

骨粗鬆症診療における骨質評価の重要性

長崎大学病院 放射線部
伊東昌子

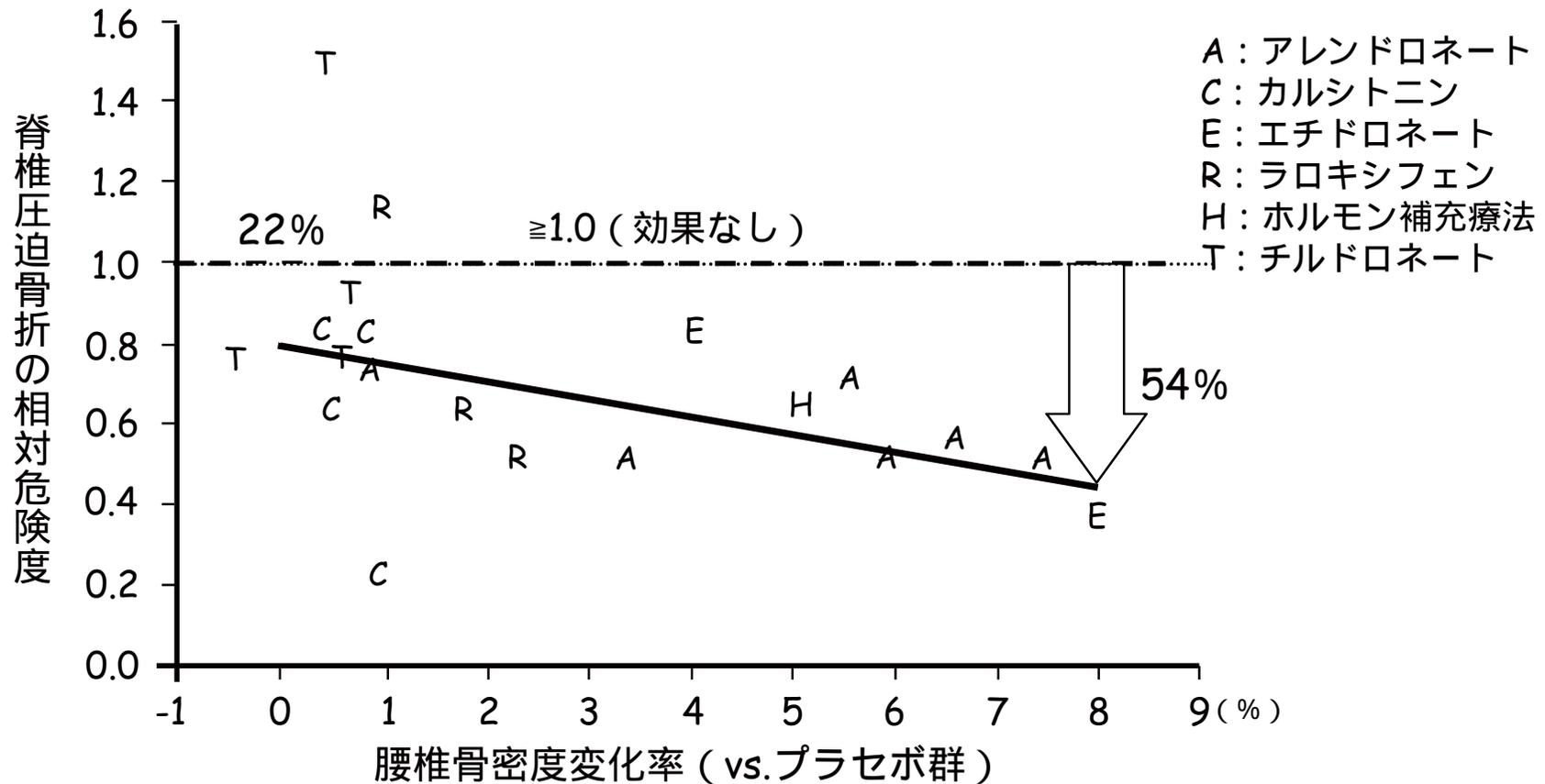
骨強度を表す概念

NIH コンセンサス ステートメント 2000



- 微細構造
- 骨代謝回転
- 微小骨折
- 石灰化

骨密度変化率と骨折相対危険度の関係



骨の強度

構造特性

- 構造（ジオメトリー）
 - サイズ
 - 形状
- 骨微細構造
 - 骨梁構造
 - 皮質骨幅と多孔性（ポロシティ）

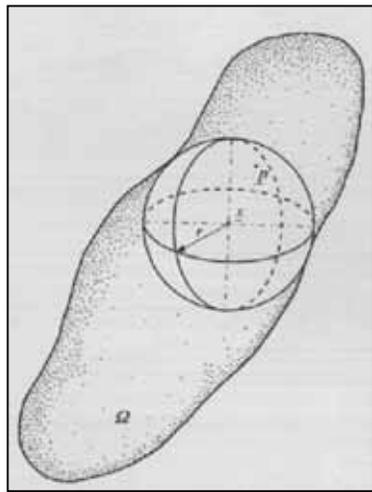
材質特性

- ミネラル
 - 全骨ミネラル
 - 骨基質のミネラル化度
 - 結晶サイズ
- コラーゲン
 - タイプ
 - 架橋
- マイクロダメージ：マイクロクラック、マイクロフラクチャー

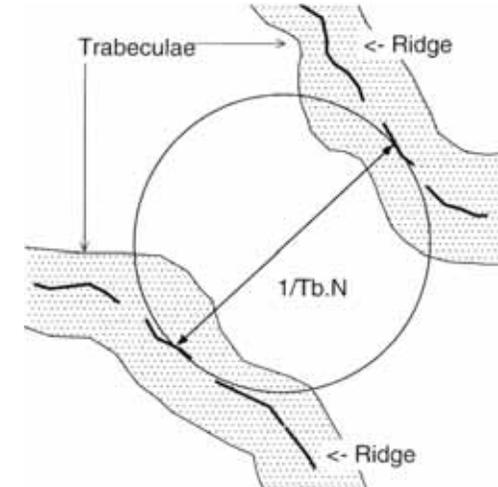
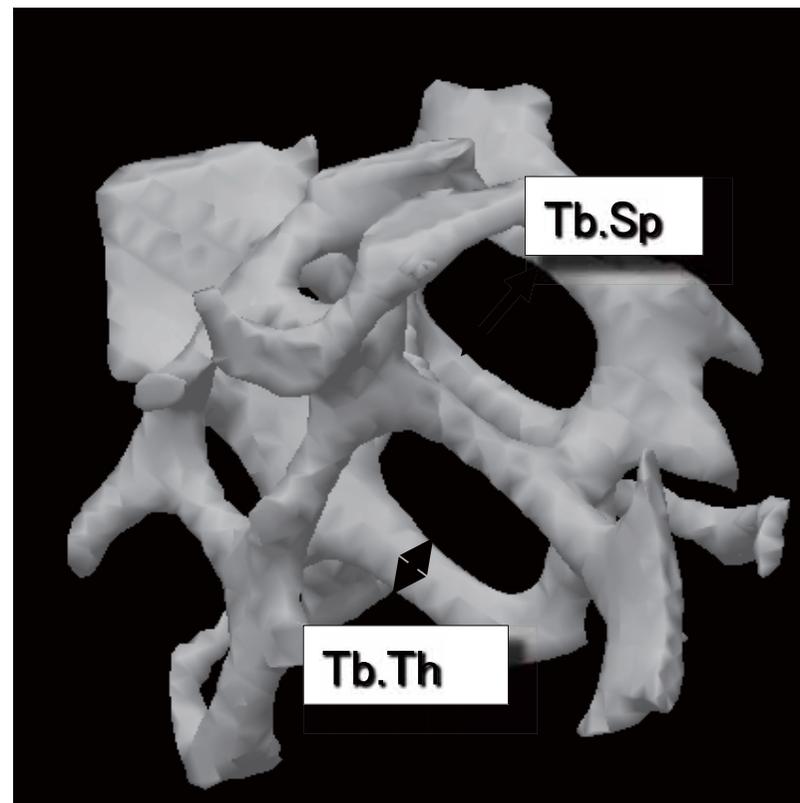
骨吸収と骨形成（リモデリング）

海綿骨微細構造の評価と骨強度

組織形態計測パラメター



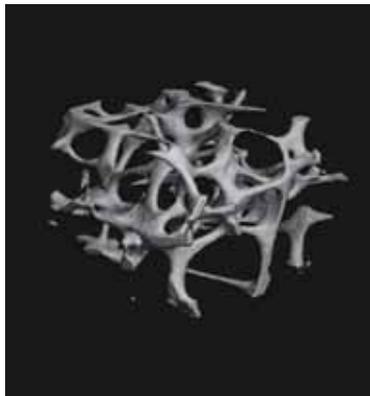
Hildebrand T, Ruegsegger P
J Microscopy 185:67-75, 1997



直接三次元計測: Tb.Th, Tb.Sp, Tb.N, etc

空間的構造を表すパラメター

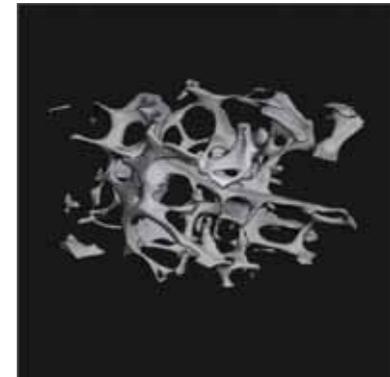
structure model index
(SMI)
骨梁の形態



degree of anisotropy
(DA)
骨梁の方向性



Connectivity density
骨梁の連結性

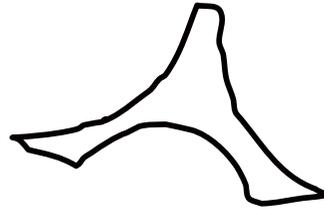


TPTD治療前後の骨梁構造の変化

ベースライン

治療後

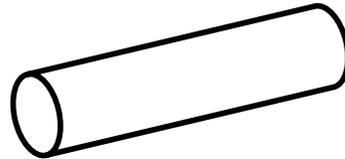
BV/TV
(2D)



