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Uncertainty Evaluation of Skeleton Plutonium Activity Concentration Estimated from a Latent Bone Model

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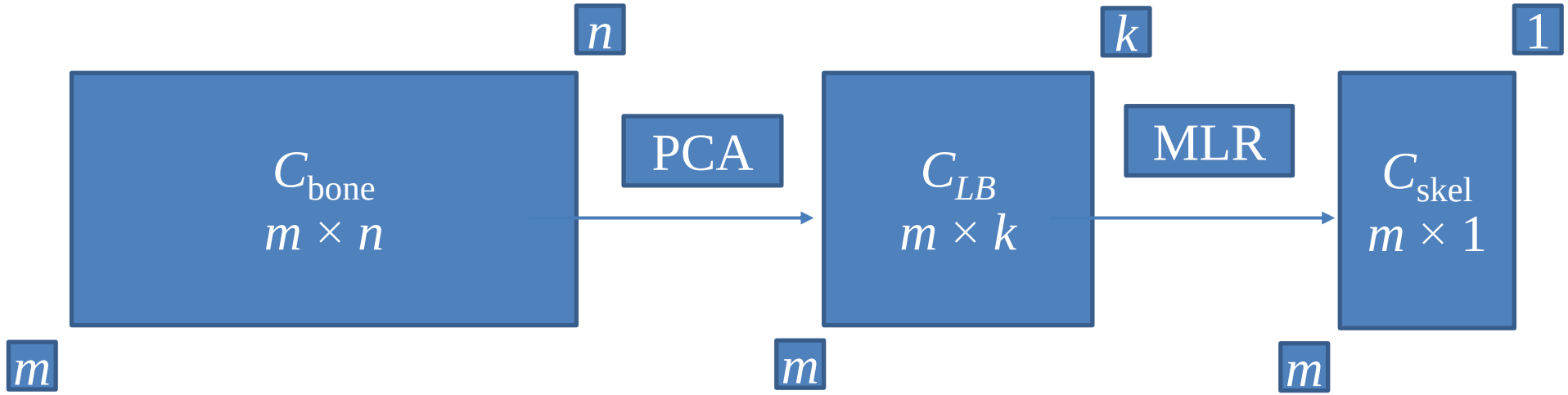
Principal Component Regression (PCR)
- *Latent Bone Modeling (LBM)* -



m: number of cases
n: number of bones
k: number of latent bone variables

PCA: Principal Component Analysis
MLR: Multiple Linear Regression

USTUR Bone Dataset

Pu exposure

Whole-body

19 cases

× 90 samples†

'Healthy': 14

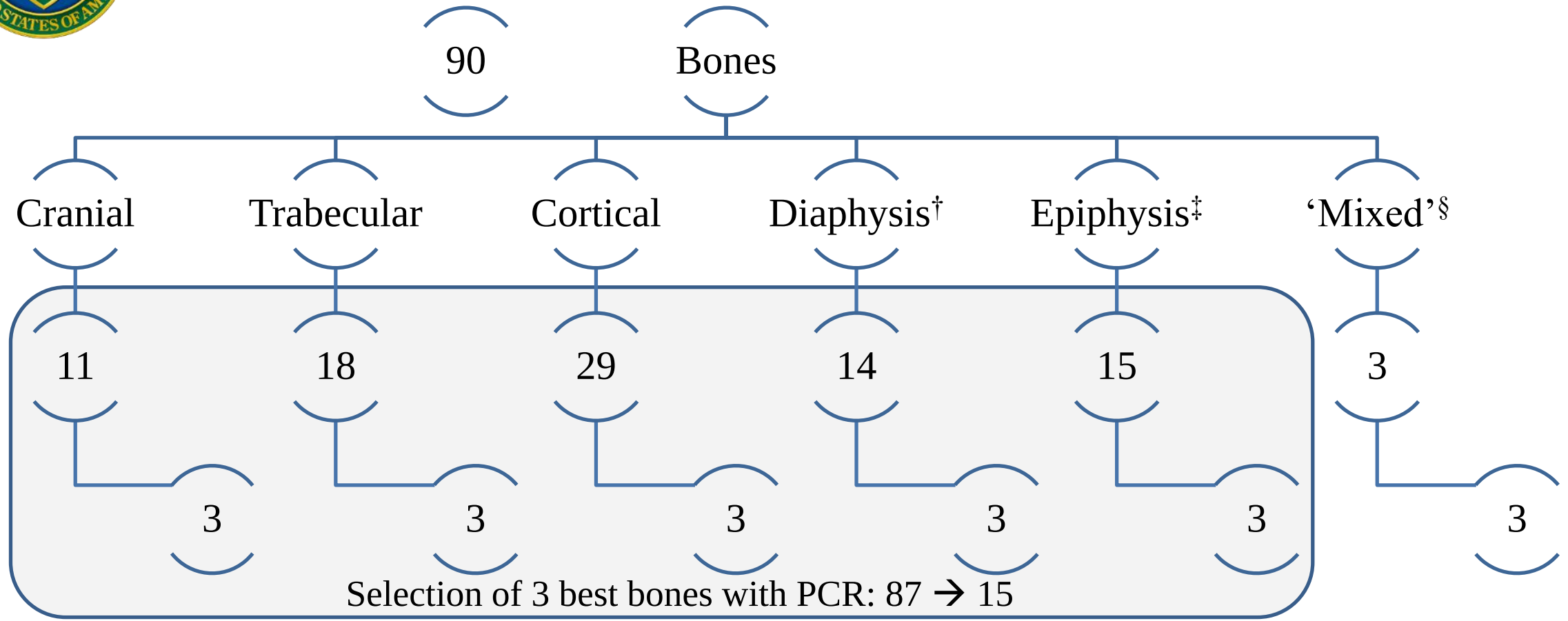
Osteoporotic: 5‡

- 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}

† - single bone ≠ one sample for radiochemical analysis, *e.g.* femur bone is dissected into 5 samples

