OsteoSort

User Manual

Reivison 13.JULY.2017

TABLE OF CONTENTS

TABLE OF CONTENTS

METHODS

PAIRS

Pair-matching follows the procedures by Lynch *et al.* (2017) and Byrd and LeGarde (2014). The summed difference between left and right homologous measurements is calculated from a reference sample and case comparison. The reference sample is used as a representative of the left-right differences seen in a population. The comparison D-value has zero or the mean of the reference D-values subtracted, which is then divided by the standard deviation of reference D-values to produce a t-statistic. This t-statistic is compared to a t-distribution to produce a p-value where the degrees of freedom are equal to the reference sample minus one. Any p-value that is less than or equal to the alpha level is considered too different in size to have originated from a single individual, and any p-value greater than the alpha level indicates a similarity in size, suggesting the elements may belong to a single individual. It is important to note that a p-value greater than the alpha level does not confirm the elements originated from a single individual, but rather, indicates a comparison that cannot be excluded.

Using this methodology various statistical variations can be produced by manipulating the D-value, mean, and alpha level (Figure 1). Multiple variations of the D-value can be calculated including the summed differences (Model A and B), absolute value of summed differences (Model C; Lynch *et al.* 2017), and half-normal transformed absolute value of summed differences (Model D; Lynch *et al.* 2017). The default model (Model D) is the absolute D-value with half-normal transformation using the mean of the reference and an alpha level of 0.05.

$$D = \sum a_i - b_i \qquad \bar{x} = 0 \qquad t = \frac{D_{com} - \bar{x}}{s_{D_{ref}}}$$

(A)

$$D = \sum a_i - b_i \qquad \bar{x} = \frac{\sum D_{ref}}{N} \qquad t = \frac{D_{com} - \bar{x}}{s_{D_{ref}}}$$

(B)

$$D = \sum |a_i - b_i| \qquad \bar{x} = \frac{\sum D_{ref}}{N} \qquad t = \frac{D_{com} - \bar{x}}{s_{D_{ref}}}$$

(C)

$$D = \left(\left(\sum |a_i - b_i|\right) + 0.00005\right)^{0.33} \qquad \bar{x} = \frac{\sum D_{ref}}{N} \qquad t = \frac{D_{com} - \bar{x}}{s_{D_{ref}}}$$

(D)

Figure 1 – Pair-matching statistical models using a mean of 0 (A), mean of reference D-values (B), mean of reference and absolute D-values (C), and half-normal transformation mean of reference absolute D-values (D).

METHODS

ARTICULATIONS

Articulation-matching follows the procedure by Byrd and LeGarde (2014). Given the similarity to pair-matching, the same procedures apply here. However, unlike pair-matching, specific measurements are used for articulation-matching. These measurements include:

- **Hum_06 – Uln_11**
- **Hum_06 – Rad_04**
- **Hum_07 – Sca_03**
- **Hum_07 – Sca_04**
- **Fem_04 – Osc_17**
- **Fem_03 – Tib_02**

While it is possible to manipulate the statistical model, it is currently recommended to use the original statistical model where the sum of difference between measurements is calculated for the reference sample and comparison (Figure 2). More research is underway to improve this statistical model. The comparison D-value has the mean of the reference D-values subtracted, which is then divided by the standard deviation of reference D-values to produce a t-statistic. This t-statistic is compared to a t-distribution to produce a p-value where the degrees of freedom are equal to the reference sample minus one. Any p-value that is less than or equal to the alpha level is considered too different in size to have originated from a single individual, and any p-value greater than the alpha level indicates a similarity in size, suggesting the elements may belong to a single individual. It is important to note that a p-value greater than the alpha level does not confirm the elements originated from a single individual, but rather, indicates a comparison that cannot be excluded.

$$\boldsymbol{D = \sum a - b}$$

$$\boldsymbol{\overline{x} = \frac{\sum D_{ref}}{N}}$$

$$\boldsymbol{t = \frac{D_{com} - \overline{x}}{s_{D_{ref}}}}$$

Figure 2 – Articulation-matching model using the sum difference of measurements and the mean of the reference D-values.

METHODS

ASSOCIATIONS

Two methods of association are supported. The original following the procedure by Byrd and LeGarde (2014), and an ordination method (Lynch 2018).

The original association approach calculates the natural log of the sum of measurements of a bone from reference data with known associations. This sum of measurements is considered an acceptable index of the size of the bone. A simple linear regression model is calculated between each bone types reference data where the independent variable is the bone you are using to associate with another type. The natural log of the sum of measurements is calculated for each bone within a case comparison (Figure 3).

$$\boldsymbol{X = log_e \sum x_i}$$

$$\boldsymbol{Y = log_e \sum y_i}$$

Figure 3 – Association calculation for the independent and dependent bones.

Testing the null hypothesis that the bones are similar in size is based on checking that the case comparisons fall within a prediction interval calculated from the regression model. Originally a 90% prediction interval was recommended. The natural log summed value from the independent bone in a case comparison is used to predict what the dependent natural log summed value is. A 90% prediction interval around that point estimate is calculated and compared to the dependent natural log value from the case comparison. If that case comparison falls between the upper and lower bounds of the point estimates prediction interval, the null hypothesis is accepted.

The latest way to test the hypothesis is to calculate a t-statistic from the case comparison where y^ is the predicted value from the regression, y_i is the dependent natural log of summed measurements from the case comparison, S.E. is the standard error of the model, N is the sample size of the reference data, x_i is the independent natural log of summed measurements from the case comparison, x is the independent natural log of summed measurements of the reference data, and s_x is the standard deviation of the independent natural log of summed measurements of the reference data (Figure 4).

METHODS

$$t = |y^{\wedge} - y_i| \Big/ \left[(S.E.) * \sqrt{\left[1 + \left(\frac{1}{N}\right) + (X_i - X)^2 / (N * S_x{}^2)\right]} \right]$$

Figure 4 – t-statistic calculation from the case comparison.

This calculates a t-statistic which is compared to the t-distribution producing a p-value where the degrees of freedom are equal to the sample size minus 2. If the p-value is less than or equal to the alpha level, the case comparison is excluded. If the p–value is greater than the alpha level, it is considered too similar in size to be excluded.

The new model conducts two independent principal component analyses on each elements reference sample. The resulting principal components from both analyses are used in a canonical correlation analysis to identify the variation that correlates best between the two elements. The first canonical variates is subsequently used in simple linear regression to produce an algebraic equation. Each element in the case comparison has the measurement multiplied by the respective coefficient in the principal components analysis to produce principal components which are then multiplied by the respective coefficients from the canonical correlation analysis. The independent canonical variate is then used in the algebraic equation to predict what the dependent canonical variate score would be. If the actual case comparison dependent canonical variate score falls within the prediction interval, it is considered too similar to be excluded, and if the dependent value falls outside of the prediction interval, it is considered too dissimilar to be from a single individual.

The statistical models can be manipulated by choosing which measurements can be included and which prediction interval level or alpha level will be applied. The default uses the ordination method with all measurements and a 0.95 prediction interval.

METHODS

OUTLIERS

Identifying outliers is relatively simple. There are two approaches which can be applied. The first calculates the mean and standard deviation and the medium and quartiles of measurements within an element. These can be separated into standard deviation or quartile groups to identify who has the largest and smallest measurements relative to the assemblage. The second approach calculates the stature for the for each maximum length measurement and the mean and standard deviation and the medium and quartiles of the statures. These can be separated into standard deviation or quartile groups to identify who is the shortest and tallest relative to the assemblage. This allows comparison with existing antemortem data to quickly identify particular individuals. The stature data includes the following:

- **FDB-19th-century-cstat-any**
- **FDB-19th-century-cstat-white-male**
- **FDB-19th-century-cstat-white-female**
- **FDB-19th-century-cstat-black-male**
- **FDB-19th-century-cstat-black-female**
- **FDB-20th-century-fstat-any**
- **FDB-20th-century-fstat-white-male**
- **FDB-20th-century-fstat-white-female**
- **FDB-20th-century-fstat-black-male**
- **FDB-20th-century-fstat-black-female**
- **FDB-20th-century-fstat-hispanic-male**
- **Trotter-any-male**
- **Trotter-white-male**
- **Trotter-black-male**
- **Genoves-cstat-mexican-female (femur and tibia only)**
- **Genoves-cstat-mexican-male (femur and tibia only)**

REFERENCE DATA

The reference sample consists of data for the scapula, clavicle, humerus, ulna, radius, os coxa, femur, tibia, and fibula. The populations represented include European American, African American, and Asian. The reference is comprised of individuals from the Forensic Data Bank, Terry Collection, Hamann-Todd Collection, and Defense POW/MIA Accounting Agency case work. The data is not split by population as current research suggests there is little if any difference between populations in the amount of asymmetry and proportion. Further, it is not always possible to identify sex and ancestry from every element in an assemblage, so combining demographics allows a more practical reference data set for realistic commingled situations.

SINGLE COMPARISON

USER INTERFACE

The single comparison interface allows an analyst to conduct a one-to-one case comparison. The three methods currently supported include pair-matching, articulation, and association. Selecting between these options will dynamically generate the user input interface (Figure 5). Under pair and association, the **measurements** drop down menu allows the selection of standard or supplement measurements. Under articulation, there is no measurement selection as the method depends on one specific measurement per bone. The **predictor** drop down menu allows the selection of which element will be used as the independent variable with bone1 indicating the left column and bone2 indicating the right column. See the CoRA Measurement Guide for definitions and references for the measurement numbers.

