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Comparison of Two Methods to Estimate Skeletal Plutonium Concentration from Limited Sets of Bones

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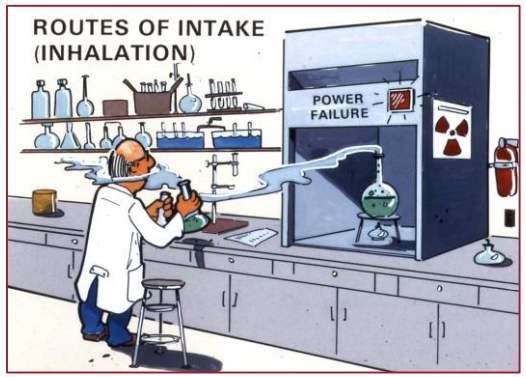
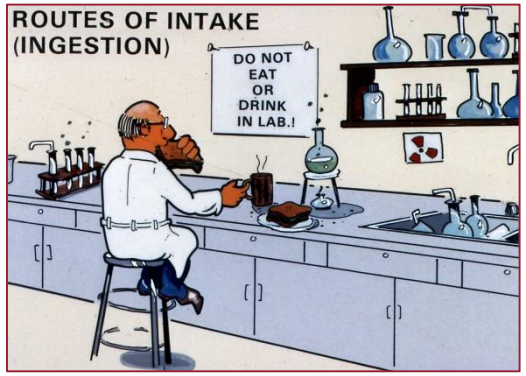
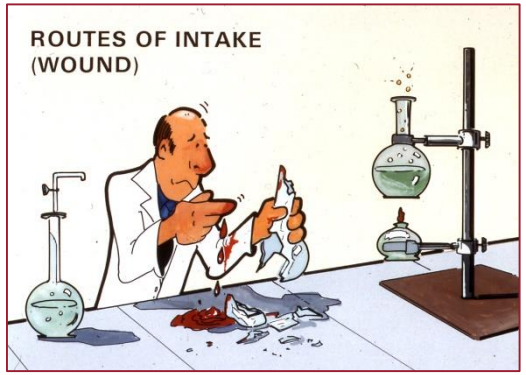
USTUR Bone Series

- WAM-C.4 08:45 Comparison of Two Methods to Estimate Skeletal Plutonium Concentration from Limited Sets of Bones
- WAM-C.5 09:00 Latent Bone Modeling Approach to Estimate Plutonium Activity Concentration in Human Skeleton
- WAM-C.6 09:15 Effect of Osteoporosis on Latent Bone Models to Estimate Plutonium Activity Concentration in Human Skeleton
- WAM-C.7 09:30 Uncertainty Evaluation of Skeleton Plutonium Activity Concentration Estimated from a Latent Bone Model
- WAM-C.8 09:45 Latent Bone Modeling Approach to Select Best Combination of Bones for Estimating Plutonium Activity Concentration in Human Skeleton