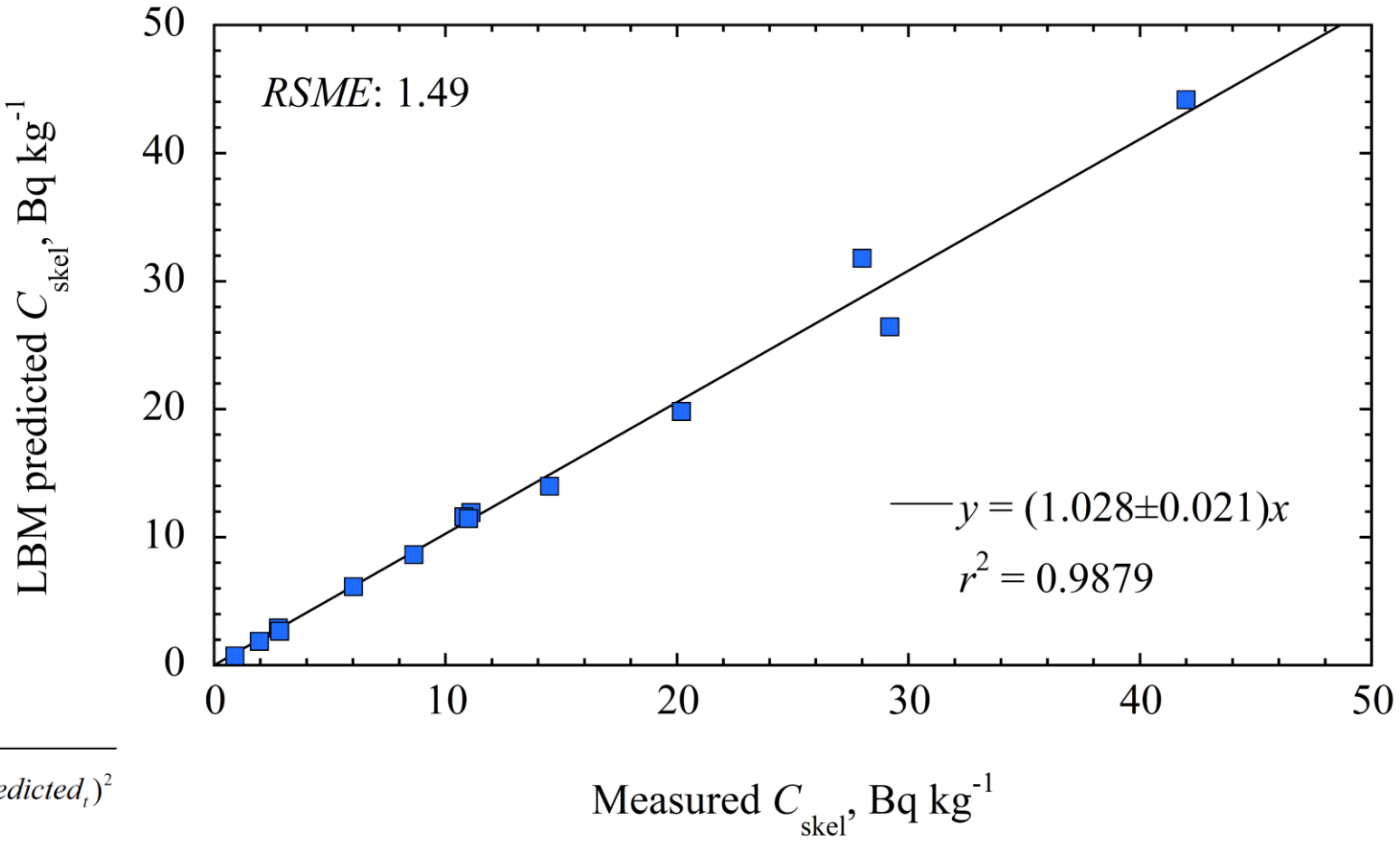
‡ - diagnosis from individual medical records