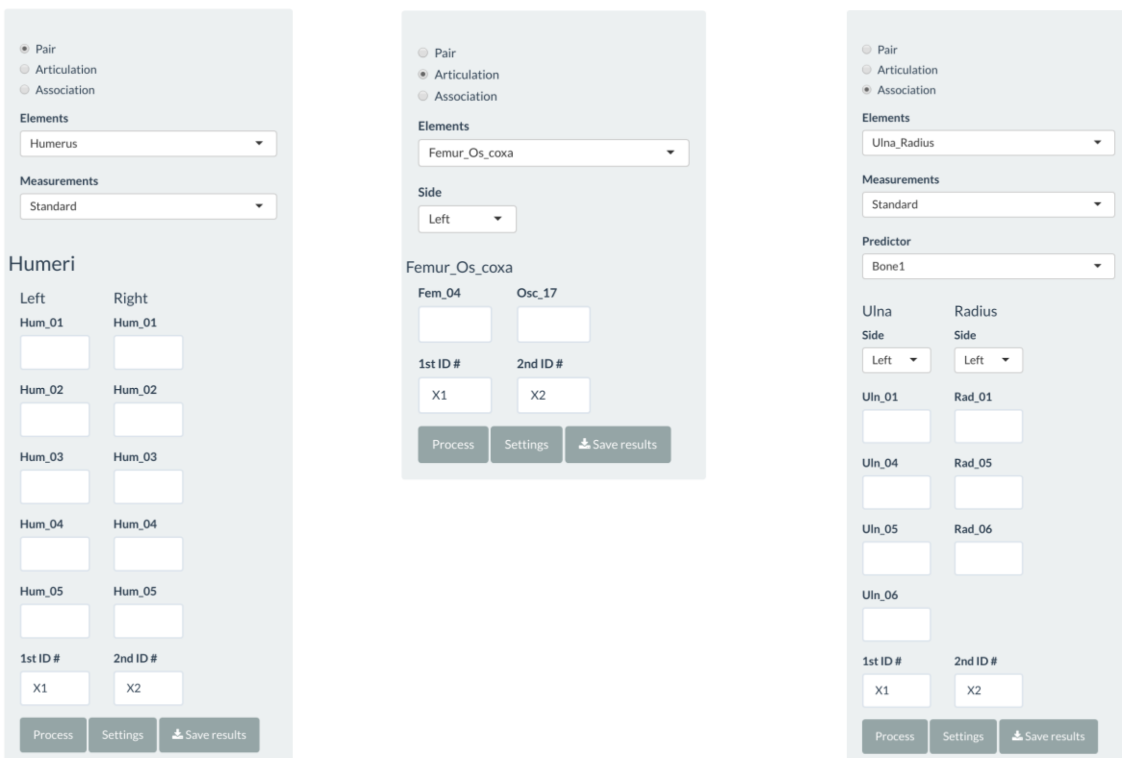


Figure 5 – Single comparison interface.

SINGLE COMPARISON

STATISTICAL PARAMETERS

The statistical parameters tab allows the manipulation of the statistical models (Figure 6). **PCA-CCA-Regression** switches between simple linear regression and the ordination approach. The ordination approach is the default. **Use alpha levels for regression** will calculate a t-statistic for the simple linear regression and use a p-value rather than prediction interval for excluding. The **Prediction Interval Level** slider allows setting the interval for the regression models. The **Alpha Level** slider will change the cut-off point for excluding comparisons for pair-matching, articulation, and association if using simple linear regression. The default is 0.05, but commonly 0.01 can be applied. The alpha level must be evaluated in light of the assemblage being analyzed. As a general rule, the smaller the alpha level the better the accuracy will be and the higher the alpha level the more exclusions can be made. A balance between the two must be chosen by the analyst.

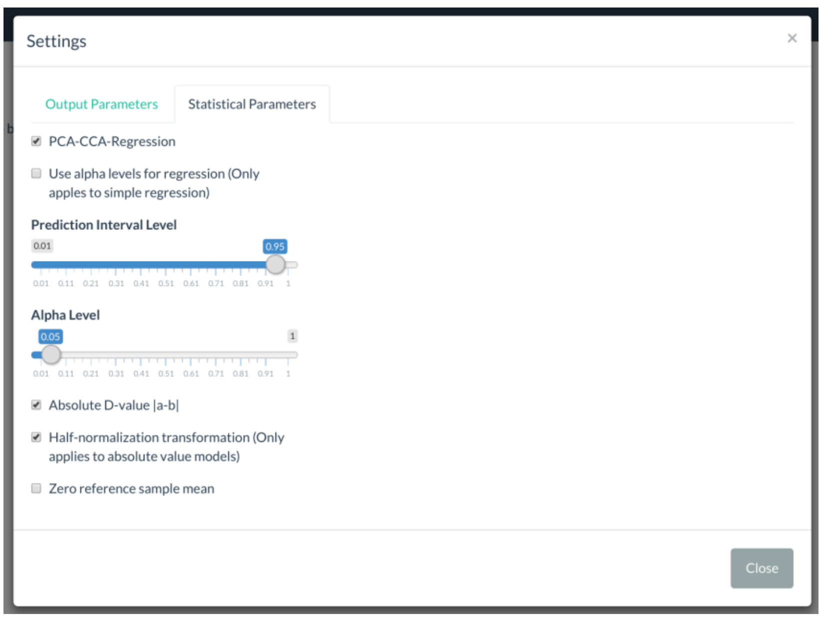


Figure 6 – Single comparison statistical parameters.

Absolute D-value (|a-b|) checkbox selects whether the summed absolute value of differences between measurements will be calculated or the summed difference between measurements (a-b). This applies not only to the case comparison, but to the reference data. The **half-normalization transformation** only applies to the Absolute D-value model. The **zero reference sample** mean checkbox will change the reference mean to zero within the t-statistic calculation. This tests the hypothesis that there are zero differences between paired elements. The default option is the mean of the reference.

OUTPUT PARAMETERS

This tab allows the selection for using excel files and a plot for output (Figure 7). The default is set to excel files. This will split the results by exclusions and non-exclusions.

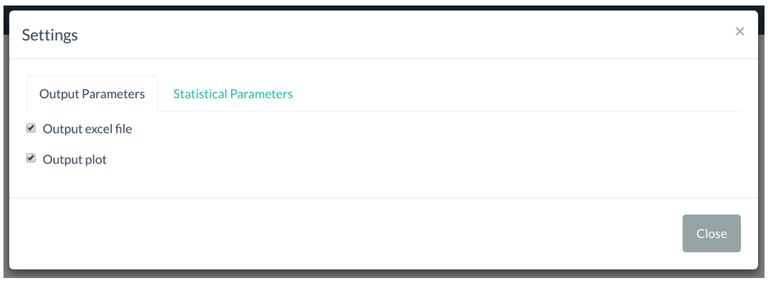


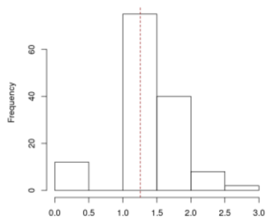
Figure 7 – Single comparison output parameters.

INTERPRETING RESULTS

For pair-matching and articulation-matching, if the case comparison p-value is less than or equal to the alpha level (0.05 default) than the comparison is excluded (Figure 8). If the case comparison is greater than the alpha level it is considered not excluded or a "potential match". However, caution must be applied when interpreting a non-exclusion as this does not confirm that the two elements originate from the same individual. That assessment must be made independent of OsteoSort. For association, if the case comparison falls outside of the prediction interval (0.90 default) than the case comparison is considered excluded (Figure 8). If the case comparison falls within the prediction interval it is considered not excluded or a "potential match".

The graph indicates the distribution of reference data and where your comparison falls within the reference. For pair-matching and articulation-matching a histogram is produce with a red line indicating your individual. If no red line is visible, the comparison is completely outside of the reference distribution. For association a scatterplot is produced with lines indicating the prediction interval, mean, and a blue dot indicating where the comparison falls within the reference data. Similarly, if no blue dot is visible, the comparison falls outside of the reference data.

SINGLE COMPARISON



Show entries

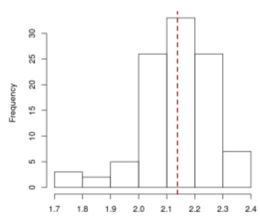
Search:

ID	Side	Element	ID	Side	Element	Measurements	p.value	# of measurements	Sample size	mean	sd
X1	left	humerus	X2	right	humerus	Hum_01	0.5458	1	137	1.3198	0.5442

Showing 1 to 1 of 1 entries

Previous 1 Next

(A)



Show entries

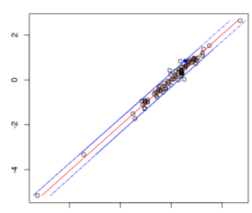
Search:

ID	Side	Element	ID	Side	Element	Measurements	p.value	# of measurements	Sample size
X1	Left	Os_coxa	X2	Left	Femur	Osc_17, Fem_04	0.491	1	102

Showing 1 to 1 of 1 entries

Previous 1 Next

(B)



Show entries

Search:

ID	Side	Element	ID	Side	Element	RSquared	Sample	p-value	Result
X2	left	radius	X1	left	ulna	0.978	90		Cannot Exclude

Showing 1 to 1 of 1 entries

Previous 1 Next

(C)

Figure 8 – Single comparison pair-match (A), articulation (B), and association (C) results.

SINGLE COMPARISON

SAVING RESULTS

After selecting the appropriate options for output files selecting **save results** will compress the data into a .zip archive and prompt you for download.

MULTIPLE COMPARISON

USER INTERFACE

The multiple comparison interface allows an analyst to conduct one-to-many comparisons. The three methods currently supported include pair-matching, articulation, and association. Selecting between these options will dynamically generate the user input interface (Figure 9). Under pair and association, the **measurements** drop down menu allows the selection of standard or supplement measurements. Under articulation, there is no measurement selection as the method depends on one specific measurement per bone. The **predictor** and **predicted** labels indicate which side will be used as the independent and depdendent variables. See the CoRA Measurement Guide for definitions and references for the measurement numbers. The **Browse** button allows you to upload a .CSV file based off of the template containing your measurement data for a full assemblage. **Clear Data** button will clear the uploaded data, allowing another dataset to be uploaded.