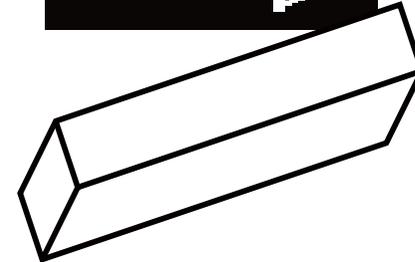
$p=0.001$
14.3%



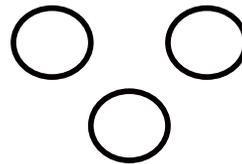
SMI (3D)



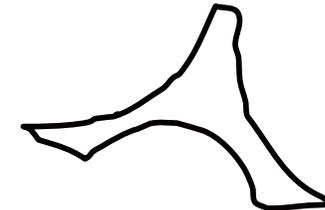
$p=0.025$
-12.2%



連結密度
(3D)



$p=0.034$
19.1%



皮質骨厚
(3D)

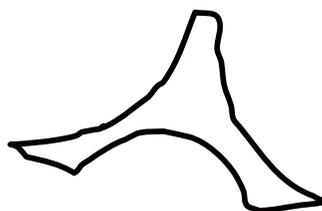


$p=0.012$
22.0%

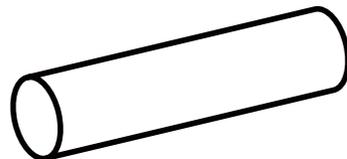


加齢に伴う骨梁構造の変化

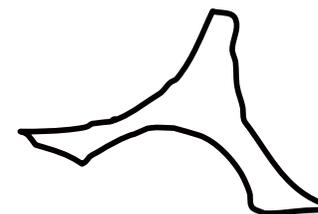
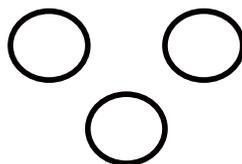
BV/TV
(2D)



SMI (3D)



連結密度
(3D)

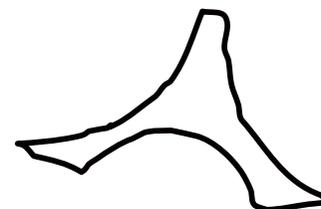
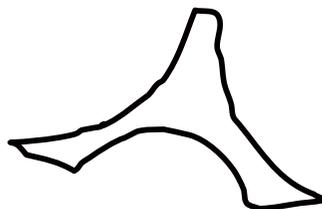


皮質骨厚
(3D)

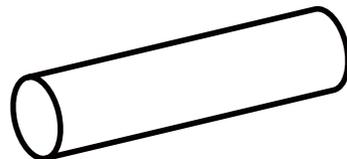


骨粗鬆症患者における骨梁構造の劣化 ベースライン

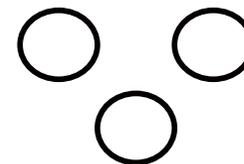
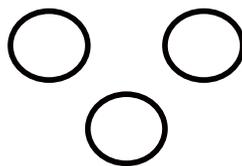
BV/TV
(2D)



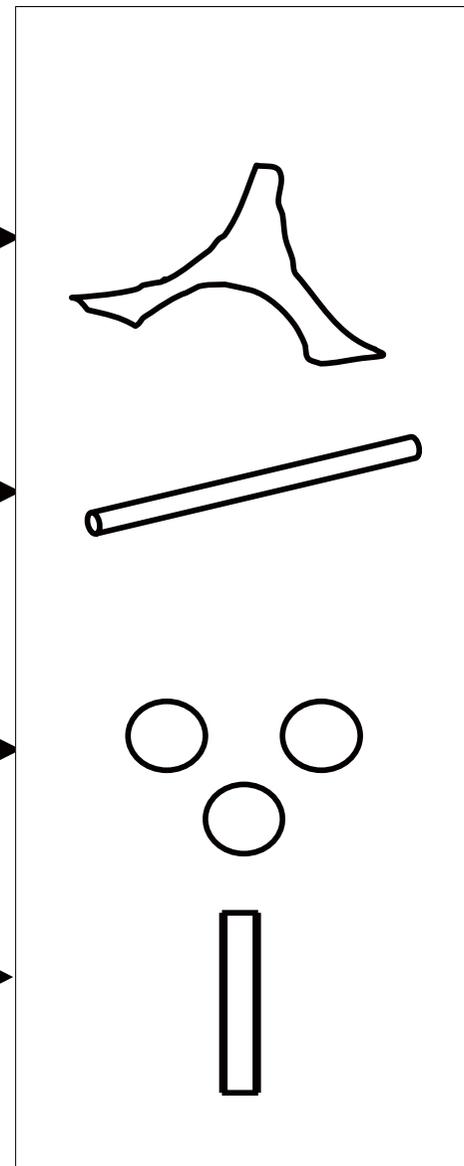
SMI (3D)



連結密度
(3D)



皮質骨厚
(3D)

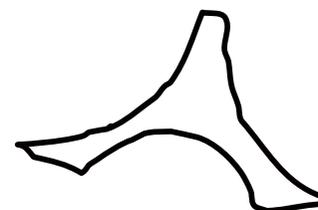
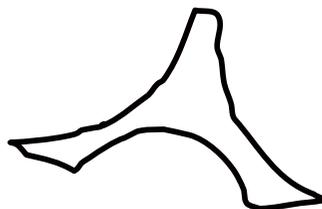


骨吸収抑制剤投与前後の骨梁構造の変化

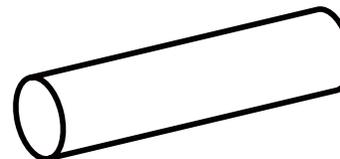
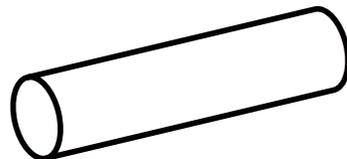
ベースライン

治療後

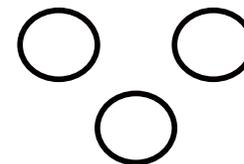
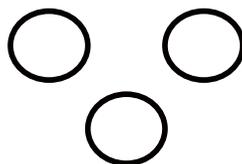
BV/TV
(2D)



SMI (3D)



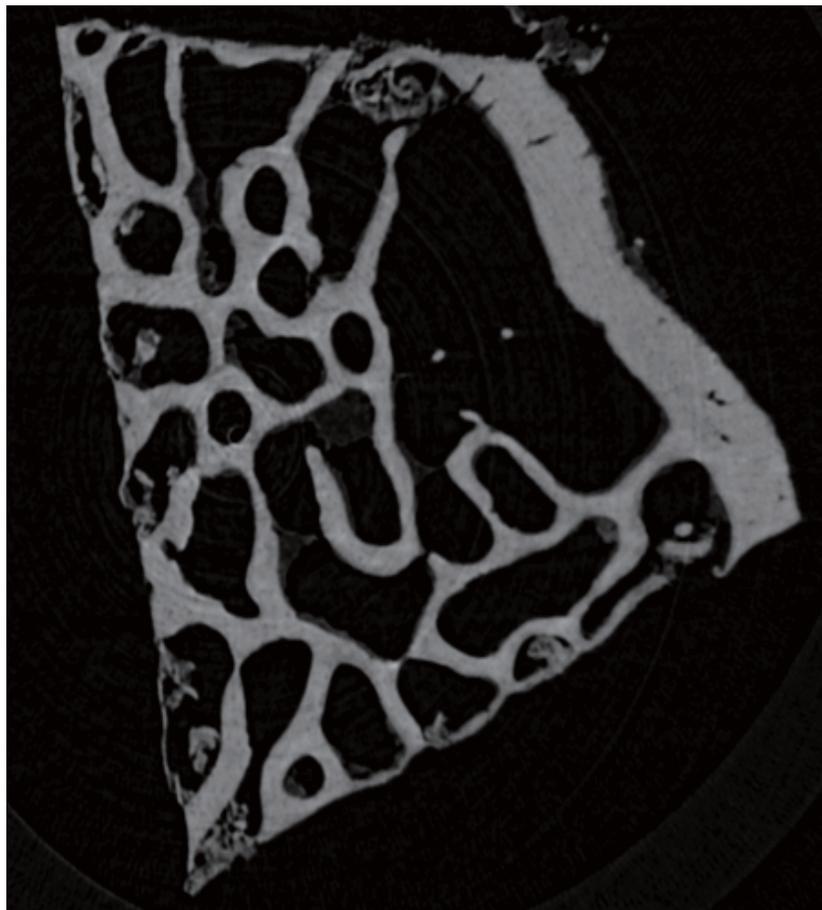
連結密度
(3D)



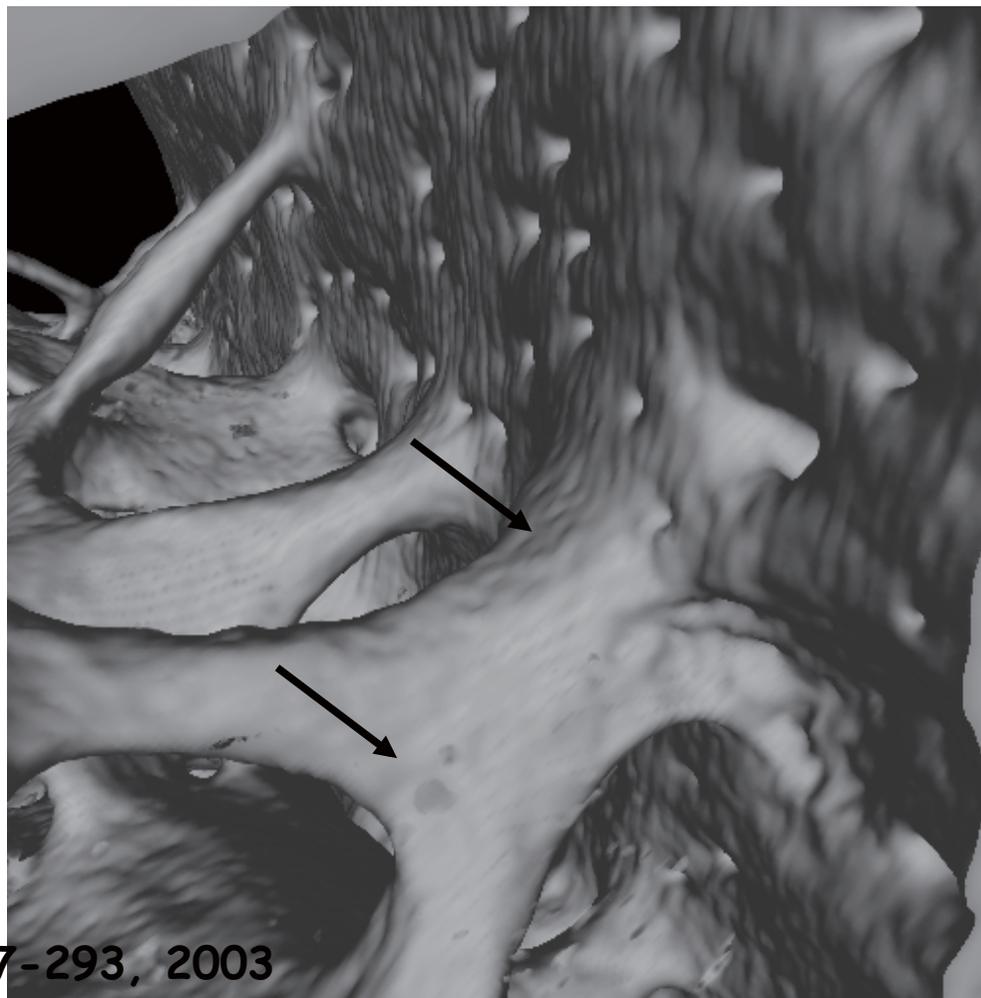
皮質骨厚
(3D)



