- Bone microstructure
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High-Resolution Bone Imaging

Technical considerations:
• Trabeculae have a diameter between 50 and 200 μm.
• Cortical thickness varies between 0.2 to 5 mm.
High-Resolution Bone Imaging

Micro Computed Tomography (µCT):
- spatial resolution up to 8 µm³
- ex-vivo
High-Resolution Bone Imaging

Trabecular bone microstructure analysis:

normal bone sample  galaxy  osteoporotic bone sample

Räth et al. Bone 2013
Clinical MDCT and MRI

→ have not sufficient spatial resolution to reveal the true bone microstructure
Clinical MDCT versus HR-pQCT

<table>
<thead>
<tr>
<th></th>
<th>MDCT vs. HR-pQCT</th>
<th>MDCT vs. FL</th>
<th>HR-pQCT vs. FL</th>
</tr>
</thead>
<tbody>
<tr>
<td>BV/TV</td>
<td>0.90 (p&lt;0.001)</td>
<td>0.79 (p=0.004)</td>
<td>0.69 (p=0.020)</td>
</tr>
<tr>
<td>TbN [mm⁻¹]</td>
<td>0.78 (p=0.001)</td>
<td>0.73 (p=0.011)</td>
<td>0.86 (p=0.001)</td>
</tr>
<tr>
<td>FD</td>
<td>0.60 (p=0.038)</td>
<td>0.69 (p=0.018)</td>
<td>0.85 (p=0.003)</td>
</tr>
</tbody>
</table>

Baum et al. Journal of Bone and Mineral Metabolism 2014
Prediction of Bone Strength beyond BMD

Trabecular bone microstructure analysis:

→ allowed for a significant better prediction than DXA-BMD alone: up to $R(\text{adj})=0.87$

Baum et al. Osteoporosis International 2010
Prediction of Bone Strength beyond BMD

Trabecular bone microstructure analysis:

normal

osteoporotic

Baum et al. Journal of Bone and Mineral Metabolism 2013
Prediction of Bone Strength beyond BMD

Finite Element Models:
X-ray Dark-Field Vector Radiography (XVR)

XVR: Prediction of Bone Strength

Malecki et al. Plos One 2013
XVR: Prediction of Bone Strength

Baum et al. under review
Prediction of Bone Strength beyond BMD

Bone strength primarily reflects the integration of BMD and bone quality.

Bone quality includes:
- Bone microstructure
- Bone composition
Bone Composition assessed by MRS

Bone marrow fat content:

Karampinos et al. under review
MRS: Prediction of Bone Strength

Bone marrow fat content:

Karampinos et al. under review
Imaging-based fracture risk prediction

• Automatic detection of osteoporotic fractures
• High-resolution bone imaging:
  Microarchitecture assessed by MDCT, MRI and XVR
• Imaging of bone composition:
  Bone marrow fat content assessed by MRS
Thanks for your attention.

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