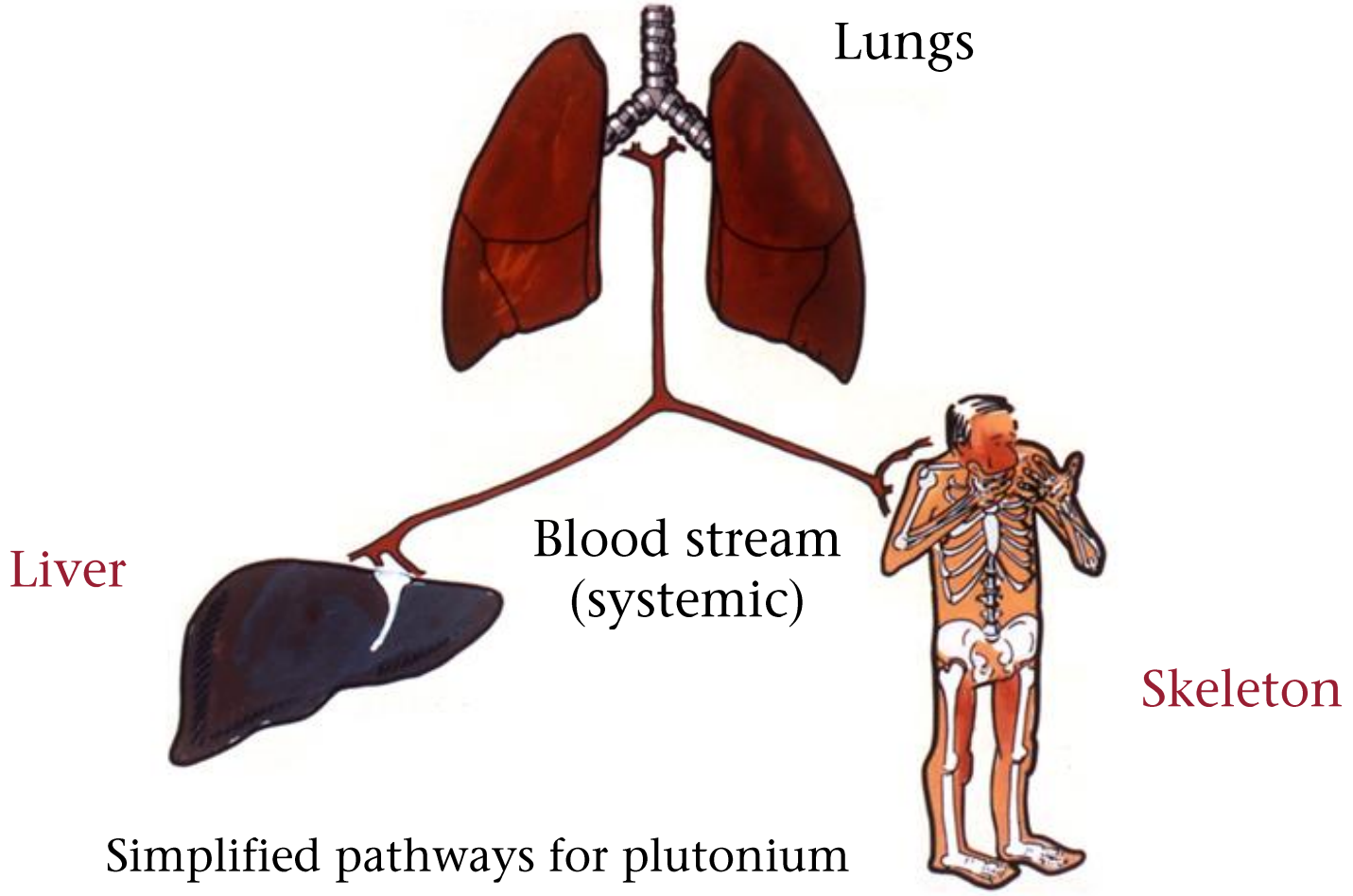
Why Plutonium in the Skeleton?







- Plutonium is a *bone-seeker*



Simplified pathways for plutonium

Total Plutonium in Skeleton: *Analysis of Selected Bones*

$$A(\text{Bq}) = M(\text{kg}) \times C_{\text{skel}}(\text{Bq kg}^{-1})$$

- Relationship between plutonium concentration of bone (C_{bone}) or bone group and total skeleton plutonium concentration (C_{skel}):

1. Simple (or mass-weighed) average: $C_{\text{skel}} = (\sum_{i=1}^{n} C_{\text{bone},i})/n$
2. Single bone linear model ('best bone'): $C_{\text{skel}} = r \times C_{\text{bone}}$
3. Group bone linear model: $C_{\text{skel}} = r \times (\sum_{i=1}^{n} C_{\text{bone},i})/n$
4. Multiple linear model: $C_{\text{skel}} = a_1 \times C_{\text{bone,1}} + a_2 \times C_{\text{bone},2} + \ldots + a_n \times C_{\text{bone,n}}$
5. Latent bone model: $C_{\text{lb1}} = a_1 \times C^s_{\text{bone,1}} + a_2 \times C^s_{\text{bone,2}} + \ldots + a_n \times C^s_{\text{bone,n}}$

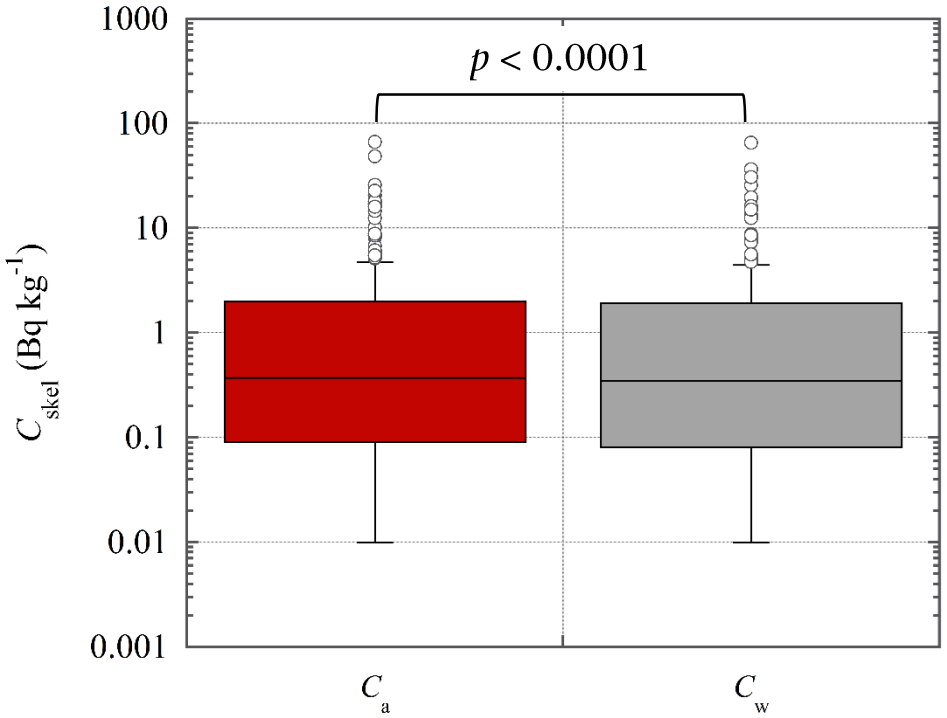
Total Plutonium in Skeleton: *Analysis of Half Skeleton*