放射光CT (6 ミクロン)

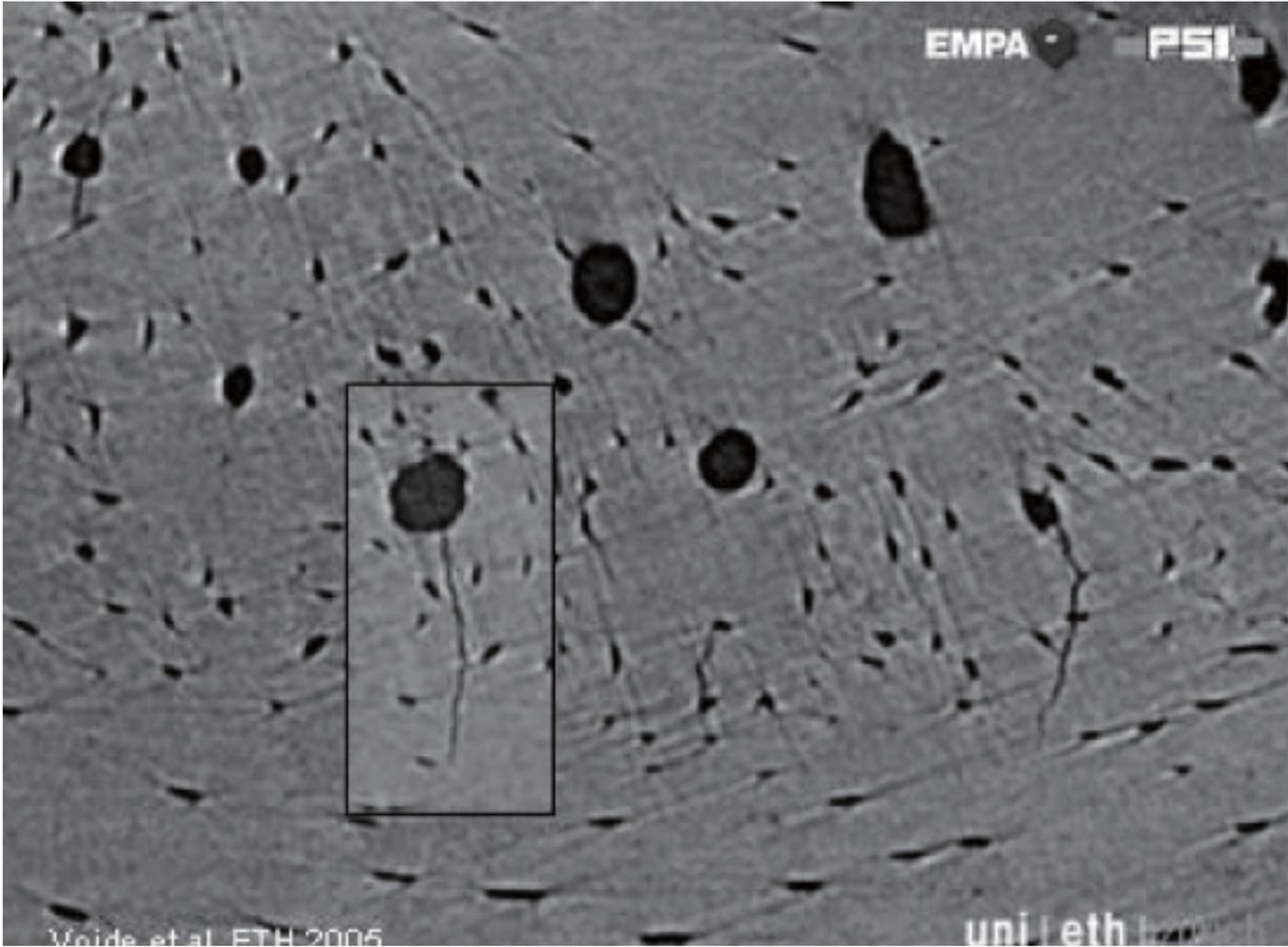


ラット椎体

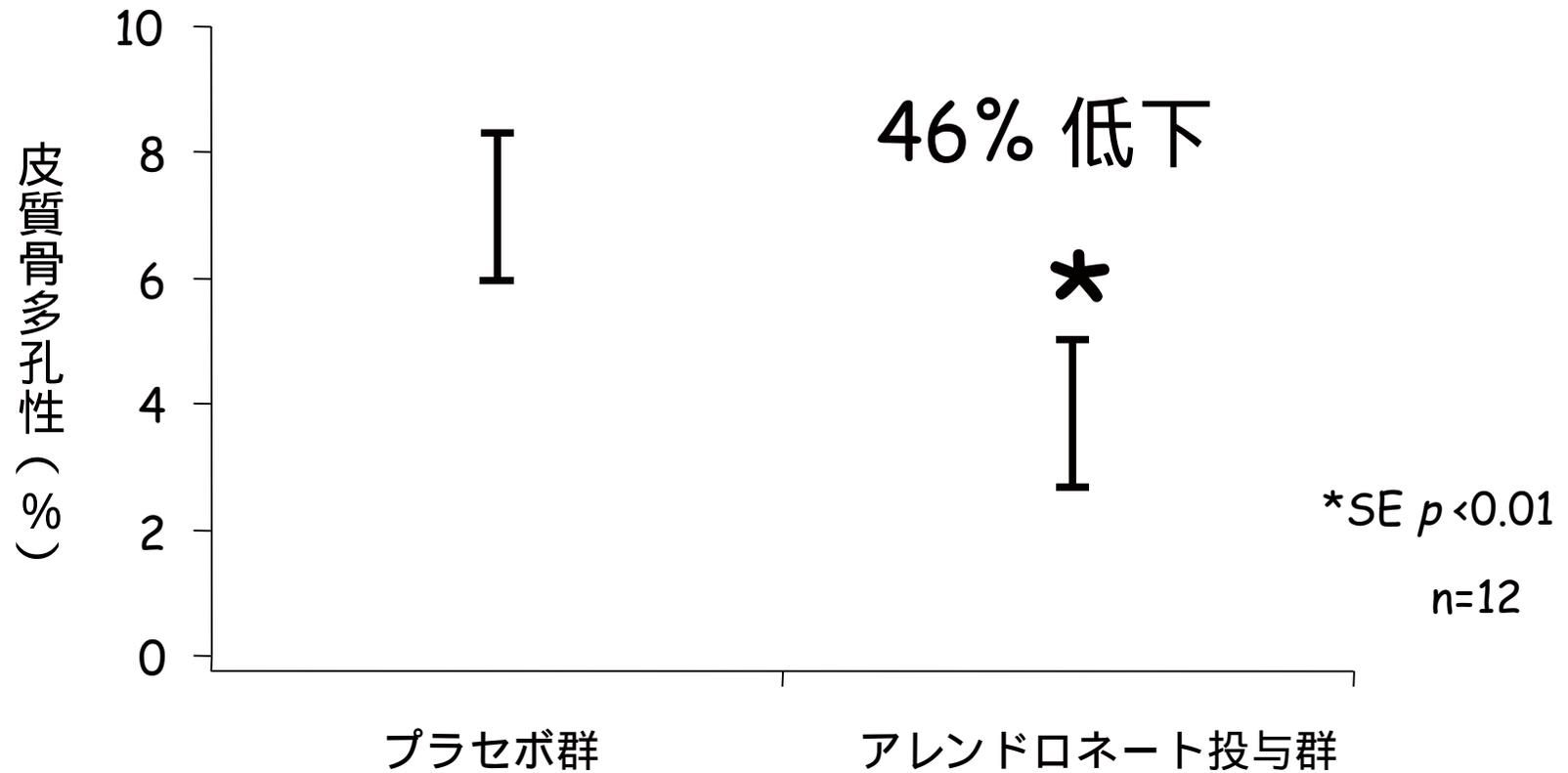


M Ito, et al. J Bone Miner Metab 21:287-293, 2003

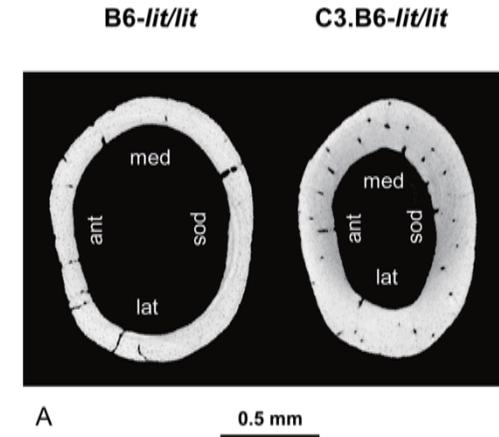
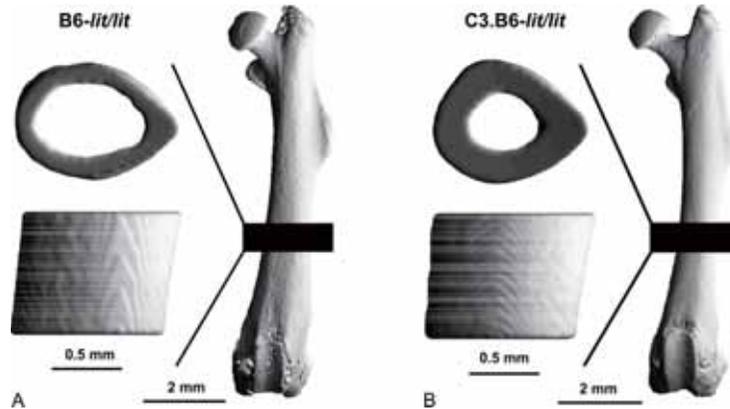
皮質骨微細構造の評価と骨強度



