STANDARD OPERATING PROCEDURE FOR MICROSCRIBE 3-DIMENSIONAL DIGITIZER AND CRANIOMETRIC DATA

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PREFACE

This document was developed as a component of the 2016 *Assessing Cognitive Bias, Method Validation, and Equipment Performance for the Forensic Anthropology Laboratory* project funded by the National Institute of Justice. The purpose of this project was to improve method validation and equipment performance procedures related to specific analyses, such as the collection of 3-dimensional (3D) craniometric data. In order to validate the equipment used to collect craniometric data (e.g., the MicroScribe 3D digitizer), proper equipment procedures needed to be written.

This standard operating procedure (SOP) is one of the grant products. It provides detailed information about the MicroScribe digitizer, how to use the associated software program (i.e., 3Skull), original and newly developed cranial landmark definitions, new diagrams specifically for digitizing, and tips for troubleshooting. This SOP was written specifically for the Forensic Anthropology Division (FAD) at the Harris County Institute of Forensic Sciences (HCIFS) to meet the needs and requirements of our accreditation program; it is therefore based on the equipment and software programs used by the FAD (i.e., MicroScribe G2LX digitizer, 3Skull software, and Fordisc 3.1 software). Other data collection equipment and analytical software can be used with this SOP, although adjustments will be required.

As a product of federal funding, this SOP is being freely shared with the anthropological community. The goal of this document is to build upon past and present craniometric data collection guides/manuals by emphasizing the digitization of cranial landmarks. Drawing on various literature and personal communications, this document is a comprehensive reference for the equipment, procedures, and techniques used to digitally collect craniometric data.

How to Use this Document

We are providing two copies of this document: 1) PDF of the FAD's current MicroScribe and Craniometrics SOP, and 2) Word document of the same SOP with the information specific to the FAD and/or HCIFS removed. The PDF cannot be altered. The Word document is a template that can and should be modified as you see fit. Fill in the areas of blue text with the information appropriate for your operation or laboratory. To avoid formatting issues, the images in this SOP have been moved to a new Appendix 6. These images can be left as an appendix, reordered in the document, or used separately. Please cite the images as they are labeled.

Please note that this document does not discuss calibration of the MicroScribe digitizer. At HCIFS, calibration of equipment is discussed in a separate SOP titled Equipment and Reagents. As a part of your quality assurance program, your digitizer should be calibrated on a regular schedule. When modifying this SOP, a section regarding calibration can be included.

Disclaimer

Like all SOPs, this is a living document. It is not intended to be the governing document on the use of the MicroScribe digitizer or the collection of craniometric data. It is our hope that this document and the guidance provided herein continues to improve as we strive towards achieving consistency in the field of forensic anthropology. As such, we welcome comments or feedback regarding corrections or additions. **NOTE: This SOP follows the landmark order associated with the current landmark list for 3Skull (Lndmrk13F, as of November, 2018). As with all software, please check that you are operating the most current version and modify this SOP as needed**.

SOP TABLE OF CONTENTS

A table of contents is not needed for this SOP. It is provided here as an overview so you can determine which sections you want to edit, rearrange, or add/remove for your office/lab

Policy: The section, divison, or lab name here is responsible for constructing biological profiles for unknown skeletal remains, which may require metric analyses.

Purpose: To establish proper use of the MicroScribe Digitizer, 3Skull software, and Advantage Data Architect software. Provide steps to transfer data to the FORDISC program.

Scope: These procedures apply to all forensic anthropology staff, forensic anthropology fellows, and forensic anthropology interns who perform anthropological analyses.

Author: This policy is maintained by name/title of individual responsible.

1. EQUIPMENT FUNCTION

1.1. MicroScribe G2LX digitizer is a powerful tool for performing 3-Dimensional (3D) data collection from the cranium and mandible. The equipment collects coordinate data from osteometric landmarks used in the estimation of sex and ancestry for unknown skeletal remains.

1.2. The collection of 3D landmark coordinates can replace or compliment the 2-Dimensional (2D) collection procedures for the cranium and mandible, which are collected using spreading and sliding calipers and a mandibulometer.

1.3. The collected landmark coordinates are converted into measurements that can be imported into FORDISC or 3D-ID analytical software.

2. EQUIPMENT LOCATION

2.1. The MicroScribe digitizer, computer and associated software are located enter location of equipment here. Access to the room is limited to enter information if applicable.

2.2. The MicroScribe transportation case is located enter location here and should be used when transporting the MicroScribe to other locations.

2.2.1. When carrying the MicroScribe (moving it to a different location without packing it in the transportation case), one must follow the proper handling instructions provided in MicroScribe User Guide (Revware).

2.2.2. When transporting the MicroScribe to locations outside of the Anthropology Laboratory, it should be packed in the transportation case with the antistatic pink foam. Refer to the User Guide for packing and unpacking instructions.

3. EQUIPMENT COMPONENTS

3.1. The MicroScribe G2LX digitizer consists of a base with an articulated arm that terminates in a stylus. Affixed to the stylus is a removable tip that screws in and remains attached unless the tip is being replaced or the unit is being transported. It is recommended to securely affix the digitizer to the workspace using screws.

3.2. The following items connect to the base of the unit:

- USB cable or serial cable to connect to the computer
- Power supply cable (may be necessary for laptop, but not desktop)
- Hand switch input accessory (a foot pedal can replace this accessory)

3.3. The computer is located next to the MicroScribe workstation and contains the software needed to run the equipment and transfer data to the FORDISC program. A laptop computer is also available in the Anthropology Laboratory that is preloaded with the necessary software.

3.4. A tri-column stand, currently made of air-hardened clay, is located next to the digitizer and is used to hold a cranium when digitizing. Other apparatuses are acceptable as long as it is stable and the osteometric landmarks are not obstructed.

3.5. A mandibulometer, located in the Anthropology Laboratory, is used to hold a mandible when digitizing. Alternatively, a piece of plexiglass with a beveled edge could be used (see 5.2.6.1).

3.5.1. The mandibulometer can be placed at any location on the digitizer workspace as long as the digitizer arm can easily reach all osteometric points and its location does not interfere with the tri-column stand.

3.5.2. Once a position is selected it is good practice to secure the mandibulometer with pieces of clay.

3.6. A small mirror is located on the digitizer workspace to assist with collecting osteometric points on the inferior aspects of the cranium.

4. SOFTWARE USED IN DIGITIZING

4.1. 3Skull: 3Skull (or ThreeSkull) facilitates the capture of 3-D landmark coordinates using a MicroScribe digitizer. There are instructional videos for locating cranial landmarks, using 3Skull, and analyzing craniometric data located at http://math.mercyhurst.edu/~sousley/Videos/. The 3Skull software and updates can be requested via email through the aforementioned website.

4.2. Advantage Data Architect (ADA): ADA is a free program that assists in designing, creating and maintaining the database layer of a developer's applications. Updates can be downloaded from the ADA website, now part of Sybase (http://devzone.advantagedatabase.com/dz/content.aspx?Key=20&Release=19&Product=8&Platform=6).

4.3. FORDISC: Analytical software that uses statistical methods to estimate sex, ancestry, and stature from skeletal measurements. FORDISC employs multivariate statistical classification methods including linear discriminant function analysis. FORDISC is updated through the update application located in the USB key files.

4.4. 3D-ID: Analytical software that provides geometric morphometric tools to aid in the assessment of sex and/or ancestral affiliation using three-dimensional coordinates of anatomical points taken from the cranium. Geometric morphometrics is an approach to shape analysis that incorporates the geometry of specimens into the analysis of their shapes. Steps for entering data into 3D-ID are not currently covered in this version of the SOP, but will be added in a future version.

5. PREPARING TO DIGITIZE

5.1. Equipment Check: The following procedure is a general check list with troubleshooting techniques that should be performed before every use. When first learning the digitizer system the analyst should refer to the MicroScribe User Guide on the Revware CD. If issues occur that cannot be resolved following the troubleshooting techniques provided below, refer to the User Guide.

5.1.1. The digitizer is typically connected to the computer and should not be moved. If the base is not secured directly to the workspace by screws, use small pieces of clay to provide stability.

5.1.2. Check all cords to ensure a tight fit. Note: Be careful when connecting the USB cord into the port if the cord is not connected.