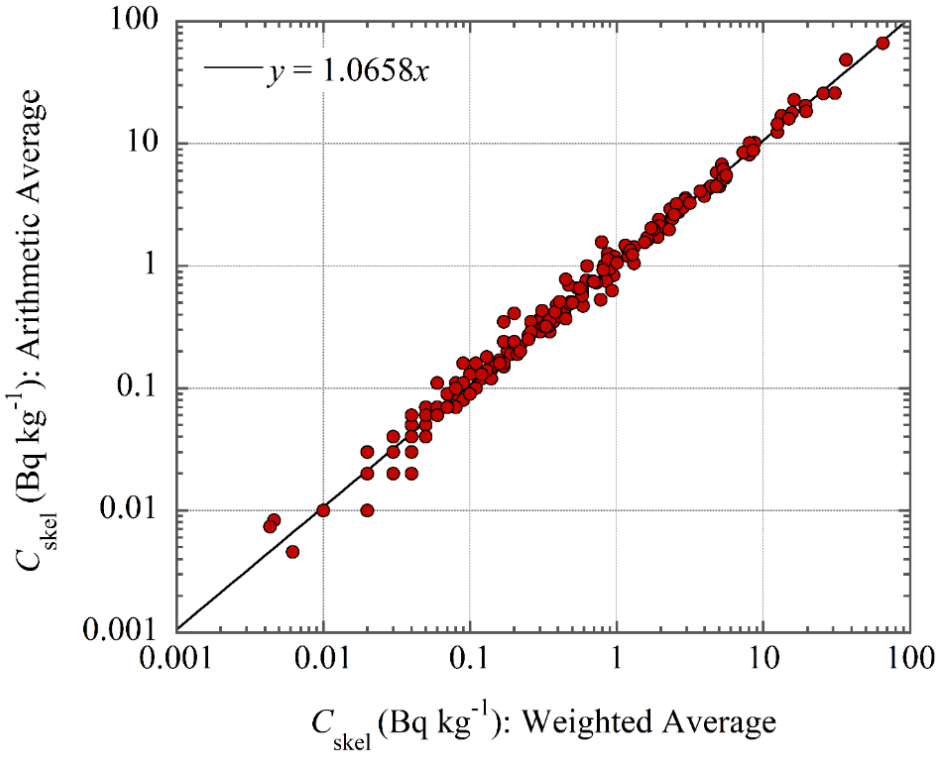
…at the United States Transuranium and Uranium Registries (USTUR):

- Bone samples collected post-mortem from whole-body tissue donors – individuals with known uptake of plutonium (≥2 nCi)
- All bones from the *right side* of the skeleton and *odd* ribs and vertebrae are radiochemically analyzed (A_{right}); each C_{bone} is calculated. For *even* rib and/or vertebra, C_{bone} is estimated as average of adjacent *odd* ribs and/or vertebrate
- To reduce uncertainty in A_{skel} estimation – no assumption on skeleton bilateral symmetry is made: $A_{skel} \neq A_{right} \times 2$
- Activity in the *left side* (A_{left}) is estimated as a sum of (measured) C_{bone} × autopsy (measured) weight of a 'matching' bone
- Total activity, $A_{skel} = A_{right} + A_{left}$ and 'true' concentration, $C_{skel} = A_{skel}/M_{skel}$
- **C_{skel} is a mass-weighted average of the entire skeleton**

USTUR Motivation

- Estimate plutonium C_{skel} for 232 partial-body tissue donors with 2 to 8 most commonly collected and analyzed bone samples
- For limited set of bones, C_{skel} can be estimated as (1) arithmetic average (C_a) or (2) mass-weighted average (C_w) concentrations ($p < 0.05$)





