A New Method to Assess Bone Loss in Radiographs of Fragmentary Second Metacarpals

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Statement of Problem

Individuals with low amounts of cortical bone may be at greater risk for postmortem damage due to increased bone fragility. The exclusion of these individuals from second metacarpal radiogrammetry analyses could mean an important part of the skeletal assemblage is overlooked, possibly misrepresenting bone health and loss in the past.

We suggest a modified clinical technique, comparable with traditional cortical index measurements, which will allow palaeopathologists to include incomplete second metacarpals in cortical bone analyses.

Background & Rationale

Second metacarpal (MC2) radiogrammetry:

- Provides clinical evidence for bone density and fracture risk (Haara et al. 2006; Dequeker 1976).
- Is often used in paleopathological investigations of disease and/or age related bone loss (e.g., Ives and Brickley 2005; Mays 2006).
- Requires intact metacarpals (e.g., Ives and Brickley 2004, Mays 1996).
- Will exclude some MC2s due to insufficient preservation. Inclusion criteria differ among studies, but at least 19% of MC2s will likely be omitted from analyses (e.g., Beauchesne 2012; Gilmour dissertation research; Mays 1996).

Digital x-ray radiogrammetry (DXR):

- Is a fully automated method, limiting user error (Rosholm et al. 2001).
- Generates an overall cortical index based on a series of transverse measurements in a region of interest (ROI) (Hyldstrup and Nielsen 2001; Rosholm et al. 2001).
- May be as effective as other methods (e.g., radiographic absorptiometry) in identifying individuals at risk for osteoporotic fractures (Adams 2010; Bouxsein et al. 2002; Kälvesten et al. 2016).

This research adapts DXR for paleopathological application using common imaging software. The modified version measures the *area* of cortical bone within a standard-sized ROI placed over the narrowest part of the metacarpal diaphysis.

This revised DXR method allows fragmentary elements to be included in cortical bone analyses and provides a comparable and reliable alternative to traditional radiogrammetry.

Materials

Complete MC2s from two 1st-4th century Roman sites, Ancaster, UK (n=48) and Vagnari, Italy (n=8) (Figure 1), were radiographed to quantify cortical bone amounts. Skeletal sex and age were estimated and grouped into age categories using standards outlined in Buikstra and Ubelaker (1994) (Table 1). Individuals 15 years or older were included and the adolescent age category was amended to reflect this.

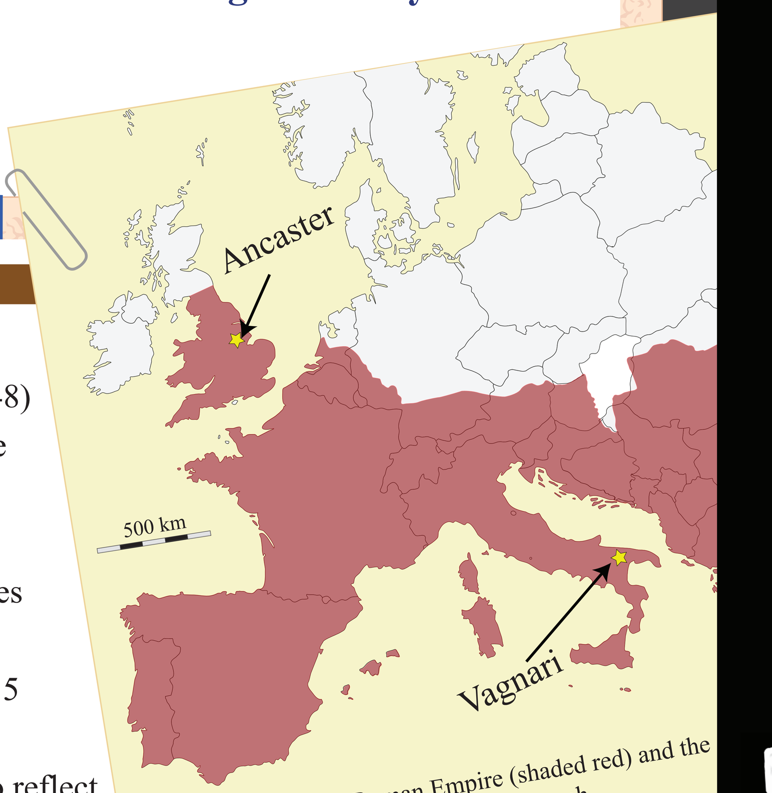


Figure 1 - Map of the Roman Empire (shaded red) and the locations of the sites included in this research.