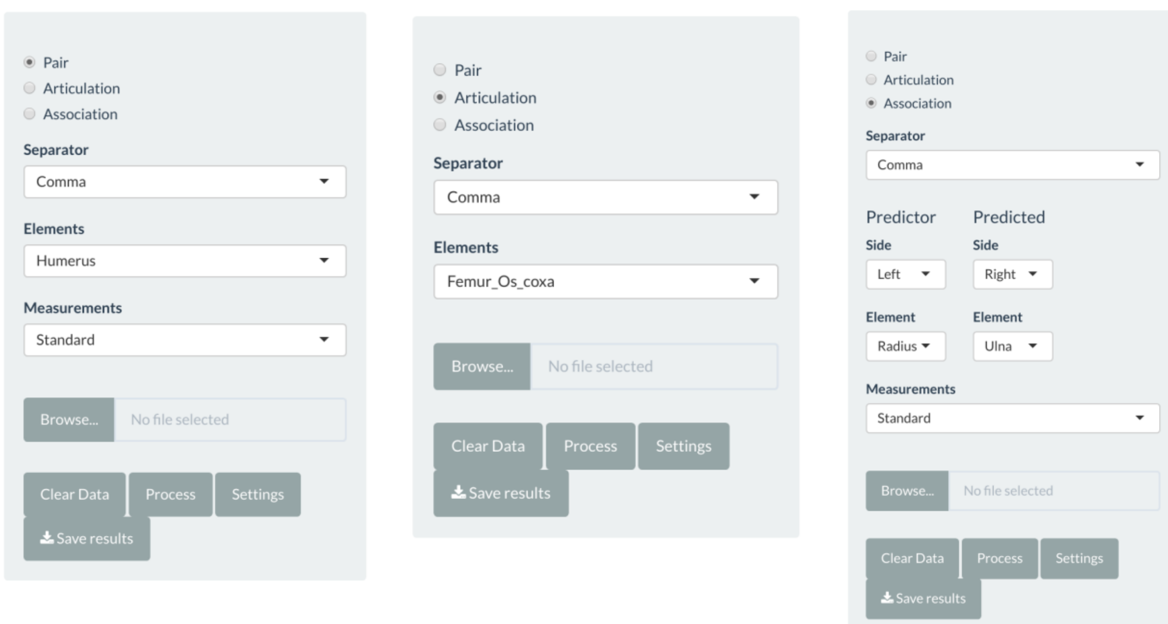


Figure 9 – Multiple comparison interface.

TEMPLATE

Using multiple comparison requires uploading data in .CSV format. A template is provided through OsteoSort with the column names required for uploading data.

STATISTICAL PARAMETERS

The statistical parameters tab allows the manipulation of the statistical models (Figure 10). **PCA-CCA-Regression** switches between simple linear regression and the ordination approach. The ordination approach is the default. **Use alpha levels for regression** will calculate a t-statistic for the simple linear regression and use a p-value rather than prediction interval for excluding. The **Prediction Interval Level** slider allows setting the interval for the regression models. The **Alpha Level** slider will change the cut-off point for excluding comparisons for pair-matching, articulation, and association if using simple linear regression. The default is 0.05, but commonly 0.01 can be applied. The alpha level must be evaluated in light of the assemblage being analyzed. As a general rule, the smaller the alpha level the better the accuracy will be and the higher the alpha level the more exclusions can be made. A balance between the two must be chosen by the analyst.

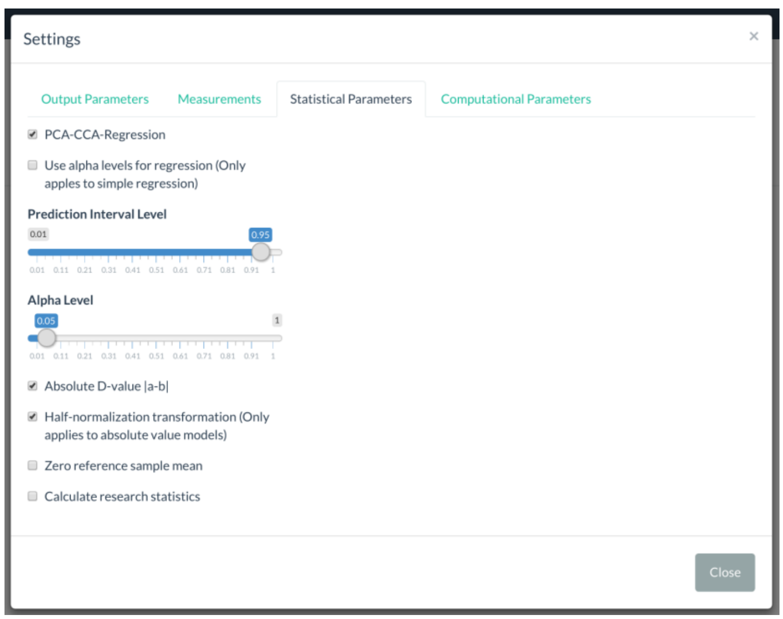


Figure 10 – Single comparison statistical parameters.

Absolute D-value (|a-b|) checkbox selects whether the summed absolute value of differences between measurements will be calculated or the summed difference between measurements (a-b). This applies not only to the case comparison, but to the reference data. The **half-normalization transformation** only applies to the Absolute D-value model. The **zero reference sample** mean checkbox will change the reference mean to zero within the t-statistic calculation. This tests the hypothesis that there are zero differences between paired elements. The default option is the mean of the reference. **Calculate research statistics** will generate performance statistics based on the assumption that the correct pair-match or association has the same **ID** in the .CSV data.

MEASUREMENT PARAMATERS

The measurements tab allows the manipulation of which measurements to include in all three analyses (Figure 11). Manipulating the measurement slider will indicate the minimum number of measurements required before a comparison will be analyzed. The default is one measurement.

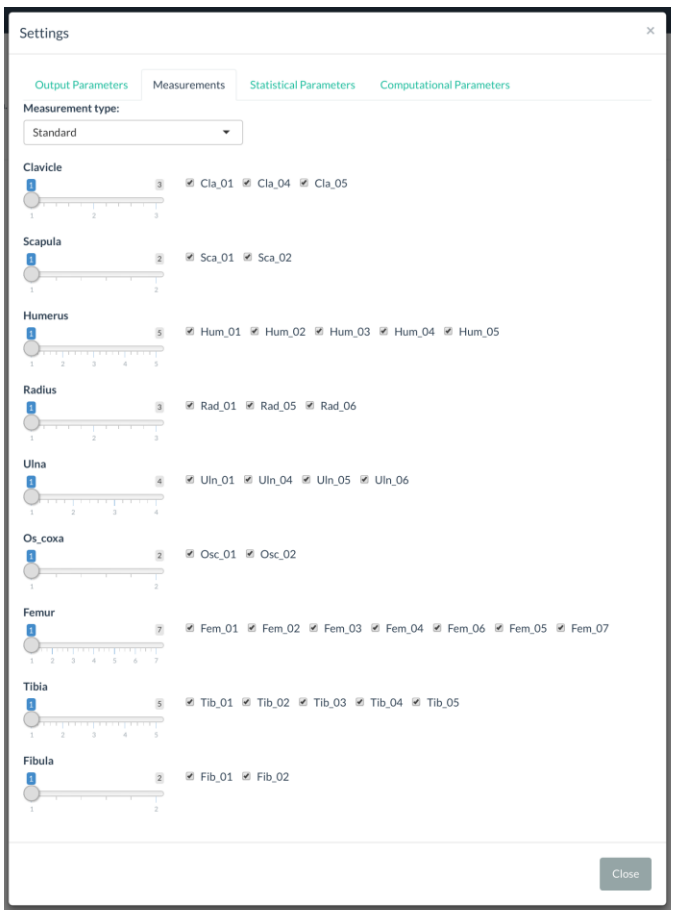


Figure 11 – Multiple comparison measurement parameters.

MULTIPLE COMPARISON

OUTPUT PARAMETERS

This tab allows the selection for using excel files for output (Figure 12). The default is set to excel files. This will split the results by exclusions and non-exclusions. Selecting the individual specimen file will generate a plain-text document for each individual, in the case of single comparison, one for the 1st ID # and the 2nd ID #. However, the individual files take considerably longer to generate.

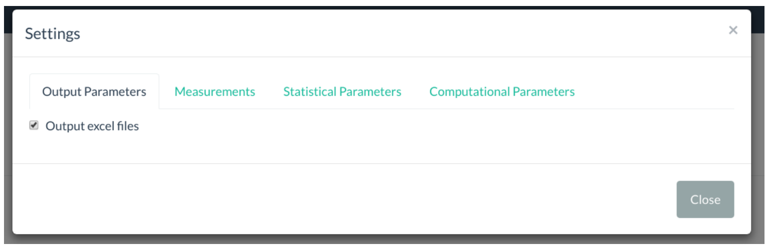


Figure 12 – Multiple comparison output parameters.

COMPUTATIONAL PARAMETERS

The computational parameters allow the setting of cores to be used for parallel processing (Figure 13). The default is one. This is fully supported under Linux and OSX, but only partially supported under Windows. Development is underway for full implementation under Windows.

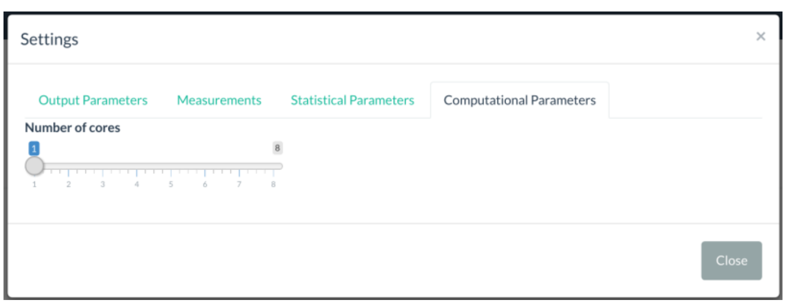


Figure 13 – Multiple comparison computational parameters.

INTERPRETING RESULTS

For pair-matching and articulation-matching, if the case comparison p-value is less than or equal to the alpha level (0.05 default) than the comparison is excluded (Figure 14). If the case comparison is greater than the alpha level it is considered not excluded or a “potential match”. However, caution must be applied when interpreting a non-exclusion as this does not confirm that the two elements originate from the same individual. That assessment must be made independent of OsteoSort. For association, if the case comparison falls outside of the prediction interval (0.90 default) than the case comparison is considered excluded (Figure 14). If the case comparison falls within the prediction interval it is considered not excluded or a “potential match”. Given the large amount of comparisons, graphs are not generated for multiple comparison.