Reduced Dataset: ‘Best’ 18 Bones



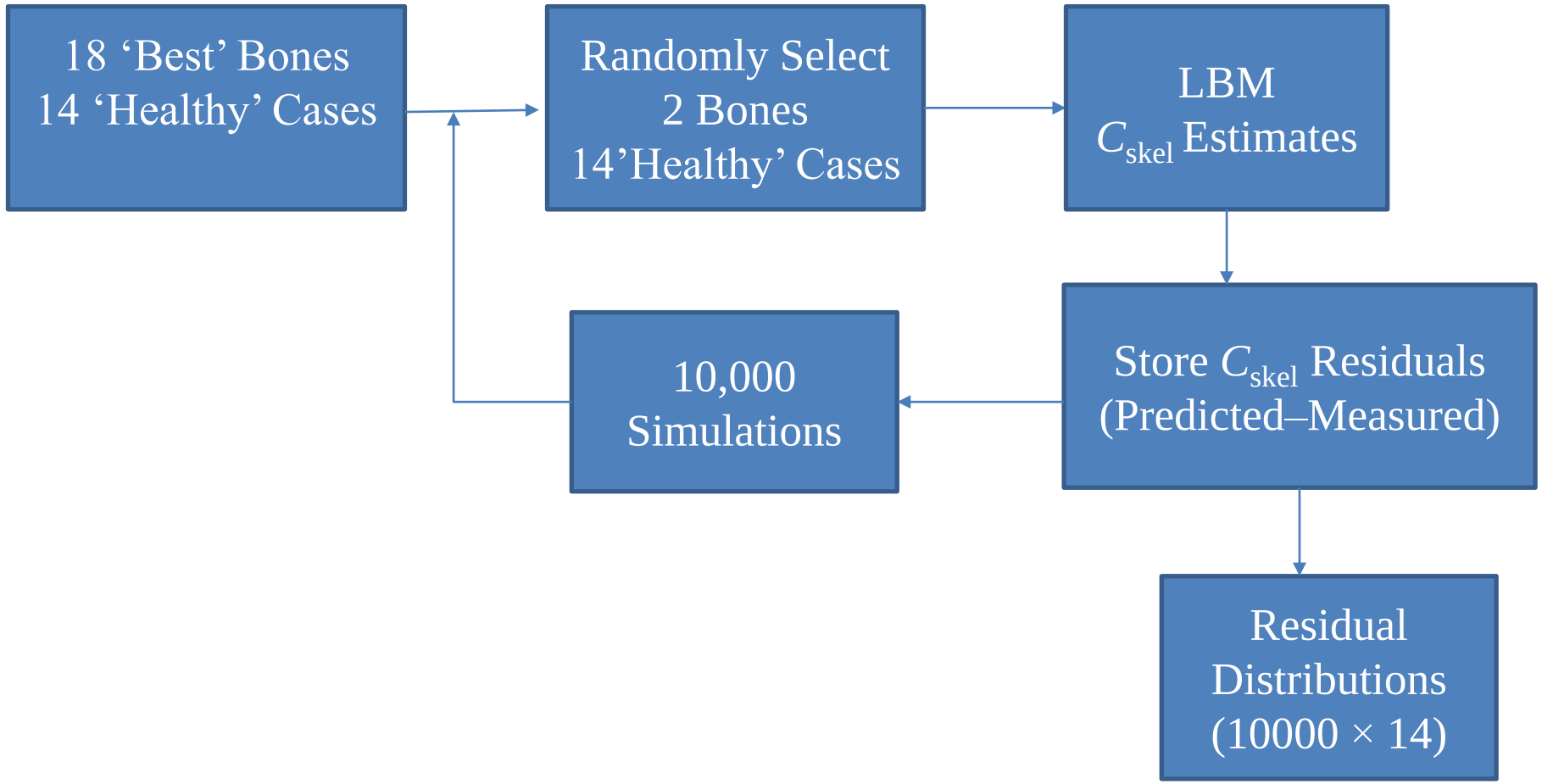
† - shafts of the long bones; ‡ - ends of the long bones + patella
§ - cervical vertebra #1 whole, hand and wrist, foot and ankle

