

# Subadult Virtual Anthropology Database (SVAD) Data Collection Protocol: Cranial Macromorphoscotics on Virtual 3D Crania

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This document presents the standardized protocol developed to score cranial macromorphoscopic traits on 3D renderings of subadult crania obtained from computed tomography scans. This protocol was developed as part of National Institute of Justice Award 2019 DU-BX-0039. If the methodology presented herein is used or mentioned in a presentation or publication, then this document needs to be cited. Additionally, we strongly encourage all research using this protocol to be submitted to the Subadult Virtual Anthropology Database (SVAD) Zenodo Community to facilitate sharing and discovery of information (<https://zenodo.org/communities/svad/?page=1&size=20>).

## **Data**

Thirteen cranial macromorphoscopic traits are scored using ordinal scales following Hefner and Linde (2018); the definitions are *verbatim* but the illustrations are specific to computed tomography scans. ***Any additional comments pertaining to data collection on virtual crania will appear in bold and italics within the original definition or as comments below it.*** Full explanations, pictures, frequencies per population, etc., can be found in Hefner and Linde (2018) and the MMS user guide (Hefner et al. 2018). Additional references include Hefner (2009), Hefner (2018), and Kamnikar et al. (2018).

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## **Notes**

*If the trait is not obviously there, it is not there.*

### **Scoring missing data (NA/-1)**

Score NA if you cannot observe the trait because the anatomical element is damaged or missing.

Score -1 if you do not feel comfortable scoring the trait even though it is observable (*i.e.*, no score really seems to fit the trait), or if you cannot decide between two scores.

# Definitions and Illustrations of Macromorphoscopic Traits on Computed Tomography Scans

## Anterior Nasal Spine (ANS)

A small bony feature located at the inferior border of the nasal aperture (Fig. 1). To score this trait, the cranium should be viewed laterally to assess the degree of projection of ANS.

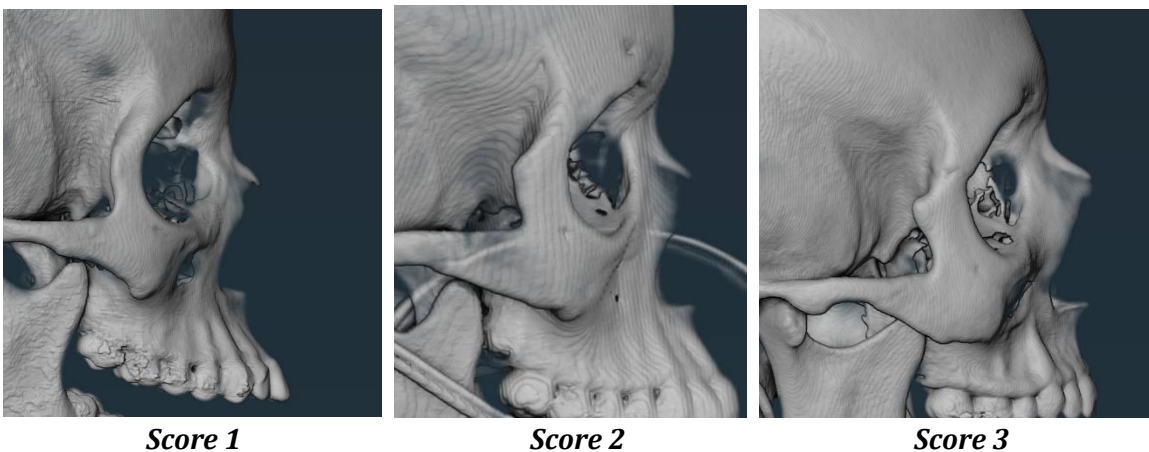
### Scoring

*Score 1:* Slight ANS, minimal-to-no projection of the ANS beyond the Inferior Nasal Aperture (INA) (**not pinchable**).

*Score 2:* Intermediate ANS, a moderate projection of the ANS beyond the INA (**somewhat pinchable**).

*Score 3:* Marked ANS, a pronounced projection of the ANS beyond the INA (**very pinchable**).

\* Do not score if the individual is edentulous.



*Fig. 1: Three scores for the ANS.*

## **Inferior Nasal Aperture (INA)**

The most inferior portion of the nasal aperture, which, when combined with the lateral alae, constitutes the transition from nasal floor to the vertical portion of the maxillae, superior to the anterior dentition (Fig. 2). Specifically, this trait aims to assess the transition from the nasal floor to the vertical portion of the maxilla. The left portion of the inferior nasal aperture should be assessed.

### **Scoring**

*Score 1:* Sloping of the nasal floor, which starts inside the nasal cavity and terminates on the vertical surface of the maxilla. This gradual slope is a smooth transition between the two anatomical areas of bone.

*Score 2:* Sloping from the floor of the nasal cavity to the vertical surface of the maxilla. However, to differentiate from the previous state, the slope begins more anteriorly in the nasal aperture and exhibits more angulation at the opening of the nasal aperture.

*Score 3:* A steep transition from the nasal floor to the vertical maxilla. There is no slope, however there is no intervening projection or sill. This morphology closely resembles a right angle, although a more blunted form may be present.