MULTIPLE COMPARISON

Statistical analysis complete.
Number of comparisons conducted: 82302
Total specimens tested: 575
Number of specimens with 1 or more potential matches: 575
Total number of potential matches: 23442
Mean number of potential matches per specimen: 81.5 (14.2 %)
Standard deviation of potential matches: 48.8
Total number of exclusions: 58860 (71.5 %)

Not excluded Excluded

Show 10 entries Search:

ID	Side	Element	ID	Side	Element	Measurements	p.value	# of measurements	Sample size	mean	sd
CIL 2003-116G-01X-232C201	left	humerus	CIL 2003-116G-01X-232C202	right	humerus	Hum_01, Hum_02, Hum_03, Hum_04, Hum_05	0.3933	5	137	1.8289	0.3492
CIL 2003-116G-05X-219D201	left	humerus	CIL 2003-116G-01X-232C202	right	humerus	Hum_01, Hum_02, Hum_03, Hum_04, Hum_05	0.1977	5	137	1.8289	0.3492
CIL 2003-116G-05X-219F201	left	humerus	CIL 2003-116G-01X-232C202	right	humerus	Hum_01, Hum_02, Hum_03, Hum_04, Hum_05	0.1591	5	137	1.8289	0.3492
CIL 2003-116G-07X-217C201	left	humerus	CIL 2003-116G-01X-232C202	right	humerus	Hum_01, Hum_02, Hum_03, Hum_04, Hum_05	0.0531	5	137	1.8289	0.3492
CIL 2003-116G-07X-237C201	left	humerus	CIL 2003-116G-01X-232C202	right	humerus	Hum_02	0.3654	1	137	0.8294	0.495
CIL 2003-116G-08X-223F201	left	humerus	CIL 2003-116G-01X-232C202	right	humerus	Hum_01, Hum_02, Hum_03, Hum_04, Hum_05	0.4664	5	137	1.8289	0.3492
CIL 2003-116G-10X-256D201	left	humerus	CIL 2003-116G-01X-232C202	right	humerus	Hum_02	0.1946	1	137	0.8294	0.495
CIL 2003-116G-11X-249D201	left	humerus	CIL 2003-116G-01X-232C202	right	humerus	Hum_01, Hum_02, Hum_03, Hum_04, Hum_05	0.2011	5	137	1.8289	0.3492
CIL 2003-116G-12X-252A201	left	humerus	CIL 2003-116G-01X-232C202	right	humerus	Hum_01, Hum_02, Hum_03, Hum_04, Hum_05	0.0651	5	137	1.8289	0.3492
CIL 2003-116G-12X-252D201	left	humerus	CIL 2003-116G-01X-232C202	right	humerus	Hum_02	0.9439	1	137	0.8294	0.495

Showing 1 to 10 of 23,442 entries Previous 1 2 3 4 5 … 2345 Next

(A)

Statistical analysis complete.
Number of comparisons conducted: 161428
Total specimens tested: 1140
Number of specimens with 1 or more potential matches: 1139
Total number of potential matches: 99953
Mean number of potential matches per specimen: 175.5 (15.4 %)
Standard deviation of potential matches: 56.3
Total number of exclusions: 61475 (38.1 %)

Not excluded Excluded

Show 10 entries Search:

ID	Side	Element	ID	Side	Element	Measurements	p.value	# of measurements	Sample size
CIL 2003-116G-01X-232C401	left	femur	CIL 2003-116G-01X-232C901	left	os_coxa	Fem_04, Osc_17	0.8734	1	102
CIL 2003-116G-01X-233E401	left	femur	CIL 2003-116G-01X-232C901	left	os_coxa	Fem_04, Osc_17	0.5394	1	102
CIL 2003-116G-01X-234A401	left	femur	CIL 2003-116G-01X-232C901	left	os_coxa	Fem_04, Osc_17	0.0617	1	102
CIL 2003-116G-01X-235A401	left	femur	CIL 2003-116G-01X-232C901	left	os_coxa	Fem_04, Osc_17	0.1671	1	102
CIL 2003-116G-04X-56A401	left	femur	CIL 2003-116G-01X-232C901	left	os_coxa	Fem_04, Osc_17	0.5392	1	102
CIL 2003-116G-04X-56B401	left	femur	CIL 2003-116G-01X-232C901	left	os_coxa	Fem_04, Osc_17	0.645	1	102
CIL 2003-116G-04X-56C401	left	femur	CIL 2003-116G-01X-232C901	left	os_coxa	Fem_04, Osc_17	0.9434	1	102
CIL 2003-116G-04X-56D401	left	femur	CIL 2003-116G-01X-232C901	left	os_coxa	Fem_04, Osc_17	0.322	1	102
CIL 2003-116G-04X-56E401	left	femur	CIL 2003-116G-01X-232C901	left	os_coxa	Fem_04, Osc_17	0.6076	1	102
CIL 2003-116G-04X-56G401	left	femur	CIL 2003-116G-01X-232C901	left	os_coxa	Fem_04, Osc_17	0.892	1	102

Showing 1 to 10 of 99,953 entries Previous 1 2 3 4 5 … 9996 Next

(B)

Statistical analysis complete.
Number of comparisons conducted: 140
Total specimens tested: 24
Number of specimens with 1 or more potential matches: 22
Total number of potential matches: 28
Mean number of potential matches per specimen: 2.5 (10.4 %)
Standard deviation of potential matches: 1.2
Total number of exclusions: 112 (80 %)

Not excluded Excluded

Show 10 entries Search:

ID	Side	Element	ID.1	Side.1	Element.1	RSquared	Sample	Result
90	left	ulna	2	left	radius	0.979	90	Cannot Exclude
90	left	ulna	4	left	radius	0.979	90	Cannot Exclude
91	left	ulna	7	left	radius	0.979	90	Cannot Exclude
91	left	ulna	8	left	radius	0.979	90	Cannot Exclude
91	left	ulna	9	left	radius	0.979	90	Cannot Exclude
92	left	ulna	7	left	radius	0.979	90	Cannot Exclude
92	left	ulna	8	left	radius	0.979	90	Cannot Exclude
92	left	ulna	9	left	radius	0.979	90	Cannot Exclude
93	left	ulna	4	left	radius	0.979	90	Cannot Exclude
93	left	ulna	7	left	radius	0.979	90	Cannot Exclude

Showing 1 to 10 of 28 entries Previous 1 2 3 Next

(C)

Figure 14 – Multiple comparison pair-match (A), articulation (B), and association (C) results.

SAVING RESULTS

After selecting the appropriate options for output files selecting **save results** will compress the data into a .zip archive and prompt you for download.

OUTLIER METRIC ANALYSIS

USER INTERFACE

The outlier metric analysis interface allows an analyst to conduct one-to-many comparisons (Figure 15). **Browse** allows the upload of data in the specified .CSV template.

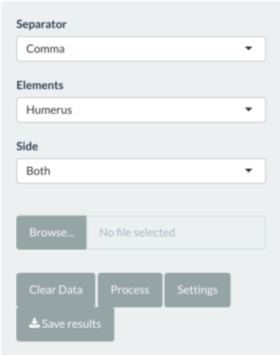


Figure 15 – Outlier metric analysis user interface.

MEASUREMENT PARAMETERS

Allows the selection of which measurement to use for outlier analysis (Figure 16). Only one measurement per element may be used.

Figure 16 – Measurement parameter user interface.

OUTLIER METRIC ANALYSIS

STATISTICAL PARAMETERS

The statistical parameters allow the selection of standard deviations or quartiles for identifying outliers (Figure 17). Selecting one will dynamically switch the sliding between standard deviations and interquartile ranges, which allow the setting of where the outlier cutoff should fall. The default is 2 for standard deviations and 1.5 for interquartile range. Selecting the slider will create a second, allowing a cutoff range to be specified for the outliers to fall between.

Figure 17 – Statistical parameter user interface.

OUTPUT PARAMETERS

This tab allows the selection for using excel files and a plot for output (Figure 18). The default is set to excel files. This will split the results by exclusions and non-exclusions.

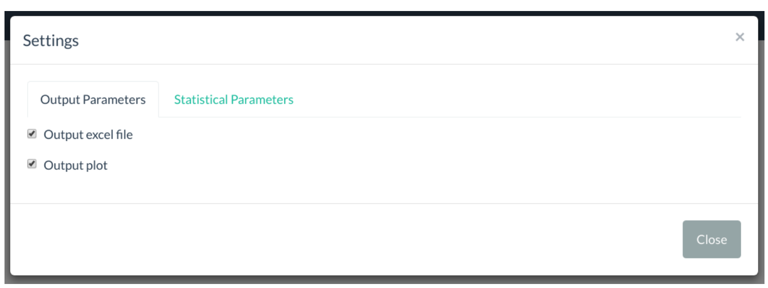
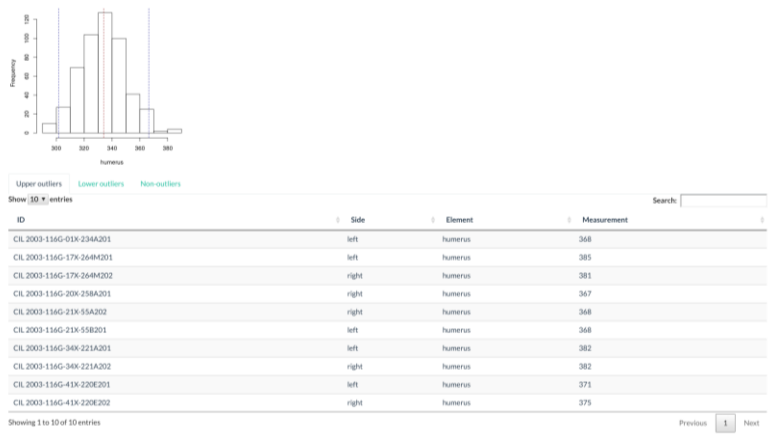


Figure 18 – Outlier metric comparison output parameters.

INTERPRETING RESULTS

The results produce a table with three tabs (Figure 19). The first two specifies the outliers above and below the standard deviation or interquartile cutoff values or ranges. The third specifies the elements that are not outliers. The graph indicates the distribution of the assemblage with the mean indicated by the red dashed line, and the cutoff values indicated by the blue dashed lines.



ID	Side	Element	Measurement
CIL 2003-116G-01X-234A201	left	humerus	368
CIL 2003-116G-17X-264M201	left	humerus	385
CIL 2003-116G-17X-264M202	right	humerus	381
CIL 2003-116G-20X-258A201	right	humerus	367
CIL 2003-116G-21X-55A202	right	humerus	368
CIL 2003-116G-21X-55B201	left	humerus	368
CIL 2003-116G-34X-221A201	left	humerus	382
CIL 2003-116G-34X-221A202	right	humerus	382
CIL 2003-116G-41X-220E201	left	humerus	371
CIL 2003-116G-41X-220E202	right	humerus	375

Figure 19 – Outlier metric analysis results.

SAVING RESULTS

Save results will compress the data into a .zip archive and prompt you for download. This includes the graph and excel files split by outlier groups.