LBM Leave-One-Out Cross Validation
18 'Best' Bones and 14 'Healthy' Cases

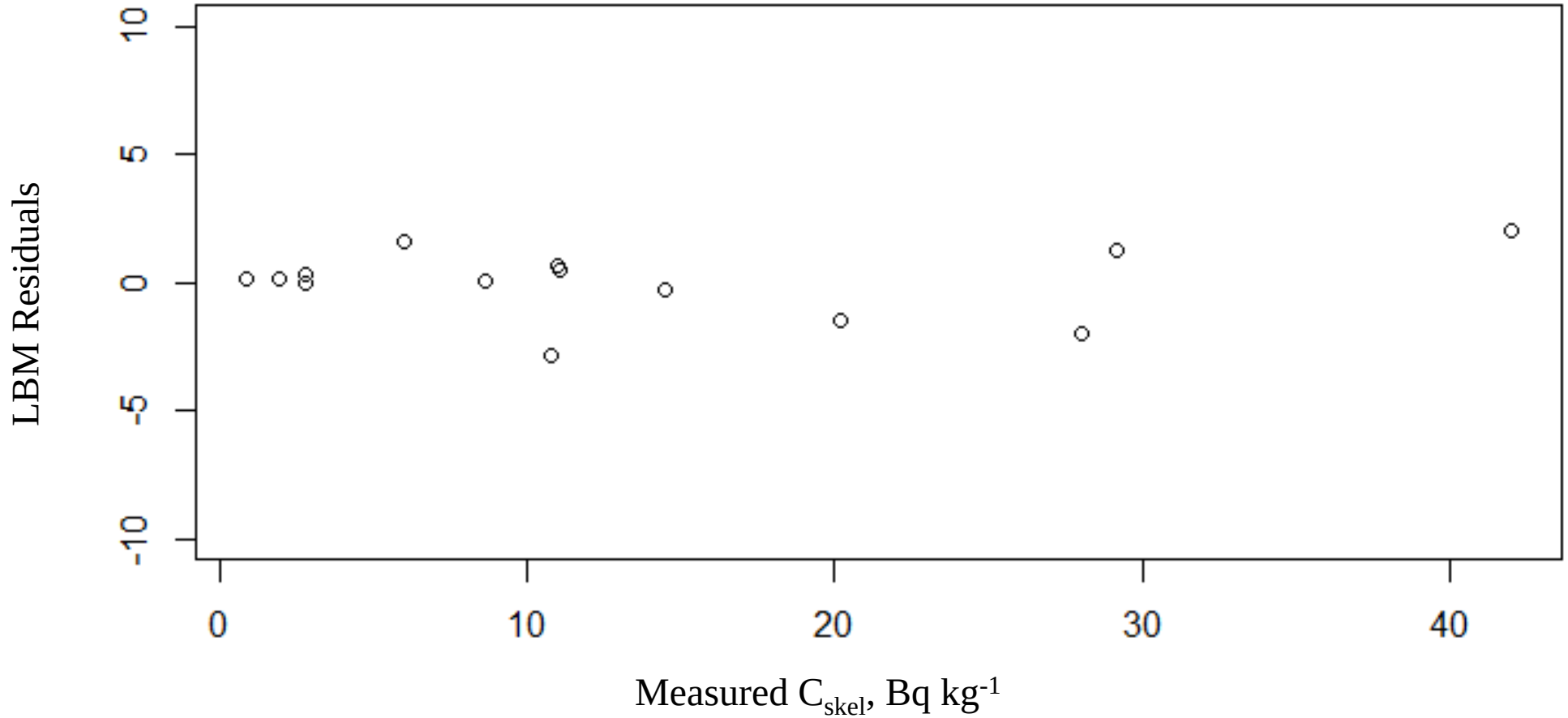


$$RMSE = \sqrt{\frac{1}{N}\sum_{t=1}^{N}(observed_t - predicted_t)^2}$$

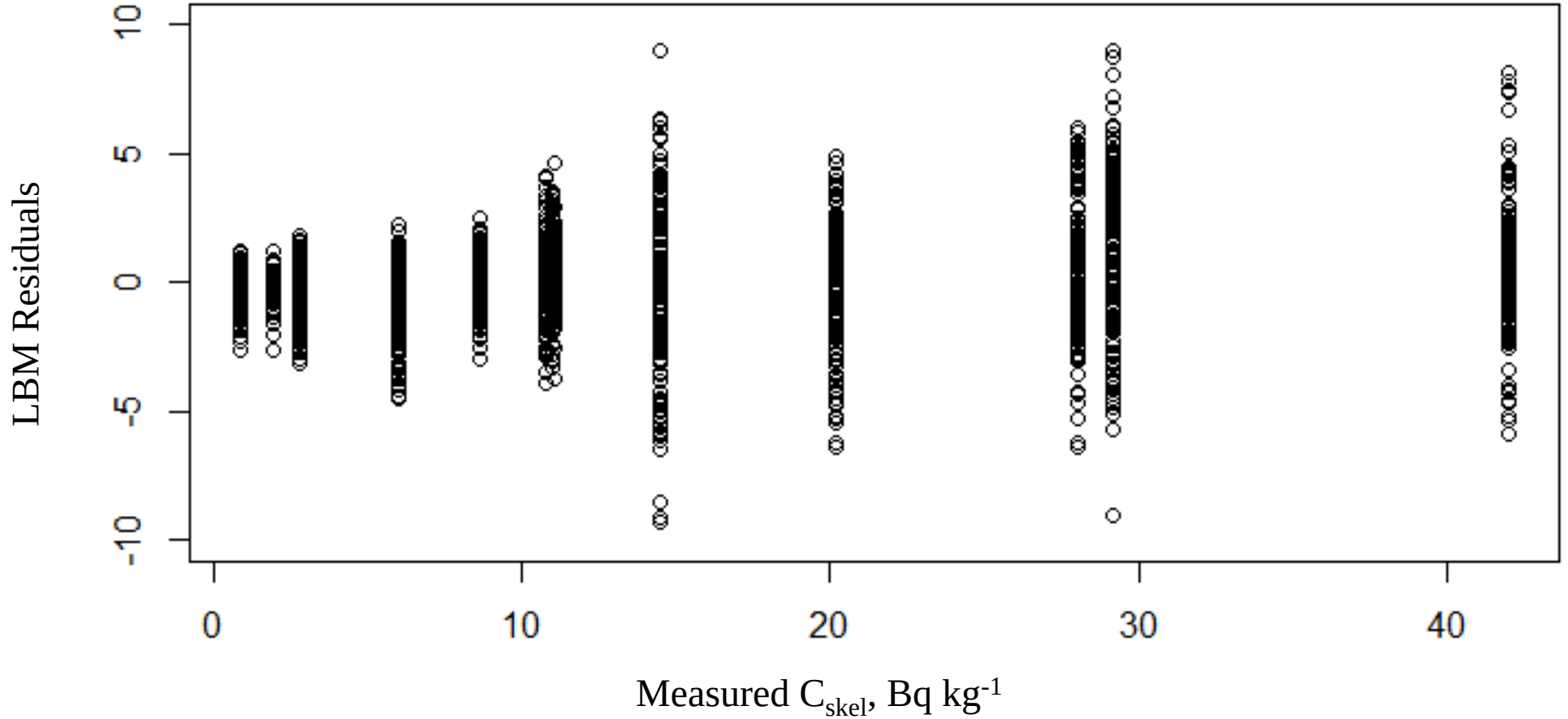
Simulations to Determine Uncertainty of LBM C_{skel} Estimate (Two Sample Bones Example)



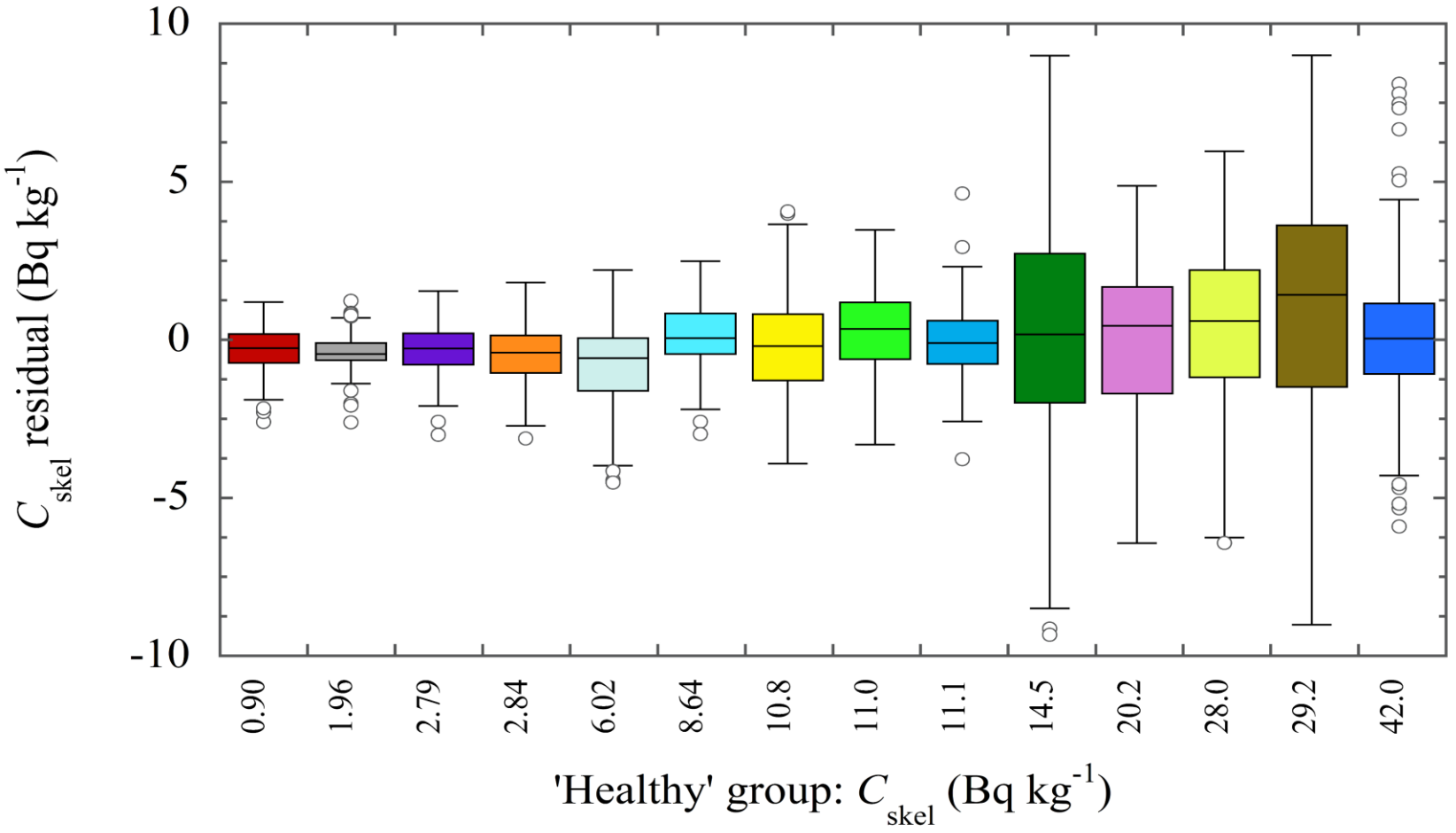
‘Best’ 18 Bones and 14 Cases:
- *Two Bones and One Simulation* -