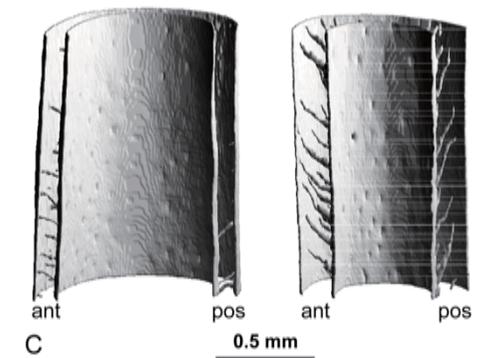
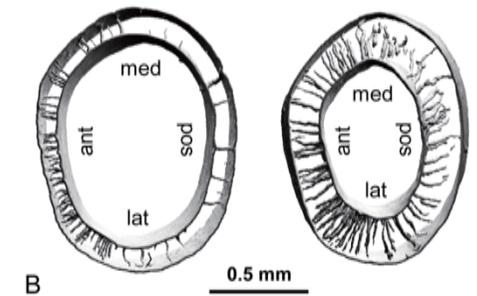
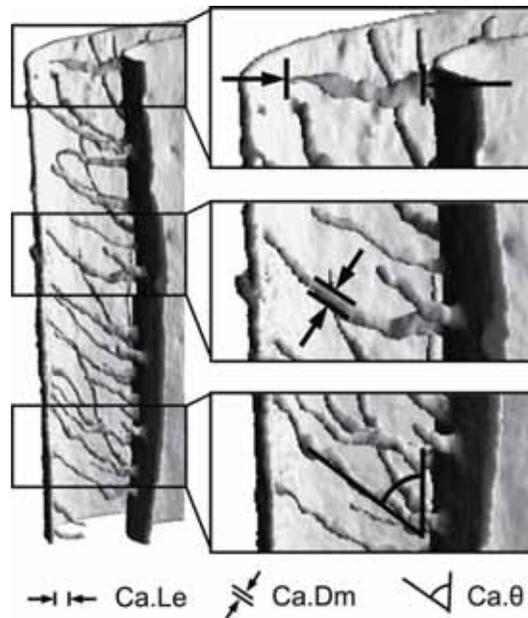
皮質骨の多孔性の低下



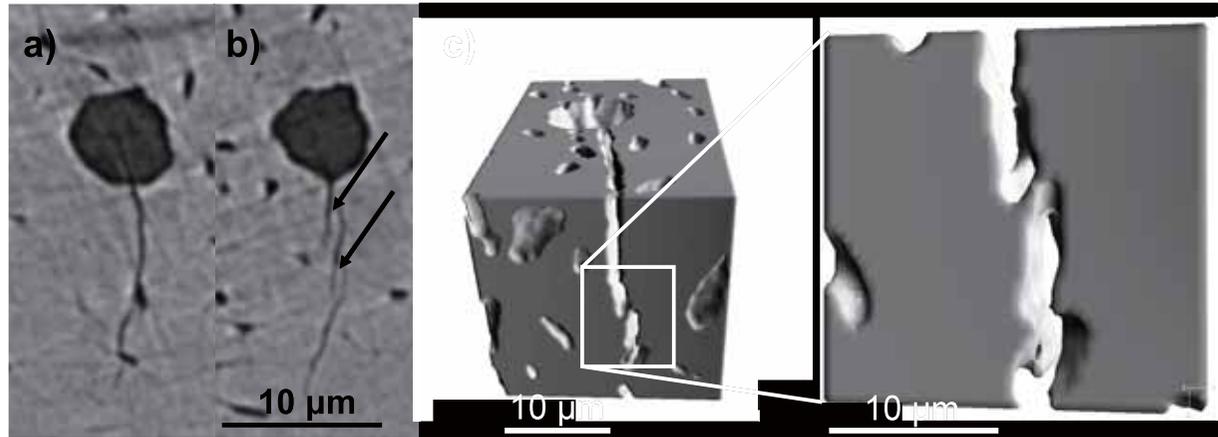
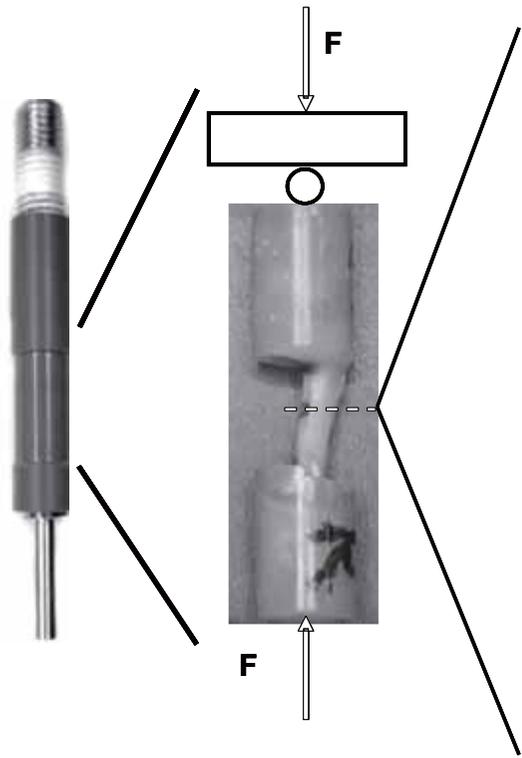
Vascular network and osteocyte lacunae