5.1.3. Make sure the stylus tip is securely screwed into the stylus. When the device is “homed” (see below) the stylus tip must be fully screwed in and in the proper resting position.

5.1.4. If the digitizer’s green light is not on, unplug the power source then plug it back in. Also check that the computer is on. Refer to Table 1 for signal light messages. If the digitizer is connected to USB power only, the light may be solid red when opening the 3Skull software. This will change to green once homed (see 5.1.5).

5.1.5. The digitizer needs to be “homed” prior to use in order for the coordinates to be accurately recorded. The stylus should be in the proper resting (home) position in the stylus holder (see Figure 1). Once in the proper position, the white Homing button located on the back of the base is pressed.

5.1.6. Check the current state of the digitizer system as indicated on the LED signal light system on the system base. Table 1 provides the key for the LED status. If the issue still persists, contact enter appropriate contact person.

Table 1. LED signal light messages (Revware Systems 2009).

LED Status	Device Status	Details
OFF	OFF	The MicroScribe system is not powered through the external power supply.
RED (Flashing)	Powered	The MicroScribe system is not homed (the Home button has not been pressed) and is not communicating with the computer.
RED	Not homed	The MicroScribe system is communicating with the computer but has not been homed (the Home button has not been pressed).
GREEN (Flashing)	Connection lost	The MicroScribe system has been homed (the Home button has been pressed), but is not communicating with the computer.
GREEN	Normal Operation	Normal operations: the device has been homed (the Home button has been pressed) and is communicating with the computer.

5.2. Preparing the Cranium and Mandible: The following section provides the steps that must be performed to prepare the cranium and mandible for digitizing.

5.2.1. Prior to digitizing it is important to be familiar with the osteometric landmark definitions and classifications. Appendix 1 provides a quick reference sheet for osteometric landmarks, arcs, and subtenses. Appendix 2 provides full landmark definitions for digitizing. Appendix 3 provides the original landmark definitions per Howells (1973). Appendix 4 lists the measurement abbreviations and landmark classification (Type I, II, III). Appendix 5 provides illustrations for osteometric landmark and arc locations.

NOTE: There are 111 landmarks (78 cranial, 25 mandibular, and 8 calculated points) that are collected by 3Skull. Not all of these landmarks are used for craniometric analysis or computation of interlandmark distances. For example, FORDISC uses 56 landmarks and 3D-ID uses 34 landmarks for the calculations that assist with determining ancestry and sex. It is encouraged to collect as many landmarks as possible for each cranium for future research or analyses as landmarks not currently employed by FORDISC or 3D-ID may become useful as research develops (Ousley and Spradley, personal communication).

5.2.2. Prior to placing the cranium on the tri-column stand, osteometric landmarks that are instrumentally determined need to be marked with a pencil. It is helpful to use a magnifying glass and direct light to clearly see the landmarks. Refer to the items highlighted in gray in Appendix 1: Osteometric Landmarks, Arcs, and Subtenses, and Appendix 3: Illustrations for Osteometric Landmark Locations that need to be premarked.

5.2.3. Although Appendix 1 and 3 indicate which landmarks require premarking, it is advisable to mark all points, even Type I landmarks, prior to digitizing to make them easy to locate. The following osteometric points are much easier to digitize if premarked:

- Asterion L and R (#s 57 and 68)
- Lambda (# 56)
- Basion (# 70)
- Opisthion (# 69)
- FOB point L and R (#s 71 and 72)
- Nasale inferius L and R (#s 9 and 10)

5.2.4. Place a **skinny rubber band** around the alveolus prior to placing the cranium on the tri-column stand. This facilitates the capture of the Alveolon landmark. This rubber band can be positioned across the maxillae (making sure that Prosthion-Howells is still accessible) or it can be drawn up over the nasal bones; placement is determined by how tight the rubber band is (it needs to be a tight, secure fit).

5.2.5. Stabilize the cranium on the tri-column stand and position it to avoid interference with any landmarks that will be digitized. Once the position is determined, use small pieces of clay[1] on the tips of the columns to mount and secure the cranium. **Note**: the orientation of the cranium is not important as long as osteometric points are not obstructed and the plane does not change during digitizing.

5.2.5.1. Two columns are typically positioned behind the mastoids making sure that Asterion is not covered. The bottom of each mastoid is avoided due to access to the left and right craniometric point, Mastoideale.

5.2.5.2. The third column is typically placed under either the left or right molars, making sure Staurion and the space above the 1st and 2nd molars are not obstructed.

5.2.5.3. The cranium should be positioned with enough distance for the digitizer arm to reach all of the landmarks. A quick check should be performed to ensure the furthest landmarks are reachable and that the landmarks on the cranial base are reachable.

5.2.6. Stabilize the mandibulometer within the workspace using small pieces of clay or a mounting plate. Once the mandibulometer is stable, place the mandible on it and adjust the measuring plates. Once the angle is correct, move the adjustable plates away from the bone to allow access with the digitizer stylus. **Note**: the location of the mandibulometer is not important as long as it does not change during digitizing and all landmarks can be reached by the digitizer.

5.2.6.1. Some practitioners prefer to use an acrylic (plexiglass) plate with one edge cut on an angle (beveled edge) instead of a mandibulometer (Figure 2). This acrylic plate can be used, but it must be immobile once the digitizing begins.

[1] A kneaded eraser (art eraser) and poster tac mixture will not transfer oil to the specimen and is more adhesive than clay.

5.2.6.2. Once the cranium and mandible are positioned and digitizing begins, they cannot be moved or slightly bumped out of position. Some practitioners prefer to digitize the entire cranium first, and then move on to stabilizing and digitizing the mandible. This helps to avoid any obstructions that the mandible, mandibulometer, or acrylic plate may cause.

5.3. Preparing the 3Skull Program or any other data collection program your lab uses for Data Collection:

5.3.1. Open the 3Skull program folder on the attached Laboratory computer's Desktop or locate the program here include direct digital file link if applicable. The program should display a message indicating that the digitizer is connected. If the message is not displayed, close the program and hold the white Home button on the back of the digitizer base for a few seconds before opening the program again.

5.3.2. Once the 3Skull program is open and the control screen is visible, complete these steps:

5.3.2.1. Enter the case number category (i.e., ML, OC, or IO use your office/lab's case coding) for the specimen in the case field (CATKEY) and the numeric case number in the field labeled "Individual."
5.3.2.2. Enter the initials of the analyst in the "Recorder" field.
5.3.2.3. Select the coordinate table into which the data will be entered. Choose "3DCoords.adt" (which stores the raw x, y, and z coordinates). If it does not exist, create it by selecting "New."
5.3.2.4. Create a new "cran" file with [CASENUMBER]**cran**[Initials].adt (which converts landmarks to interlandmark distances [i.e., measurements]) by clicking on the "New" button on the right.
5.3.2.5. Select the most current landmark table which provides the landmark ordering for 3Skull. "**Lndmrk13F.ADT**" is the most current file. If it does not exist, download it from here (http://math.mercyhurst.edu/~sousley/Software/), save it to the "refdbs" folder within the digital 3Skull folder, close and then reopen 3Skull.
5.3.2.6. Click the "Start" button on the screen to begin digitizing.
5.3.2.7. Once digitizing begins you must complete the measurement session—this includes the arcs.

NOTES: 1) When creating new database files you must type "**Coords**" and "**Cran**" into the file name as listed above. 2) All landmarks, arcs, and notes must be entered during one session. Once the 3Skull data collection screen is closed, this case cannot be re-opened in 3Skull.

6. DIGITIZING THE CRANIUM AND MANDIBLE

6.1. Collecting Osteometric Data using 3Skull or any other data collection program your lab uses:

6.1.1. Best practice suggests testing the MicroScribe prior to each digitizing session. The following steps are performed to test the digitizer:

- After clicking the Start button, click on the "Test" box in the upper right corner (it will fill in with a check mark).
- Using a ruler or sliding caliper (or another instrument with known measurements), place the stylus tip at the first point to be measured.
- Press the trigger capture button on the hand held switch or foot pedal accessory to record the current stylus tip position and then the yellow "Ready" label will be displayed.
- Move the stylus tip to another point on the ruler or caliper and press the capture button. The calculated distance in mm (with two decimals) will be displayed (example: 25.74). You can measure the distance between two more points by repeating the procedure.
  Note: the digitizer is not accurate to hundredths of a millimeter, but the values are displayed nonetheless.
- To end the Test mode, click the "Test" box again. The check mark will disappear. If errors are noted, recalibrate the MicroScribe. Once the "Test" box is un-clicked, make sure to begin digitizing at "prosthion-Howells" or click "Erase XYZ" to clear all test data.