Table 1 - Number of second metacarpals observed at Ancaster and Vagnari by age and sex.

Age	Ancaster, UK		Vagnari, Italy		Total	
	F	M	F	M	F	M
Adolescent (15-19)	0	2	2	0	2	2
Young Adult (20-34)	16	2	0	3	16	5
Middle Adult (35-49)	17	7	1	2	18	9
Old Adult (50+)	4	0	0	0	4	0
Total	37	11	3	5	40	16

F=Female; M=Male

Anterior-posterior (AP) radiographs of each MC2 were taken using a Vidisco portable digital X-Ray unit (Figure 2). MC2s were placed dorsal-side against the plate to minimize distortion. A 25.4mm diameter lead ball was included to calibrate the images.

Figure 2 - Golden Engineering XR200 X-Ray source and FlashX Pro Digital Detector Array (DDA) set up portably.

X-Ray Unit specifications:

- Fixed beam intensity (150 kV and 1.0 mA)
- Variable exposure time settings
- MC2s required an average exposure time of 1.02 ± 0.13 seconds

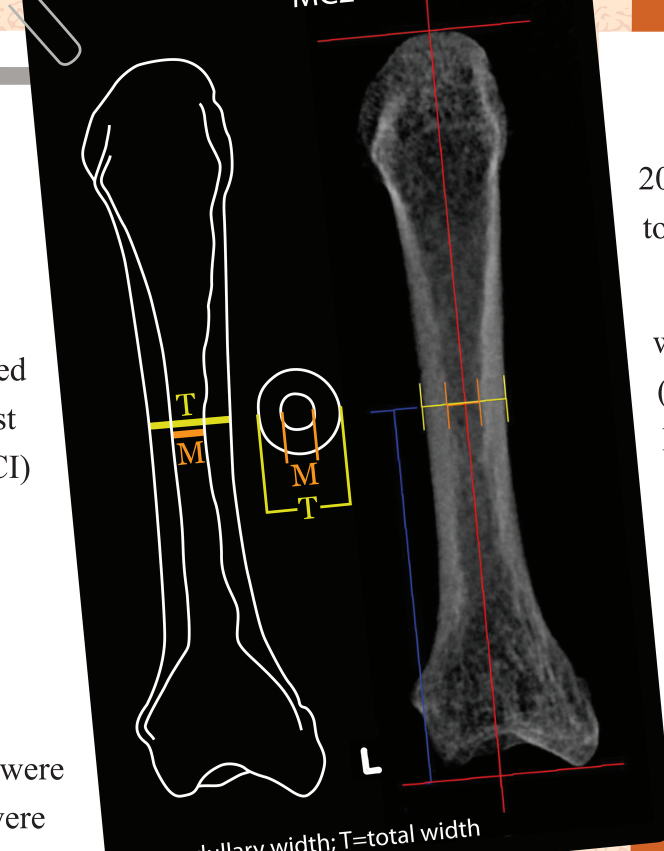
Measurement Methods

Radiogrammetry:

The midshaft of each MC2 was identified using Vidisco Xbit Pro X-Ray Inspection System software (Version 3.1.1.3 [NDT], Vidisco Ltd.). Endosteal cortical margins were determined after Ives and Brickley (2004). Total (T) and medullary (M) cortical widths were measured perpendicular to the MC2's longitudinal axis to the nearest 0.1mm (Figure 3) and used to calculate cortical indices (CI) (see equation below).

$$CI = \frac{(T - M)}{T} \times 100$$

Figure 3 Ancaster Skeleton 62 MC2 — Cortical Index Measurement Locations



M=medullary width; T=total width

Region of Interest (ROI) Method:

Using Adobe Photoshop CC (2015), the radiographs were calibrated and two rectangular regions of interest (ROI) were created for each MC2:

- One standard-sized 19mm ROI (after Rosholm et al. 2001)
- One ROI scaled to 30% of the MC2's total length

The ROI boxes were placed over the narrowest part of the MC2 diaphysis (see Figures 4 and 5). The cortical bone within each ROI was selected, and the area of the selected bone was calculated automatically in Photoshop.