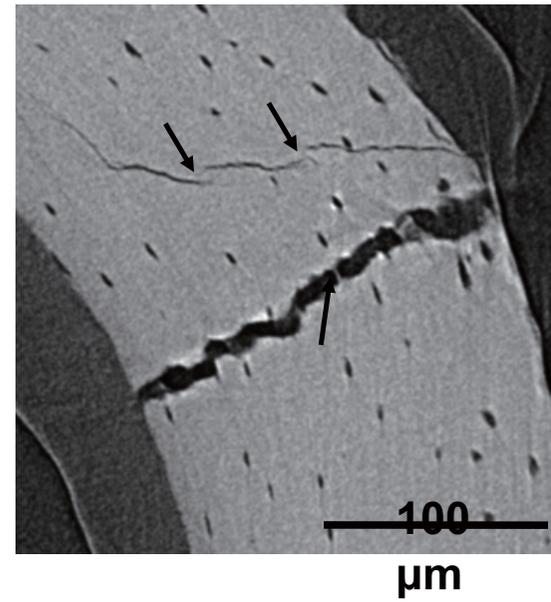
Nano-CT



Schneider P, et al. JBMR 22:1557-1570, 2007



50 μm

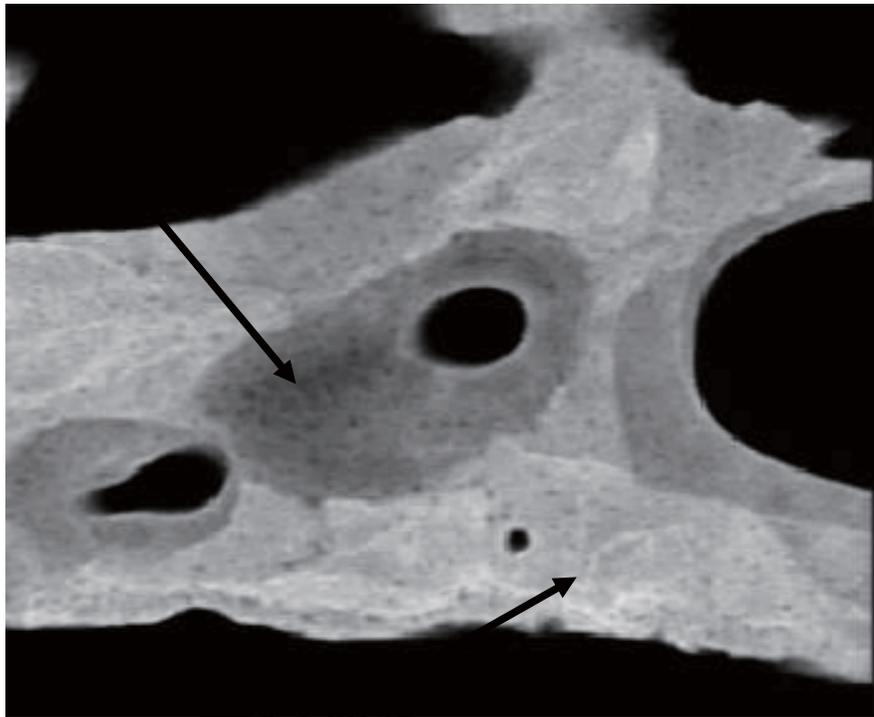


骨石灰化度の評価と骨強度

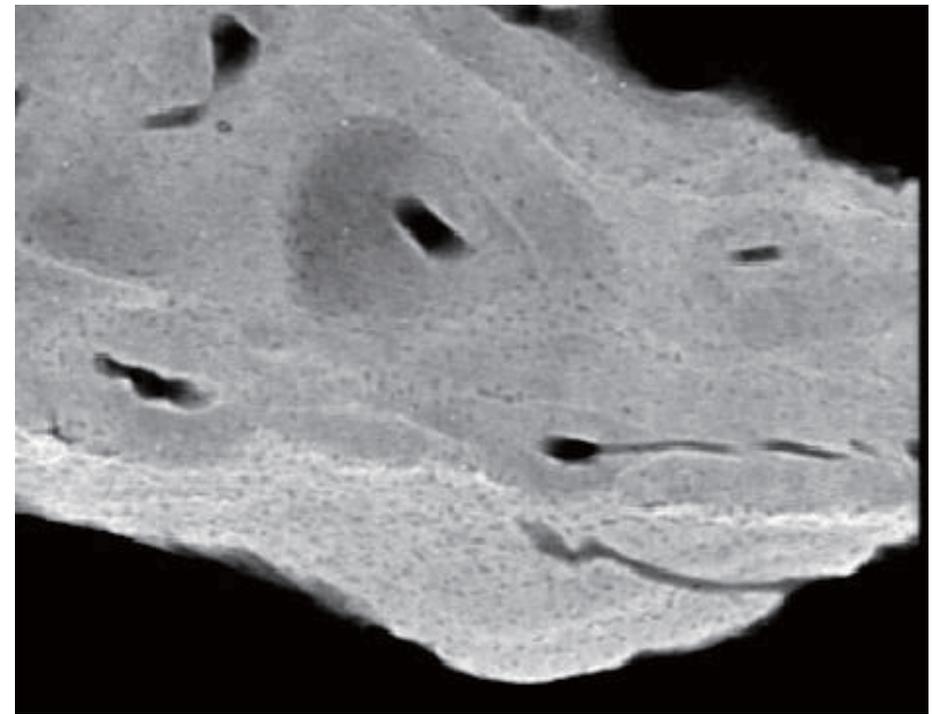
石灰化度の状態

不均一

均一

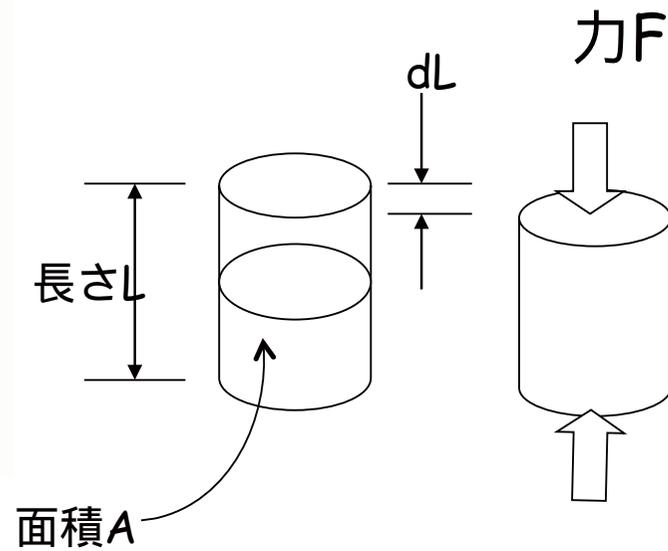
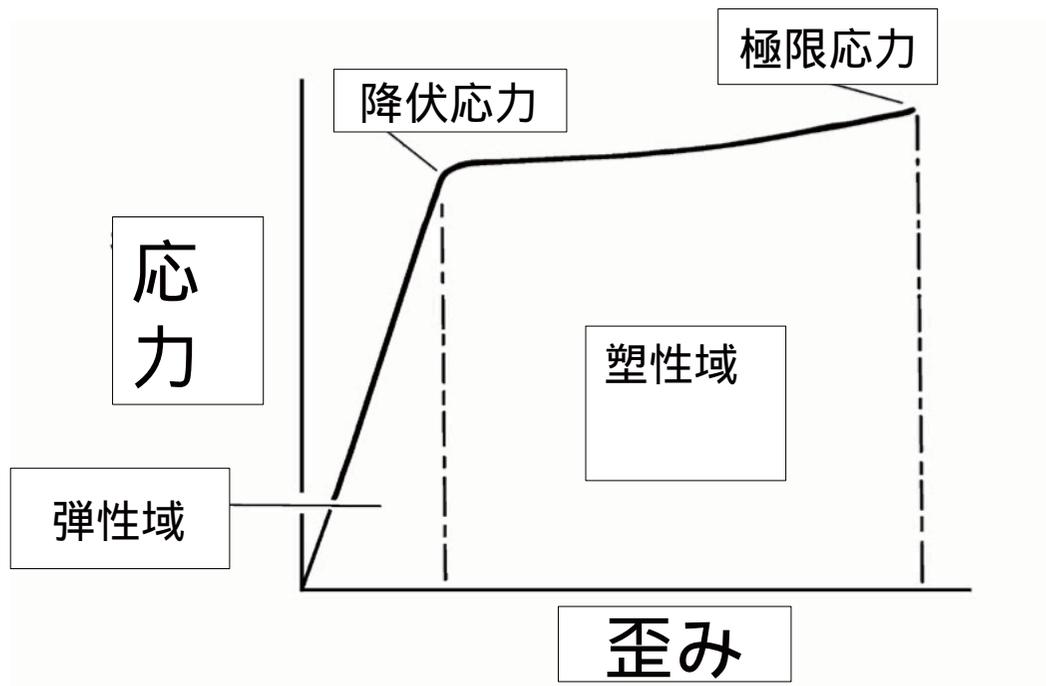


不均石灰化



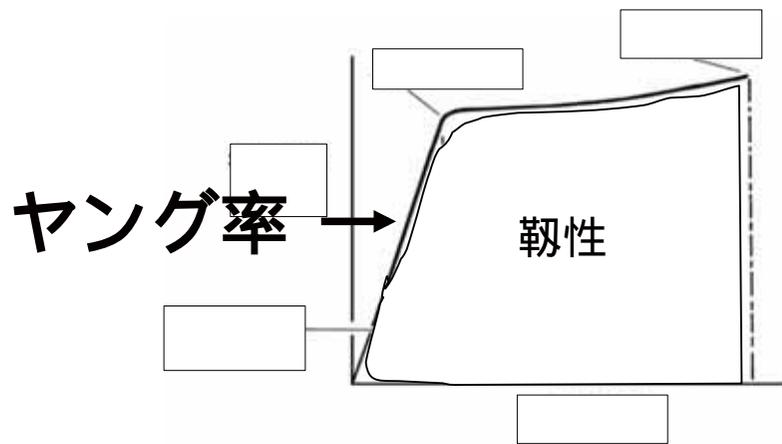
Boivin GY et al. *Bone* 27:687-694; 2000