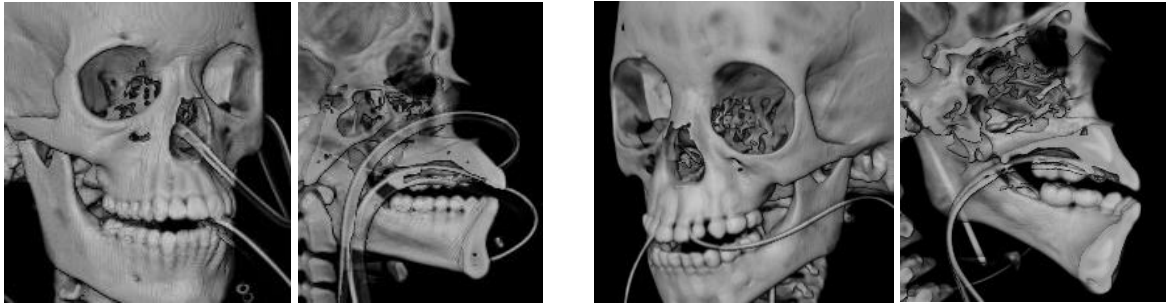
*Score 4:* A character state that shows any superior incline of the anterior nasal floor. This leads to the creation of a weak ridge of bone that crosses the anterior nasal floor perpendicularly, resulting in a partial nasal sill.

*Score 5:* A pronounced ridge (or nasal sill) obstructing the nasal floor to maxilla transition.

### **Comments**

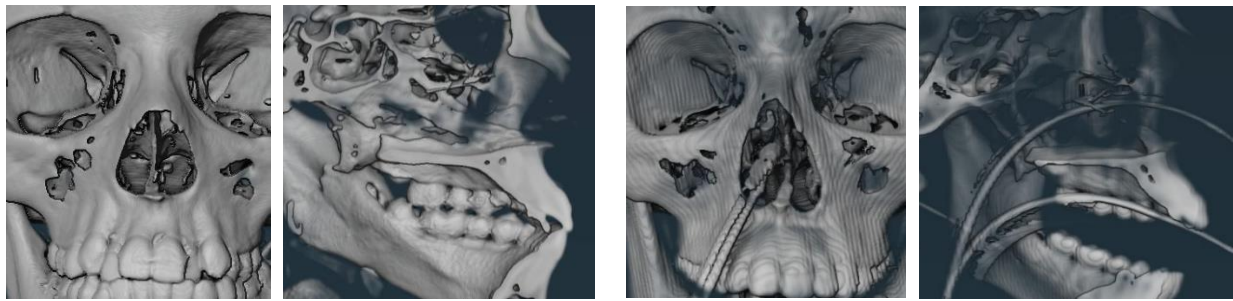
Attempt to locate the midpoint of the left side to score and look at it face forward first, then at the cross-section before scoring. If uncertain between two scores, retain the highest one, as it means that a more advanced/steep sloping was observed.

To help score this trait in Amira™, click on the green lozenge (your object) and select Orthoslice (orange lozenge). In the Properties pane below, place the orthoslice in the sagittal plane by selecting the (yz) Orientation option. Scroll through the slices until you reach a slice positioned at a point that corresponds to the middle of the left side of the nasal spine. A score is assigned based on the aspect of the slope for the transition between the nasal floor and the maxilla.



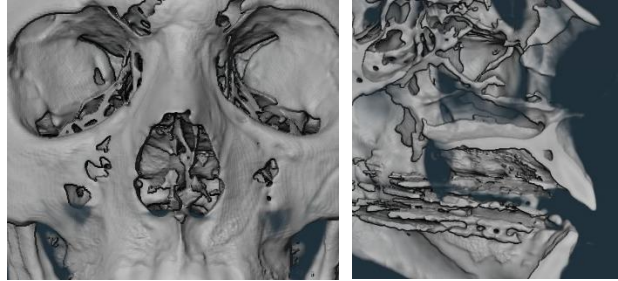
*Score 1*

*Score 2*



*Score 3*

*Score 4*



*Score 5*

*Fig. 2: Anterior (left square) and cross-sectional (right square) views for each of the five INA scores.*

### **Interorbital Breadth - subadult (IOB\_sub)**

The space between both orbits relative to the facial skeleton (Fig. 3). IOB\_sub is essentially visually observing the space between two cranial landmarks at left and right dacryon and comparing it to upper facial breadth (left *frontomalare temporale* to right *frontomalare temporale*).

#### **Scoring**

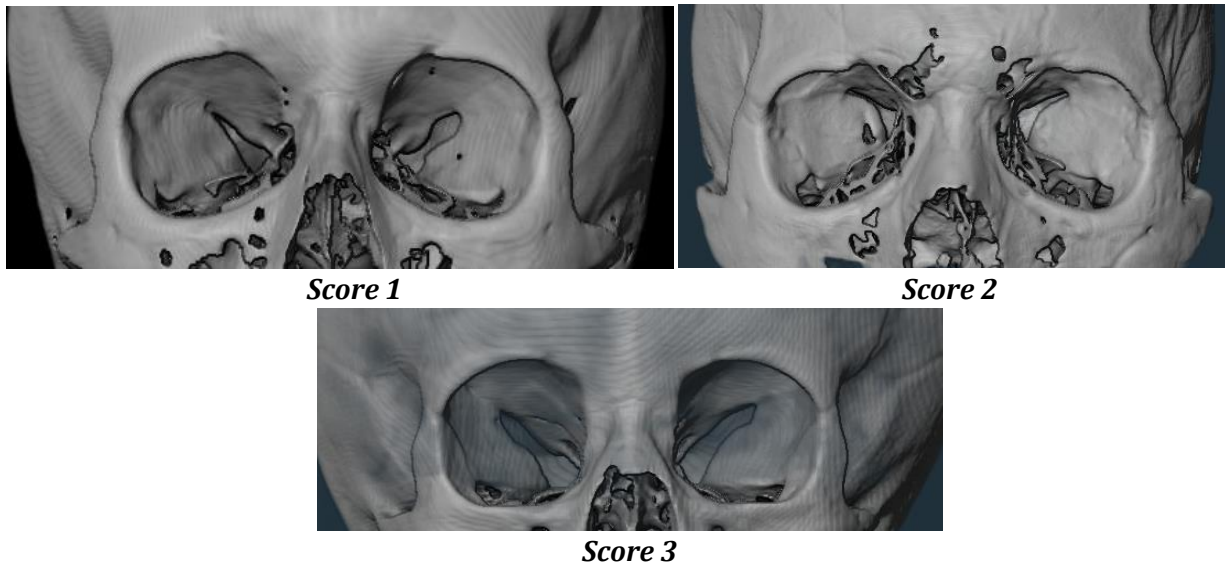
*Score 1:* Narrow or 1:5 ratio of the interorbital space relative to the upper facial skeleton.