Spearman's rank correlation coefficient tests were used to assess the relationships between standardized ROIs, scaled ROIs, and cortical indices.

Figure 4 Ancaster Skeleton 62 — ROI applied to a complete MC2

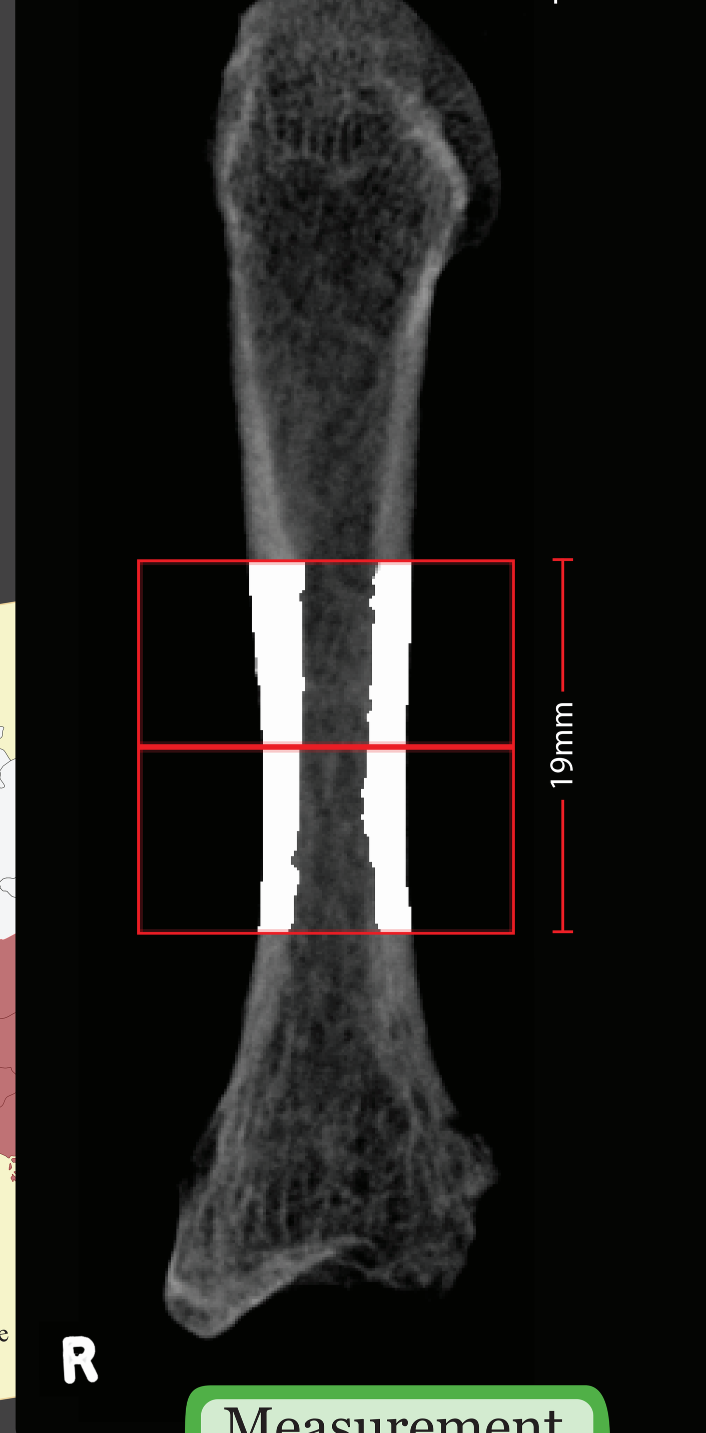