6.1.2. After testing the MicroScribe, but before digitizing, best practice suggests noting whether the cranium has any anomalies that may skew the collected data (e.g., trauma, pathology, taphonomy, missing elements, etc.). In the "Cranial reshaping" box, the default is an "N" indicating the cranium is normal and has no anomalies. If any of the aforementioned anomalies are present on the cranium, type a "Y" in the box and describe the pathology, taphonomy, trauma, or missing elements in the Comments box at the bottom; this will clarify why some of the landmarks are skewed or could not be recorded.

6.1.3. To begin digitizing, click on the "X" coordinate field of the first measurement and place the stylus on the landmark. Once the stylus is in position, press the trigger capture button on the hand held switch accessory to capture the point.

6.1.3.1. The 3Skull program will navigate the analyst through the osteometric points and automatically advance to the next landmark once the capture trigger is pressed on the hand held device. Sometimes 3Skull may not advance automatically, or may skip a landmark; be sure to note which landmarks you are collecting as you proceed.

6.1.3.2. The analyst can manually cycle through the points using the <<Previous<< and >>Next>> buttons. Manual control allows the analyst to go back and recapture a point or skip landmarks that are not present on the specimen due to taphonomy or lack of point clarity. **Note**: it is easy to accidentally skip a landmark or capture the wrong landmark; the analyst should regularly double check he/she is capturing the correct landmark.

6.1.3.3. Pressing "Erase XYZ" will remove data from a previous entry and allow for reentry of the point. Recapturing the point without pressing "Erase XYZ" will also overwrite the existing x,y,z coordinates. The analyst may need to click on the "X" coordinate field after erasing XYZ, if the coordinate field is not highlighted in green.

6.1.3.4. **IMPORTANT NOTE**: If estimating a landmark because of damage or missing elements, it **MUST BE** noted (in 3Skull comments section) that it is an estimate. Caution should be taken in using estimated landmarks.

6.1.4. Once the osteometric landmarks for the cranium are captured, the program will move to the mandible landmarks. Follow the same procedures listed in 6.1.3.1 through 6.1.3.3.

6.1.5. The following landmarks are taken on the mandibulometer or the workspace surface and an acrylic plate (if you do not have a mandibulometer), rather than the bone:

- Pogonion (#79)
- Mandibular Angle Base Left (#87)
- Mandibular Angle Base Right (#100)
- Superior Condyle Posterior Left (#92)
- Superior Condyle Posterior Right (#96)

6.1.6. These points provide the following measurements:

- Pogonion to Mandibular Angle Base = Measurement of Mandible Length
- Pogonion to Mandibular Angle Base to Sup Condyle Post = Measurement of Angle

6.1.7. If a practitioner prefers not to digitize the mandible with the MicroScribe, the interlandmark distances and angle can be acquired using standard calipers and a mandibulometer. These measurements can be manually entered into the 3Skull interlandmark results, or data review, screen prior to saving.

6.1.8. Once the osteometric landmarks for the cranium and mandible are captured, the arcs will need to be recorded. The arcs are recorded in a separate box on the left side of the screen, which can be recorded at any time during the process; however, it is recommended to complete the landmarks first.

NOTE: Some practitioners prefer to capture the arcs prior to digitizing the mandible so all aspects of the cranium have been captured in the event that the cranium is bumped while working with the mandible.

6.1.8.1. The arcs are taken following a specific pathway (posterior to anterior or anterior to posterior) that changes depending on the arc being captured. Refer to the arc pathway arrows provided in Appendix 5: Illustrations for Osteometric Landmark and Arc Locations.

6.1.8.2. Click on the arc measurement abbreviation and place the stylus at the starting point, make sure the measurement is highlighted in green.

6.1.8.3. Press and release the capture trigger when the stylus is at the starting point of the arc. CAREFULLY drag the stylus across the surface of the bone to the terminal point. Press and release the capture trigger at the terminal point of the arc. Below are some helpful tips for taking arcs:

- The number of points should increase (in the small box to the right of the arc abbreviation) and the computer should make "beeping" noises as the stylus is dragged and points are collected. The numbers provided represent the number of points taken in the arc, not the measurement value.
- When you press and release the capture trigger at the terminal point of the arc, make sure the arc abbreviation turns back to yellow (i.e., the digitizer is no longer recording points) before moving the stylus.
- DO NOT scrape the cranium with the stylus. Too much pressure on the stylus may also cause the cranium to move.

6.1.8.4. The speed at which you take the arcs will determine the quality of the measurements. For the parietal arc (PAA), aim for 170 points or higher and for the nasal arc (NAA), aim for at least 30 points. See section 9.8 for guidance on arcs. Do not take the arc too quickly or too slowly.

6.1.9. Once all the landmarks and arcs are captured, click "Add to DBs" on the 3Skull screen. This will save these data to the previously configured database files in the 3Skull folder.

6.1.10. 3Skull will run a measurement check to see if any points are determined to be possible errors or outliers, but they are population specific and may not apply to the individual you are digitizing. If there are no issues these data will populate the 3Skull interlandmark results, or data review, screen. If an error occurs follow these steps:

- Write down the measurement(s) with error and the landmarks associated with the measurement(s).

- Examine the errors by navigating back through the landmarks contributing to the measurement(s). Retake the points and click "Add to DBs" and the data will open the 3Skull interlandmark results screen. If the error persists, then manually check the measurement and if it is correct click the "Skip Meas. Checks" box and "Add to DBs."
- Manually check that the Radiometer landmarks (i.e., the floating points inside the EAM used to mimic a radiometer) were taken correctly. In the 3Skull interlandmark results screen Basion Radius (BAR) plus Bregma Radius (BRR) should approximately equal Basion Bregma height (BBH) (BAR + BRR = BBH). If this sum is not correct, then the Radiometer landmark symmetry is off and the points should be retaken following the steps above.
- If an error is noted by the analyst, but not flagged when adding to DBs, the "Redo" button can be clicked in the data summary screen to return to the data collection screen. Repeat the above steps.
- An analyst can manually check several Interlandmark distances (ILD) with calipers as an additional quality measure.
- If there are no errors, click "OK" and close the program. Note that these data can be examined again for errors when imported into Advantage Data Architect or the FORDISC program.

6.1.11. Open the 3Skull data folder and locate the "cran" file. Clicking on the file will open the data in the Advantage Data Architect program. Review the data to make sure it transferred correctly and close Advantage Data Architect. For casework it is recommended to create a new cran file for every case rather than stacking cases in the same database file. Therefore, when viewing in the ADA there should only be data from one case. This allows for easy exporting into FORDISC. If one file is used to collect data from multiple crania, additional steps (not covered in this SOP) are required to export the data into FORDISC.

6.2. Importing the data into FORDISC or any other data collection program your lab uses

6.2.1. Open FORDISC and load the saved "cran" file into FORDISC from the 3Skull folder. Note that an error will occur if 3Skull and/or Advantage Data Architect are still open.

6.2.2. Analyze the data using standard procedures for FORDISC (Ousley and Jantz, 2012; Jantz and Ousley, 2017).

6.2.3. Save the file in the FORDISC folder on the FORDISC USB key and in the digital case folder and print out the analytical log.

6.3. Remove the cranium from the tri-column stand and the mandible from the mandibulometer. Erase all pencil marks.

7. FILE MANAGEMENT

7.1. Place a copy of the 3skull [cran] file(s) in the appropriate digital case folder located in link to digital case file, if applicable.

7.2. Place a copy of the FORDISC file(s) in the appropriate digital case folder located in link to digital case file, if applicable.

8. EQUIPMENT MAINTENANCE

8.1. The Microscribe system can remain plugged in when it is not in use. The system should not be moved or bumped.

8.2. Never connect any external cables (i.e., hand switch or foot pedal accessory cord) while the power supply or USB cable is connected, otherwise damage may occur.

8.3. Periodically the equipment should be cleaned using compressed air and lens wipes to remove dust. Avoid chemical cleaners.

