Effect of Osteoporosis on Latent Bone Models to Estimate Plutonium Activity Concentration in Human Skeleton

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Osteoporosis and Bone Quality

- Osteoporosis (*porous bone*): bone disease that occurs when the body loses too much bone, makes too little bone, or both

- Measure: bone mineral density of the lumbar spine and/or hip

- Bone quality categories:
    - Normal   } 'Healthy' group (in this study)
    - Osteopenia
    - Osteoporosis   } Osteoporotic group
    - Established osteoporosis

https://smart.servier.com/
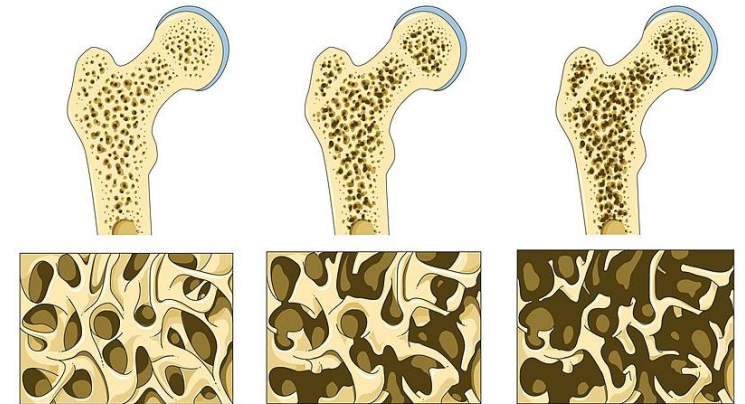
Plutonium Deposition and Retention: Osteoporosis

Tolmachev SY, Avtandilashvili M, Kathren RL. *Estimation of total skeletal content of plutonium and* [241]*Am from analysis of a single bone*. Health Physics 117 (2): 202–210; 2019

- Evidence that osteoporosis affects deposition, long-term retention, and distribution of plutonium and americium in human skeleton

- Coefficients of deposition, $K_{dep} = A_{patella}/A_{skel}$, and power fit models, $A_{skel} = a \times (A_{patella})^b$, were different for 'healthy' and osteoporotic groups

How much does osteoporosis affect latent bone model (LBM) for skeleton plutonium concentration, C_{skel}, estimation?

Material and Methods (I)

- Data from 19 whole-body tissue donors to the United States Transuranium and Uranium Registries (USTUR) were used

- Latent variable (bone) modeling was performed using principal component regression (PCR)

- Principal component analysis (PCA) was used for reduction of number of (highly correlated) variables - plutonium concentrations in bones (C_{bone})

- Multiple linear regression (MLR) was used to correlate latent variable (C_{lb}) with skeleton plutonium concentration (C_{skel})

WAM–C.5   JY Zhou, et al. Latent Bone Modeling Approach to Estimate Plutonium Activity Concentration in Human Skeleton

Principal Component Regression (PCR)

n

k

1

C_{bone}
$m \times n$

PCA

C_{lb}
$m \times k$

MLR

C_{skel}
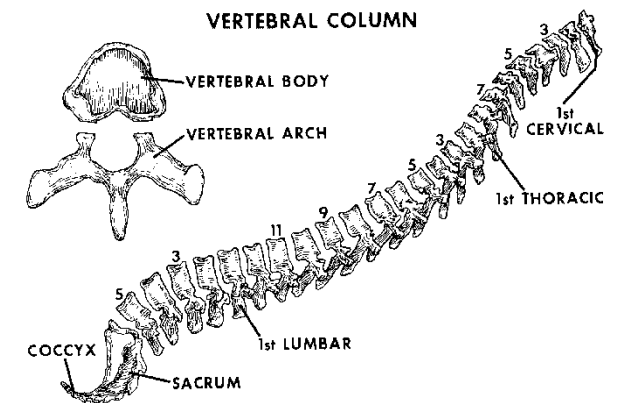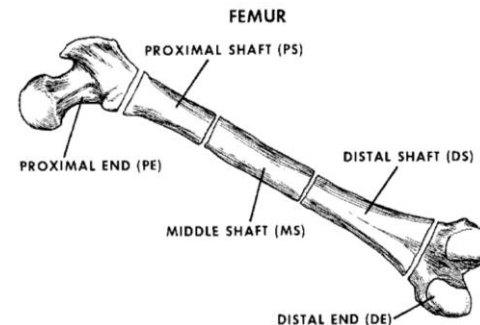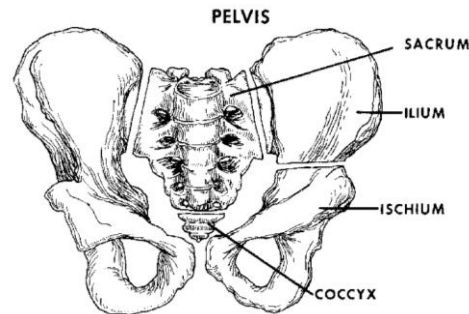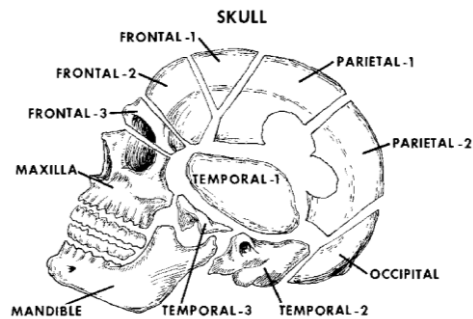$m \times 1$