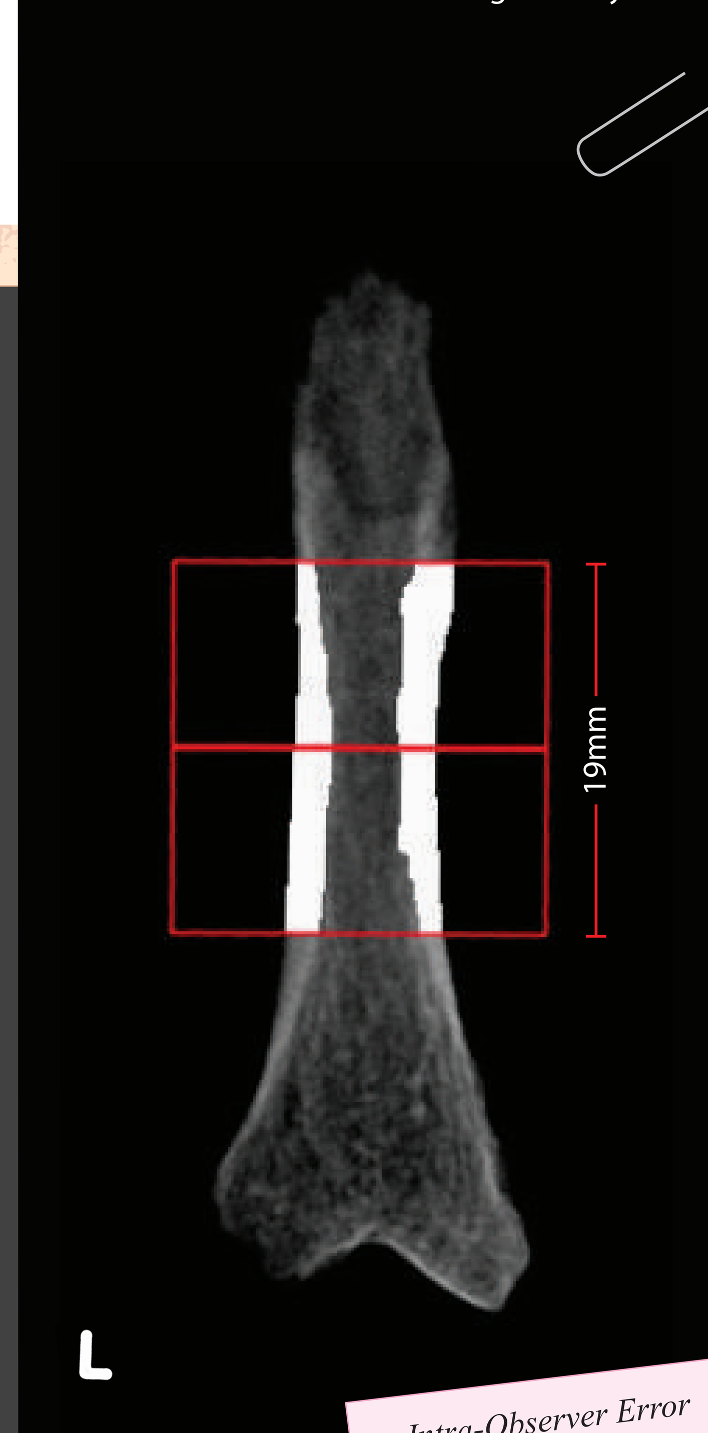


Figure 5 Ancaster Skeleton 171 — ROI applied to a fragmentary MC2



Measurement Results

Standardized (19mm) ROIs were significantly correlated with both scaled ROIs (30% total length) and cortical indices (see Figures 6 and 7).