OUTLIER STATURE ANALYSIS

USER INTERFACE

The outlier stature analysis interface allows an analyst to conduct one-to-many comparisons (Figure 20). Population allows the selection of reference population for the calculating stature. Browse allows the upload of data in the specified .CSV template.

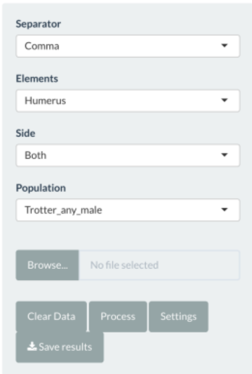


Figure 20 – Outlier stature analysis user interface.

MEASUREMENT PARAMETERS

Allows the selection of which measurement to use for outlier analysis (Figure 21). Only one measurement per element may be used.

Figure 21 – Measurement parameter user interface.

OUTLIER STATURE ANALYSIS

STATISTICAL PARAMETERS

The statistical parameters allow the selection of standard deviations or quartiles for identifying outliers (Figure 22). Selecting one will dynamically switch the sliding between standard deviations and interquartile ranges, which allow the setting of where the outlier cutoff should fall. The default is 2 for standard deviations and 1.5 for interquartile range. Selecting the slider will create a second, allowing a cutoff range to be specified for the outliers to fall between.

Figure 22 – Statistical parameter user interface.

OUTPUT PARAMETERS

This tab allows the selection for using excel files and a plot for output (Figure 23). The default is set to excel files. This will split the results by exclusions and non-exclusions.

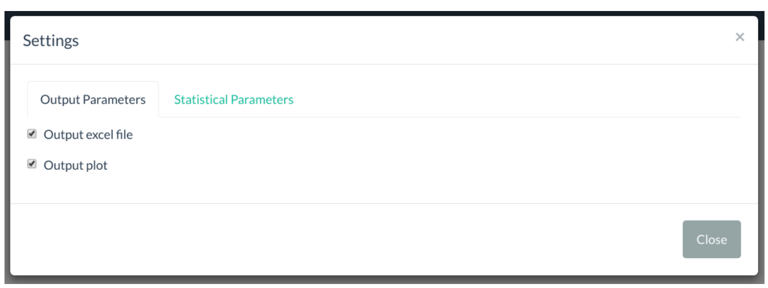
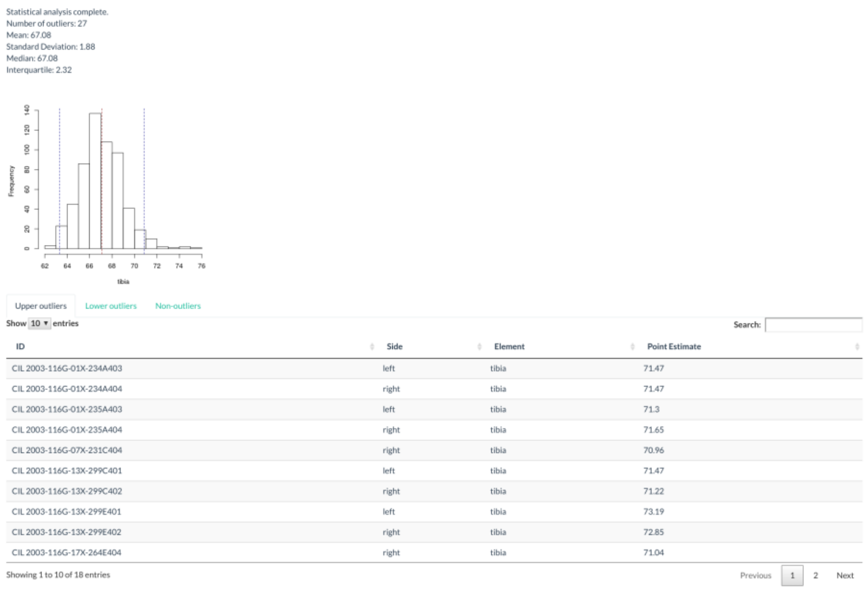


Figure 23 – Single comparison output parameters.

INTERPRETING RESULTS

The results produce a table with three tabs (Figure 24). The first two specifies the outliers above and below the standard deviation or interquartile cutoff values or ranges. The third specifies the elements that are not outliers. The graph indicates the distribution of the assemblage with the mean indicated by the red dashed line, and the cutoff values indicated by the blue dashed lines.



ID	Side	Element	Point Estimate
CIL 2003-116G-01X-234A403	left	tibia	71.47
CIL 2003-116G-01X-234A404	right	tibia	71.47
CIL 2003-116G-01X-235A403	left	tibia	71.3
CIL 2003-116G-01X-235A404	right	tibia	71.65
CIL 2003-116G-07X-231C404	right	tibia	70.96
CIL 2003-116G-13X-299C401	left	tibia	71.47
CIL 2003-116G-13X-299C402	right	tibia	71.22
CIL 2003-116G-13X-299E401	left	tibia	73.19
CIL 2003-116G-13X-299E402	right	tibia	72.85
CIL 2003-116G-17X-264E404	right	tibia	71.04

Figure 24 – Outlier metric analysis results.

SAVING RESULTS

Save results will compress the data into a .zip archive and prompt you for download. This includes the graph and excel files split by outlier groups.

CORA MEASUREMENT GUIDE

This is an edited copy of the CoRA measurement guide containing only the measurements currently used in OsteoSort. Measurements are from a variety of sources, and are referenced with the measurement description.

CLAVICLE

01 Maximum Length of the Clavicle: The maximum distance between the most extreme ends of the clavicle. *Instrument*: osteometric board.

Comment: Place the bone on the osteometric board and place the sternal end of the clavicle against the vertical end board. Press the movable upright against the acromial end and move the bone up, down and sideways until the maximum length is obtained (Martin and Knussmann 1988: 197, #1; Langley *et al.* 2016: 73, #38).

02 Maximum Diameter of the Clavicle at Midshaft: The maximum diameter of the bone measured at midshaft. *Instrument*: sliding caliper.

Comment: Determine the midpoint of the diaphysis on the osteometric board and mark it with a pencil. Place the bone between the two arms of the caliper and rotate the bone until the maximum diameter is obtained (Langley *et al.* 2016: 73, #39).

03 Minimum Diameter of the Clavicle at Midshaft: The minimum diameter of the bone measured at midshaft. *Instrument*: sliding caliper.

Comment: Determine the midpoint of the diaphysis on the osteometric board and mark it with a pencil. Place the bone between the two arms of the caliper and rotate the bone until the minimum diameter is obtained (Langley *et al.* 2016: 74, #40).

04 Sagittal (Anterior-Posterior) Diameter at Midshaft: The distance from the anterior to the posterior surface at midshaft. *Instrument:* sliding caliper.

Comment: Determine the midpoint of the diaphysis on the osteometric board and mark it with a pencil. Then determine sagittal diameter (Moore-Jansen *et al.* 1994, #36).

05 Vertical (Superior-Inferior) Diameter at Midshaft: The distance from the superior to the inferior surface at midshaft. *Instrument:* sliding caliper.

Comment: Taken perpendicular to sagittal diameter (Moore-Jansen *et al.* 1994, #37).

06 Maximum Width at the Distal End: The maximum width of the distal end of the clavicle where the calipers are in contact with the rough attachment area, taken perpendicular to the shaft. Avoid angling the calipers (Byrd and Adams 2015, #37A). *Instrument*: sliding caliper.

07 Breadth at the Inflexion Point at the Distal End: Anchor the caliper in the concave curve of the inflexion point at the distal end of the clavicle and place the other jaw of the caliper on the opposite side usually on or near the tubercle (Byrd and Adams 2015, #37B). *Instrument*: sliding caliper.

08 Maximum Thickness at the Inflexion Point at the Distal End: The maximum thickness in the same vertical plane as the previous measurement (take perpendicular to breadth at the inflection point measurement) (Byrd and Adams 2015, #37C). *Instrument*: sliding caliper.

09 Maximum Anterior-Posterior Width at the Proximal End: The maximum anterior-posterior width of the proximal end (be sure to hold in anatomical position) (Byrd and Adams 2015, #37D). *Instrument*: sliding caliper.

SCAPULA

01 Height of the Scapula (Anatomical Height): The distance from the most superior point of the cranial angle to the most interior point on the caudal angle (Martin and Knussmann 1988:197, #1; Langley *et al.* 2016: 74, #41). *Instrument*: sliding caliper or osteometric board.

02 Breadth of the Scapula (Anatomical Breadth): The distance from the midpoint on the dorsal border of the glenoid fossa to midway between the two ridges of the scapular spine on the vertebral border. *Instrument*: sliding or spreading caliper.

Comment: Project a line through the obtuse angle of a triangle formed by the vertebral border and the two ridges of the spine, dividing it into two equal halves. The medial measuring point is located where this line intersects the vertebral border (Hrdlicka 1920: 131; Langley *et al.* 2016: 74, #42).

03 Glenoid Cavity Height: The distance from the most superiorly located point on the margin of the glenoid cavity to the most inferiorly located point on the margin, taken perpendicular to glenoid cavity breadth. Often a distinct rim is visible (look at the fossa from the side and take the measurement at the apex of the ridges). In cases of severe lipping, this measurement should not be taken (Martin and Knussmann 1988: 198, #12; Langley *et al.* 2016: 74, #44; Byrd and Adams 2015, #39A). *Instrument*: sliding caliper.

04 Glenoid Cavity Breadth: Maximum distance from the ventral to dorsal margins (anterior/posterior) of the glenoid cavity, taken perpendicular to glenoid cavity height. In cases of severe lipping, this measurement should not be taken (Martin and Knussmann 1988: 198, #13, Langley *et al.* 2016: 74, #43). *Instrument*: sliding caliper.

Comment: Place one flat surface of the jaw of the calipers on the anterior side of the glenoid fossa and place the flat surface of the other jaw on the posterior side with both jaws oriented parallel to the long axis of the bone (Byrd and Adams 2015, #39B).

05 Minimum Length from Scapular Notch to Axillary Border: This measurement is the minimum distance from the superior border (typically in the notch) to the axillary border. Anchor a jaw of the caliper in the notch and use the other jaw to find the minimum distance to a point on the axillary border (Byrd and Adams 2015, #39D). *Instrument*: sliding caliper.

HUMERUS

01 Maximum Length of the Humerus: The distance from the most superior point on the head of the humerus to the most inferior point on the trochlea. *Instrument*: osteometric board.