Seeman E. *Advances in Osteoporotic Fracture Management* 2: 2-8, 2002

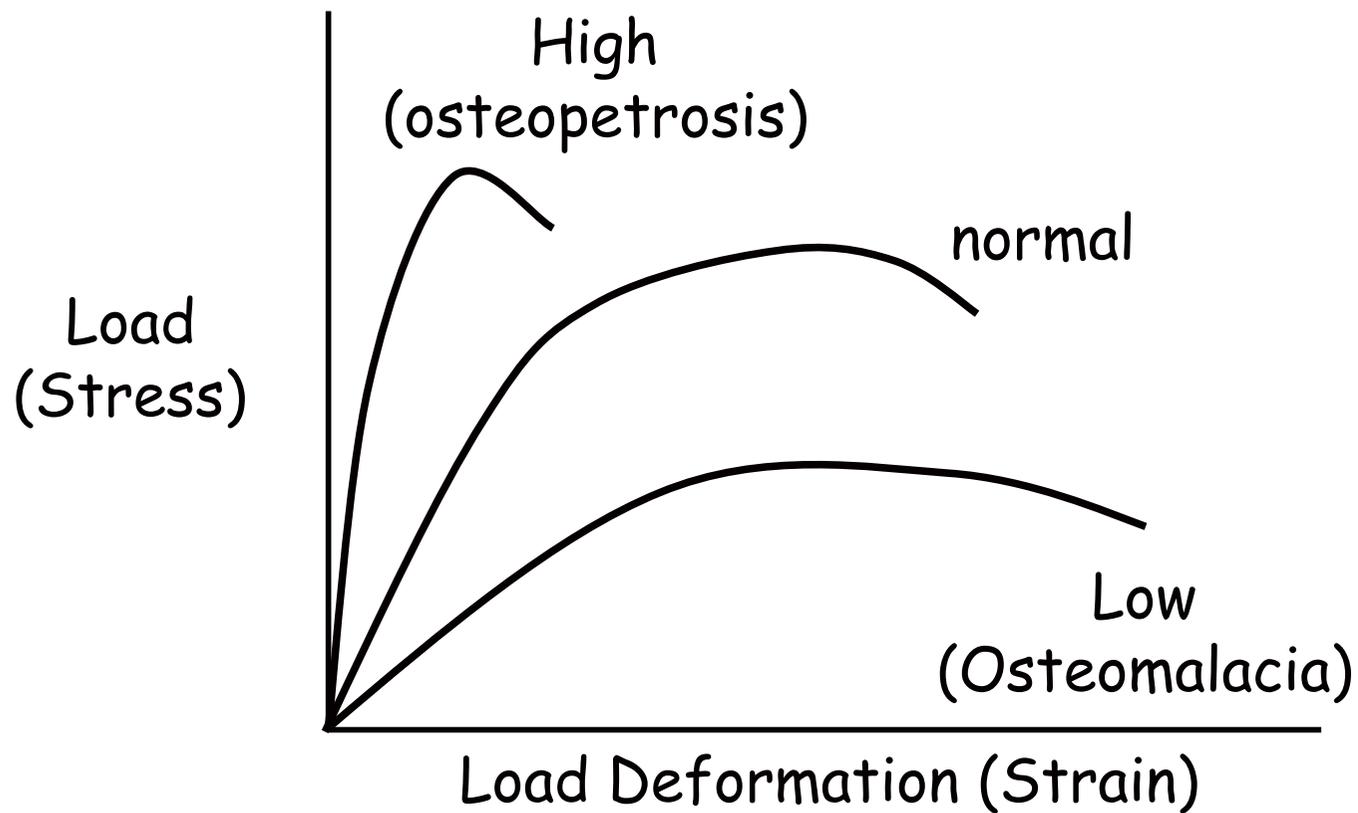


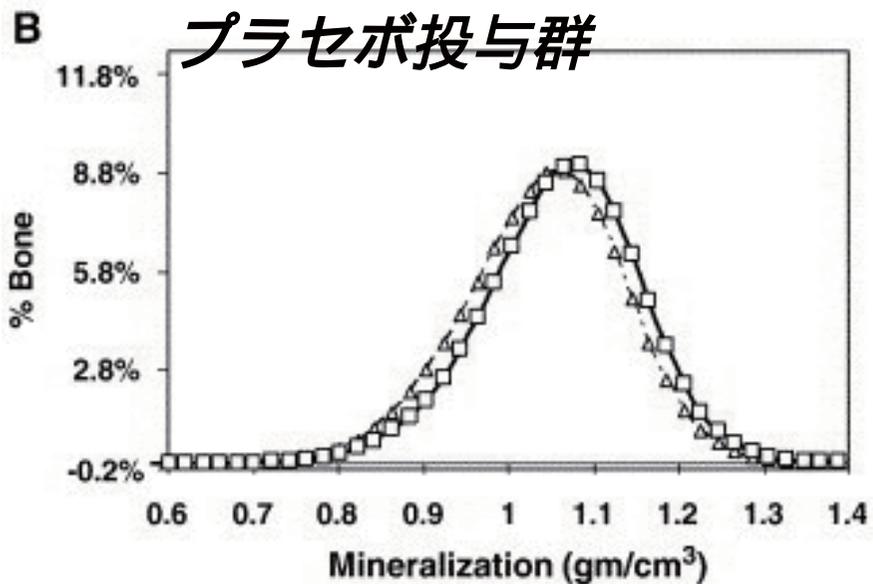
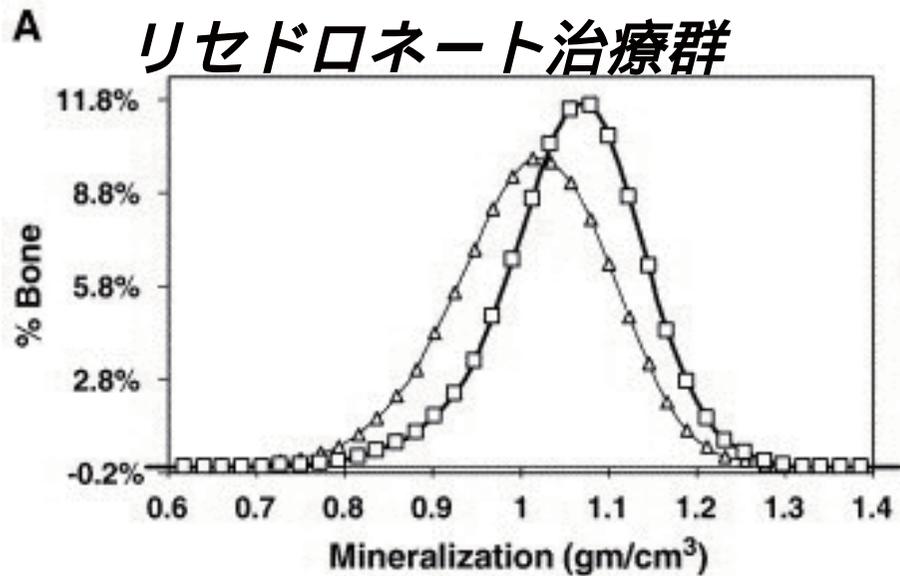
$$\text{応力} = F / A$$

$$\text{歪み} = dL / L$$



石灰化度の骨力学特性への影響

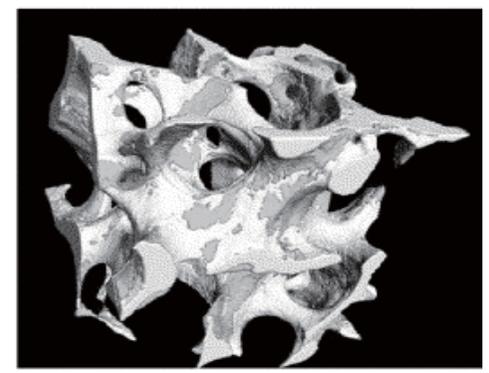




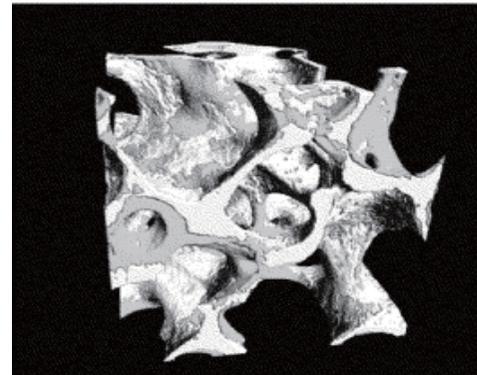
(A) Risedronate - Baseline



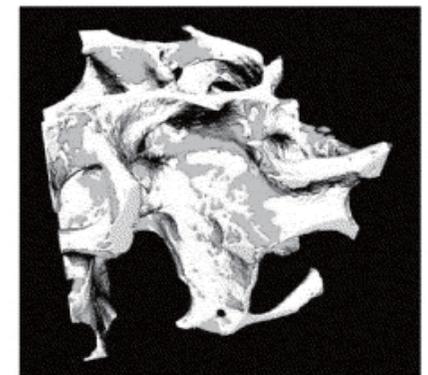
(A) Risedronate - 3 Year



(B) Placebo - Baseline



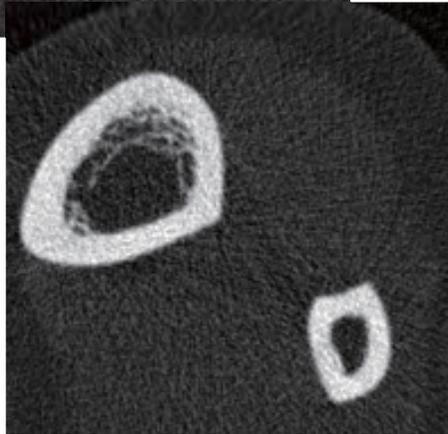
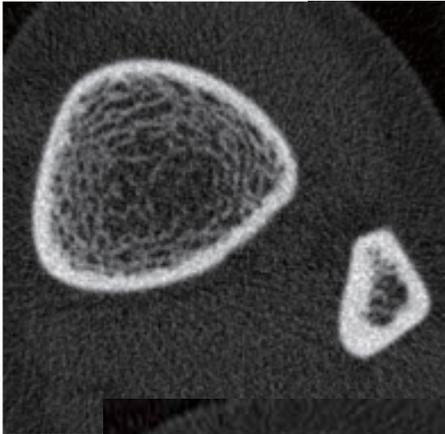
(B) Placebo - 3 Year



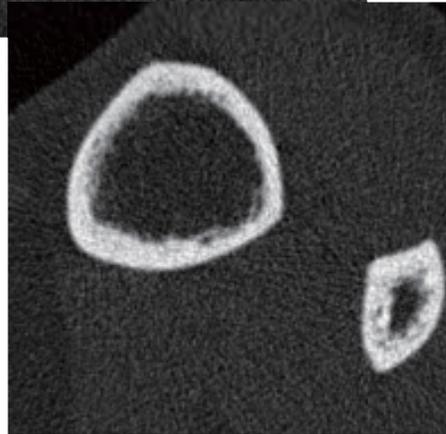
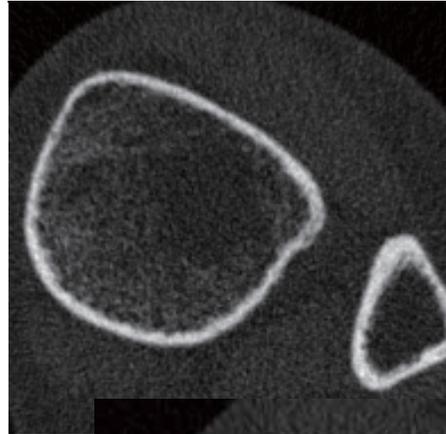
Borah, et al. Bone 37:1-9, 2005

*in vivo*骨構造解析と骨強度

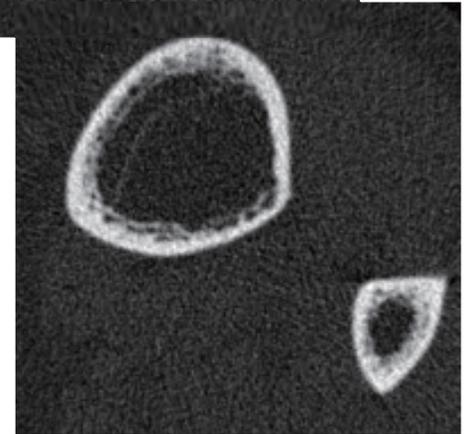
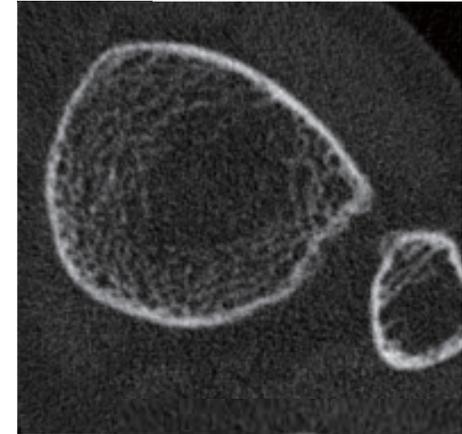
脛骨遠位部と脛骨骨幹部



25 歳
閉経前



65 歳
閉経後



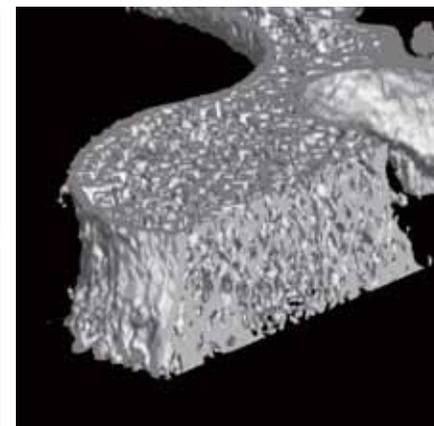
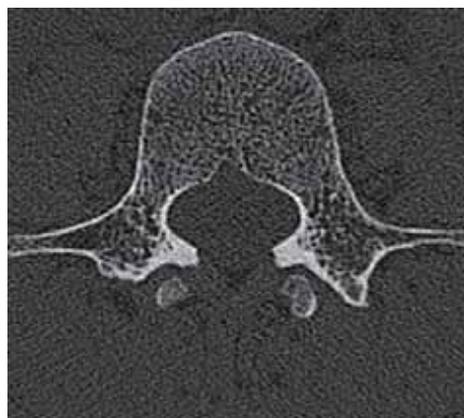
70 歳
骨粗鬆症

臨床用CT:MDCT 画像(L3)
2 D 画像

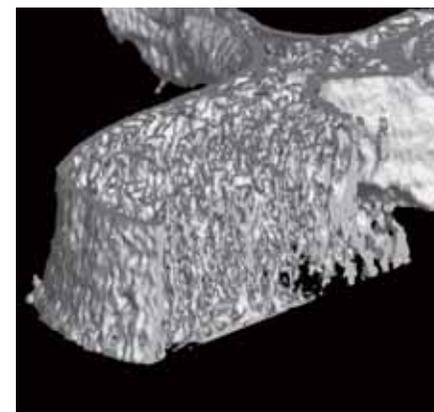
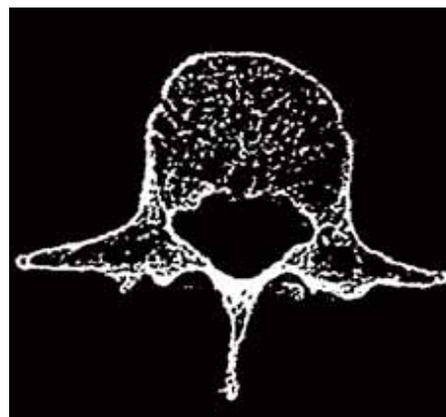
二値化画像