8.4. An annual maintenance is performed by a certified vendor (See SOP discussing calibration and equipment maintenance; or add description about calibration here).

9. TROUBLESHOOTING

9.1. Refer to the User Guide (on the Revware CD) for troubleshooting the MicroScribe system. If the system will not turn on, disconnect all cables and start with connecting the power supply before reattaching the other cables.

9.2. Avoid singularities when capturing points:

9.2.1. Excessive torque to the digitizer arm may produce a singularity, which will cause inaccurate data collection.

9.2.2. Do not take “bound” points (such as in a divot, corner, or channel) while the stylus and the forearm of the device are aligned (Figure 3).

9.3. If captured points appear to be incorrect, the digitizer may need to be recalibrated. Make sure the stylus is in the correct Home position and push the “Home” button. An easy way to spot check accuracy is to take several interlandmark distances (e.g. BBH, BNL, GOL, ZYB, etc.) with the spreading and sliding calipers and compare results. The “Test” function (see section 6.1.1) is another form of spot checking.

9.4. If a point is located in a location with an atypical deep groove or deep suture, DO NOT place the stylus all the way into the feature.

9.5. For complex or obliterated sutures, trace their paths with a pencil and mark the point of intersection. Examples: Lambda with ossicles or when the coronal suture

meets the sagittal suture (Bregma) at different points (meaning the sutures are off-set). See Figures 4-8 below.

9.6. Points along the cranial base may be difficult to see due to the positioning of the cranium on the tri-column stand. A small mirror can be used to guide the stylus to the hard-to-see points.

9.7. Guidance and tips for taking difficult osteometric points; **Please read complete definitions for these landmarks (Appendix 2 and 3) prior to taking them:**

9.7.1. In order to take **Alveolon**, the analyst should place a skinny rubber band on the alveolus prior to placing the cranium on the tri-column stand; take the point in the middle of the rubber band; touch, but do not depress the rubber band.
9.7.2. **Alare** is taken on the anterior surface of the nasal margin (i.e., not inside the nasal aperture).
9.7.3. **Ectoconchion** is taken at the most anterior margin of the orbital rim.
9.7.4. **Orbital height** is taken slightly inside the orbital rims.
9.7.5. **Radiometer point**, is taken by inserting the stylus tip all the way into the EAM, then pulling it half way out, taking the measurement with the stylus "floating" in the cavity rather than against the wall. The stylus should be level with the imaginary straight line connecting the two EAMs. One way to do this is to place both index fingers outside of the EAMs to help visualize the connecting line. Visualizing taking this point with a radiometer is helpful (Figure 9).
9.7.6. **Most inferior nasal border** (i.e., actual floor of the nasal cavity) is taken inside the nasal aperture if there is nasal guttering. If there is a nasal sill, and you cannot reach the stylus inside the nasal aperture (to reach the floor), then place the stylus on the anterior surface of the maxilla to approximate the location of the nasal floor (Figure 10 and Appendix 2).
9.7.7. **Jugale** is taken on the postero-lateral angle on the lateral surface.
9.7.8. **Marginal process** is taken postero-laterally.
9.7.9. **Sphenion** and **Krotaphion** cannot be taken when there is frontal-temporal articulation (Figure 11 and Appendix 2), which is common in African and sometimes Asian ancestry, a notch bone is present (Figure 12 and Appendix 2), or the sutures are obliterated.
9.7.10. **Basion** and **Opisthion** are located on the midpoint of the foramen magnum margins (Figure 12 and Appendix 2).
9.7.11. **Staurion** may be difficult if the sutures meet unevenly. When this occurs, draw lines to create a point of intersection (see Figure 5 above).
9.7.12. **Hormion** is taken posterior to the vomer at the midline, not into the anterior deflection if it is present (Figure 13 and Appendix 2).
9.7.13. **Dacryon** is located at the apex of the lacrimal fossa, on the frontal bone. Mark the point carefully with a pencil (unless marking with a pencil will cause damage) on both sides to assist with data collection. Details are provided below to help evaluate the location of this landmark:

- In the ideal well-preserved specimen, the groove will be clearly defined with the apex corresponding well with the inner wall of the orbit as viewed by sighting. The groove will be bisected by the lacrimo-maxillary suture, which will meet the fronto-lacrimal and fronto-maxillary sutures (the frontal bone) at the groove's apex. The inner border of the orbit, curving down from above, will form a slight promontory overhanging the apex of the groove and just lateral to it. The point determined should be on the frontal bone (Howells 1973: 167).
- There is much variation from the above pattern: the fossa may be shallow with a broad or ill-defined apex; the suture may be obliterated; the lacrimal bone itself may be absent anatomically or lost postmortem. Approximate the point defined above, i.e., the apex, by using, in order of priority:
  - the lacrimal fossa observed from directly above, a view which makes it easy to determine its course and the proper point of its apex;
  - the promontory on the frontal bone – the best guide when the lacrimal bone is broken out entirely;
  - the posterior border of the fossa – the point never lies posterior or lateral to it, but may approach it;
  - the lacrimo-maxillary suture, when the structures are whole but the form of the fossa is shallow and undefined;
  - there is often a small foramen just at the apex of the fossa, which may be used as a guide, though it is apt to lie slightly mesial to the apex proper (Howells 1973: 167).

9.7.14. **M1 anterior point** and **Ectomalare** are located on the alveolus. M1 anterior point is not located not between the roots of the first molar and second premolar (Figure 15). **DO NOT** capture these points if the cranium is edentulous.

9.8. Guidance for taking Arc measurements (see Appendix 5 for diagrams):

9.8.1. When taking the **Occipital Arc** (OCA), if an inion hook is present, draw the stylus up to the base of the hook and press the capture trigger, bypass the hook, then continue measuring to lambda.

9.8.2. When taking the **Nasal Arc** (NAA), follow the midline rather than the suture. NOTE: The point can still be taken if the anterior portions of the nasals are missing, considering that the purpose of the NAA is to get at the deepest point on the nasal bone profile. Draw the stylus as far anteriorly as possible along the nasals until you reach the damaged ends, then stop.

9.8.3. Be aware the **Malar Arc** (MAA or MLS) has a high interobserver error. Try to draw the stylus in as straight a line as possible between zygoorbitale and zygotemporale inferior, at the level of the zygomaticofacial foramen.

10. APPENDICES

Appendix 1: List of Osteometric Landmarks, Arcs, and Subtenses

11. REFERENCES

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Appendix 1: List of Osteometric Landmarks, Arcs, and Subtenses[1]

NOTE REGARDING LANDMARK NUMBERING: multiple landmark lists are available and the ordering of the landmarks vary. The most recent landmark list for 3Skull is "**Lndmrk13F**" (as of November, 2018) and it contains a total of 111 landmarks. The Lndmrk13F file and older landmark files (i.e., Lndmrk11HMP and Lndmrk12M) can be found/downloaded here: http://math.mercyhurst.edu/~sousley/Software/. The number(s) and ordering of landmarks are subject to change, so please be aware of which landmark list is selected before digitizing with 3Skull. Also note that FORDISC and 3D-ID do not use all 111 landmarks to estimate sex and ancestry. It is important to collect all 111 landmarks since they may become useful as future research explores cranial geometric variation.

#	Landmark	Measurement	Brief Description
1	Prosthion-Howells	BPL, NPH	Midline point at the most anterior point on the alveolar process of the maxillae.
2	Prosthion-Martin	UFHT	Midline point at the inferior tip of the alveolar process of the maxillae
3	Subspinale	SSR, SSS	The deepest point seen in the profile below the anterior nasal spine.
4	Alare L	NLB	The most lateral point on the margin of the nasal aperture taken on the anterior surface.
5	Most inferior nasal border L	NLH	Actual floor of the nasal cavity, taken inside the nasal aperture if there is guttering or the stylus will fit into the nasal aperture. If there is a nasal sill, place stylus on the anterior surface of the maxilla to approximate the location of nasal floor.
6	Most inferior nasal border R	NLH	
7	Alare R	NLB	The most lateral point on the margin of the nasal aperture taken on the anterior surface.
8	Zygoorbitale L	MOW, IML, XML	The intersection of the orbital margin and the zygomaticomaxillary suture.
9	Nasale inferius L		The most inferior point where the nasal touches the maxilla.
10	Nasale inferius R		
11	Zygoorbitale R	MOW, IML, XML	The intersection of the orbital margin and the zygomaticomaxillary suture.
12	Lower orbital border L/R	OBH (inf. point)	The height between the upper and lower borders of the left orbit, perpendicular to the long axis of the orbit and bisecting it. Internal measurement.
13	Upper orbital border L/R	OBH (sup. point)	
14	Cheek height superior point L/R	WMH	The minimum distance, in any direction, from the lower border of the orbit to the lower margin of the maxilla, medial to the masseter attachment.
15	Cheek height inferior point L/R	WMH	
16	Ectoconchion L	OBB, EKB	The intersection of the most anterior surface of the lateral border of the orbit and a line bisecting the orbit along its long axis.
17	Dacryon L	OBB, DKB	Anterior border of the junction of the lacrimal and frontal. Apex of lacrimal fossa on the frontal bone.