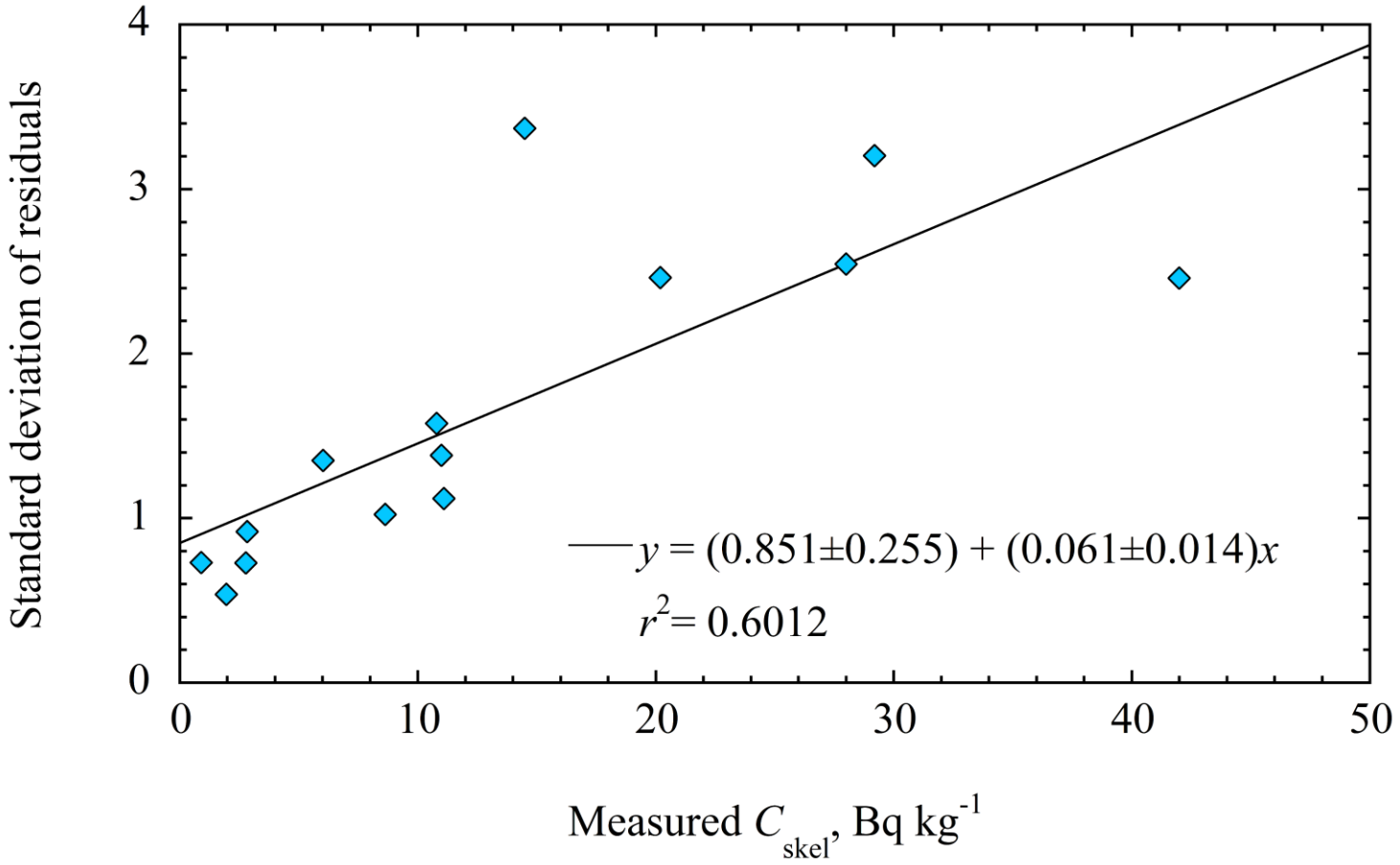
‘Best’ 18 Bones and 14 Cases:
- *Two Bones and 10,000 Simulations* -