USTUR Research Question

- Which of two plutonium concentrations C_a or C_w gives a better estimate of C_{skel} using limited set of bones

$$C_{skel} = C_a = (\sum_{i=1}^{n} C_{\text{bone},\, i})/n \qquad (1)$$

$$C_{skel} = C_w = (\sum_{i=1}^{n} A_{\text{bone},\, i})/(\sum_{i=1}^{n} M_{\text{bone},\, i}) \qquad (2)$$

Materials and Methods

- Data from 19 whole-body tissue donors to the United States Transuranium and Uranium Registries (USTUR) were used
- C_a and C_w were calculated for ten bone groups with combinations of 2 to 8 most frequently analyzed bone samples
- Effect of osteoporosis was investigated using C_a/C_{skel} and C_w/C_{skel} ratios
- Accuracy of C_{skel} estimates by C_a and C_w was assessed and compared for 'healthy' group using C_a/C_{skel} and C_w/C_{skel} ratios
- Bone ash fraction was used to evaluate how well analyzed bone groups represent total skeleton

Materials and Methods: *Bone Dataset*

Pu exposure — Whole-body — 19 cases × 90 samples

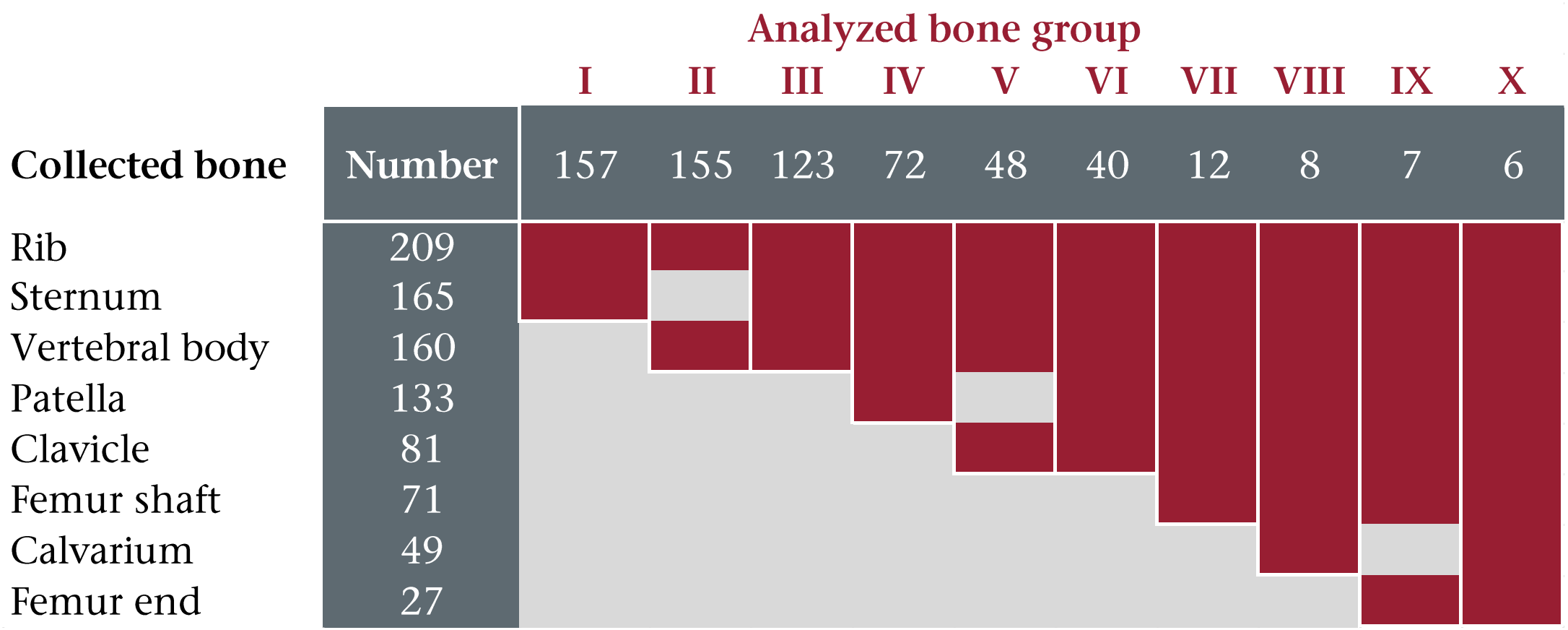
- Age: 73.8 ± 10.4 (54 – 90) y
- A_{skel}: 9.0 – 1,183.8 Bq
- C_{skel}: 0.9 – 122.3 Bq kg^{-1}