Comment: Place the humerus on the osteometric board so that its long axis parallels the instrument. Place the head of the humerus against the vertical end board and press the movable upright against the trochlea. Move the bone up, down and sideways to determine the maximum distance (Hrdlicka 1920:126; Langley *et al.* 2016: 74, #45).

02 Epicondylar Breadth of the Humerus: The distance from the most laterally protruding point on the lateral epicondyle to the corresponding projection on the medial epicondyle (Martin and Knussmann 1988: 199, #4; Langley *et al.* 2016: 74, #46). *Instrument*: osteometric board or sliding calipers.

03 Vertical Diameter of Head: The distance between the most superior and inferior points on the border of the articular surface. *Instrument*: sliding caliper.

Comment: Do not include arthritic lipping which may be present on the perimeter of the joint surface. This diameter is not necessarily the maximum head diameter (Martin and Knussmann 1988: 200, #10; Langley *et al.* 2016: 74, #47).

04 Maximum Diameter of the Humerus at Midshaft: The maximum diameter of the humeral shaft at midshaft. *Instrument*: sliding caliper.

Comment: Determine the midpoint of the diaphysis on the osteometric board and mark with a pencil. Using sliding calipers to measure with one hand, rotate the bone with the other hand until the maximum diameter is obtained. (Martin and Knussmann 1988: 199, #5; Langley *et al.* 2016: 74-75, #48).

05 Minimum Diameter of the Humerus at Midshaft: The minimum diameter of the humeral shaft at midshaft. *Instrument*: sliding caliper.

Comment: Determine the midpoint of the diaphysis on the osteometric board and mark with a pencil. Using sliding calipers to measure with one hand, rotate the bone with the other hand until the minimum diameter is obtained. (Martin and Knussmann 1988: 199, #6; Langley *et al.* 2016: 75, #49).

06 Total Breadth of the Capitulum-Trochlea: The breadth of the capitulum and trochlea at the distal humerus. One end of the sliding calipers is positioned parallel to the flat, spool-shaped surface of the trochlea (medial), and the other end is moved until it comes into contact with the capitulum (lateral) (Byrd and Adams 2003, #41A). *Instrument*: sliding caliper.

07 Anterior-Posterior Breadth of the Head: The maximum breadth of the humeral head taken in the anterior-posterior direction on the articular surface. This measurement is taken perpendicular from the vertical diameter of the humeral head (Byrd and Adams 2003, #42A). *Instrument*: sliding caliper.

08 Minimum Diameter of the Diaphysis: The minimum diameter of the humeral diaphysis taken in any direction perpendicular to the shaft. This measurement should be taken on the oval part of the shaft, superior to the flattening observed around the olecranon fossa and the lateral supracondylar ridge. Often it is found near midshaft (Byrd and Adams 2003, #44B). *Instrument*: sliding caliper.

09 Maximum Diameter of Diaphysis at the Deltoid Tuberosity: The maximum diameter of the diaphysis within the length of the deltoid tuberosity. Rotate and slide the element to find the maximum diameter (Byrd and Adams 2015, #44D). *Instrument*: sliding caliper.

RADIUS

01 Maximum Length of the Radius: The distance from the most proximally positioned point on the head of the radius to the tip of the styloid process without regard to the long axis of the bone. *Instrument*: osteometric board.

Comment: Place the proximal end against the vertical upright of the osteometric board and press the movable upright against the distal end. Move the bone up, down and sideways to obtain the maximum length (Martin and Knussmann 1988: 201, #1; Hrdlicka 1920: 127; Langley *et al.* 2016: 75, #50).

02 Maximum Diameter of the Radius at Midshaft: The maximum diameter of the radial shaft taken at midshaft. *Instrument:* sliding caliper.

Comment: Mark the midshaft of the bone with a pencil. Using sliding calipers to measure with one hand, rotate the bone with the other hand until the minimum diameter is obtained (Langley *et al.* 2016: 75, #51).

03 Minimum Diameter of the Radius at Midshaft: The minimum diameter of the radial shaft taken at midshaft. *Instrument*: sliding caliper.

Comment: Mark the midshaft of the bone with a pencil. Using sliding calipers to measure with one hand, rotate the bone with the other hand until the minimum diameter is obtained (Langley *et al.* 2016: 75, #52).

04 Maximum Diameter of the Head: The maximum diameter of the radial head measured on the margin of the head that articulates with the ulna. The bone is rotated until the maximum distance is obtained (Montagu 1960: 68; Langley *et al.* 2016: 75, #53; Byrd and Adams 2003, #47D). *Instrument*: sliding caliper.

05 Anterior-Posterior (Sagittal) Diameter at Midshaft: The distance between anterior and posterior surfaces at midshaft. *Instrument:* sliding caliper.

Comment: Determine the midpoint of the diaphysis on the osteometric board and mark with a pencil. Measure sagittal diameter at that point. This measurement is almost always less than the medial-lateral diameter (Moore-Jansen *et al.* 1994, #46).

06 Medial-Lateral (Transverse) Diameter at Midshaft: The distance between medial and lateral surfaces at midshaft. *Instrument:* sliding caliper.

Comment: Perpendicular to anterior-posterior diameter (Moore-Jansen *et al.* 1994, #47).

07 Maximum Diameter at the Radial Tuberosity: The maximum shaft diameter on the radial tuberosity. Position the calipers around the tuberosity and rotate the bone until the maximum distance is obtained (Byrd and Adams 2003, #47A). *Instrument*: sliding caliper.

08 Maximum Diameter of the Diaphysis Distal to the Radial Tuberosity: The maximum shaft diameter distal to the radial tuberosity, positioned along the interosseous crest. The bone should be rotated to find the maximum distance (Byrd and Adams 2003, #47B). *Instrument*: sliding caliper.

09 Minimum Diameter of the Diaphysis Distal to the Radial Tuberosity: The minimum shaft diameter anywhere distal to the radial tuberosity. The bone may be rotated to find the minimum distance (Byrd and Adams 2003, #47C). *Instrument*: sliding caliper.

10 Breadth of the Distal Epiphysis: The maximum distance from the ulnar notch to the lateral aspect of the styloid process. The medial protrusions (articular borders of the ulnar notch) are placed against the vertical endboard of the osteometric board (sliding calipers may also be used) and the movable portion is applied to the lateral surface of the styloid process to find the maximum breadth (Byrd and Adams 2015, #47E). *Instrument*: sliding caliper.

ULNA

01 Maximum Length of the Ulna: The distance between the most proximal point on the olecranon and the most distal point on the styloid process. *Instrument*: osteometric board.

Comment: Place the proximal end of the ulna against the vertical end board. Press the movable upright against the distal end while moving the bone up, down and sideways to obtain the maximum length (Hrdlicka 1920; 127; Martin and Knussmann 1988: 204, #1; Langley *et al.* 2016: 75-76, #54).

02 Maximum Midshaft Diameter of the Ulna: The maximum diameter of the diaphysis at midshaft. *Instrument*: sliding caliper

Comment: Mark the midshaft of the bone with a pencil. Using sliding calipers to measure with one hand, rotate the bone with the other hand until the maximum diameter is obtained (Langley *et al.* 2016: 76, #55).

03 Minimum Midshaft Diameter of the Ulna: The minimum diameter of the diaphysis at midshaft. *Instrument*: sliding caliper.

Comment: Mark the midshaft of the bone with a pencil. Using sliding calipers to measure with one hand, rotate the bone with the other hand until the minimum diameter is obtained (Langley *et al.* 2016: 76, #56).

04 Anterior-Posterior (Dorso-Volar) Diameter: The maximum diameter of the diaphysis where the crest exhibits the greatest development in the anterior-posterior (dorso-volar) plane (Moore-Jansen *et al.* 1994, #49). *Instrument:* sliding caliper.

05 Medial-Lateral (Transverse) Diameter: The distance between medial and lateral surfaces at the level of greatest crest development. *Instrument:* sliding caliper.

Comment: Taken perpendicular to anterior-posterior diameter (Moore-Jansen *et al.* 1994, #50).

06 Physiological Length of the Ulna: The distance between the deepest point on the articular surface of the coronoid process on the guiding ridge and the most inferior point on the distal articular surface of the ulna. *Instrument*: spreading caliper.

Comment: Do not include the styloid process or the groove between the styloid process and the distal articular surface (Martin and Knussmann 1988: 204, #2; Langley *et al.* 2016: 76, #57).

07 Minimum Circumference of the Ulna: The least circumference near the distal end of the bone (Martin and Knussmann 1988: 204, #3; Langley *et al.* 2016: 76, #58). *Instrument*: tape.

08 Olecranon Breadth: The maximum breadth of the olecranon process, taken perpendicular to the longitudinal axis of the semilunar notch (Martin and Knussmann 1988: 206, #6; Langley *et al.* 2016: 76, #59). *Instrument*: sliding caliper.

09 Minimum Diameter of the Diaphysis including Interosseous Crest: Locate the minimum diameter of the diaphysis along the portion of the bone that includes the interosseous crest. This measurement may not necessarily include the interosseous crest, but should be taken on that part of the shaft that exhibits the crest. This measurement is not always near the distal end of the crest (Byrd and Adams 2003, #51A). *Instrument:* sliding caliper.

10 Minimum Diameter of the Diaphysis: This measurement will be found near the distal epiphysis of the ulna. The bone should be rotated in order to locate the minimum distance (Byrd and Adams 2003, #51B). *Instrument:* sliding caliper.

11 Breadth of the Semilunar Notch: This is a measure of only the distal surface of the semilunar notch (the base). *Instrument:* sliding caliper.

Comment: In order to obtain the distance, one end of the calipers is positioned within the radial notch (approximate midpoint), roughly parallel to the shaft. The other end of the calipers is applied to the medial edge of the semilunar notch to obtain the maximum distance. Calipers can be angled (Byrd and Adams 2003, #51C).

OS COXA

01 Maximum Innominate Height: The distance from the most superior point on the iliac crest to the most inferior point on the ischial tuberosity (Martin and Knussmann 1988: 213, #1). *Instrument*: osteometric board or spreading caliper.

Comment: When using an osteometric board, place the ischium against the vertical end board and press the movable upright against the iliac crest. Move the ilium sideways and up and down to obtain the maximum distance (Hrdlicka 1920: 135; Langley *et al.* 2016: 77, #64).