KEY

These points must be marked prior to setting the cranium on the stand.

[1] Appendix 1 is a quick reference guide with abbreviated descriptions of landmarks. See Appendices 2 and 3 for full landmark descriptions.

#	Landmark	Measurement	Brief Description
18	Nasale superius L		The most superior point where the nasal touches the maxilla.
19	Nasomaxillary suture pinch L	WNB	The minimum transverse breadth across the two nasal bones.
20	Nasomaxillary suture pinch R	WNB	
21	Nasale superius R		The most superior point where the nasal touches the maxilla.
22	Dacryon R	DKB	Anterior border of the junction of the lacrimal and frontal. Apex of lacrimal fossa on the frontal bone.
23	Ectoconchion R	EKB	The intersection of the most anterior surface of the lateral border of the orbit and a line bisecting the orbit along its long axis.
24	Zygion R	ZYB	Maximum lateral extent of the zygomatic arch.
25	Zygotemporale inferior R	IML, XML	Point at the inferior zygotemporal suture on the zygomatic process.
26	Zygotemporale superior R	IML, XML	Point at the superior zygotemporal suture on the zygomatic process.
27	Zygomaxillare R	ZMB	Intersection of zygomaxillary suture and limit of the attachment of the masseter muscle, on the facial (most anteriorly projecting) surface of the zygomaxillary suture.
28	Zygomaxillare L	ZMB, IML	
29	Zygotemporale superior L		Point at the superior zygotemporal suture on the zygomatic process.
30	Zygotemporale inferior L	IML, XML	Point at the inferior zygotemporal suture on the zygomatic process.
31	Zygion L	ZYB	Maximum lateral extent of the zygomatic arch.
32	Jugale L	JUB	Deepest curvature of the zygomatic angle, taken laterally, not on the margin.
33	Marginal process lateral L		Point at the lateral-most aspect of the marginal process of the zygomatic.
34	Frontomalare temporale L	UFBR	Point where the frontozygomatic suture crosses the temporal line.
35	Frontomalare anterior L	FMB, NAS	Point where the frontozygomatic suture intersects with the orbit.
36	Frontotemporale L	WFB	Point generally anterior and medial along the temporal line (minimum frontal breadth).
37	Sphenofrontale L		Point where the sphenoid, frontal, and zygomatic sutures intersect.
38	Sphenion L		The anterior tip of the parietal (the intersection of the parietal and sphenoid at the coronal suture).
39	Krotaphion L		The superior-posterior tip of the greater wing of the sphenoid.
40	Maximum frontal point L	XFB	Instrumentally-determined, maximum frontal breadth; on the coronal suture.
41	Stephanion L	STB, STS	Point where the coronal suture crosses the temporal line (left and right).
42	Stephanion R	STB, STS	
43	Maximum frontal point R	XFB	Instrumentally-determined, maximum frontal breadth; on the coronal suture.
44	Krotaphion R		The superior-posterior tip of the greater wing of the sphenoid.

KEY

These points must be marked prior to setting the cranium on the stand.

#	Landmark	Measurement	Brief Description
45	Sphenion R		The anterior tip of the parietal.
46	Sphenofrontale R		Point where the sphenoid, frontal, and zygomatic sutures intersect.
47	Frontotemporale R	WFB	Point generally anterior and medial along the temporal line on the frontal bone that, when paired with Frontotemporale L, measures the minimum frontal breadth.
48	Frontomalare anterior R	FMB, NAS	Point where the frontozygomatic suture intersects with the orbit. Point is taken anterior.
49	Frontomalare temporale R	UFBR	Point where the frontozygomatic suture crosses the temporal line. This is taken on the frontozygomatic suture at the most lateral point – wherever that point may be.
50	Marginal process lateral R		Point at the lateral-most aspect of the marginal process of the zygomatic.
51	Jugale R	JUB	Deepest curvature of the zygomatic angle, taken laterally, not on the margin.
52	Nasion	NOL, NLH, NAS	Point of intersection of the nasofrontal suture and the mid-sagittal plane, on the frontal bone.
53	Glabella	GOL	The most forwardly projection point in the mid-sagittal plane at the lower margin of the frontal bone.
54	Supraglabellare	GLS	The point at which the convex profile of the frontal bone changes to join the prominence of the glabellar region.
55	Bregma	FRC, PAC, BBH	Point where the coronal and sagittal sutures intersect.
56	Lambda	PAC, OCC	Point where the sagittal and lambdoidal sutures meet.
57	Asterion L	ASB	The point where the lambdoidal, parietomastoid, and occipitomastoid sutures meet.
58	Eurion L	XCB	Instrumentally-determined, ectocranial point of greatest cranial breadth.
59	Radiometer point L	radii NAR, BRR.	Taken inside the EAM, “floating.” Refer to section 9.7 for instructions.
60	Porion L	MDH	Point at the most superior aspect of the EAM.
61	Mastoideale L	MDH	Point at the most inferior tip of the mastoid.
62	Radiculare L	AUB	Deepest point on the zygomatic root (bi-auricular breadth).
63	Radiculare R	AUB	
64	Radiometer point R	radii NAR, BRR.	Taken inside the EAM, “floating.” Refer to section 9.7 for instructions
65	Porion R	MDH	Point at the most superior aspect of the EAM.
66	Mastoideale R	MDH	Point at the most inferior tip of the mastoid.
67	Eurion R	XCB	Instrumentally-determined, ectocranial point of greatest cranial breadth.
68	Asterion R	ASB	The point where the lambdoidal, parietomastoid, and occipitomastoid sutures meet.
69	Opisthion	FOL	Midline point at the posterior margin of the foramen magnum.
70	Basion	BBH, BNL	Midline point at the anterior margin of the foramen magnum.
71	FOB Point R	FOB	Foramen magnum breadth.
72	FOB Point L	FOB	

KEY

These points must be marked prior to setting the cranium on the stand.

#	Landmark	Measurement	Brief Description
73	Hormion		The most posterior midline point on the vomer.
74	Alveolon	MAL	Use rubber band. Point on the interpalatal suture where the line drawn between the posterior ends of the alveolar ridges crosses the midline.
75	Staurion		The point at the intersection of the median and transverse palatine sutures.
76	Ectomolare L	MAB	Widest part of the alveolar maxilla, around M2.
77	M1 Anterior Point L	AVR	Anterior/mesial margin of the left first molar, on the alveolus.
78	Ectomolare R	MAB	Widest part of the alveolar maxilla, around M2.