3 D 画像

62歳女性
骨折既往なし



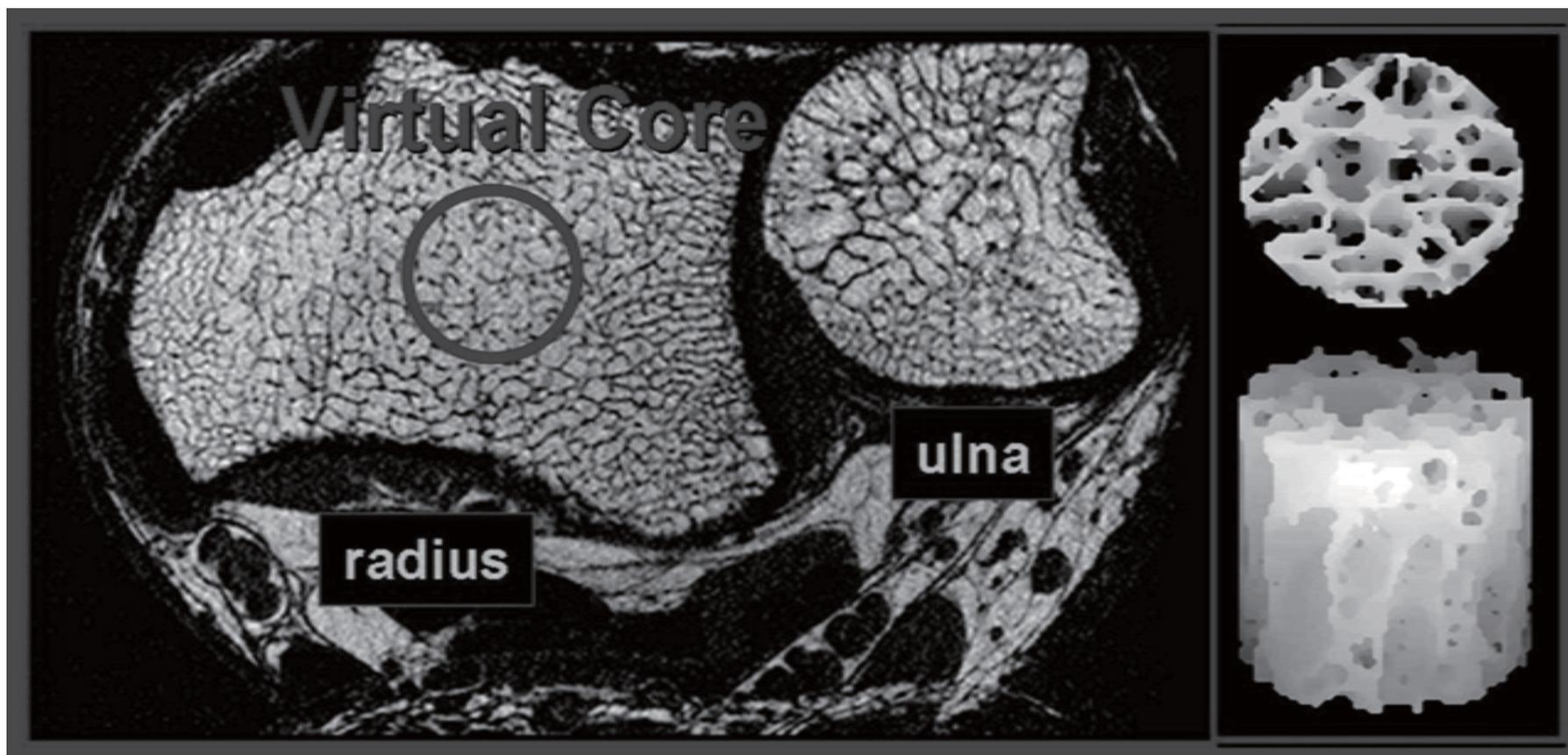
62歳女性
T12に圧迫骨折



骨折の検出能：ROC解析とオッズ比

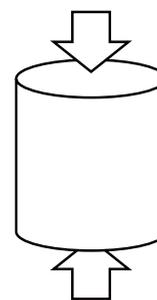
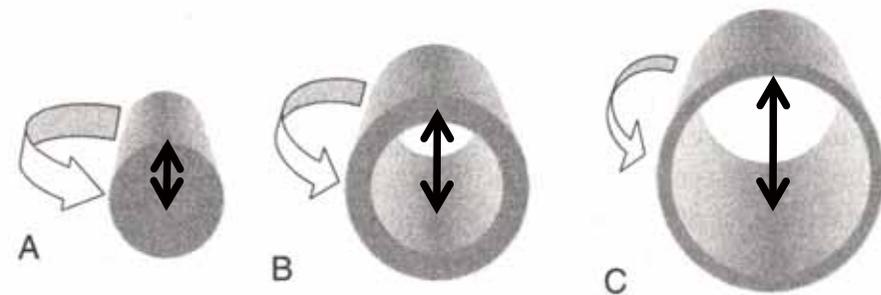
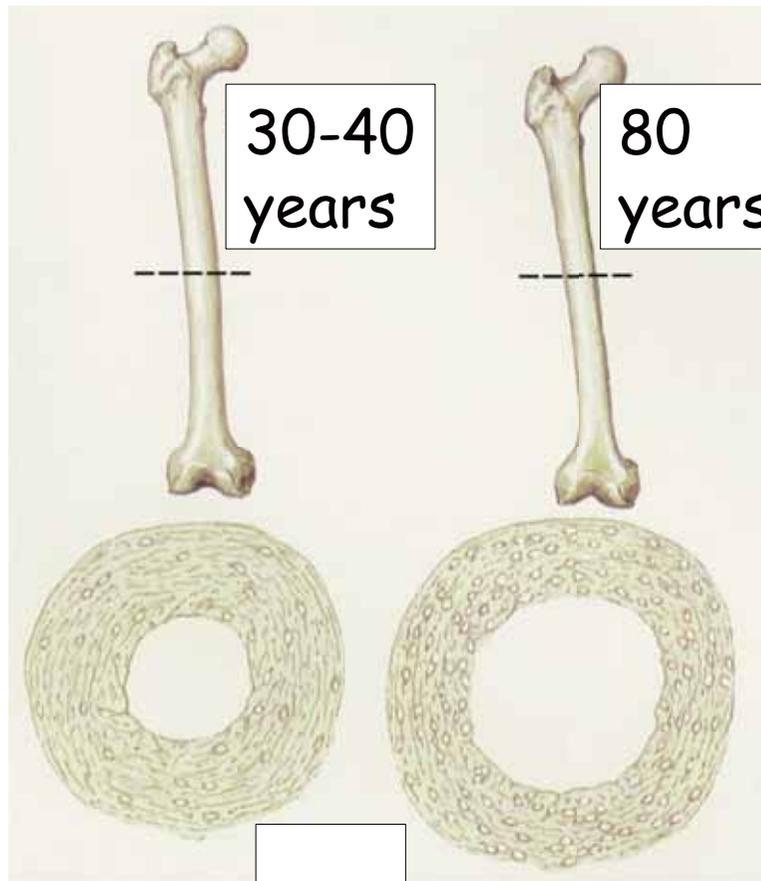
| パラメター | AUC (ROC) | <i>p</i> | オッズ比 (95%CI) | <i>p</i> |
|------------------------------|---------------|----------|-----------------|----------|
| MDCT | | | | |
| 骨梁構造パラメター | | | | |
| SMI | 0.928 ± 0.027 | 0.0001 | 16.0 (5.3-48.4) | 0.0001 |
| app BV/TV(%) | 0.811 ± 0.048 | 0.0001 | 13.6 (4.3-42.4) | 0.0001 |
| Euler's number | 0.857 ± 0.043 | 0.0001 | 13.1 (4.5-38.1) | 0.0001 |
| app Tb.Sp(mm) | 0.818 ± 0.048 | 0.0001 | 7.4 (2.8-19.8) | 0.0001 |
| fractal dimension | 0.735 ± 0.059 | 0.0001 | 7.4 (2.6-20.7) | 0.0005 |
| app Tb.N(1/mm ³) | 0.810 ± 0.049 | 0.0001 | 6.6 (2.5-17.4) | 0.0005 |
| app Tb.Th(mm) | 0.674 ± 0.059 | 0.01 | 5.5 (1.6-18.5) | 0.01 |
| DA | 0.627 ± 0.063 | 0.05 | 3.5 (1.2-10.2) | 0.05 |
| QCT (mg/cm ³) | 0.870 ± 0.040 | 0.0001 | 12.7 (4.4-36.4) | 0.0001 |
| DXA (g/cm ²) | 0.647 ± 0.062 | 0.05 | 4.8 (1.5-14.8) | 0.005 |