*Score 2:* Intermediate or 1:4 ratio of the interorbital space relative to the upper facial skeleton.

*Score 3:* Broad or 1:3 ratio of the interorbital space relative to the upper facial skeleton.

#### **Comments**

IOB\_sub is a slightly modified version of the MMS definition of IOB adapted to subadult individuals. Make sure the threshold value you have selected for visualizing the skull includes the ethmoid, as you have to be able to place/see both left and right dacryons to evaluate IOB\_sub. If not, play with the threshold value until you do before scoring.



*Fig. 3: Three scores associated with IOB.*

### **Malar Tubercle (MT)**

A caudally protruding tubercle on the inferior margin of maxilla and zygomatic bones (Fig. 4). This feature is commonly located at the inferior end of the zygomaticomaxillary suture. ***In case of asymmetry, the side with the greatest expression of MT should be scored.*** Note that a completely absent MT is rare. A score is assigned based on the extent of the bone protruding past the ruler's inferior edge.

#### **Scoring**

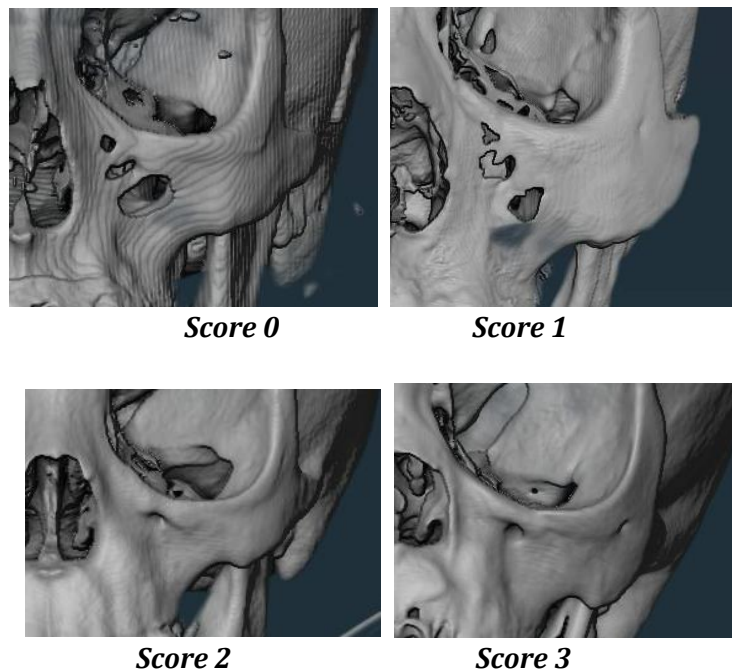
*Score 0:* There is no projection of bone.

*Score 1:* There is a trace tubercle, approximately 2 mm or less below the edge of the bone.

*Score 2:* The tubercle exhibits a medium protrusion, approximately 2 to 4 mm below the edge of the bone.

*Score 3:* There is a pronounced tubercle that protrudes approximately 4 mm or more below the edge of the bone.

A malar tubercle might be present on either the maxilla, zygomatic, or at the zygomaticomaxillary suture. Observations should not consider any tubercles on the lateral portion of the zygomatic arch. When a tubercle is directly on or just posterior to the zygomaticomaxillary suture, the slice should extend from the deepest incurvature of the maxilla to a point approximately 0.5 cm lateral to zygomaxillare.



*Fig. 4: Four scores associated with MT.*



### **Nasal Aperture Shape (NAS)**

This trait is assessed by observing both the lateral contours of the nasal aperture and, their greatest projection on the lateral margins (left alare - right alare distance).

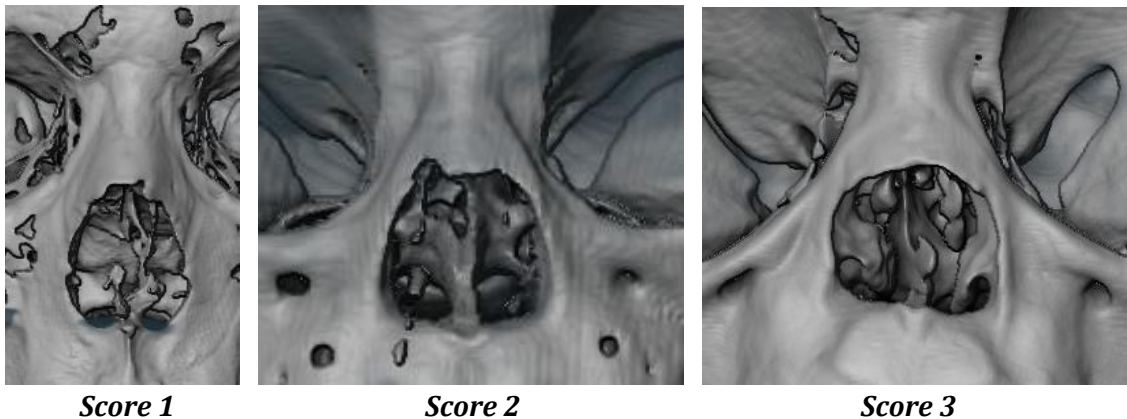
#### **Scoring**

*Score 1:* Teardrop/pear shape, with a projection of the lateral margins intermediate to character states 2 and 3 (inferior third).