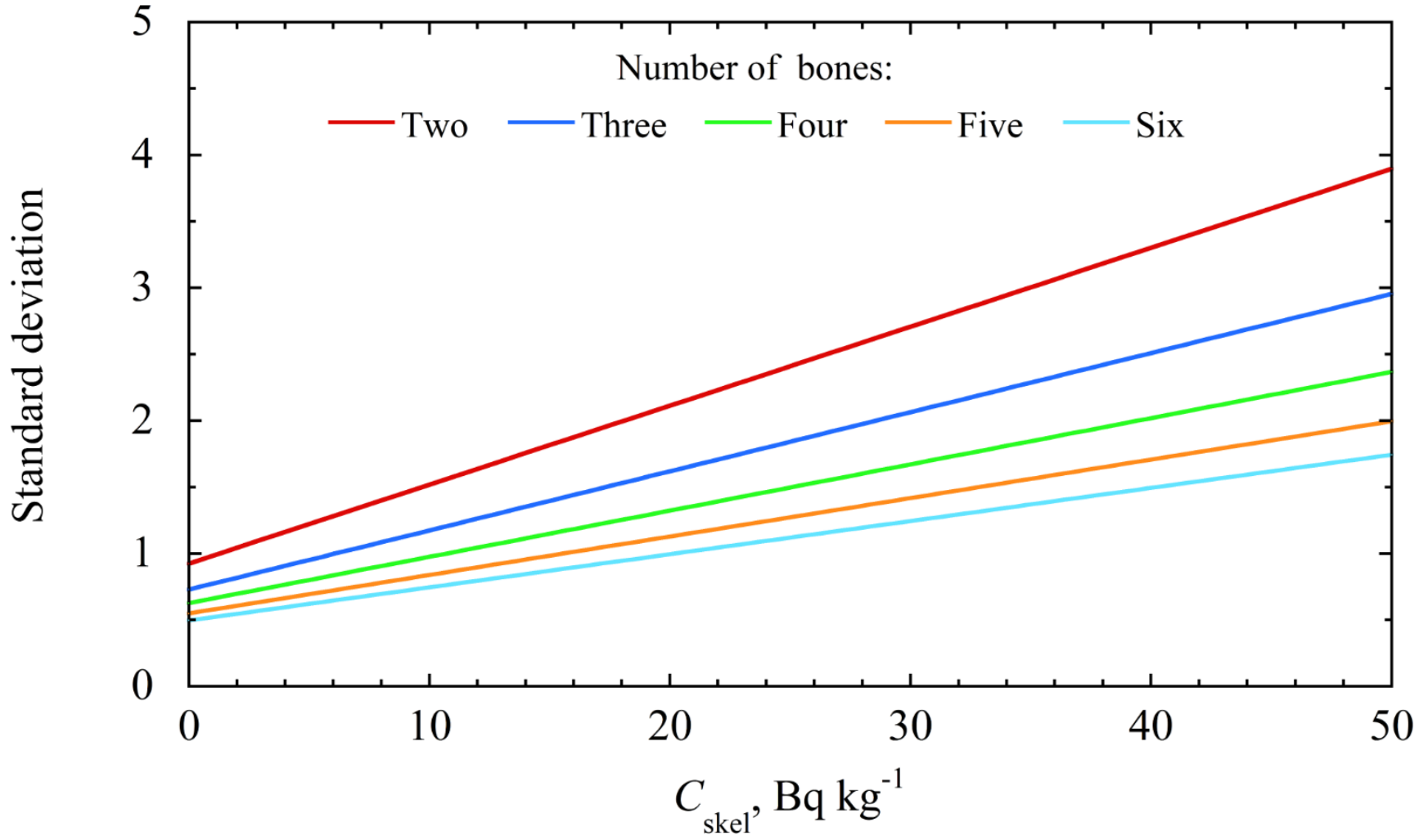
Boxplot of LBM C_{skel} Residuals, 10,000 Simulations ('Best' 18 Bones, 14 Cases, 2 Sample Bones)