m

m

m
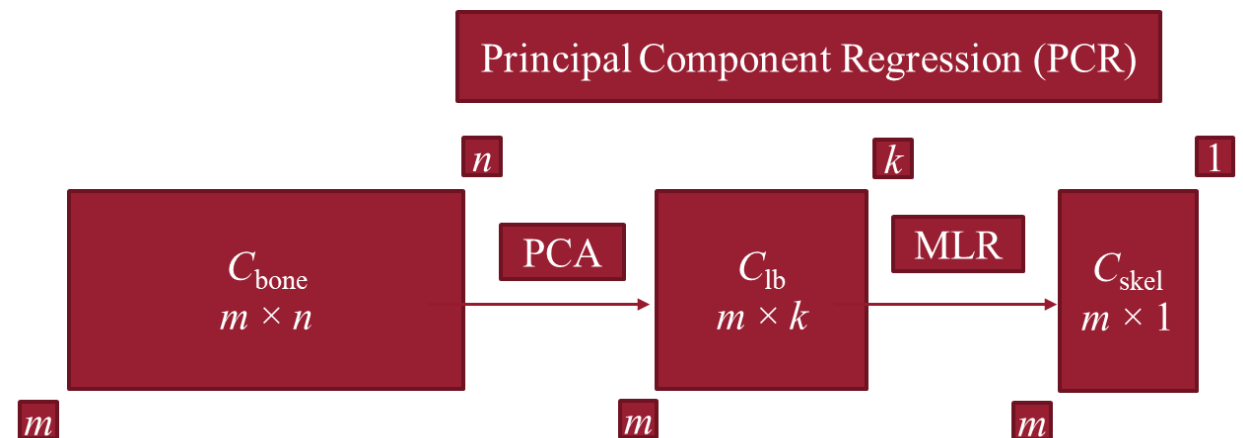
Material and Methods (II)

- Relative standard error (RSE) was used as a criteria to compare LBM for C_{skel} estimation for all cases *vs* that for 'healthy' group

$$RSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{(n - p - 1)}}$$

- Reduction of RSE was investigated in terms of:
  - bone structure type
  - number of analyzed bones

USTUR Bone Dataset

Pu exposure   Whole-body   19 cases

× 90 samples[†]

'Healthy': 14   Osteoporotic: 5[‡]