*Score 2:* Bell shape, with greatest lateral projection at the inferior margin of the nasal aperture.

*Score 3:* Bowed, with the greatest projection at the lateral margins at the midline.

This trait is scored by placing the cranium in anatomical position and examining the anterior portion of the face (Fig. 5). The relative shape of the nasal aperture is assessed, with emphasis in determining the location of the greatest projection of the lateral margins of the nasal aperture lateral walls.



*Fig. 5: Three scores associated with NAS.*

### **Nasal Aperture Width (NAW)**

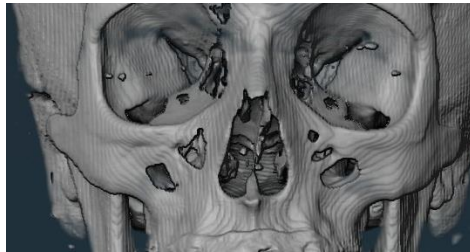
The width of the nasal aperture relative to the entire facial skeleton (Fig. 6). Assessed using a ratio of nasal aperture width to the overall width of the facial skeleton/bi-zygomatic breadth).

#### **Scoring**

*Score 1:* NAW is narrow; ratio of 1:5 (NAW: width of facial skeleton).

*Score 2:* NAW is intermediate; ratio of 1:4 (NAW: width of facial skeleton).

*Score 3:* NAW is broad; ratio of 1:3 (NAW: width of facial skeleton).



**Score 1**



**Score 2**



**Score 3**

*Fig. 6: Three scores associated with NAW.*

## **Nasal Bone Contour (NBC)**

The contour of the midfacial region, particularly the contour of the nasal bones and the frontal process of the maxilla, c. 1 cm below nasion (Fig. 7). You should also view the area from above by moving the cranium to assess whether it is rounded/oval (scores 0 or 1) or more vertical with walls (scores 2 to 4).

### **Scoring**

*Score 0:* Low and rounded NBC.

*Score 1:* An oval contour, with elongated, high, and rounded lateral walls.

*Score 2:* Steep lateral walls and a broad (roughly 7 mm or more), flat superior surface “plateau,” noted as a flat cluster in the midline.

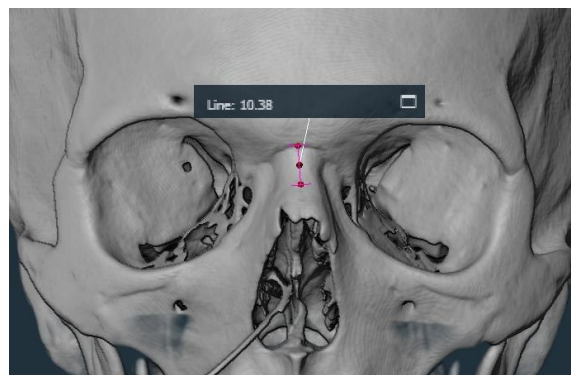
*Score 3:* Steep-sided lateral walls and a narrow superior surface “plateau”.

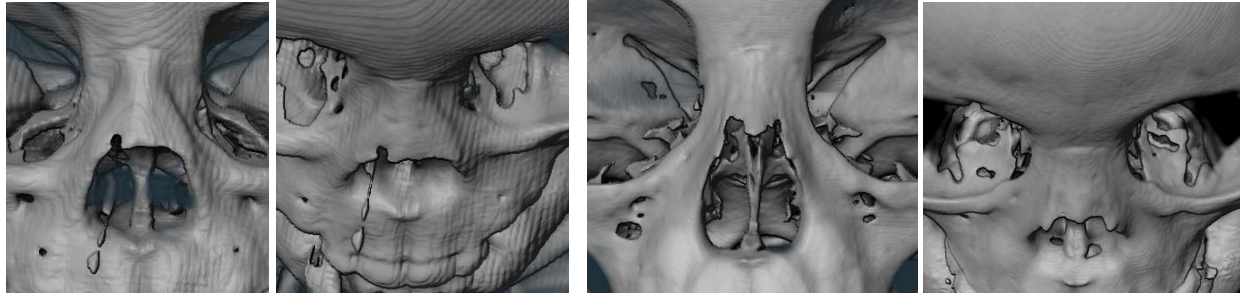
*Score 4:* Triangular cross-section, lacking a superior surface “plateau”.

### **Comments**

Visual interpretation of nasal bone contour is not the most effective manner of analysis due to high inter- and intra-observer error (Kamnikar et al. 2018), which is why we recommend the following to score NBC in Amira™:

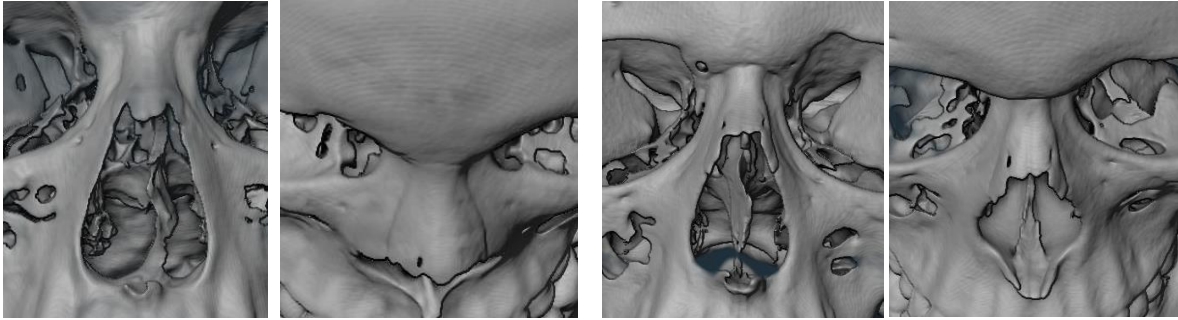
- Use the measuring tool to place yourself 1cm below nasion.
- Navigate to the top of the toolbar on the right and click on the small ruler icon. A yellow [Measurement] lozenge should appear in “Project View”.
- Click on it and select the Measurement in the “Properties” pane below.
- Go to the “Viewing” pane and click on nasion to place the start of the measurement. As you move your mouse, the value will increase. Stop at 10mm to place the end of your measurement and observe NBC in that particular region.