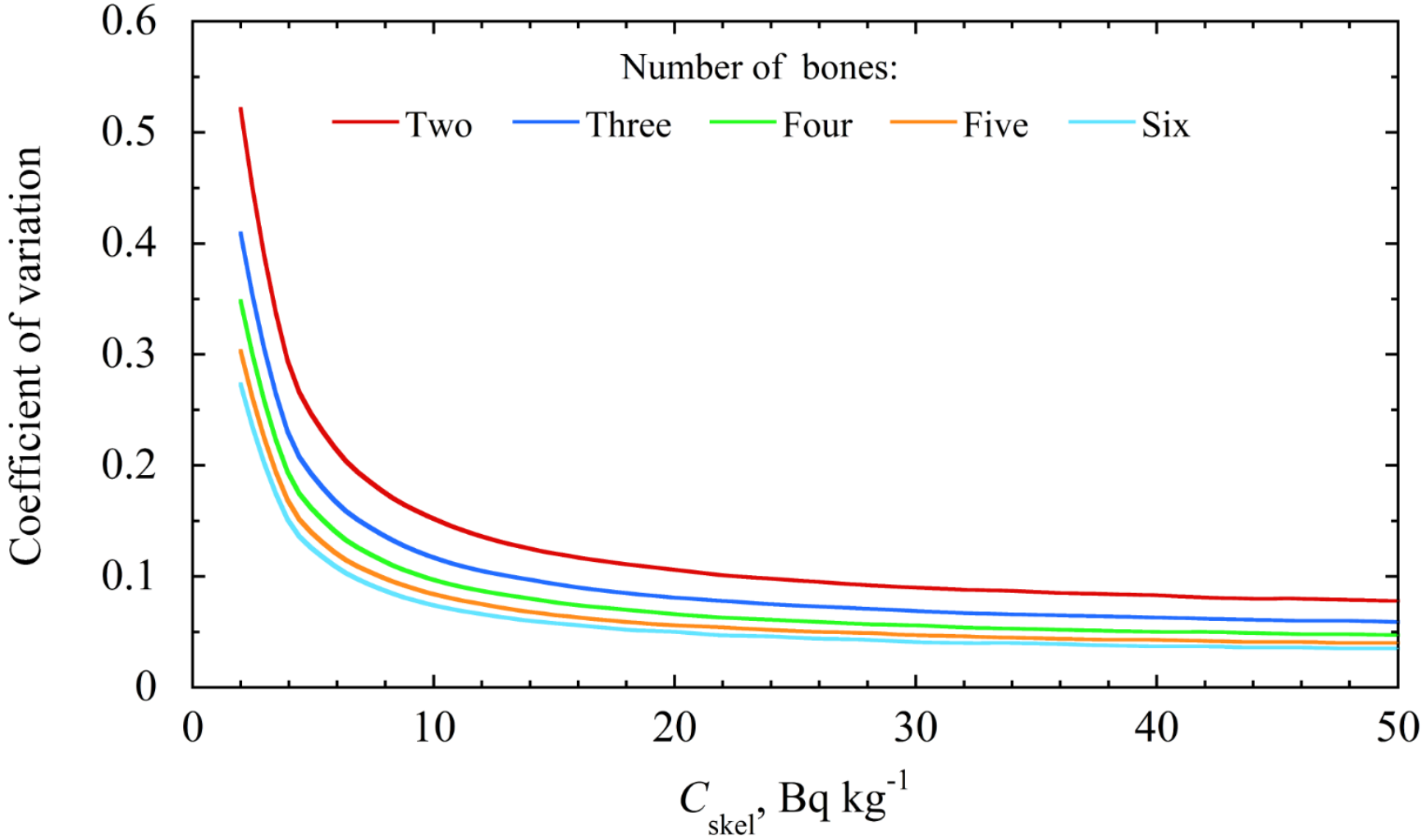
Linear Model to Determine LBM C_{skel} Uncertainty



LBM C_{skel} Uncertainty Estimates (14 'Healthy' Cases and 18 'Best' Bones)



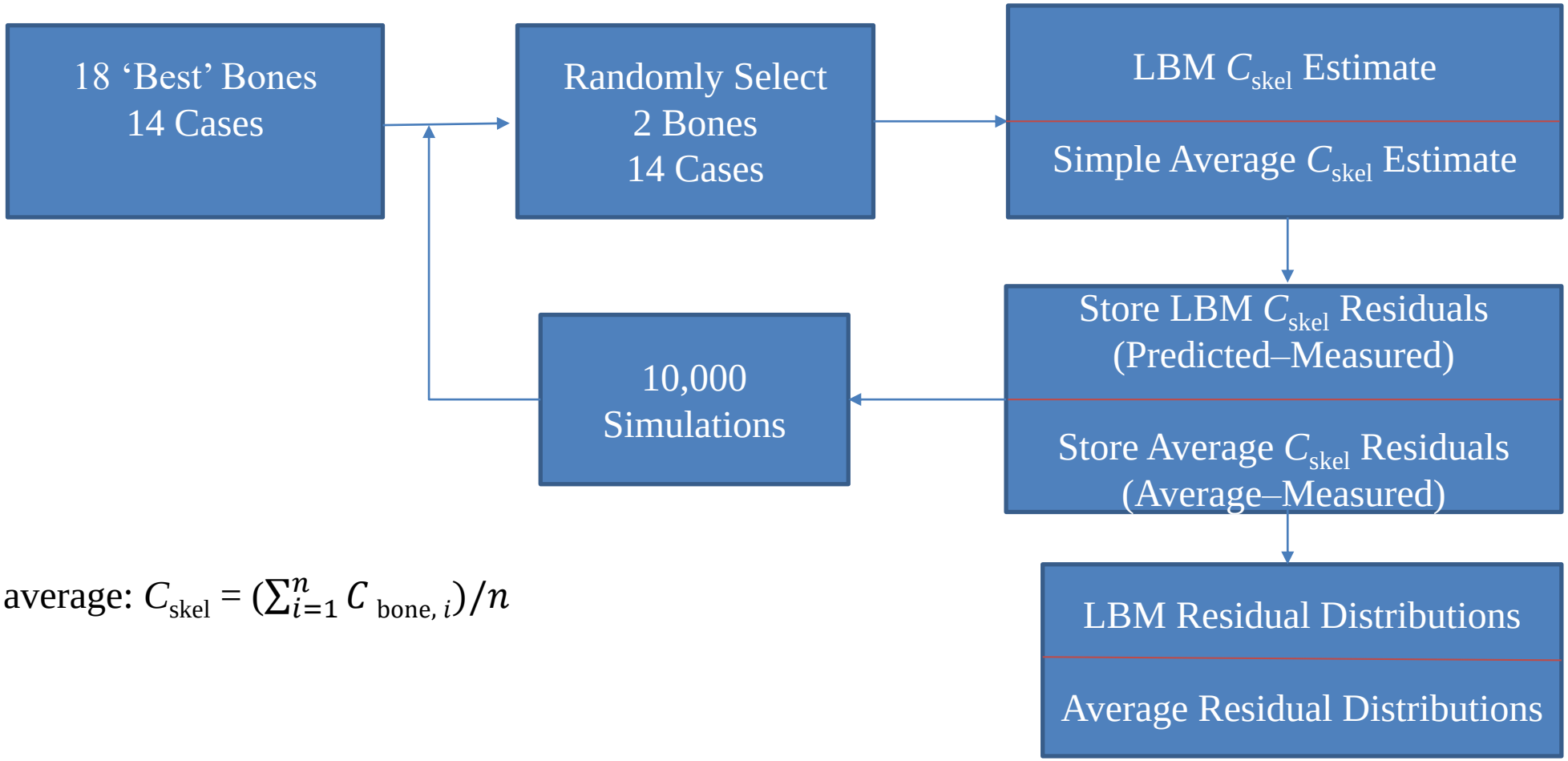
LBM C_{skel} Uncertainty Estimates (14 'Healthy' Cases and 18 'Best' Bones)