02 Maximum Iliac Breadth: The distance from the anterior superior iliac spine to the posterior superior iliac spine (Martin and Knussmann 1988: 213, #2; Langley *et al.* 2016: 77, #65). *Instrument*: spreading caliper.

03 Pubis Length: The distance from the point in the acetabulum where the three elements of the os coxae meet to the upper end of the pubic symphysis. *Instrument:* sliding caliper.

Comment: The measuring point in the acetabulum may be identified in the adult by (1) an irregularity which is frequently visible, both on the acetabular and pelvic surfaces; (2) a change in thickness which may be seen by holding the bone up to a light; (3) a notch often present in the border of the articular surface in the acetabulum. In measuring the pubis, care should be taken to hold the caliper parallel to the long axis of the bone (Moore-Jansen *et al.* 1994, #58).

04 Ischium Length: The distance from the point in the acetabulum where the three elements meet to the deepest point on the ischial tuberosity. *Instrument:* sliding caliper.

Comment: Ischium length should be measured approximately perpendicular to pubis length (Moore-Jansen *et al.* 1994, #59).

05 Minimum Iliac Breadth (WIB): The minimum distance measured from the area below the anterior inferior iliac spine to the most inward curvature of the greater sciatic notch (Langley *et al.* 2016: 77, #66; Byrd and Adams 2015, #59D). *Instrument*: sliding caliper.

06 Maximum Pubis Length (XPL): The distance between symphysion (the most superior point on the symphyseal face) to the farthest point on the acetabular rim. *Instrument*: spreading caliper.

Comment: The measurement is taken to the rim itself (not inside or outside the rim) (Langley *et al.* 2016: 77, #67).

07 Minimum Pubis Length (WPL): The distance between symphysion (the most superior point on the symphyseal face) to the closest point on the acetabular rim. *Instrument*: spreading caliper.

Comment: The measurement is taken to the rim itself (not inside or outside the rim) (Langley *et al.* 2016: 77, #68).

08 Ischial Length (ISL): The distance from the point on the acetabular rim where the iliac blade meets the acetabulum to the most medial point on the epiphysis of the ischial tuberosity. *Instrument*: sliding caliper.

Comment: If the borders of the epiphysis cannot be determined, do not take this measurement (Langley *et al.* 2016: 77, #69).

09 Minimum Ischial Length (WISL): The distance from the most medial point on the epiphysis of the ischial tuberosity to the closest point on the acetabular rim. *Instrument*: sliding caliper.

Comment: If the borders of the epiphysis cannot be determined, do not take this measurement (Langley *et al.* 2016: 78, #70).

10 Maximum Ischiopubic Ramus Length (XIRL): The distance from the most inferior point on the symphyseal face to the most distant point on the ischial tuberosity (Langley *et al.* 2016: 78, #71). *Instrument*: sliding caliper.

11 Anterior Superior Iliac Spine to Symphysion (ASISS): The measurement from the apex of the anterior superior iliac spine (most projecting area or point) to symphysion (Langley *et al.* 2016: 78, #72). *Instrument*: sliding caliper.

12 Maximum Posterior Superior Iliac Spine to Symphysion (PSISS): The maximum measurement from the posterior border of the posterior superior iliac spine to symphysion (Langley *et al.* 2016: 78, #73).

Instrument: sliding caliper.

13 Maximum Apical Border to Symphysion (WAS): The minimum measurement from symphysion to the apex (anterior border) of the auricular surface (Langley *et al.* 2016: 78, #74). *Instrument*: sliding caliper.

14 Thickness of the Ilium at the Sciatic Notch: Position one end of the calipers along the arcuate line, adjacent to the apex of the auricular surface. Slide the opposing end of the calipers to the posterior surface of the ilium to obtain the measurement (Byrd 2008, #59A). *Instrument:* sliding caliper.

15 Maximum Breadth of the Ischium: Position one end of the calipers in the obturator foramen and place the other end on the ischial tuberosity. Move the calipers around to find the maximum distance (Byrd and Adams 2015, #59B). *Instrument:* sliding caliper.

16 Minimum Breadth of the Pubis: Position the calipers along the iliopubic ramus; rotate and slide the calipers to find the minimum distance. Use the pointed edges of the calipers instead of the flat so as not to obstruct the measurement (Byrd and Adams 2015, #59C). *Instrument:* sliding caliper.

17 Maximum Diameter of the Acetabulum: The maximum distance of the acetabulum taken at any two points along the articular border of the lunate surface (look at the acetabulum from the side and take the measurement at the peaks of the ridges). This distance is commonly found in line with the iliac crest and the ischial tuberosity (Byrd 2008, #59E). *Instrument:* sliding caliper.

FEMUR

01 Maximum Length of the Femur: The distance from the most proximal point on the head of the femur to the most distal point on the medial or lateral femoral condyle (Martin and Knussmann 1988: 216, #1). *Instrument*: osteometric board.

Comment: Place the femur parallel to the long axis of the osteometric board and resting on its posterior surface. Press the medial or lateral condyle against the vertical end board while applying the movable upright to the femoral head. Move the bone up, down, and sideways until the maximum length is obtained (Hrdlicka 1920: 128; Langley *et al.* 2016: 78, #75).

02 Bicondylar Length of the Femur: The distance from the most proximal point on the head of the femur to a plane drawn between the inferior surfaces of the distal condyles . *Instrument*: osteometric board.

Comment: Place the femur on the osteometric board so that the bone is resting on its posterior surface. Press both distal condyles against the vertical end board while applying the movable upright to the head of the femur (Martin and Knussmann 1988: 216, #2; Hrdlicka 1920: 128; Langley *et al.* 2016: 78, #76).

03 Epicondylar Breadth of the Femur: The distance between the two most projecting points on the epicondyles. *Instrument*: osteometric board.

Comment: Place the femur on the osteometric board so that it is resting on its posterior surface. Press one of the epicondyles against the vertical end board while applying the movable upright to the other condyle. (Martin and Knussmann 1988: 218, #21; Langley *et al.* 2016: 79, #77).

04 Maximum Diameter of the Femur Head: The maximum diameter of the femur head measured on the border of the articular surface. *Instrument*: sliding caliper.

Comment: Rotate the arms of the caliper around the femur head to find the maximum diameter. (Dwight 1905: 21; Montagu 1960: 70; Langley *et al.* 2016: 79, #78).

05 Anterior-Posterior (Sagittal) Subtrochanteric Diameter of the Femur: The anterior-posterior diameter of the proximal end of the diaphysis measured perpendicular to the transverse diameter at the point of the greatest lateral expansion (See definition #65 for approximate location on the femoral shaft for this measurement). This diameter is oriented perpendicular to the anterior surface of the femur neck (Martin and Knussman 1988: 217, #10; Langley *et al.* 2016: 80, #80). *Instrument*: sliding caliper.

06 Medial-Lateral (Transverse) Subtrochanteric Diameter of the Femur: The transverse diameter of the proximal portion of the diaphysis at the point of its greatest lateral expansion. *Instrument*: sliding caliper.

Comment: The transverse diameter is oriented parallel to the anterior surface of the femur neck. Close attention should be paid to assessing this plane in femoral necks with a significant degree of torsion. In cases where this cannot be determined (e.g. where the lateral surfaces remain parallel) this measurement is recorded in the region 2-5 cm below the lesser trochanter (Martin and Knussman 1988: 217 #9; Langley *et al.* 2016: 79-80, #79).

07 Anterior-Posterior (Sagittal) Midshaft Diameter: The distance between anterior and posterior surfaces measured approximately at the midpoint of the diaphysis, at the highest elevation of linea aspera. *Instrument:* sliding caliper.

Comment: The sagittal diameter should be measured perpendicular to the anterior bone surface (Moore-Jansen *et al.* 1994, #66).

08 Medial-Lateral (Transverse) Midshaft Diameter: The distance between the medial and lateral surfaces at midshaft, measured perpendicular to the anterior-posterior diameter (Moore-Jansen *et al.* 1994, #67). *Instrument:* sliding caliper.

09 Maximum Midshaft Diameter of the Femur: The maximum diameter of the femoral shaft taken at midshaft. *Instrument*: sliding caliper.

Comment: Mark the midshaft of the bone with a pencil. Using sliding calipers to measure with one hand, rotate the bone with the other hand until the maximum diameter is obtained (Langley *et al.* 2016:

80, #81).

10 Minimum Midshaft Diameter of the Femur: The minimum diameter of the femoral shaft taken at midshaft. *Instrument*: sliding caliper.

Comment: Mark the midshaft of the bone with a pencil. Using sliding calipers to measure with one hand, rotate the bone with the other hand until the minimum diameter is obtained (Langley *et al.* 2016: 80, #82).

11 Circumference of the Femur at Midshaft: The circumference measured at the midshaft. *Instrument*: tape.

Comment: If the linea aspera is unusually hypertrophied at midshaft, this measurement should be recorded approximately 10 mm above the midshaft (Martin and Knussmann 1988: 217, #8; Langley *et al.* 2016: 80, #83).

12 Maximum Anterio-posterior Length of the Lateral Condyle: The distance between the most anterior and posterior points on the articular surface of the lateral condyle (Martin and Knussman 1988: 219, #23). *Instrument*: sliding caliper.

Comment: Holding the femur with the distal end up, orient the measuring arms of the caliper with the long axis of the bone to obtain this measurement (Langley *et al.* 2016: 80, #84).

13 Maximum Anterio-posterior Length of the Medial Condyle: The distance between the most anterior and posterior points on the articular surface of the medial condyle (Martin and Knussman 1988: 219, #24). *Instrument*: sliding caliper.

Comment: Holding the femur with the distal end up, orient the measuring arms of the caliper with the long axis of the bone to obtain this measurement (Langley *et al.* 2016: 80-81, #84).

14 Minimum Anterior-Posterior Diameter of the Diaphysis: The minimum anterior-posterior diameter anywhere along the diaphysis. The linea aspera and condyles should be utilized in order to orient the bone in anatomical position (use the condyles to orient) (Byrd and Adams 2003, #68A). *Instrument*: sliding caliper.

15 Minimum Medial-Lateral Diameter of the Diaphysis: The minimum medial-lateral diameter anywhere along the diaphysis. The linea aspera and condyles should be utilized in order to orient the bone (should be taken in a perpendicular orientation to 68A) (Byrd and Adams 2003, #68B). *Instrument*: sliding caliper.