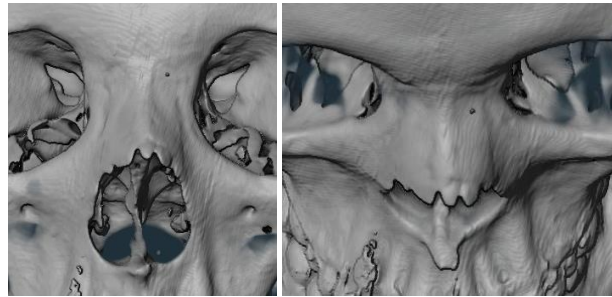
*Score 0*

*Score 1*



*Score 2*

*Score 3*



*Score 4*

*Fig. 7: Five scores associated with NBC.*

## **Nasal Bone Shape (NBS)**

The relative contour of the nasal bones at their lateral edges (Fig. 8). This trait is visualized and assessed while holding the cranium in its approximate anatomical position, with the anterior view directly in front of the observer. In order to make a correct observation, keep in mind the position of the nasal pinch (if present) and the amount of lateral bulging (if present). Do not consider the frontonasal suture, the nasal suture, or the symmetry of the nasal bones. Rather, an assessment is made of the lateral contours of the nasal bones.

### **Scoring**

*Score 1:* Lateral nasal bones edges show no nasal pinch. The nasal bones may be wide or narrow.

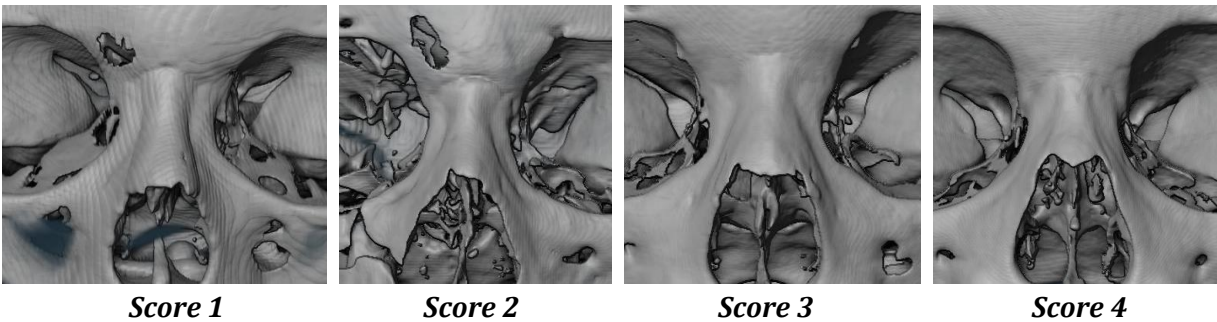
*Score 2:* Nasal bones have a superior pinch and minimal bulging on the lateral edges (note: To differentiate a score of 2 and 3, the amount of lateral bulging in the inferior region should be assessed).

*Score 3:* Lateral nasal bones edges have a superior pinch and pronounced lateral bulging of the inferior region (note: to differentiate between a score of 2 and 3, the amount of lateral bulging in the inferior region should be observed).

*Score 4:* Lateral nasal bones edges of the nasal bones form a triangle.

### **Comments**

To help score this trait in Amira™, adjust the threshold to visualize the nasal bone edges and go back and forth between this setting and the initial one.



*Fig. 8: Four scores associated with NBS.*

### **Nasal Overgrowth (NO)**

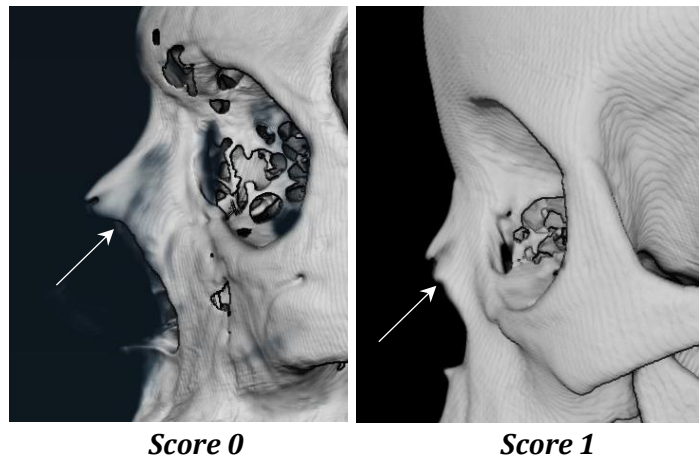
The projection of the lateral border of the nasal bones at their inferior edge beyond the maxilla at the cranial landmark *nasale inferius* (Fig. 9). This trait is visualized by close inspection of the inferior lateral border of the left nasal bone (right if left is damaged) where it articulates with the maxilla.

#### **Scoring**

*Score 0*: no bony overgrowth at *nasale inferius*.

*Score 1*: any projection of bone from the lateral border of the nasal bones beyond the maxillary border at *nasale inferius*.