‘Healthy’: 14 — Osteoporotic: 5

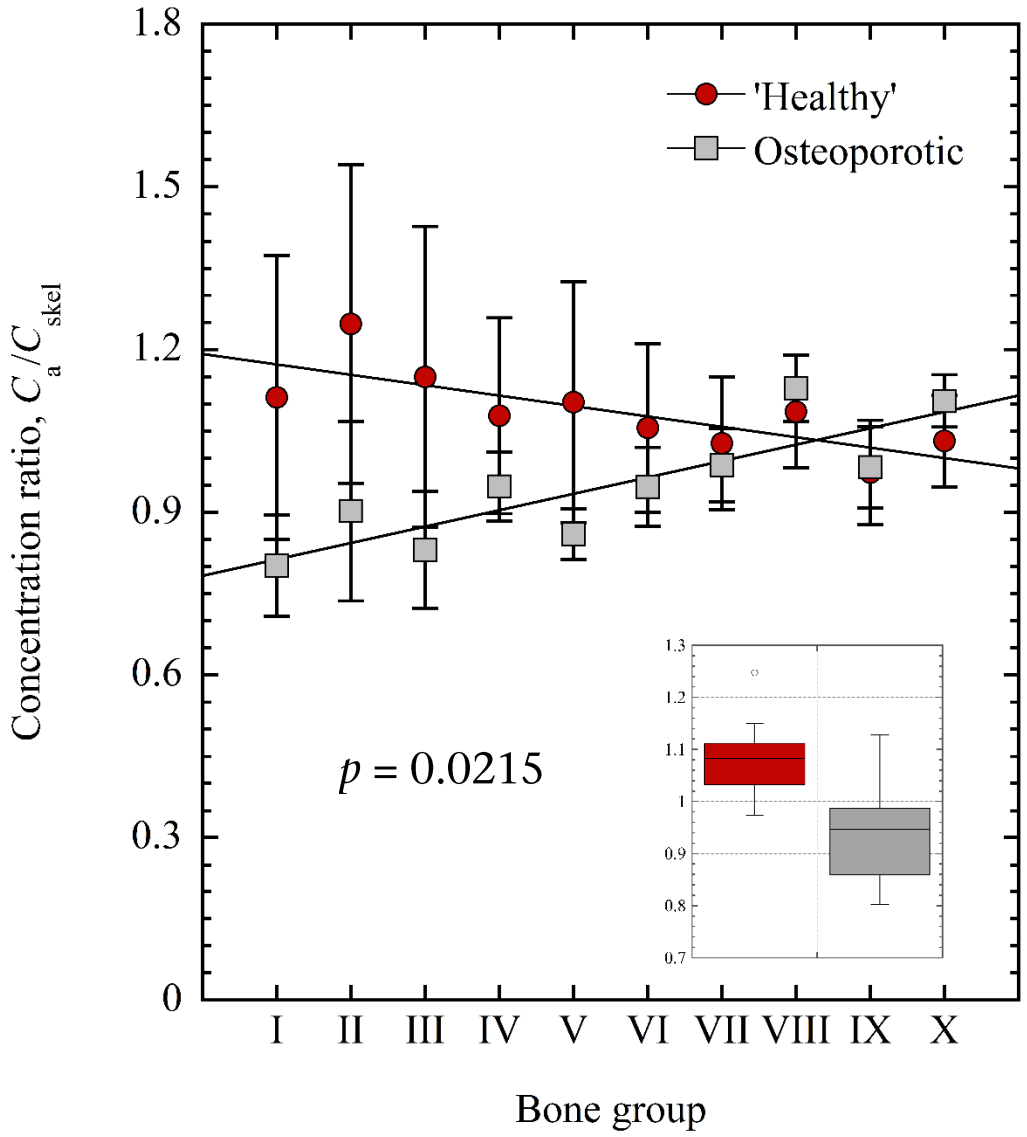
Ash fraction: 0.304±0.029 — 0.248±0.022

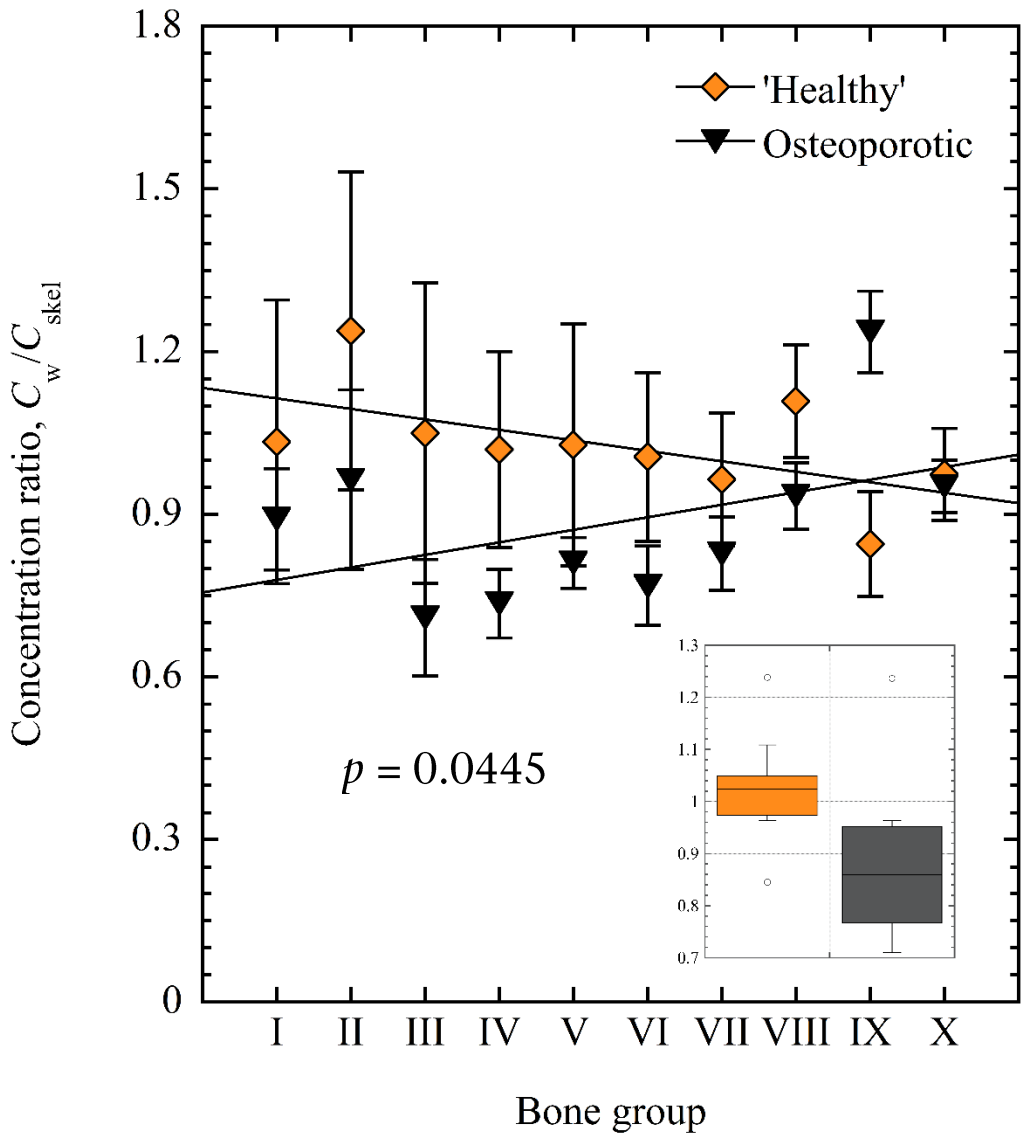
Materials and Methods: *Bone Groups*

Total of 232 partial-body cases with 2 – 8 analyzed bone samples



Results: *Effect of Osteoporosis*





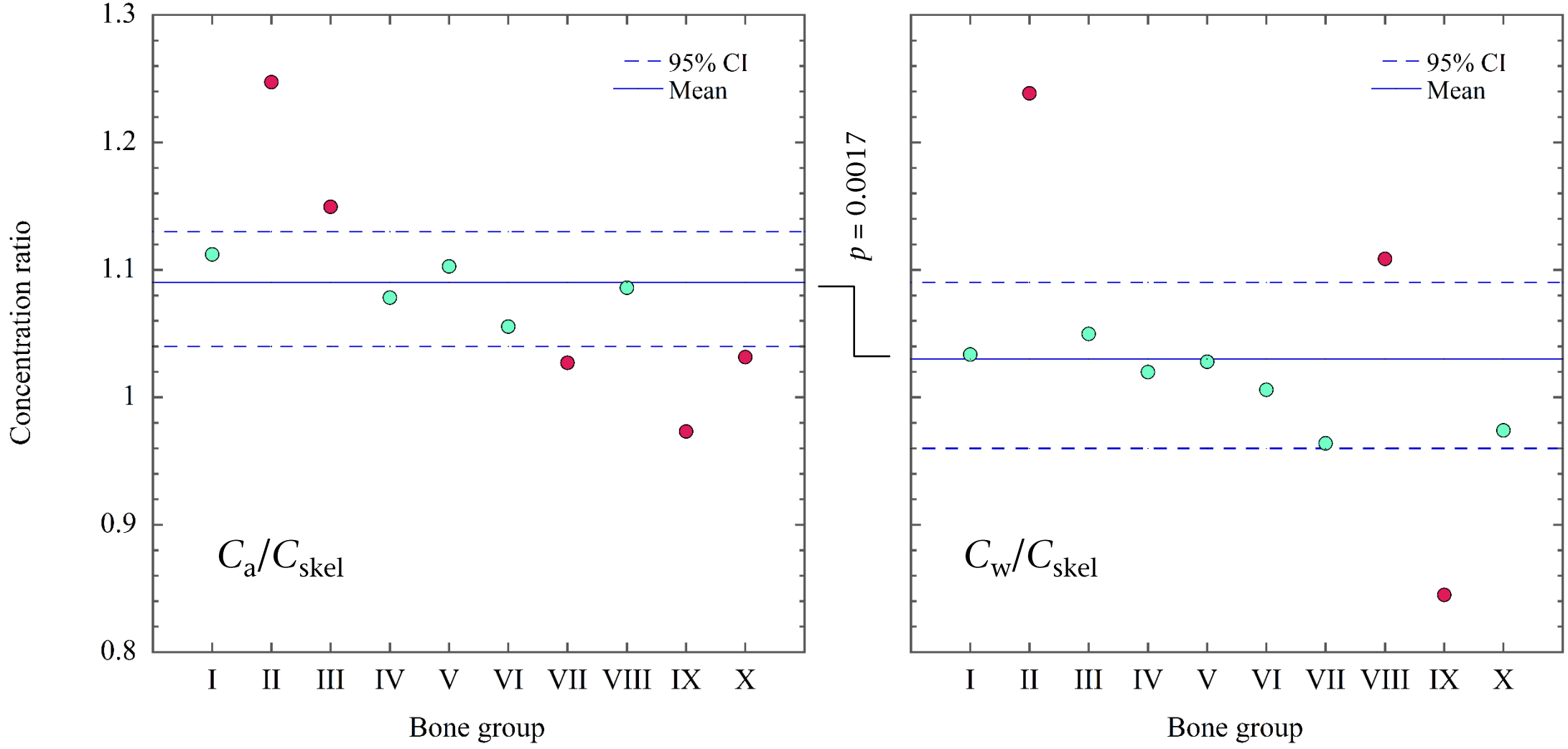