Mandible Landmarks			
#	Landmark	Measurement	Brief Definition
79	Pogonion	XRL, MAN	Most anterior midline point on the chin of the mandible.
80	Gnathion	GNI	The most inferior midline point on the mandible.
81	Infradentale	GNI	The midline point on the alveolar bone between the two central mandibular incisors.
82	HMF inferior point L/R	HMF	Mandibular body height at the mental foramen.
83	HMF superior point L/R	HMF	
84	TMF buccal point L/R	TMF	Mandibular body breadth at the mental foramen.
85	TMF lingual point L/R	TMF	
86	Gonion L	GOG	The most lateral external point at the junction of the horizontal and ascending rami.
87	Mandibular angle base L	MAN	Point on the posterior base of the mandible as if you were measuring ramus height with a mandibulometer.
88	Coronion L		Point at the tip of the coronoid process of the mandible.
89	Inf mandibular notch point L		Lowest point between condyle and coronion.
90	Condylion laterale L	BCB	Lateral-most projection of the mandibular condyle.
91	Sup condyle L		Highest point on the mandibular condyle.
92	Sup condyle post L	CDL, MAN	Perpendicular to the highest point on the mandibular condyle as if it were sitting in a mandibulometer.
93	Condylion mediale L		Medial-most projection of the mandibular condyle.
94	Condylion mediale R		Medial-most projection of the mandibular condyle.
95	Sup condyle R		Highest point on the mandibular condyle.
96	Sup condyle post R		Perpendicular to the highest point on the mandibular condyle as if it were sitting in a mandibulometer.
97	Condylion laterale R	BCB	Lateral-most projection of the mandibular condyle.
98	Inf mandibular notch point R		Lowest point between condyle and coronion.
99	Coronion R		Point at the tip of the coronoid process of the mandible.
100	Mandibular angle base R	MAN	Point on the posterior base of the mandible as if you were measuring ramus height with a mandibulometer.
101	Gonion R	GOG	The most lateral external point at the junction of the horizontal and ascending rami.
102	WRB posterior point (R or L)	WRB	Minimum ramus breadth.
103	WRB anterior point (R or L)	WRB	

KEY

These points must be marked prior to setting the cranium on the stand.

Calculated Points - No Need to Digitize			
#	**Landmark**	**Measurement**	**Brief Definition**
104	Nasal bone elevation	SIS, SIA	Calculated from nasal arc.
105	Deepest point on nasal bone profile	NDS, NDA	Calculated from nasal arc.
106	Max malar projection point L/R	MLS	Calculated from malar arc.
107	Metopion	FRF, FRS	Instrumentally-determined, point where the frontal's elevation above the chord from nasion to bregma is greatest.
108	Parietal subtense point	PAF, PAS	The maximum subtense, at the highest point on the convexity of the parietal bones, within the bregma-lambda chord, in midline.
109	Vertex radius point	VRR	Instrumentally-determined, the highest point at midline when the skull is in Frankfurt Horizontal.
110	Opisthocranion	GOL	Instrumentally-determined, the furthest point from glabella in midline.
111	Occipital subtense point	OCF, OCS	The maximum subtense, at the highest point on the convexity along the lambda-opisthion chord, in midline.
Arcs to Digitize			
#	**Arc**	**Measurement**	**Quick Description**
1	Frontal Arc	FRA	From bregma to nasion. (P to A)
2	Parietal Arc	PAA	From lambda to bregma. (P to A)
3	Occipital Arc	OCA	From opisthion to lambda. (A to P)
4	Malar Arc	MAA	From zygoorbitale to zygotemporale *inferior*. (M to L)
5	Nasal Arc	NAA	From nasion to rhinion. (S to I)

Appendix 2: Landmark Definitions for Digitizing (3Skull)

All definitions provided below are from Langley et al.'s (2016) *Data Collection Procedures 2.0* (drawn from Howells (1973) and Martin and Knussmann (1988)), unless stated otherwise. The numbers correspond with the order of appearance in 3Skull using landmark file "**Lndmrk13F**."

1. **Prosthion Howells (prosH):** The most *anterior* point on the alveolar border of the maxilla between the central incisors in the mid-sagittal plane. (Howells 1973: 169).

2. **Prosthion Martin (prosM):** The most *inferior* point on the alveolar border of the maxilla between the central incisors in the mid-sagittal plane. (Spradley, personal communication).

3. **Subspinale (ss or ssp):** The deepest point seen in the profile view below the anterior nasal spine. (Caple and Stephan 2016: 872). If there is a gap between the maxillae below the nasal spine, DO NOT insert the stylus into the gap.

4,7. **Alare (al or alarl/r):** Instrumentally determined as the most lateral point on the nasal aperture in a transverse plane, taken on the anterior margin (not inside the nasal aperture). (Caple and Stephan 2016: 872).

5,6. **Most inferior nasal border (nlhil/r):** (i.e., actual floor of the nasal cavity) is taken inside the nasal aperture if there is nasal guttering or the stylus will fit into the nasal aperture to reach the floor (Figure 9). If there is a nasal sill, and you cannot reach the stylus inside the nasal aperture, then place the stylus on the anterior surface of the maxilla to approximate the location of the nasal floor. (Spradley, personal communication). In 3Skull, Most Inferior Nasal Border is used to calculate nasal height (NLH)—the right and left sides are averaged. (Ousley, personal communication).

The lower border of the aperture is not always the most anterior edge, but the beginning of the actual floor of the nasal cavity. It is not the forward border, of any prenasal gutter or fossa. If the border is gently sloping, determine the floor of the cavity as well as possible by sighting, and make a pencil mark, being aided by any sign of a border originating from the septum, not the lateral edges. In brief, this is the height of the functional nasal structure, not taking account of special variations of the most anterior part of the opening. (Howells 1973: 175).

8,11. **Zygoorbitale (zo or zygool/r):** The intersection of the orbital margin and the zygomaxillary suture. Since the orbital border is usually softly rounded here, the point should be found midway between the facial and orbital surfaces. A small process or sliver of the malar may extend several millimeters medially from the rest of the bone just here, pushing the suture and point well inward along the orbital margin. As a convention, the point is never placed medial to the plane of the medial border of the infraorbital foramen. (Howells 1973: 170).

9,10. **Nasale inferius (nasil/r):** Termination of the intersection of the nasomaxillary suture, discounting any nasal bone overgrowth. (Spradley, personal communication).

12. **Lower orbital border (obhi):** Measured as the maximum height from the upper to the lower orbital borders perpendicular to the horizontal axis of the orbit and using the middle of the inferior border as a fixed point; slightly internal measurement (place pencil mark slightly inside orbital margin on the frontal bone). (Slice and Ross 2009: 13).

13. **Upper orbital border (obhs):** Measured as the maximum height from the upper to the lower orbital borders perpendicular to the horizontal axis of the orbit and using the middle of the inferior border as a fixed point; slightly internal measurement (place pencil mark slightly inside orbital margin of the zygomatic or maxilla, wherever the maximum height is found). (Slice and Ross 2009: 13).

14. **Cheek height superior point (wmhs):** Instrumentally determined as the minimum height of the superior zygomatic and inferior maxilla, wherever it is found, *mesial* to masseter attachment; mark the *superior* point on the orbital margin of the zygomatic. (Spradley, personal communication; Howells 1973: 180).

15. **Cheek height inferior point (wmhi):** Instrumentally determined as the minimum height of the superior zygomatic and inferior maxilla, wherever it is found, *mesial* to masseter attachment; mark the *inferior* point on the maxilla. (Spradley, personal communication; Howells 1973: 180).

16,23. **Ectoconchion (ec or ectl/r):** The intersection of the most anterior edge of the lateral orbital border and a line parallel to the superior orbital border that bisects the orbit into two equal halves. To locate ectoconchion, trace a line along the anterior edge of the lateral orbital border with a pencil. Then hold a toothpick/skewer or thin straight instrument parallel to the superior orbital margin and move it down until the orbit is divided into two equal halves, making sure to keep the toothpick parallel to the superior margin. Mark the point (ectoconchion) where the toothpick intersects with the previously traced line. (Howells 1973: 168). Ectoconchion is not sighted in relation to dacryon.

17,22. **Dacryon (d or dacl/r):** Dacryon is located on the frontal bone. When the lacrimomaxillary suture is easily found, dacryon is the point on the frontal bone where the frontal, lacrimal and maxillary sutures meet. There is often a small foramen at this point. If the lacrimomaxillary suture cannot be found, dacryon is aligned with the apex of the lacrimal fossa. If the apex is inferior to the frontal bone, a line should be extended superiorly from the apex to the frontal, and the point should be marked on the frontal. (Howells 1973: 167; Martin and Knussmann 1988: 166).

18,21. **Nasale superius (nassl/r):** Intersection of the nasomaxillary suture, the nasofrontal suture, and the frontomaxillary suture. (Spradley, personal communication).

19,20. **Nasomaxillary suture pinch (wnbl/r):** Instrumentally determined as the narrowest portion of the midline of the face, between the left and right nasomaxillary sutures. This is the minimum transverse breadth across the two nasal bones. (Slice and Ross 2009: 13; Spradley, personal communication).

24,31. Zygion (zy or zygl/r): The most laterally positioned point on the zygomatic arches. The position of zygion is defined from the measurement of bizygomatic breadth. (Martin and Knussmann 1988: 167).