If the left side is damaged, the right side may be used to assess the trait. If both nasal bones are missing, fractured (ante- or peri-mortem), or damaged, do not score nasal overgrowth. Be careful to closely examine this feature and toggle with the threshold values so that the individual is not incorrectly scored.



*Fig. 9: Two scores associated with NO.*



### **Orbital Shape (OBS)**

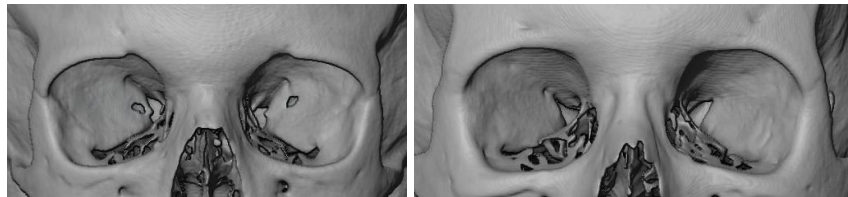
The shape of the orbit. To score OBS, visualize the cranium at a distance, covering the right orbit and view anteriorly. The orbital margins define the shape. The medial orbital border is denoted by the anterior lacrimal crest and the maxillary process of the frontal bone. Observers should assess whether the margins are angular (rectangle), curvilinear (circular), or irregular (rhombic). Bilateral asymmetry may occur. *All observations should be made on the left orbit.*

#### **Scoring**

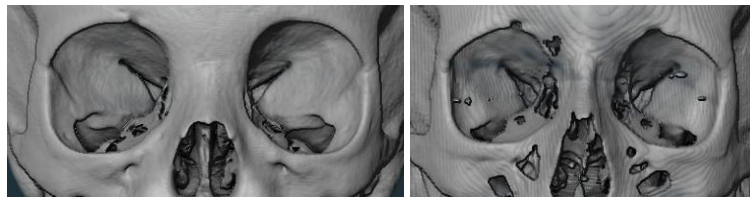
*Score 1:* Rectangular shape- Orbital horizontal margins are longer than the vertical margins, and mostly parallel. Please note the orbits may be tilted inferiorly but are still rectangular, not rhomboid.

*Score 2:* Circular shape- Orbital margin is approximately equidistant from the center at any point.

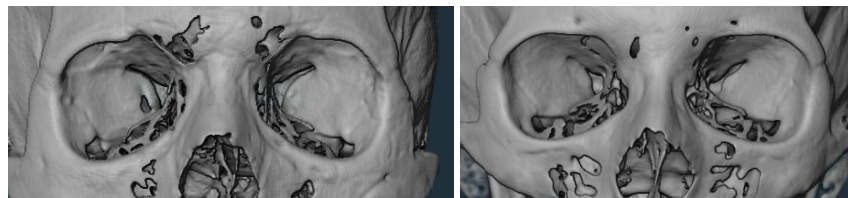
*Score 3:* Rhombic shape- Medial border height is shorter than the lateral border height (the shape resembles aviator sunglasses).



**Score 1**



**Score 2**



**Score 3**

*Fig. 10: Three scores associated with OBS.*

### **Postbregmatic Depression (PBD)**

A slight to broad depression along the sagittal suture posterior to bregma that is not the result of a pathological condition (e.g., premature synostosis). Observed in lateral profile.

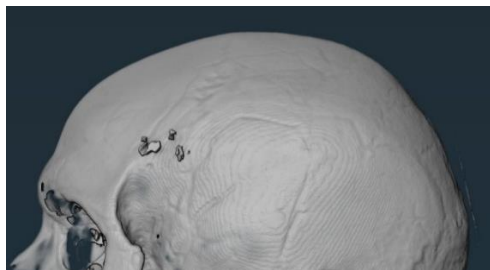
#### **Scoring**

*Score 0:* Absent (no depression posterior to bregma).

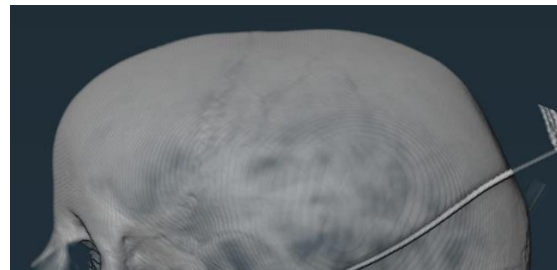
*Score 1:* Present (any depression posterior to bregma along the midsagittal plane).

Be careful scoring individuals with obliterated sutures because the bone along the suture sites may be elevated, giving the appearance of a depression for the surrounding bone. The key is to determine if the sagittal suture contours just posterior to bregma dip then extend superiorly to return to the original elevation.

Do not score if the bregmatic fontanelle is not closed.



***Score 0***



***Score 1***

*Fig. 11: Two scores associated with PBD.*



### **Posterior Zygomatic Tubercle (PZT)**

The posterior projection of the zygomatic bone as viewed laterally on the cranium. This projection, also referred to as the marginal process, is viewed at approximately the midorbit level. **If asymmetry is present between left and right, retain the highest score.** Scored by viewing the cranium in lateral view.

