Overview of pQCT

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Objectives

• Understand different methods of assessing bone in children and adults
• Optimise technique when performing pQCT
• Understand how to process and analyse the outputs generated by pQCT
• Understand and interpret assessments of bone age
How do we assess the skeleton?

- What do we want to measure?
- Clinically relevant sites
- Interpretation and what does it tell us?
- What is our research question?
- Population we want to measure
Timeline of quantitative assessment of bone

- Radiographs
- SPA
- DPA
- SXA
- QUS
- QCT
- DXA
- pQCT
- MR (axial, peripheral)
- Digital radiogrammetry
- HR axial QCT
- HR pQCT
- MDCT

Year:
- 1960
- 1970
- 1980
- 1990
- 2000
- 2010
Clinical role of bone densitometry

- Diagnosis of osteoporosis
- Prognosis - to predict fracture risk
- Therapeutic intervention
- Monitoring treatment / change
What are we measuring?

<table>
<thead>
<tr>
<th></th>
<th>BMD&lt;sub&gt;TOTAL&lt;/sub&gt;</th>
<th>BMD&lt;sub&gt;COMPARTMENT&lt;/sub&gt;</th>
<th>BMD&lt;sub&gt;MATERIAL&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DXA (g/cm²)</strong></td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td><strong>QCT (g/cm³)</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Adapted from Rauch & Schonau JBMR 2001
Bone turnover

Formation

Resorption

Gain

Maintenance

Loss
Epidemiology of fractures in the United Kingdom 1988–2012: Variation with age, sex, geography, ethnicity and socioeconomic status

Elizabeth M. Curtis a, Robert van der Velde b, Rebecca J. Moon a,c, Joop P.W. van den Bergh b,d, Piet Geusens e,f, Frank de Vries g,h, Tjeerd P. van Staa h,i, Cyrus Cooper a,j,k,v,l, Nicholas C. Harvey a,l,1
BMC/BMD & Fracture risk

- Bone mass (70%) : Independent predictor of fracture risk
- Adults: 1SD $\approx$ 1 $\frac{1}{2}$ to 3-fold
- Children: 1SD $\approx$ 2-fold
- > 50% individuals who fracture (excluding severe trauma do not have osteoporosis (T score < -2.5)

Compston et al 1995 BMJ 310: 1507-1510
Wainwright SA et al, JCEM 2005
BMC/BMD & Fracture risk

**Does not apply across populations**
- Low BMC/BMD in The Gambia & China
- Importance of bone and body size
- Low risk of fragility fracture in The Gambia & China

Dual Energy X-ray Absorptiometry
## Size dependence of DXA

<table>
<thead>
<tr>
<th></th>
<th>Small</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral weight (g)</td>
<td>16</td>
<td>54</td>
</tr>
<tr>
<td>Volume (cm$^3$)</td>
<td>8</td>
<td>27</td>
</tr>
<tr>
<td>Projected area (cm$^2$)</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>Volumetric BMD (g/cm$^3$)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Areal BMD (g/cm$^2$)</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>
Bone strength

- Structural integrity
- Size
- Morphometry
- Internal architecture
- Bone mass
- Loading conditions
- Organisation of material

Bone mass (70%) : Independent predictor of fracture risk

Adults: 1SD ≈ 1 ½ to 3-fold
Children: 1SD ≈ 2-fold

Compston et al 1995 BMJ 310: 1507-1510
Epiphysis outcome measures
Diaphysis outcome measures

- **Muscle CSA (mm$^2$)**
- **Cortical CSA (mm$^2$) & BMC (mg/mm), BMD**
- **Strength/strain index (mm$^3$)**
Ethnic differences in bone geometry in pre-menopausal women

Low vs moderate/high Ca

<table>
<thead>
<tr>
<th></th>
<th>G vs EC</th>
<th>BA vs EC</th>
</tr>
</thead>
<tbody>
<tr>
<td>vBMD</td>
<td>↑</td>
<td></td>
</tr>
<tr>
<td>BMC</td>
<td>↓</td>
<td></td>
</tr>
<tr>
<td>Med area</td>
<td>↑</td>
<td></td>
</tr>
<tr>
<td>Cort thk</td>
<td>↓</td>
<td></td>
</tr>
<tr>
<td>SSI</td>
<td>↔</td>
<td></td>
</tr>
</tbody>
</table>

vBMD = cortical volumetric bone mineral density, BMC = bone mineral content, Med area = medullary area, Cort thk = cortical thickness, SSI = bone strength
Ethnic differences in bone geometry in pre-menopausal women