- Age: $73.8 \pm 10.4\ (54 - 90)$ y
- A_skel: $9.0 - 1{,}183.8$ Bq
- C_skel: $0.9 - 122.3$ Bq kg^{-1}
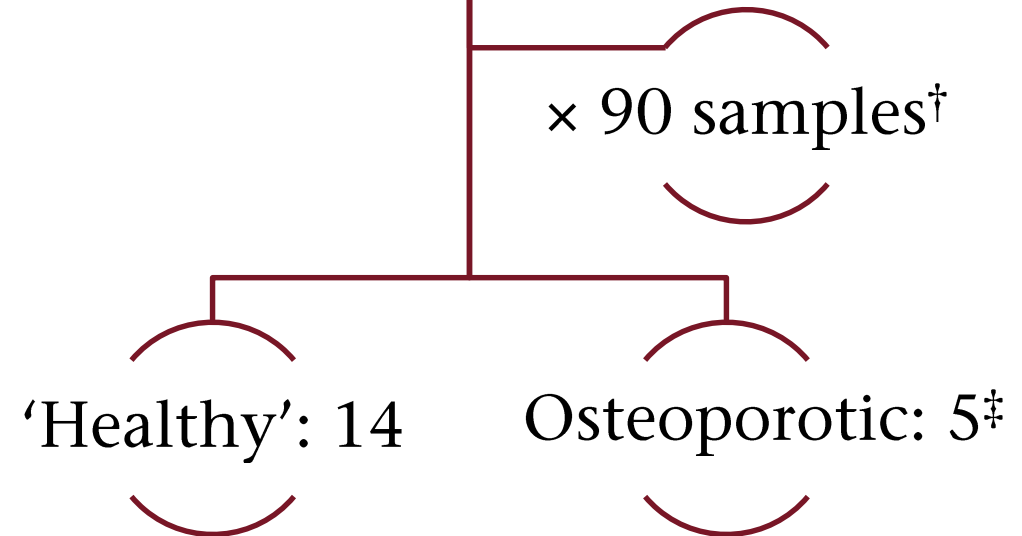
† - single bone ≠ one sample for radiochemical analysis, *e.g.* femur bone is dissected into 5 samples

‡ - diagnosis from individual medical records

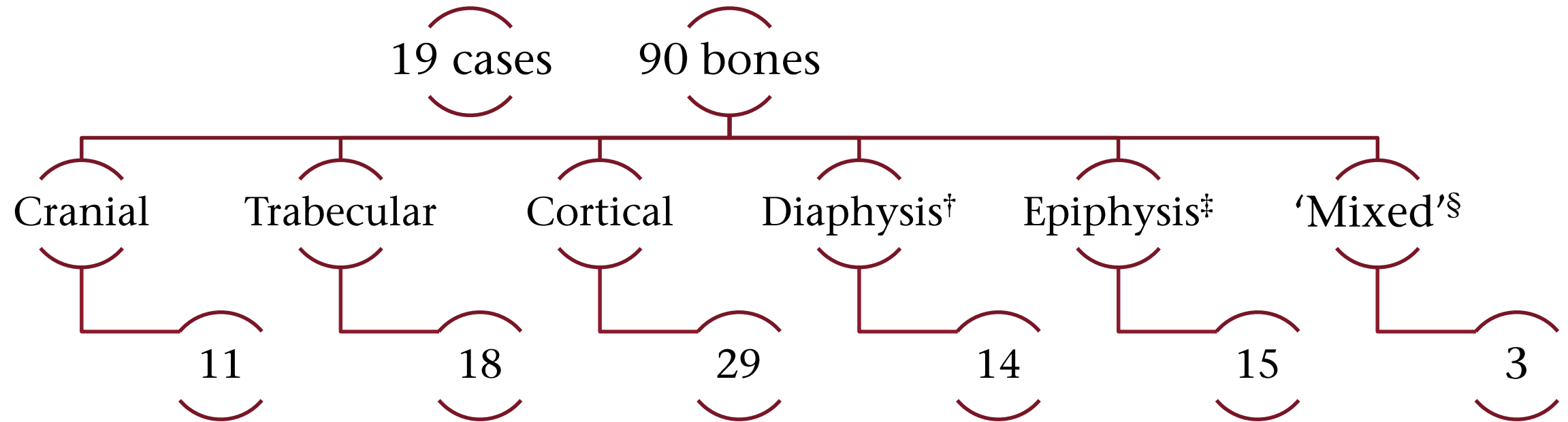# Group Comparison

	Group		p (0.05)
	'Healthy'	Osteoporotic	
Number of cases	14	5	
Age, y	71.1±10.1	81.3±7.1	0.048
Exposure, y	26.9±8.4	46.0±7.8	0.005
Skeleton weight, kg	9.94±0.98	10.4±1.3	0.419
Ash fraction, %	30.4±2.9	24.8±2.2	0.001
Plutonium C_{skel}, Bq kg^{-1}			
Range	0.9 – 42.0	9.0 – 122.3	
Mean ± SD	13.6±12.2	57.1±47.5	0.004
GM (GSD)	8.5 (3.1)	36.8 (3.2)	0.024