Results: *Arithmetic vs Weighted Average (I)*

Bone Group	f_{group}	C_a/C_{skel}	SD	C_w/C_{skel}	SD
I	0.21	1.11	0.26	1.03	0.29
II	0.22	1.25	0.29	1.24	0.30
III	0.19	1.15	0.28	1.05	0.29
IV	0.21	1.08	0.18	1.02	0.22
V	0.23	1.10	0.22	1.03	0.24
VI	0.24	1.06	0.16	1.01	0.19
VII	0.27	1.03	0.12	0.96	0.13
VIII	0.31	1.09	0.10	1.11	0.14
IX	0.27	0.97	0.10	0.84	0.08
X	0.30	1.03	0.08	0.97	0.10
	Mean	1.09		1.03	
	SD	0.08		0.10	
	95% LCI	1.04		0.96	
	95% UCI	1.13		1.09	
	f_{skel}	0.304			

f_{group}: ash fraction of individual bone group for all cases

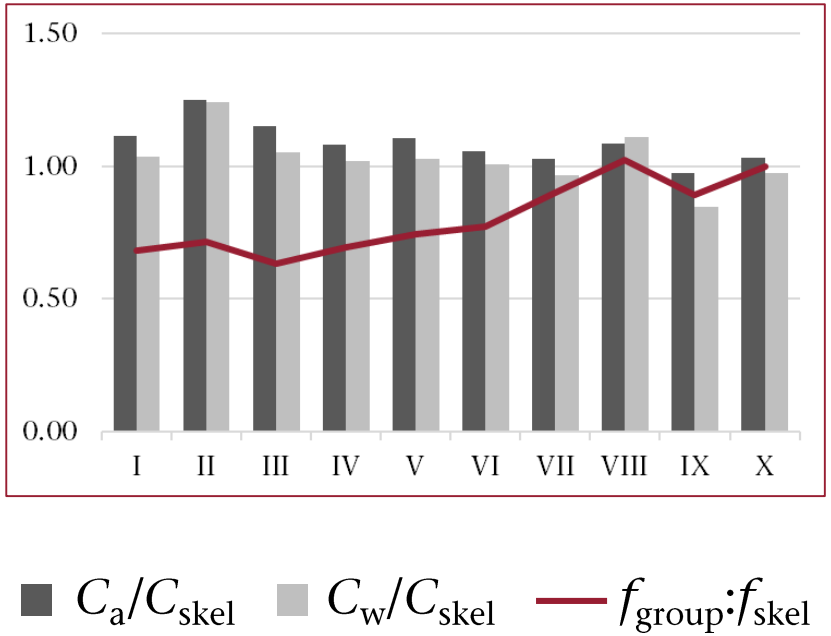
f_{skel}: average ash fraction for all groups and all cases