Low vs moderate/high Ca

- Gambian
- European Caucasian

Low vs adequate 25(OH)D

- Premenopausal British Asian
- European Caucasian

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<tr>
<td>BMC</td>
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<td>↓</td>
</tr>
<tr>
<td>Med area</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>Cort thk</td>
<td>↓</td>
<td>↓</td>
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<tr>
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vBMD = cortical volumetric bone mineral density, BMC = bone mineral content, Med area = medullary area, Cort thk = cortical thickness, SSI = bone strength

Ward et al; Bone 2007; 41: 117-121
Laskey et al; J Clin Densitom. 13(3): 247-55
Global NCD risk - GamBAS

*Growth, adult environment, musculoskeletal phenotype and fracture risk in Sub-Saharan Africa*

**AIM**

- To characterise the individual change in bone strength (BMC/D, bone geometry) during ageing in Gambian males and females
- Define ageing process in muscle
- Understanding the interaction between mechanical and non-mechanical factors (nutrition, lifestyle, hormones)

- Prospective study, M&F, 8, 5yr age range bands - 40 to 75+. Stratified by age band and gender, randomised follow-up 1.5 to 2 years. 240 per gender, ~ 30 per age band
- DXA (+LVA), pQCT, jumping mechanography and grip strength. Fasting bloods, 2hr & 24hr urine, lifestyle and medical history
- Baseline data collection complete October 2012; n=488 (227M, 262F).
### Table 3: Sub-analysis of participants who were “able” and “unable” to perform m1LH and s2LJ tests

<table>
<thead>
<tr>
<th>Body Habitus</th>
<th>n</th>
<th>Able</th>
<th>n</th>
<th>Unable</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (n, M/F)</td>
<td>362</td>
<td>185/177</td>
<td>126</td>
<td>54/72</td>
<td>0.111</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>362</td>
<td>57.1 ± 10.6</td>
<td>126</td>
<td>72.0 ± 10.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Body Weight (Kg)</td>
<td>362</td>
<td>58.4 ± 10.6</td>
<td>126</td>
<td>54.0 ± 10.0</td>
<td>0.0001</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>362</td>
<td>164.3 ± 8.3</td>
<td>126</td>
<td>160.6 ± 9.1</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>BMI (kg/cm²)</td>
<td>362</td>
<td>21.6 ± 3.5</td>
<td>126</td>
<td>20.9 ± 3.1</td>
<td>0.052</td>
</tr>
<tr>
<td>Whole body Fat Mass (kg)</td>
<td>358</td>
<td>12.7 ± 8.2</td>
<td>119</td>
<td>12.8 ± 7.5</td>
<td>0.913</td>
</tr>
<tr>
<td>Whole body Fat Mass (%BW)</td>
<td>358</td>
<td>22.3 ± 12.2</td>
<td>119</td>
<td>24.1 ± 11.7</td>
<td>0.148</td>
</tr>
<tr>
<td>Whole body Lean Mass (kg)</td>
<td>358</td>
<td>42.9 ± 8.9</td>
<td>119</td>
<td>38.7 ± 7.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Appendicular Lean mass (kg)</td>
<td>362</td>
<td>19.8 ± 4.8</td>
<td>124</td>
<td>17.2 ± 4.0</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

#### 38% Tibia

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Able</th>
<th>n</th>
<th>Unable</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ct. BMC (mg/mm)</td>
<td>326</td>
<td>314.7 ± 76.3</td>
<td>120</td>
<td>271.1 ± 80.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Ct. Area (mm²)</td>
<td>327</td>
<td>261.8 ± 58.6</td>
<td>120</td>
<td>229.8 ± 60.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>CSA (mm²)</td>
<td>326</td>
<td>411.1 ± 72.3</td>
<td>120</td>
<td>389.8 ± 62.3</td>
<td>0.005</td>
</tr>
<tr>
<td>CSMI (mm⁴)</td>
<td>326</td>
<td>13063.7 ± 5241.0</td>
<td>120</td>
<td>10911.6 ± 4152.7</td>
<td>0.0001</td>
</tr>
<tr>
<td>SSI (mm⁴)</td>
<td>326</td>
<td>1686.8 ± 455.9</td>
<td>120</td>
<td>1489.4 ± 416.7</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