25,30. Zygotemporale inferior (zytil/r): The most *inferior* point on temporozygomatic suture; if the suture is obliterated, DO NOT TAKE THE POINT. (Spradley, personal communication).

26,29. Zygotemporale superior (zytsl/r): The most *superior* point on temporozygomatic suture; if the suture is obliterated, DO NOT TAKE THE POINT. (Spradley, personal communication).

27,28. Zygomaxillare (zm or zygoml/r): The intersection of the zygomaxillary suture and the limit of the attachment of the masseter muscle, on the facial (anterior) surface of the zygomaxillary suture. If obliteration makes the facial part of the suture difficult to follow, inspection of its course, if present, on the internal surface of the arch may help. In very rare cases, and in association with an os japonicum, the suture runs more posteriorly, and over a centimeter lateral to the anterior end of the masseter attachment. Zygomaxillare anterior is then likely to be located beyond the angle of the malar; in such cases it is recommended that the point be placed on the facial surface, on the masseter limit, not more than 6-8 mm from the anterior end of the masseter area. (Howells 1973: 170).

32,51. Jugale (ju or jugl/r): Deepest point in the curvature of the frontal and temporal process of the malars (zygomatics) (Howells 1973: 175-6); taken laterally on the zygomatic, not directly on the margin (Spradley, personal communication). Caple and Stephan provide a more geometric definition: Vertex of the posterior zygomatic angle, between the vertical edge and horizontal part of the zygomatic arch. (Caple and Stephan 2016: 873).

33,50. Marginal process lateral (mpll/r): The most *posterior* portion of marginal process, taken on the lateral surface of the zygomatic. (Spradley, personal communication).

34,49. Frontomalare temporale (fmt or fmtl/r): Instrumentally determined as the most laterally positioned point on the frontomalare suture. (Martin and Knussmann 1988: 167).

35,48. Frontomalare anterior (fma or fmal/r): Most anterior projecting point on the frontomalare suture (different from the frontomalare orbitale and temporale). (Slice and Ross 2009: 13).

36,47. Frontotemporale (ft or wfbl/r): A point located generally forward and inward on the superior temporal line directly above the zygomatic process of the frontal bone. The right and left frontotemporale form the endpoints of the minimum frontal breadth measurement. (Martin and Knussmann 1988: 164). Instrumentally determined as the point of minimum breadth of the frontal bone on the temporal line.

37,46. Sphenofrontale (jnzl/r): The intersection of the sphenoid, frontal, and zygomatic sutures (i.e., the sphenozygomatic and sphenofrontal sutures). Use a mirror to help locate this point while digitizing.

38,45. Sphenion (sphn or sphl/r): Anterior end of the sphenoparietalis suture, where it meets the frontal bone. (Caple and Stephan 2016: 873). DO NOT take (or estimate) if suture is obliterated, if there is a direct frontal-temporal articulation (Figure 10), or a notch bone that involves the frontal suture (Figures 11 and 12). (Spradley, personal communication).

39,44. Krotaphion (k or krol/r): Posterior end of the sphenoparietalis suture, where it meets the squamosal part of the temporal bone. (Caple and Stephan 2016: 873). DO NOT take (or estimate) if suture is obliterated or notch bones are present (see Figure 12). (Spradley, personal communication).

40,43. Maximum frontal point (xfbl/r): Instrumentally determined with spreading caliper as the widest breadth of the frontal bone on the coronal suture; mark points with pencil (Howells 1973: 172-3).

41,42. Stephanion (st or stpl/r): The point at which the inferior temporal line crosses the coronal suture. (Caple and Stephan 2016: 873).

52. Nasion (n or nas): The point of intersection of the nasofrontal suture and the mid-sagittal plane. As a general rule nasion is located on the frontal bone. (Howells 1973: 169; Martin and Knussmann 1988: 165).

53. Glabella (g or glb): The most anteriorly projecting point in the mid-sagittal plane at the lower margin of the frontal bone, which lies above the nasal root and between the superciliary arches. The point of glabella is depressed between the confining bony ridges, and is often delineated superiorly by a shallow gutter or a transversely running indentation on the surface of the frontal bone. (Martin and Knussmann 1988: 161).

54. Supraglabellare (sg or spglb): Deepest part of the supraglabella fossa in the median plane (cannot be determined in skulls without a supraglabella fossa). (Caple and Stephan 2016: 872). The point at which the convex profile of the frontal bone changes to join the prominence of the glabellar region (Howells 1973: 181).

55. Bregma (b or brg): The posterior border of the frontal bone in the mid-sagittal plane. Normally this is the meeting point of the coronal and sagittal sutures, on the frontal bone. The latter may diverge from the midline here, however, and should not then be followed (metopic sutures should be disregarded).

In cases where the most anterior segment of the sagittal suture deflects to one side, the point of the junction of the two sutures must be projected. In cases of asymmetry of the coronal suture, the general course of the suture as a whole should be lightly drawn with a pencil, and the bregma established on this. The point should mark the limits of the frontal and parietal segments of the vault generally, not minor sutural variations. (Howells 1973: 167) (see Figure 7).

56. Lambda (l or lam): The apex of the occipital bone at its junction with the parietals, in the midline. This is normally the meeting of the sagittal and lambdoid sutures, but must be placed in the midline. There is often an apical bone at the site, in which case lambda is to

be found by extending the general curving course of each half of the lambdoid suture to their intersections with the midline; if these extensions do not meet at the midline in a single point, lambda is halfway between such intersections.

In occasional cases, the apex of the occipital makes an obvious forward excursion along the midline, away from the general course of the suture, and probably resulting from an apical bone joined to the occipital. Again, extend the course of each half of the lambdoid sutures to create a vertex. The lambdoid suture itself may be very complex or composed largely of wormian bones. Trace a pencil line along the center of such an area on each side, to find lambda as above. (Howells 1973: 168; Martin and Knussmann 1988: 162) (see Figures 4 and 5).

57,68. Asterion (ast or astl/r): The point where the temporal, parietal, and occipital bones meet. If the meeting point is occupied by a Wormian bone, extend the lambdoid suture onto its surface, and then extend the other two sutures (temporo-parietal, temporo-occipital) to the first line, finding asterion as the point midway between the intersections if these do not coincide. Use only the part of the last two sutures (ca. 1 cm) that is nearest the point when extending the lines. If the lambdoid (or other) suture is complex or composed of Wormian bones, trace a pencil line along the center of the area covered by the complexity, as well as can be done, to find the main axis of the suture. If the sutures gape at this point, leaving an open space, find Asterion on the edge of the occipital bone. (Howells 1973: 166; Martin and Knussmann 1988: 164) (see Figure 8).

58,67. Euryon/Eurion (eu or eurl/r): The most laterally positioned point on the side of the braincase. Euryon always falls on either the parietal bone or on the upper portion of the temporal bone and may be determined only by measuring maximum cranial breadth. The area of the root of the zygomatic arch, the supra-mastoid crest, and the entire adjacent region above the external auditory meatus, which sometimes exhibit excessive symmetrical lateral expansion, should be avoided when determining the position of euryon. (Martin and Knussmann 1988: 164).

59,64. Radiometer point (radptl/r): Taken by inserting the digitizer stylus tip all the way into the EAM, then pulling it half way out, taking the measurement with the stylus "floating" in the cavity rather than against the wall. The stylus should be level with the imaginary straight line connecting the two EAMs (see Figure 9). One way to do this is to place both index fingers outside of the EAMs to help visualize the connecting line. Do not angle the stylus within the EAM. (Spradley, personal communication).

60,65. Porion (po or porl/r): The most superior point along the upper margin of the external acoustic meatus. (Martin and Knussmann 1988: 164).

61,66. Mastoideale (ms or mastl/r): The most inferior point on the tip of the mastoid process. To determine the point, hold the skull base up with the lateral side facing you and mark the tip. (Martin and Knussmann 1988: 165).

62,63. Radiculare (ra or aubl/r): The point on the lateral aspect of the root of the zygomatic process at the deepest incurvature. (Martin and Knussmann 1988: 164).

69. **Opisthion (o or ops):** The point on the inner border of the posterior margin of the foramen magnum in the mid-sagittal plane (see Figure 12). (Martin and Knussmann 1988: 163).