Dataset (I): Bone Type

19 cases   90 bones

Cranial	Trabecular	Cortical	Diaphysis†	Epiphysis‡	'Mixed'§
11	18	29	14	15	3

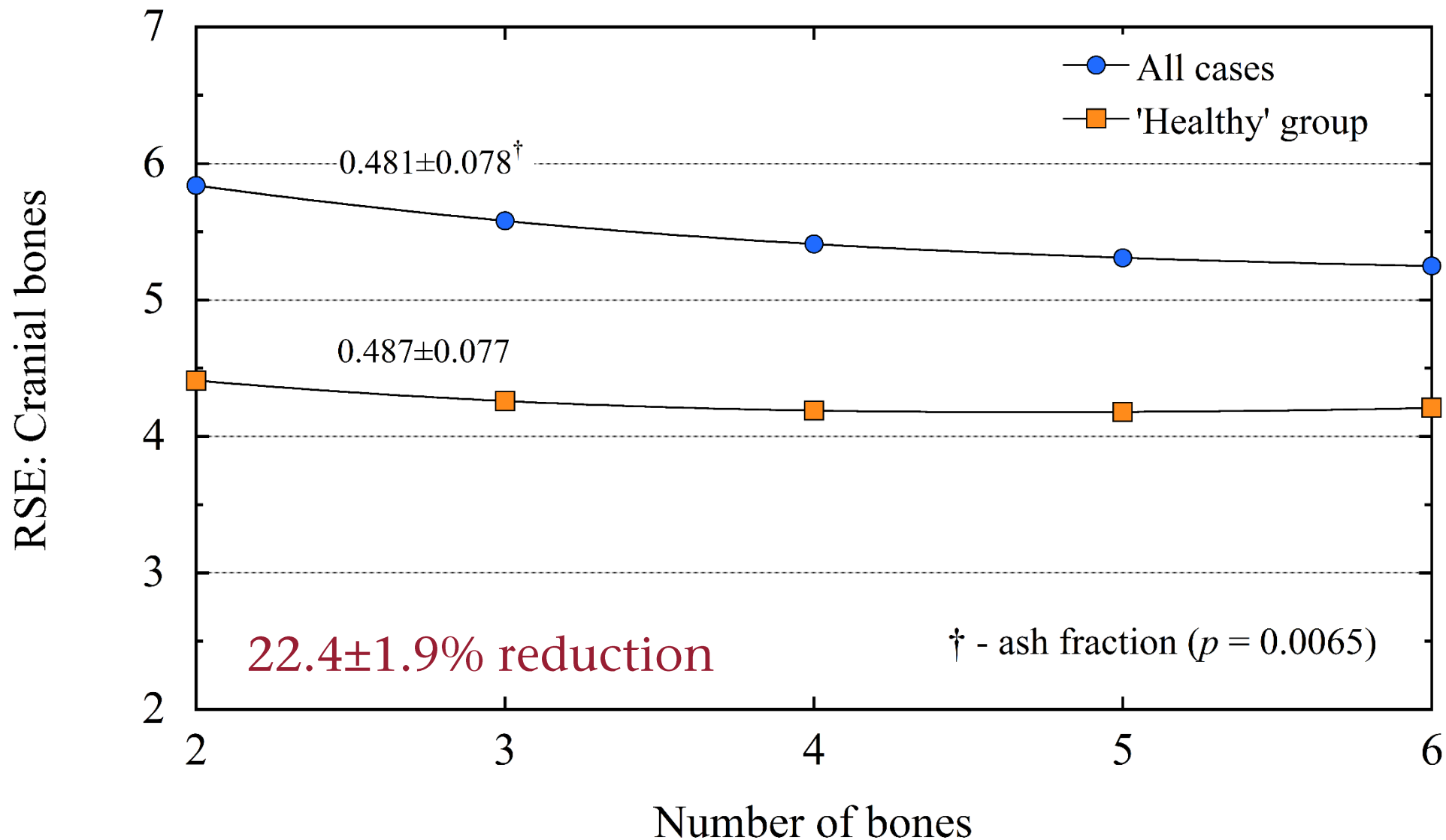† - shafts of the long bones
‡ - ends of the long bones + patella
§ - cervical vertebra #1 whole, hand and wrist, foot and ankle