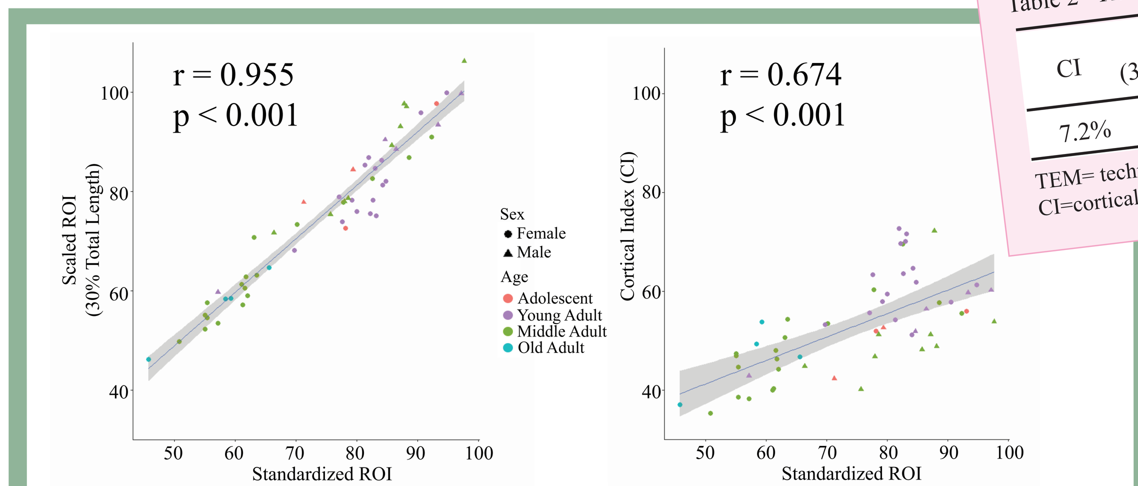


Figure 6 - Correlation between MC2 standardized (19mm) and scaled (30% total length) ROIs.

Figure 7 - Correlation between MC2 standardized (19mm) ROI and cortical index (CI).

Intra-Observer Error

A randomized selection of 15 MC2s were re-measured and the relative technical error of measurement (TEM) was used to assess the measurement repeatability (after Perini et al. 2005). Table 2 presents the TEM results. The standardized ROI measurement was the most repeatable and CI was the least.

Table 2 - Results of relative TEM intraobserver error

CI	Scaled ROI (30% total length)	Standardized ROI (19mm)
7.2%	2.3%	2.1%

TEM= technical error of measurement; CI=cortical index; ROI=region of interest.

Peak Bone Methods

Peak bone mass is typically achieved by early young adulthood (Weaver et al. 2016). As such, the CI and ROI areas of adults aged 15 to 34 (ADO and YA) were used to represent the normal range of peak cortical bone present at Ancaster and Vagnari.

The interquartile ranges (IQR), representing the median 50% of CI and ROI areas, were multiplied by 1.5 to indicate the range of normal peak cortical bone areas (after Tukey 1977). Individuals with CI or ROI areas smaller (or larger) than the IQR limits were identified as having outlying cortical bone amounts.

The rates of CI and ROI middle and old adult outliers were compared using odds ratios (OR) and chi-square tests with Yates's continuity corrections in order to determine if one method more often identified smaller amounts of cortical bone in older adults.

Peak Bone Results

Outliers: CI vs. ROI

Figures 8 and 9 indicate the female individuals with outlying CI and ROI cortical bone amounts relative to the range of peak bone at Ancaster and Vagnari. The range of male CI and ROI cortical bone amounts are shown in Figures 10 and 11.