16 Minimum Superior-Inferior Neck Diameter: The minimum distance from the superior surface to the inferior surface on the femoral neck (Seidemann *et al*. 1998). Place caliper in the saddle of the neck (superior) and close inferior caliper arm, moving as necessary to find the minimum (Byrd and Adams 2015, #68D). *Instrument*: sliding caliper.

17 Maximum Diameter along the Linea Aspera: The maximum shaft diameter at any point along the linea aspera. As the bone should be rotated to obtain the maximum distance, the measurement does not necessarily have to include the linea aspera, though it likely will (Byrd and Adams 2003, #68E). *Instrument*: sliding caliper.

TIBIA

01 Length of the Tibia: The distance from the superior articular surface of the lateral condyle of the tibia to the tip of the medial malleolus (Martin and Knussmann 1988: 220, #1). *Instrument*: osteometric board.

Comment: An osteometric board with a hole for the intercondylar eminence makes this measurement easier to take. Place the tibia on the osteometric board resting on its posterior surface with the longitudinal axis of the bone parallel to the board (Hrdlicka 1920: 129). If using an osteometric board without a hole, place the tibia on the osteometric board so that it the long axis is parallel to the board. The measurement is taken from the lateral condyle to the tip of the medial malleolus (Langley *et al.* 2016: 81, #86).

02 Maximum Proximal Epiphyseal Breadth of the Tibia: The maximum distance between the two most projecting point on the margins of the medial and lateral condyles of the proximal epiphysis. *Instrument*: osteometric board.

Comment: Place the tibia on the osteometric board resting on its posterior surface. Press the lateral condyle against the vertical end board, and place the movable upright against the medial condyle. Tibiae exhibiting marked torsion may have to be rotated to obtain the maximum breadth (Martin and Knussmann 1988: 221, #3; Langley *et al.* 2016: 81, #87).

03 Maximum Distal Epiphyseal Breadth: The distance between the most medial point on the medial malleolus and the lateral surface of the distal epiphysis. *Instrument*: osteometric board.

Comment: Place the two lateral protrusions of the distal epiphysis against the fixed side of the osteometric board and move the sliding board until it contacts the medial malleolus (Martin and Knussmann 1988: 221, #6; Langley *et al.* 2016: 81, #88).

04 Maximum Diameter at the Nutrient Foramen: The distance between the anterior crest and the posterior surface at the level of the nutrient foramen (Moore-Jansen *et al.* 1994, #72). *Instrument:* sliding caliper.

05 Medial-Lateral (Transverse) Diameter at the Nutrient Foramen: The straight line distance from the medial margin to the interosseous crest at the level of the nutrient foramen (Moore-Jansen *et al.* 1994, #73). *Instrument:* sliding caliper.

06 Circumference at the Nutrient Foramen: The circumference measured at the level of the nutrient foramen (Moore-Jansen *et al.* 1994, #74). *Instrument:* tape.

07 Maximum Midshaft Diameter of the Tibia: The maximum diameter of the tibial shaft taken at midshaft. *Instrument*: sliding caliper.

Comment: Mark the midshaft of the bone with a pencil. Using sliding calipers to measure with one hand, rotate the bone with the other hand until the maximum diameter is obtained (Langley *et al.* 2016: 81, #89).

08 Minimum Midshaft Diameter of the Tibia: The minimum diameter of the tibial shaft taken at midshaft. *Instrument*: sliding caliper.

Comment: Mark the midshaft of the bone with a pencil. Using sliding calipers to measure with one hand, rotate the bone with the other hand until the minimum diameter is obtained (Martin and Knussmann 1988: 573, #9a; Langley *et al.* 2016: 81, #90).

09 Circumference of the Tibia at the Midshaft: The circumference measured at the level of the midshaft (Martin and Knussmann 1988: 574, #10a; Langley *et al.* 2016: 82, #91). *Instrument*: tape.

10 Maximum Anterior-Posterior Diameter Distal to the Popliteal Line: This measurement should be taken at the most distal point of the popliteal line where it intersects with the margin of the diaphysis. The calipers are rotated to find the maximum distance (this is the maximum diameter of the diaphysis at this point). Note that the correct location may be difficult to determine in very gracile individuals (Byrd and Adams 2003, #74A). *Instrument:* sliding calipers.

11 Minimum Anterior-Posterior Diameter: Locate the minimum anterior-posterior distance at any point on the tibial shaft. Use the medial malleolus and anterior crest to orient the bone, particularly when torsion is present (Byrd and Adams 2003, #74B). *Instrument:* sliding calipers.

12 Maximum Anterior-Posterior Distance of the Distal Articular Surface: Locate the maximum anterior-posterior distance of the distal articular surface by viewing the element from the side to *find the peaks of the articular surface* and measuring the distance between them. Use the medial malleolus to orient the bone (Byrd and Adams 2015, #74F). *Instrument:* sliding calipers.

FIBULA

01 Maximum Length of the Fibula: The maximum distance between the most superior point on the fibular head and the most inferior point on the lateral malleolus (Martin and Knussmann 1988: 222, #1). *Instrument*: osteometric board.

Comment: Place the fibula on the osteometric board and place the tip of the lateral malleolus against the vertical end board. Press the movable upright against the proximal end of the bone while moving it up and down and sideways to obtain the maximum length (Langley *et al.* 2016: 82, #92).

02 Maximum Diameter of the Fibula at Midshaft: The maximum diameter at the midshaft. (Martin and Knussmann 1988: 222, #2). *Instrument*: sliding caliper.

Comment: Find the midpoint on the osteometric board and mark with a pencil. Place the diaphysis of the fibula between the two arms of the caliper while turning the bone to obtain the maximum diameter (Langley *et al.* 2016: 82, #93).

03 Maximum Diameter of the Diaphysis: This measurement should only be taken along the interosseous crest. Avoid measurements of the shaft near the epiphyses (Byrd and Adams 2015, #76A). *Instrument:* sliding calipers.

04 Minimum Diameter of the Diaphysis: The minimum distance at any point along the diaphysis (Byrd and Adams 2015, #76B). *Instrument:* sliding calipers.

05 Maximum Breadth at the Distal End: Place the one jaw of the caliper on the posterior portion (tubercle) and extend the other jaw to the opposite side (just above the malleolar articular surface) to find the maximum distance (Byrd and Adams 2015, #76C). *Instrument:* sliding calipers.

TECHNICAL REQUIREMENTS

Supported operating systems include Linux, macOS, and Windows 7/8/10 with R version 3.3.X or greater. 8 gigabytes of RAM or greater is recommended. All performance analyses published were conducted on Linux systems with 32-64 gigabytes of RAM. Parallel processing for analytics is only supported under Linux and macOS for the foreseeable future. This is due to memory efficiency problems with cluster sockets under windows. Parallel processing for file output is supported under all operating systems.

REFERENCES

- Adams BJ, Byrd JE. Interobserver variation of selected postcranial skeletal measurements. Journal of Forensic Science 2002;47:1193-202.
- Adams BJ, Byrd JE. Resolution of small-scale commingling: a case report from the Vietnam war. Forensic Science International 2006;156-63-9
- Byrd JE (2008). Models and methods for osteometric sorting. In Recovery, Analysis, and Identification of Commingled Human Remains, edited by B.J. Adams and J.E. Byrd. Pp. 199220. Humana Press, New Jersey.
- Byrd JE, Adams BJ (2003). Osteometric sorting of commingled human remains. Journal of Forensic Sciences, 48(4):1-8. Byrd JE, Adams BJ (2015). Updated measurements for osteometric sorting. DPAA CIL document, dated 16 December 2015.
- Byrd JE, LeGarde CB. Osteometric sorting. In: Adams BJ, Byrd JE, editors. Commingled Human Remains: methods in recovery, analysis, and identification. San Diego, CA: Academic Press, 2014:167-191.
- Dwight T (1905). The size of the articular surfaces of the long bones as characteristics of sex; an anthropological study. American Journal of Anatomy, 4: 19-32.
- Finlayson JE, Bartelink EJ, Perrone A, Dalton K. Multimethod resolution of a small scale case of commingling. Journal of Forensic Science 2016.
- Garrido-Varas C, Rathnasinghe R, Thompson T, Savriama Y. A new method to pair-match metacarpals using bilateral symmetry and shape analysis. Journal of Forensic Science 2015;60:118-123.
- Hrdlicka A (1920). Anthropometry. The Wistar Institute of Anatomy and Biology: Philadelphia.
- Karell MA, Langstaff HK, Halazonetis DJ, Minghetti C, Frelat M, Kranioti EF. A novel method for pair-matching using three-dimensional digital models of bone: mesh-to-mesh value comparison. International Journal of Legal Medicine 2016;130:1315-22.
- Langley NR, Jantz LM, Ousley SD, Jantz RL, Milner GS (2016). Data Collection Procedures for Forensic Skeletal Material 2.0. The University of Tennessee and Lincoln Memorial University: Tennessee. http://fac.utk.edu/wp-content/uploads/2016/03/DCP20_webversion.pdf
- LeGarde CB. Asymmetry of the Humerus: the influence of handedness on the deltoid tuberosity and possible implications for osteometric sorting. Master's Thesis, Missoula, MT: The University of Montana, 2012.
- Lynch, JJ, Byrd, J, LeGarde, CB. The Power of Exclusion using Automated Osteometric Sorting: Pair-Matching. Journal of Forensic Sciences 2018.
- Lynch, JJ. An analysis on the choice of alpha level in the osteometric pair-matching of the os coxa, scapula, and clavicle. Journal of Forensic Sciences 2018.

REFERENCES

- Lynch, JJ. The automation of regression modeling in osteometric sorting: an ordination approach. Journal of Forensic Sciences 2018.
- Martin R, Knussmann R (1988). Anthropologie: Handbuch der vergleichenden Biologie des Menschen. Stuttgart: Gustav Fischer. Montagu MFA (1960). A Handbook of Anthropometry. Charles C. Thomas, Springfield, Illinois.
- Moore-Jansen PM, Ousley SD, Jantz RJ (1994). Data Collection Procedures for Forensic Skeletal Material. Report of Investigations No.48. Department of Anthropology, University of Tennessee, Knoxville.
- Seidemann RM, Stojanowski CM, Doran GH. 1998. The use of the supero-inferior femoral neck diameter as a sex assessor. American Journal of Physical Anthropology, 107:305–313.