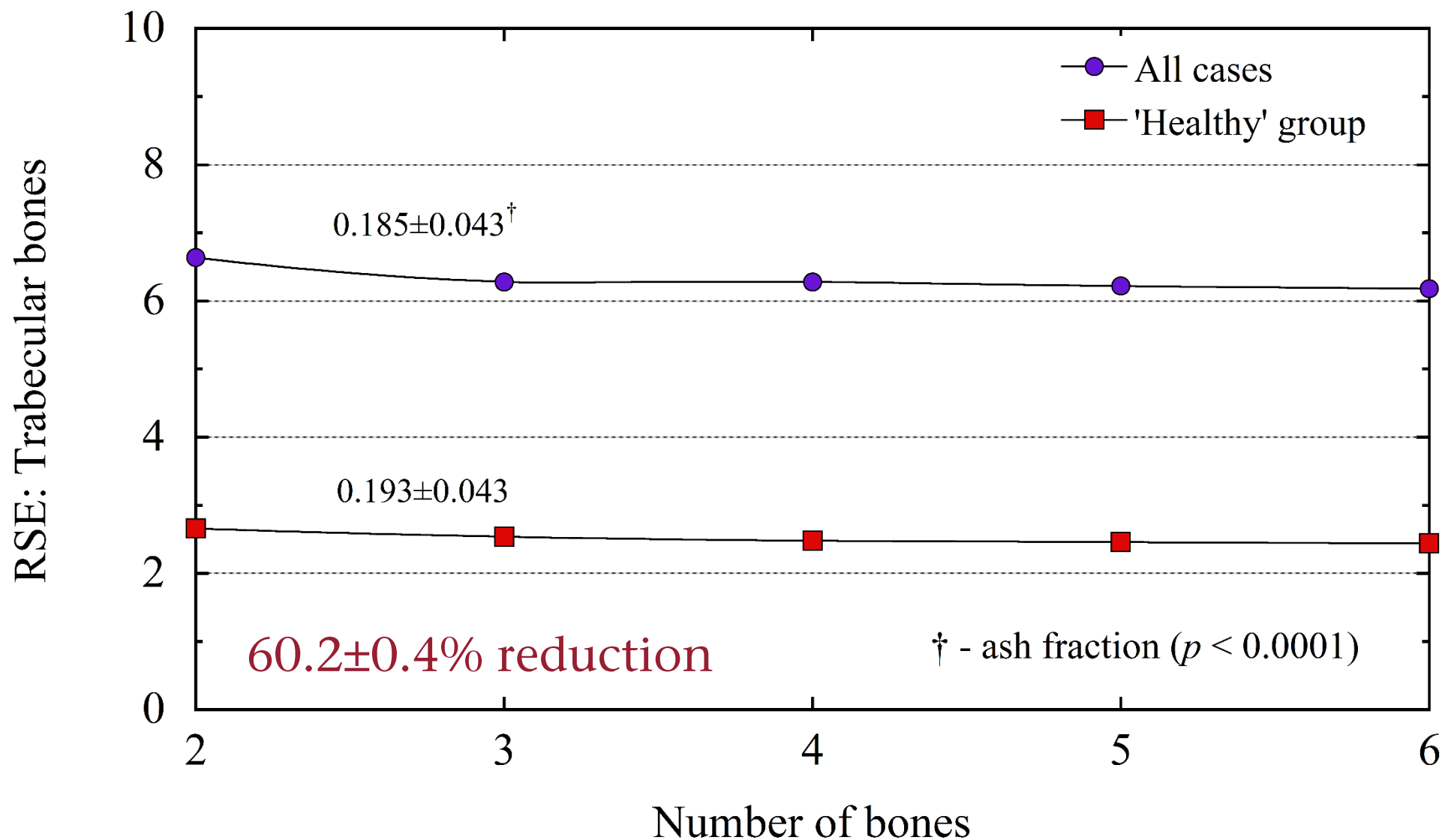# Effect of Osteoporosis on