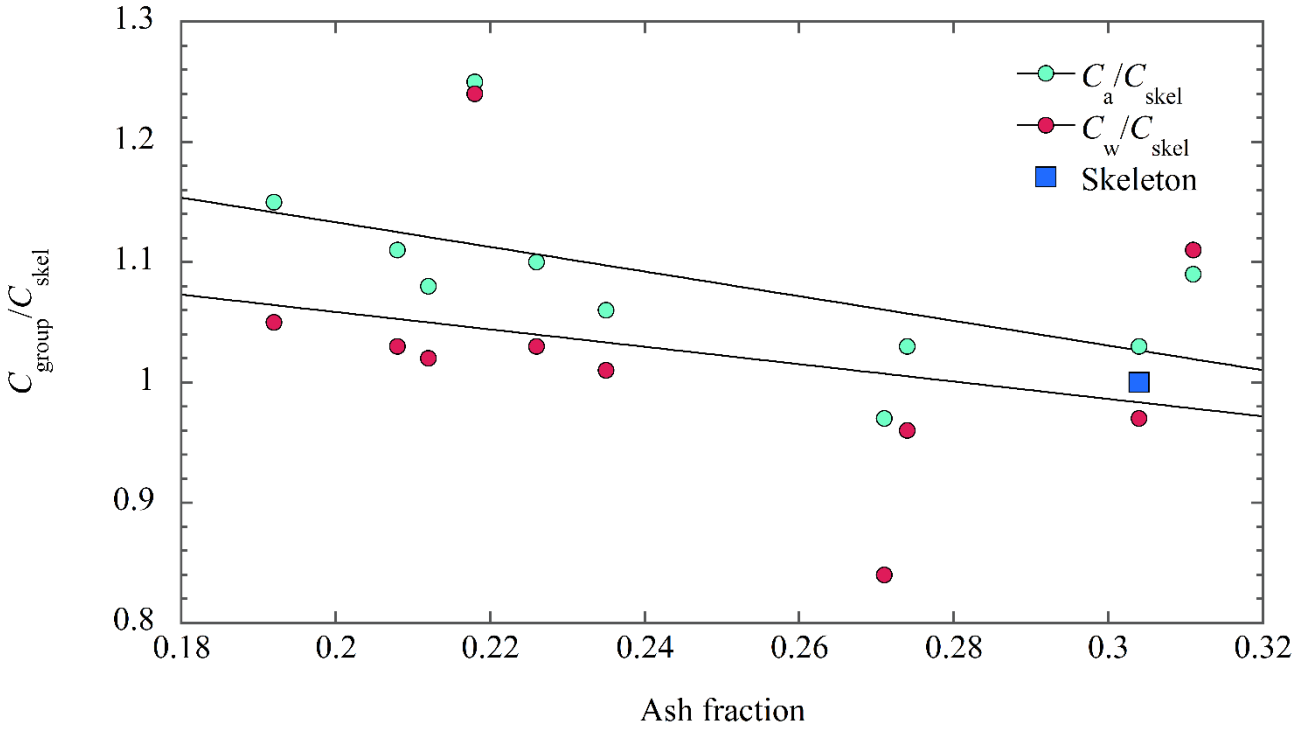
Results: *Arithmetic vs Weighted Average (II)*



Representative Sampling: *Bone Groups vs Total Skeleton*

- Ash fraction as indicator of representative sampling





Summary

- Mass-weighted concentration gives a better estimate of C_{skel} for a limited set of bones
  - ✓ Analysis of data from 19 USTUR whole-body tissue donors shows significant difference ($p = 0.0017$) between values of C_a/C_{skel} and C_w/C_{skel} measured in 10 different bone groups with combinations of 2 to 8 most frequently analyzed bone samples
  - ✓ C_w/C_{skel}: 1.03 ± 0.10 *vs* C_a/C_{skel} : 1.09 ± 0.08
- Data shows significant difference for C_{group}/C_{skel} between 'healthy' and osteoporotic cases: $p = 0.0215$ for arithmetic average and $p = 0.0445$ mass-weighted average methods
- Bone groups with ash fraction close to that of a total skeleton more accurately predict C_{skel}, regardless of method used (C_a or C_w)