Partial-Body C_{skel} Estimates: LBM vs. Simple Average

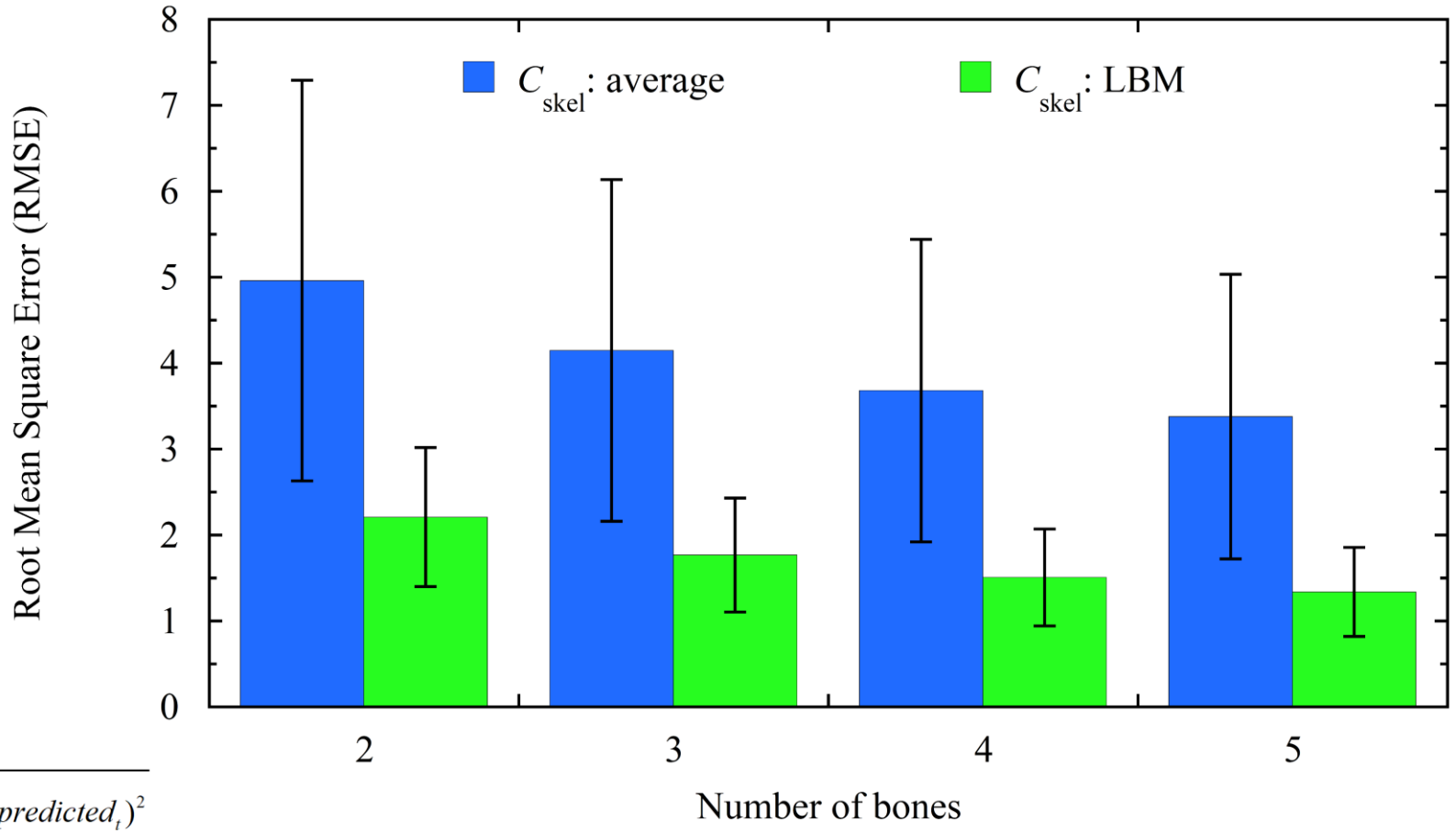
USTUR Case	Available Bones	C_{bone} Bq kg^{-1}	C_{skel} Bq kg^{-1}		Ratio
			Average	LBM	
0719	Rib, Patella	23.12, 22.39	22.8±0.5	21.9±2.2	1.04
0060	Vertebra, Rib, Sternum	7.22, 8.41, 6.98	7.5±0.8	7.4±1.0	1.02
0255	Vertebra, Rib, Sternum, Patella	4.37, 1.81, 2.36, 4.27	3.2±1.3	3.8±0.7	0.84
0631	Vertebra, Rib, Sternum, Patella	12.92, 18.91, 12.03, 12.16	14.0±3.3	13.3±1.0	1.05
0634	Vertebra, Rib, Sternum, Patella	21.82, 13.19, 14.41, 23.73	18.3±5.3	17.5±1.2	1.05
0778	Vertebra, Rib, Sternum, Patella	87.45, 84.97, 34.74, 125.48	83.2±37.2	73.9±3.1	1.12
Average					1.02±0.10

Comparison between LBM and Simple Average in Estimating C_{skel} and Its Uncertainties (Two Sample Bones Example)



Simple average: $C_{skel} = (\sum_{i=1}^{n} C_{bone,\,i})/n$

Comparison between LBM and Simple Average in Estimating C_{skel} and Its Uncertainties (Two Sample Bones Example)



$$RMSE = \sqrt{\frac{1}{N}\sum_{t=1}^{N}(observed_t - predicted_t)^2}$$

Summary

- A simulation method is developed to determine uncertainty of LBM C_{skel} estimate
- Compared to the simple average method, LBM improves accuracy of Cskel estimate by 58%, and reduces uncertainty by 67%