C_{skel}: Cranial Bones
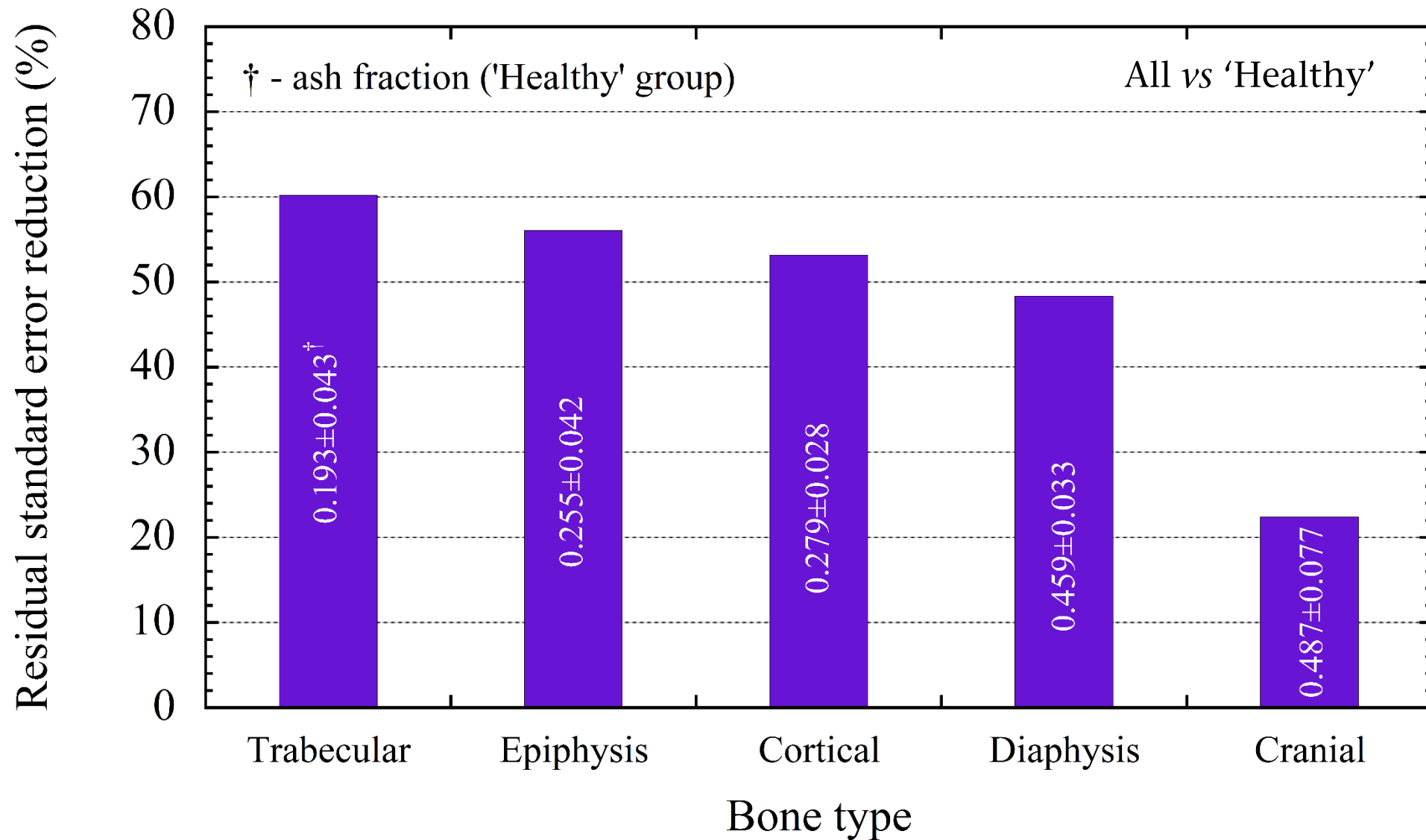