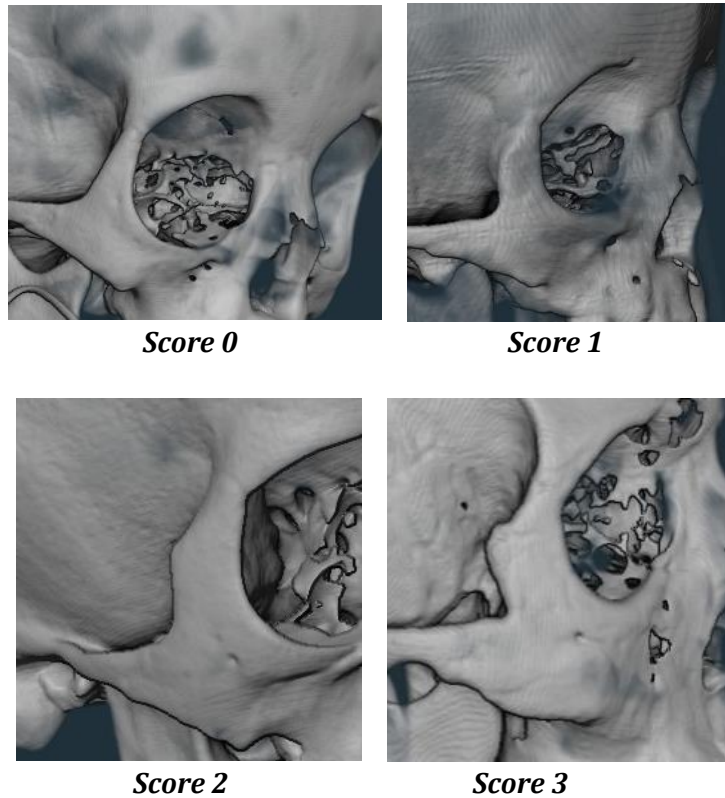
#### **Scoring**

*Score 0:* no projection of bone past the slice's edge.

*Score 1:* a weak projection of bone that extends less than 4 mm past the slice's edge.

*Score 2:* a moderate projection of bone that extends approximately 4 to 6 mm past the slice's edge.

*Score 3:* There is a marked projection of bone extending more than 6 mm past the slice's edge.



*Fig. 12: Four scores associated with PZT.*

## **Palate Shape (PS)**

The contour of the dental arcade, defined by the curvature of the hard palate in the transverse plane, as viewed from the occlusal aspect of the dentition and the inferior aspect of the maxillae. Palate shape is based on the overall morphology and arch shape of the maxillae and the relative placement of the anterior and posterior dentition, assessed as a midline projection through the individual teeth along their mesio-distal axis. To assess PS, place the cranium in the inferior view and focus on the occlusal aspect of the dentition and the inferior aspect of the maxilla. Draw an imaginary line through the midline-projection of the individual teeth along their mesio-distal axis (**blue arches in Fig.13**).

### **Scoring**

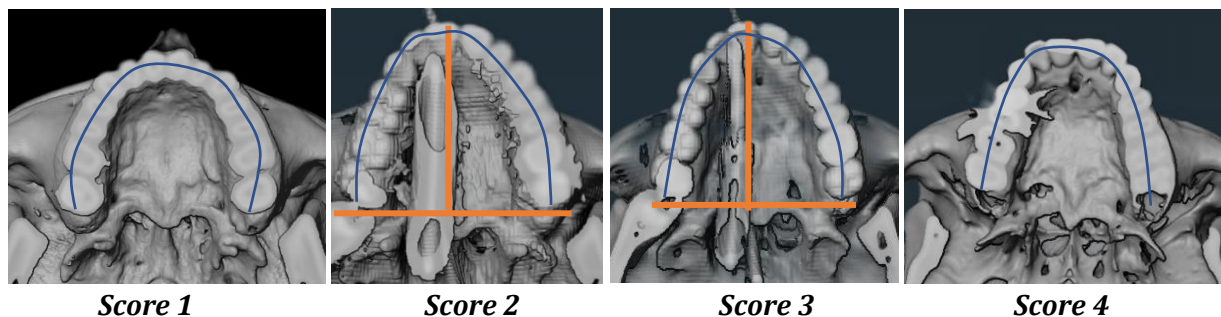
*Score 1:* elliptical; smooth, round curvature of the anterior portion of the palate combined with a mid-arch (ca. M1 and M2) widening relative to M3, contributing to the appearance of constricted (medially positioned) third molars.

*Score 2:* parabolic A; smooth rounded curvature of the anterior portion of the palate, combined with an even, gradual flaring of the placement of the posterior dentition. Somewhat equal length to breadth ratio (**orange lines on Fig. 13, Score 2**).

*Score 3:* parabolic B; smooth, rounded curvature of the anterior portion of the palate, but combined with an even, gradual flaring of the placement of the posterior dentition. The only distinction from form A is the longer relative length to breadth ratio (**orange lines in Fig. 13, Score 3**) in this form (B).

*Score 4:* hyperbolic; smooth, slightly flattened curvature of the anterior portion of the palate, combined with a straight, more-or-less parallel configuration of the posterior portions of the arch.



Do not score individuals for whom the permanent M2s have not emerged, as they have not reached their mature palate shape. It should also be noted that it may be difficult to distinguish between score 1 and 3 in individuals with resorbed 3rd molars.



*Fig. 13: Four scores associated with PS.*

# Data collection in Amira™

## 1. Opening Amira™.

Click on the “**Project**” tab to open a workspace. Before selecting anything else, click the perspective button. The button is located in a bar of other buttons just above the viewing panes and looks like an eye:  Clicking the button will change the symbol in front of the eye to parallel lines: . Use the parallel line setting for all specimen editing and measuring. **You have to reset this every time you reopen Amira™.**

Choose [**Open Data...**] (green button in the “**Project View**” pane in the upper left corner).

## 2. Loading a stack of CT scans.

Find the individual you are interested in and select all of the DICOMs in that folder (NB: not the DICOM directory). Click [**Open**]. Always select the folder that has “ST” in the name. This stands for “Soft Tissue” and has a better resolution than “Bone”. You can choose folders with names including “Head, Head-Neck”, or “Whole Body” as they all include the upper body and skull.

If you get a warning about the file size being too large, choose the radio button for “Load complete volume into memory” and click [**OK**].