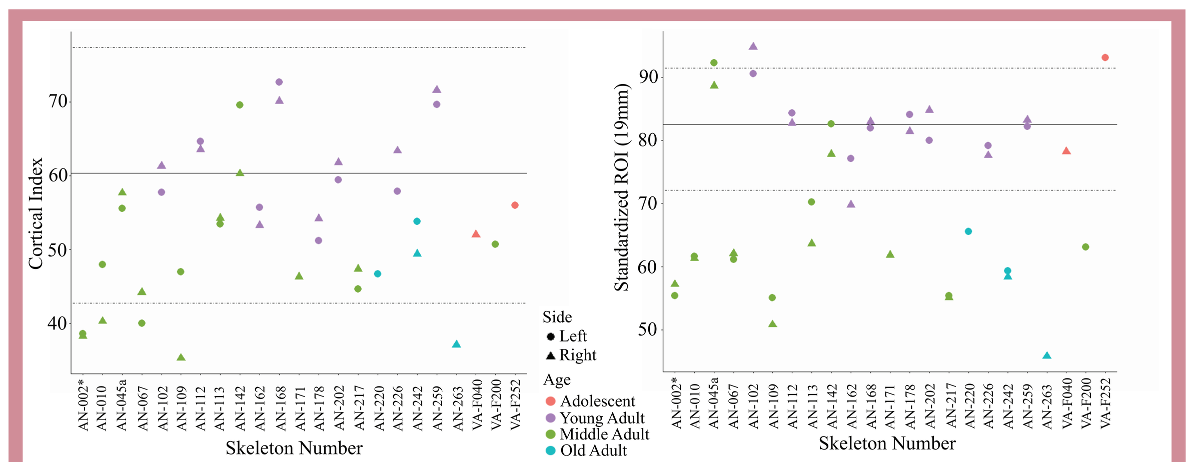


Figure 8 - Female MC2 CI. Peak cortical bone range indicated with dotted lines.

Figure 9 - Female MC2 standardized ROI. Peak cortical bone range indicated with dotted lines.

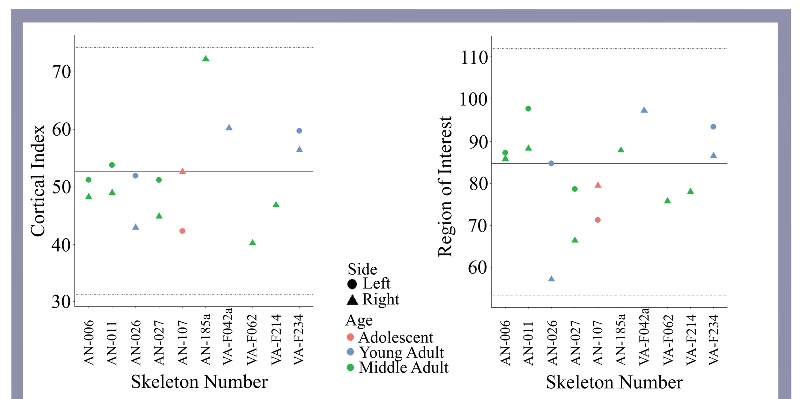


Figure 10 - Male MC2 CI. Peak cortical bone range indicated with dotted lines.

Figure 11 - Male MC2 standarized ROI. Peak cortical bone range indicated with dotted lines.

Using the ROI method, significantly more female MA and OA MC2s had lower than peak cortical bone amounts as the CI method (OR=12.0, Confidence Interval 2.9-50.3; x^2_{Yates}=11.092, df=1, p=0.001). None of the observed males had outlying CI or ROI areas.

Conclusion

A standardized ROI (19mm) was found to be a repeatable measure that was strongly correlated with cortical index (CI) and scaled ROI measures. A number of additional benefits to the standardized ROI method were also identified:

- Only requires MC2 diaphyses, allowing incomplete MC2s to be included in cortical bone analyses (e.g., Figure 5)
- ROI is a more sensitive method to quantify cortical bone present
- Accounts for cortical bone changes over a larger area, minimizing possible error associated with natural cortical undulations (e.g., points of thinner or thicker cortical bone)
- Clearly identifies age-related differences in peak bone amount
- Quick and easily applied without specialized software

Limitations & Future Research

The ROI method is a promising way to evaluate cortical bone in archaeological collections. Unlike CI, the ROI method does not exclude all incomplete MC2s. That being said, cortical surface weathering remains a concern for both CI and ROI methods and discretion should be used in interpreting results from damaged MC2s.

Moving forward, future research will:

- Compare this adapted method to the clinical DXR software
- Assess a larger sample
- Examine inter-observer error and variability

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