RSE: Cranial bones

Number of bones

0.481±0.078†

0.487±0.077

- All cases
- 'Healthy' group

22.4±1.9% reduction

$\dagger$ - ash fraction ($p = 0.0065$)

Effect of Osteoporosis on C_{skel}: Trabecular Bones

Effect of Osteoporosis on C_{skel}: Bone Type

Residual standard error reduction (%)

† - ash fraction ('Healthy' group)

All *vs* 'Healthy'

Trabecular: 0.193±0.043†
Epiphysis: 0.255±0.042
Cortical: 0.279±0.028
Diaphysis: 0.459±0.033
Cranial: 0.487±0.077

Bone type

Dataset (II): 18 'Best' Bones
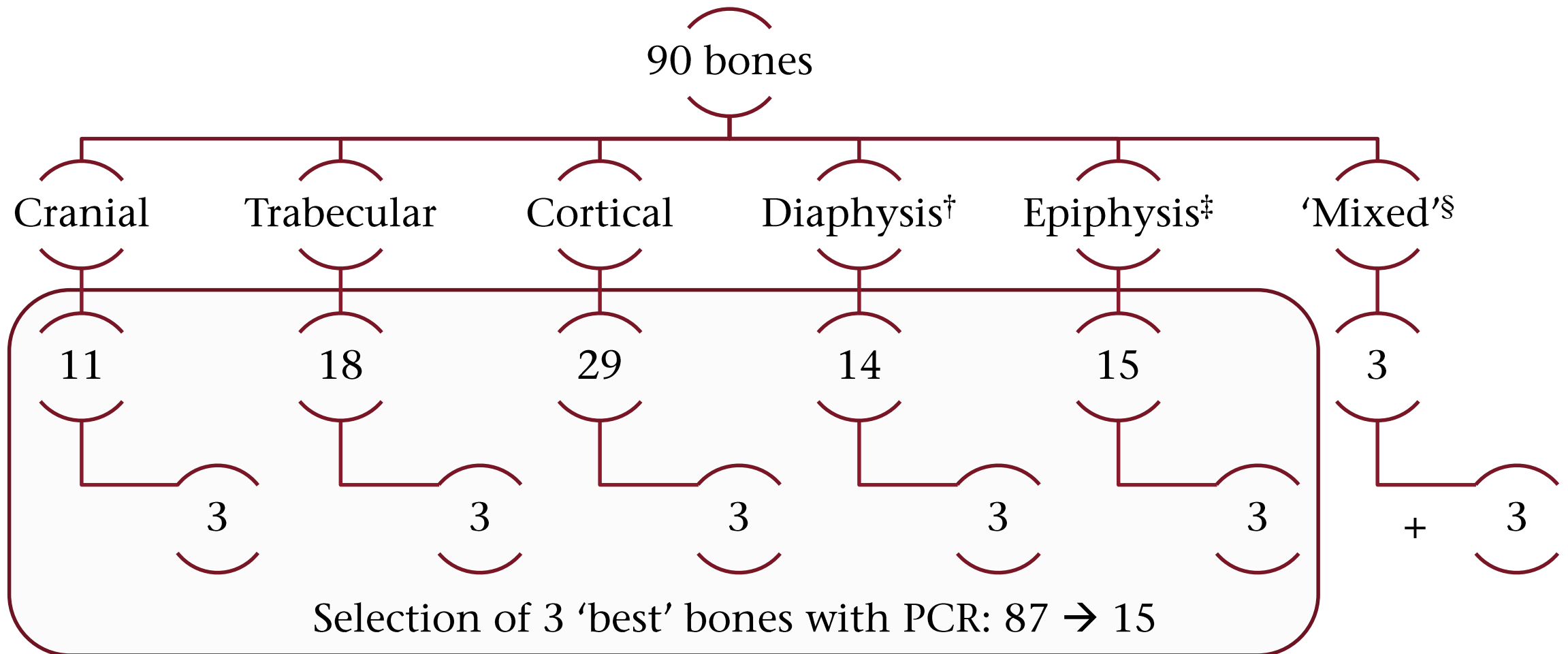
90 bones

Cranial	Trabecular	Cortical	Diaphysis†	Epiphysis‡	'Mixed'§
11	18	29	14	15	3
3	3	3	3	3	+ 3

Selection of 3 'best' bones with PCR: 87 → 15

† - shafts of the long bones
‡ - ends of the long bones + patella
§ - cervical vertebra #1 whole, hand and wrist, foot and ankle