#### 66% Tibia

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Able</th>
<th>n</th>
<th>Unable</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSMA (mm²)</td>
<td>319</td>
<td>5368.8 ± 1131.3</td>
<td>118</td>
<td>4665.2 ± 1077.0</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Muscle Density (mg/cm³)</td>
<td>311</td>
<td>70.4 ± 2.8</td>
<td>117</td>
<td>68.5 ± 2.8</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Grip strength (kg)</td>
<td>362</td>
<td>27.6 ± 9.3</td>
<td>126</td>
<td>20.1 ± 7.2</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

#### CRT

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Able</th>
<th>n</th>
<th>Unable</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative force (N/kg)</td>
<td>357</td>
<td>1.4 ± 0.3</td>
<td>126</td>
<td>1.3 ± 0.4</td>
<td>0.352</td>
</tr>
<tr>
<td>Relative power (W/kg)</td>
<td>357</td>
<td>8.0 ± 2.8</td>
<td>126</td>
<td>5.8 ± 1.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Time per test (s)</td>
<td>357</td>
<td>4.7 ± 1.5</td>
<td>126</td>
<td>6.3 ± 1.9</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

All values are mean ± SD. Bold indicates p<0.05. BMI, body mass index; BW, body weight; Ct, cortical; BMC, bone mineral content; CSA, cross-sectional area; CSMI, cross-sectional moment of inertia; SSI, stress strain index; CSMA, cross-sectional muscle area; s2LJ, single two-legged jump; SD, standard deviation; m1LH, multiple one leg hop; CRT, chair rise test.
How do we analyse a pQCT scan?

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Objectives

- Understand different methods of assessing bone in children and adults
- Optimise technique when performing pQCT
- Understand how to process and analyse the outputs generated by pQCT
- Understand and interpret assessments of bone age
Analysis of Width and Density of Cortex

T. N. Hangartner, Wright State University, Dayton, OH
Need separate approach for analyzing cortical width and cortical density.
Threshold Influences Measured
Size and Density

Original Image

\[ T_1 = 97\% \]

\[ T_2 = 81\% \]

\[ T_3 = 65\% \]

\[ T_4 = 50\% \]

\[ T_5 = 36\% \]

\[ T_6 = 22\% \]

\[ T_7 = 8\% \]

T. N. Hangartner, Wright State University, Dayton, OH
Regions of Interest (ROI)
Regions of Interest (ROI)

Tibia
CALCBD
CORTBD

Images are not for diagnostic purposes

Results CORTBD, ROI: "RADIUS"

Density: 124.0 [mg/cm²] ±/−(0.0)  
Area: 84.3 mm²/2  
Attenuat.: 0.420 [Houns]
Muscle

Images are not for diagnostic purposes

Results CALCBD, ROI: "MUSCLE+Bone_AR," F03F05

<table>
<thead>
<tr>
<th>Region</th>
<th>Total</th>
<th>Trabecular</th>
<th>Cortical + sub-cortical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>155.0</td>
<td>155.0 +/- (0.0)</td>
<td>0.0 +/- (0.0)</td>
</tr>
<tr>
<td>Area</td>
<td>3182.0 mm^2 (12728#)</td>
<td>3182.0 mm^2 (12728#)</td>
<td>0.0 mm^2 (0#)</td>
</tr>
</tbody>
</table>

PARAMETER | TREND | REFERENCE | PRINT | OK
---|---|---|---|---
MENU / ANALYSIS / RESULTS / CALCBD | | | | |
Muscle & bone - example
Examples of anomalies
Madelung's deformity – Turner's syndrome
Incorrect reference line – clue high Z-scores
C2P1 not worked – what should we do?
4% Distal tibia scans grade 0 - 3
66% Proximal tibia scans grade 0 - 3
Madelungs deformity – Turners syndrome
C2P1 not worked – what should we do?
Extra thick cortices

Anatomy different – circular radius & ulna
Harris growth arrest line – illness, bisphosphonate treatment