高解像度MR



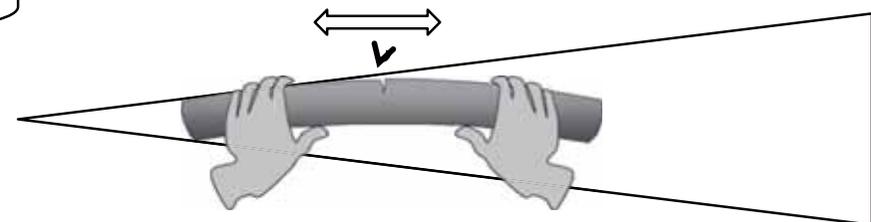
骨ジオメトリーの評価と骨強度

Cross-sectional area and bending strength



Same cross-sectional area

Same compression strength



骨外膜性骨形成
骨面積の増大

治療

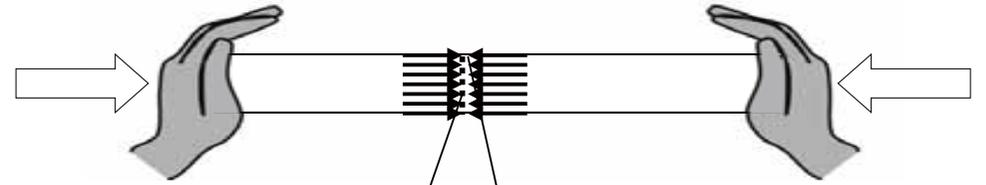
皮質骨内膜面骨吸収
骨髓腔の拡大
皮質骨の菲薄化

海綿骨吸収
骨梁構造の劣化
海綿骨密度の減少

皮質骨多孔化
皮質骨骨密度の減少

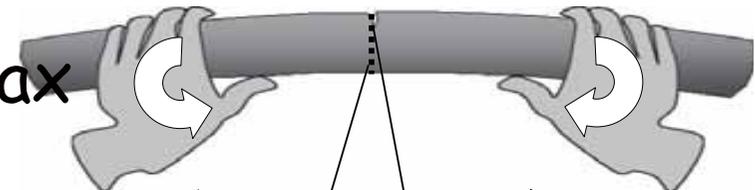
圧縮強度 compression

CSA



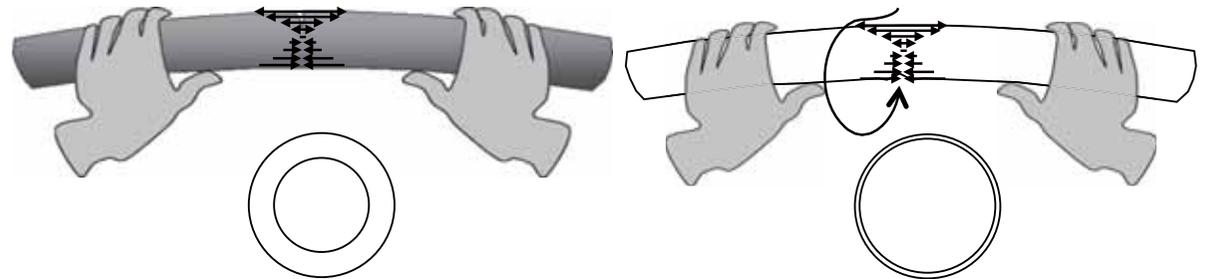
曲げ強度 bending

Section Modulus (SM) = $CSMI/d_{max}$



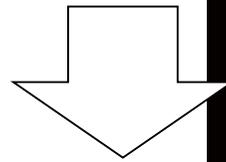
座屈 buckling

Buckling Ratio (BR) = $d_{max}/CoTh$

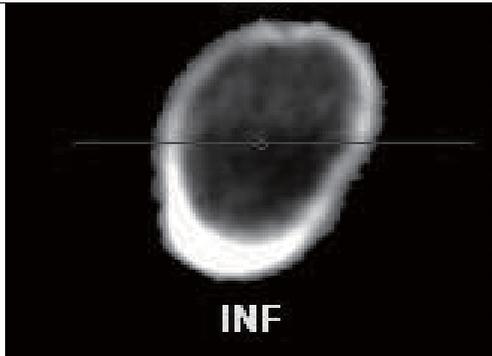


courtesy of Dr.T. Beck

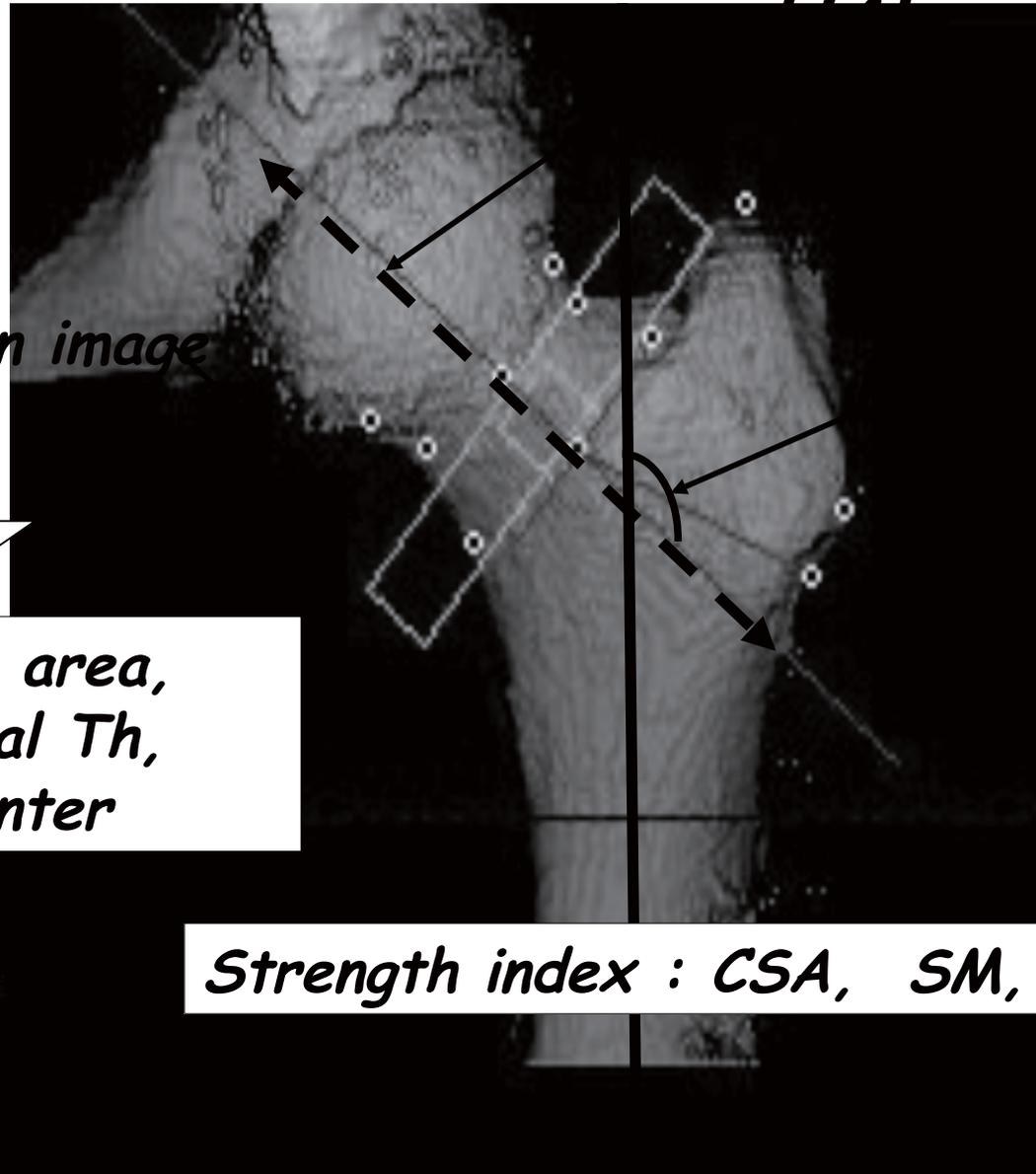
*FN
cross-section image*



*BMD, bone mass, area,
curvature, cortical Th,
distance to center*



INF

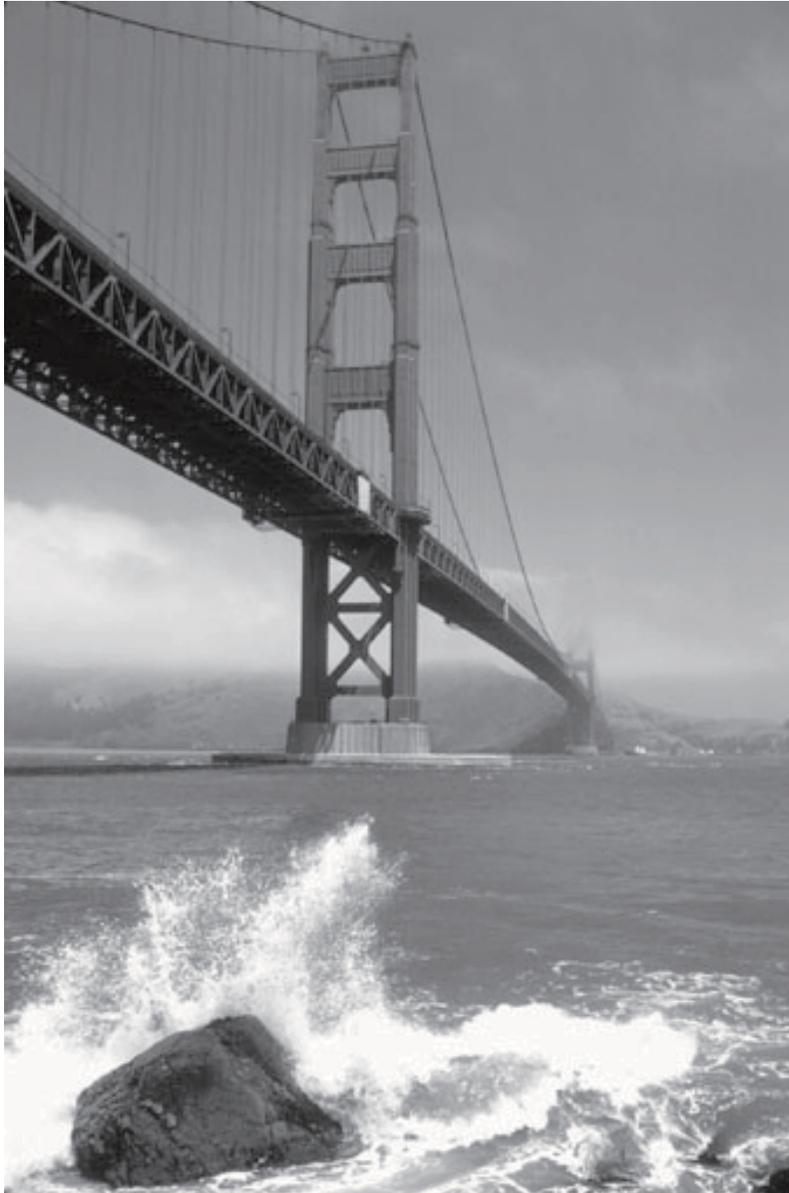


Strength index : CSA, SM, BR

臨床用CTを用いた 大腿骨近位部ジオメトリー解析

- 対象：
頸部骨折群 (n=20)とその対照群 (n=20)
転子部骨折群(n=16)とその対照群(n=16)
年齢を一致させたcase-control study
- 頸部骨折：頸部長が長い、断面二次モーメントが低い、座屈比が高い
- 転子部骨折：頸部皮質骨面積が小さい

M Ito, et al. Bone 2010



***Finite element analysis
(FEA)
有限要素解析***