Effect of Osteoporosis on C_{skel}: Number of Bones

Summary

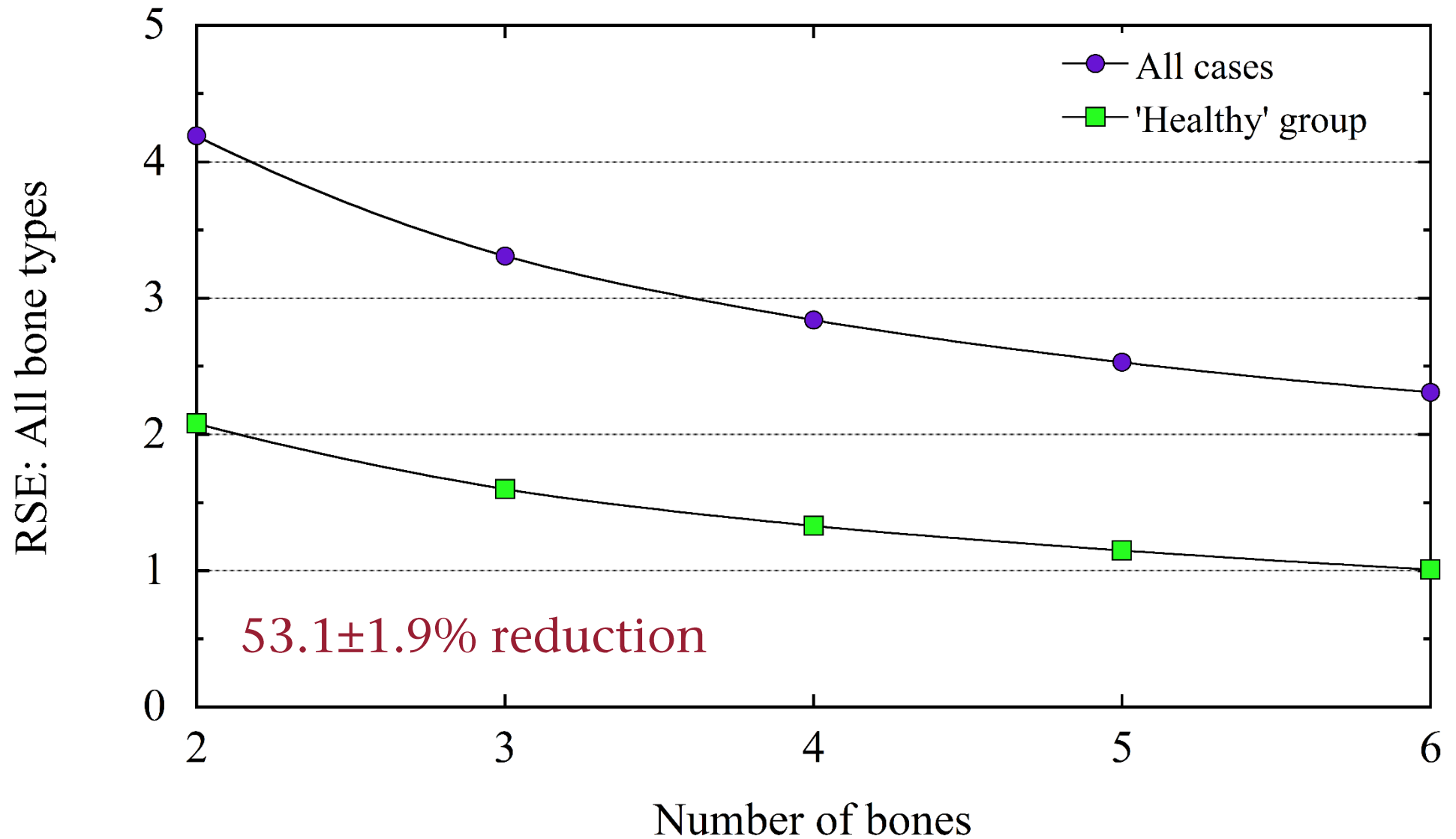- Osteoporosis affects estimation of plutonium activity concentration in human skeleton, C_{skel}, using LBM approach

- Trabecular bones are affected the most (~60%) while cranial bones are the least affected (~20%). Effect of osteoporosis decreases with increase of bone corticality (high ash fraction)

- Overall, ~ 50% improvement in the LBM C_{skel} prediction was observed by separating 'healthy' and osteoporotic groups

Effect of osteoporosis

Bone ash fraction