A dialog box called “**DICOM Loader**” will prompt you to check the parameters of the DICOM stack. Scroll through the window and if everything looks good (not out of order numbering, gaps in the data, etc.), click [**OK**]. Any errors will be shown as red numbers in the list of DICOMs. If that is the case, only select the DICOM files that appear in black by pressing shift and clicking on the first and last DICOM of the stack that you want to open.

## 3. Visualizing the CT slices.

The file appears as a green lozenge in the “**Project View**” pane. Select the orange [**Orthoslice**] tab in the “**Project View**” pane. The CT slice should appear in the viewing console on the right. You can change the plane of the slice view by selecting xy, xz, or yz in the console header. If the hand is selected in that header, you can use it to move the exam around. You can also scroll through the slices by clicking the **box next to the “Slice Number” line** in the “**Properties**” pane and using the mouse to scroll or moving the cursor between the two triangles.

## 4. Creating a Volume Rendering of the skull.

*Select the green lozenge.* Click on the yellow [**Volume Rendering**] button. The soft tissue of the scanned body should appear in the viewing console on the right. You can use the mouse on hand mode to turn the body around at different angles.

In the “**Properties**” pane, move the left cursor of the “**Colormap**” higher to adjust the masking value (the number on the left). This allows you to hide soft tissue and only visualize bones or teeth, the further you adjust the value. Higher values will only allow to visualize the densest

elements (metal, teeth, etc.). You can also type a value in that left box and lower the right slider as well. If you cannot see the teeth, you can move the body around and/or unselect the orange square in the [**Orthoslice**] lozenge to hide the contents of the CT slice. A good range of values should encompass part of the grey peaks you can see in the “**Colormap**”.

To adjust the transparency, in the “**Properties**” pane, click on the [**Edit box**] of the Colormap line. You can scroll down the menu and choose one of the colormap options. You can always revert back to the original setting if necessary by selecting it in the “**Edit**” box.

## 5. Creating an Isosurface of the skull (optional).

If the volume rendering visualization is not satisfactory, click on the yellow [**Volume Rendering Settings**] lozenge that appeared and select the [**Isosurface Rendering**] button at the top of the “**Project View**” pane. Click on the **small orange square** of the [**Volume Rendering**] lozenge to hide it.

Select the *Isosurface Rendering* lozenge again. In the “**Threshold**” section, move the slider to adjust the masking value (the number on the right). This allows you to hide soft tissue and only visualize bones, the further you adjust the value. Higher values will only allow to visualize the densest elements (metal, teeth, etc.). You can also type a value in the box. If you cannot see the bones, you can move the body around and/or unselect the orange square in the [**Orthoslice**] lozenge to hide the CT slice.

## 6. Some adjustments

To adjust the transparency, select the [**Volume Rendering**] lozenge. In the “**Properties**” pane, **click on the [**Edit box**] of the “Colormap” line**. You can scroll down the menu and choose one of the Colormap options. You can revert back if necessary at any point.

You can also do this by adjusting the value of “**Opacity**” below (from 0 to 1)

### **Comments**

If you need to hide some parts of the body to facilitate scoring (like lower jaw, half of the skull, upper teeth, vertebrae, ribs, etc.), *select the orange Orthoslice* lozenge. In the “**Properties**” pane, click on the icon that looks like a cube with a green line crossing it (**the Clip tool**). Click on it once to hide half of the body, click on it again to see the full body and click on it a third time to see the other half of the body. You can do this in every plane, by changing the plane from xy to xz and yz in the “**Orientation**” line and in the viewing console while the [**Orthoslice**] lozenge is selected and by keeping that Clip tool selected. This will hide whatever structures are in front or behind the slice in question.

To scroll through that subset of the reconstruction, select the [**Orthoslice**] lozenge and go through “**Slice Number**” in the “**Properties**” pane.

These combinations of the different plane views of the [**Orthoslice**] and the Clip tool help you hide/see particular structures to facilitate scoring. Play around with all three planes and the clip tool to change views as needed.

If you want to hide the slice contents from view and only see the reconstruction, click on the small orange box of the [**Orthoslice**] lozenge. Click it back to visualize slice contents.

If you want to hide more of the bone and the less dense parts of the teeth to improve visualization of the roots for example, you can further adjust the threshold value in the “**Colormap**” to a higher range.

## Saving the data in a csv/excel spreadsheet and in RDS format

Because csv files can be easily corrupted, it is recommended to save each csv file on a regular basis into RDS format.

To do this, open RStudio and run the following code:

```
library(tidyr)
```

```
library(dplyr)
```

```
library(readr)
```

```
library(base)
```

- If you haven't installed these packages before, please do so prior by running the code:  
`install.packages("package_name")`

```
#Load old csv file and save it as a RDS file
```

```
File_name <- read_csv("~/path/to/database/File_name.csv")
```

```
write_rds(File_name, "~/path/ to/database/File_name.rds", row.names=FALSE)
```

- The new RDS file will be automatically created in that location (following the path you wrote).

**Create a copy of the csv file prior to additional data collection and collect in the new copy.**

Update the last identifier number every time you modify it (*i.e.*,

**"projectname\_typeofdata\_identifier\_xxx\_yyy"** to

**"projectname\_typeofdata\_identifier\_xxx\_zzz"**). That way, data is added on a regular/weekly basis and if something happens to the file, you can always revert to the previous one as a backup. You will then save each new weekly csv file as a RDS file so you have backups in RDS formats.

## References

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Hefner JT, Plemons AM, Kamnikar KR, Ousley SD, Linde KC (2018) *Macromorphoscopics Software Version 1.61 User Manual*. V 1.0, 85p.

Kamnikar KR, Plemons AM, Hefner JT (2018). Intraobserver Error in Macromorphoscopic Trait Data, *Journal of Forensic Sciences* 63(2):361-370.