70. **Basion (ba or bas):** The point at which the anterior border of the foramen magnum is intersected by the mid-sagittal plane opposite Nasion (na). In rare cases the determination of the position of basion may be made difficult by a thickening of the anterior margin (see Figure 13). (Howells 1973: 166).

71,72. **FOB Point (fobl/r):** Instrumentally determined, widest breadth of foramen magnum, perpendicular to foramen magnum length. This point is on the inner border of the lateral margins, not on the endocranial or ectocranial surfaces of the foramen magnum margin. Mark left and right sides prior to digitizing. (Spradley, personal communication).

73. **Hormion (ho or hor):** Median point where the vomer and sphenoid bones meet (see Figure 14). (Caple and Stephan 2016: 871).

74. **Alveolon (alv):** The point where the mid-sagittal plane of the palate is intersected by a line connecting the posterior borders of the alveolar crests. To assist in locating the point, place a thin rubber band or wire against the posterior margins of the alveolar processes of the maxilla. (Martin and Knussmann 1988:167).

75. **Staurion (sr or staur):** Point of intersection between the median and interpalatine suture and transverse palatine suture (Frassetto, 1918; Skrzat et al., 2003). In some skulls, the two halves of the transverse palatine suture do not meet at the same point on the median plane; in these cases, the point nearer to the [incisive fossa] was considered. (Moreira et al. 2008).

76,78. **Ectomolare (ecm or ecml/r):** The most lateral point on the buccal surface of the alveolar margin. This point is generally positioned on the alveolar margin of the second maxillary molar. (Martin and Knussmann 1988: 167).

77. **M1 Anterior Point (avrpt):** On the alveolus, at the anterior/mesial margin of the left first molar, at approximately the level where the root enters the alveolus (Figure 15). (Spradley, personal communication).

79. **Pogonion (pg or malapt):** Most anterior median point on the mental eminence of the mandible. (Caple and Stephan 2016: 871).

80. **Gnathion (gn or gniipt):** The lowest point on the inferior margin of the mandibular body in the mid-sagittal plane. Frequently, gnathion is not the most inferiorly located point of the mandible, as the more laterally placed elements of the mandible may be extending far more inferiorly. This is particularly the case in mandibles with broad and square chin development. (Martin and Knussmann 1988: 167).

81. **Infradentale (id or gnispt):** The point between the lower incisor teeth where the anterior margins of the alveolar processes are intersected by the mid-sagittal plane. (Martin and Knussmann 1988: 167).

82. **HMF inferior point (hmfipt):** The *inferior* point when HMF is instrumentally determined with a sliding caliper; the maximum distance from the alveolar process to the inferior border of the mandible, perpendicular to the mental foramen (Martin and Knussmann 1988: 183). Mark point with pencil.

83. **HMF superior point (hmfspt):** The *superior* point when HMF is instrumentally determined with a sliding caliper; the maximum distance from the alveolar process to the inferior border of the mandible, perpendicular to the mental foramen (Martin and Knussmann 1988: 183). Mark most *superior* point with pencil.

84. **TMF buccal point (tmfbpt):** The *buccal* point when TMF is instrumentally determined with a sliding caliper; the maximum breadth of mandibular body at the level of the mental foramen, roughly perpendicular to the long axis of the mandibular body, but the orientation is highly variable from individual to individual. (Martin and Knussmann 1988: 183). Mark point with pencil.

85. **TMF lingual point (tmflpt):** The *lingual* point when TMF is instrumentally determined with a sliding caliper; the maximum breadth of mandibular body at the level of the mental foramen, perpendicular to the long axis of the mandibular body. (Martin and Knussmann 1988: 183). The point should be approximately on the opposite side of the bone from the mental foramen. The point should be on or very near the mental foramen. (Ousley, personal communication). Mark point with pencil.

86,101 Gonion (go or gonl/r): Point on the mandible where the inferior margin of the mandibular corpus and the posterior margin of the ramus meet, i.e., the point on the mandibular angle which is directed most inferiorly, posteriorly, and laterally. If the mandibular angle is not pronounced, position the mandible with the angle facing upward. Gonion is positioned at the highest point of the curvature where the posterior margin of the ramus and the inferior border of the body meet. The point can also be found with the assistance of a mandibulometer by halving the mandibular angle and marking the point on the lateral border of the angle. When measuring the bigonial diameter the most lateral position of the angles should be chosen as measuring points. (Martin and Knussmann 1988: 168).

87,100 Mandibular angle base (man(l/r)ipt): Posteroinferior to gonion (go), taken on the mandibulometer or the work surface, not on the mandible. This landmark replicates the point at which the imaginary lines for maximum ramus height (XRH) and mandibular length (MLN) intersect (i.e., where the mandibulometer horizontal base and the posterior board meet. This landmark is used to calculate maximum ramus height (XRH), mandibular length (MLN), and mandibular angle. (Ousley, personal communication).

88,99. Coronion (cr or coronl/r): The tip of the coronoid process of the mandible. (Caple and Stephan 2016: 872).

89,98. Inferior mandibular notch point (imnptl/r): Point at the deepest incurvature of the mandibular notch (between the coronoid and the condyle), on the margin of the notch.

90,97. Condylion laterale (cdl or latcndl/r): The most lateral points of the mandibular condyles. (Martin and Knussmann 1988: 168).

91,95. Sup condyle (supcnd(l/r)S): Most distant point on the mandibular condyle from the gonial angle. Instrumentally determined with a mandibulometer, if possible (i.e., point at which the horizontal plate of the mandibulometer rests on the condyle when the mandible is stabilized between the anterior and posterior movable boards). Mark with a pencil.

92,96. Sup condyle post (supcnd(l/r)P): Most *posterior* point on the mandibular condyle. Replicating the point at which the posterior aspect of the mandibular condyle would rest against the movable posterior board of the mandibulometer. Mark with a pencil. This landmark is used to calculate maximum ramus height (XRH) and mandibular angle. (Ousley, personal communication).

93,94. Condylion mediale (cdm or medcndl/r): Most medial point on the mandibular condyle. (Caple and Stephan 2016: 872).

102. WRB posterior point (wrbppt): Instrumentally determined with sliding caliper; the minimum breadth of mandibular ramus, perpendicular to the posterior border of the ramus; taken at the "waist" of the ramus where the distance between the anterior and posterior margins of the ramus is smallest. (Martin and Knussmann 1988: 183). Mark point on *posterior* ramus margin with pencil.

103. WRB anterior point (wrbapt): Instrumentally determined with sliding caliper; the minimum breadth of mandibular ramus, perpendicular to the posterior border of the ramus; taken at the "waist" of the ramus where the distance between the anterior and posterior margins of the ramus is smallest. (Martin and Knussmann 1988: 183). Mark point on *anterior* ramus margin with pencil.

Arc. Rhinion (rhi): Most rostral (anterior) point on the internasal suture. Cannot be determined accurately if nasal bones are broken distally. (Caple and Stephan 2016: 872).While this is not landmark taken in 3-Skull, the definition is needed for understanding how to measure the nasal arc.

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Appendix 3: Howells (1973) Landmark Definitions

The landmarks and measurements written below are the original Howells (1973)[1] definitions, corresponding notes, and citations. The information was retrieved from the original publication and from the following web address: http://www.cleber.com.br/howells.html. They have been included to demonstrate the complexity of the definitions and to provide a comprehensive accounting for how the original instruments were used to located these landmarks. It is advised that these definitions be consulted when a question about the exact placement of a landmark arises.

HOW TO READ HOWELLS:

- The two or three letters after the name of the landmark or measurement (either lower case or capital) is the abbreviation (e.g., "as" for Asterion, "fm:a" for Frontomalare anterior, "BNL" for Basion-nasion length).
- The alphanumeric code after the measurement abbreviation (e.g., "Ia," IIa," "IIIa," "IIb," "IIIb," "IIIc," and "IIId") refers to the original instruments used by Howells. These instruments are listed below following the definitions. Some, such as the sliding (IIb) and spreading calipers (Ia) we still use today, but others (i.e., radiometer (IIIb) and simometer (IIIc)) we do not. These have been replaced by the digitizer.
- The landmark/measurement definition is the first italicized sentence(s). The non-italicized text that follows provides further clarification.
- The various letters in parenthesis or following "Equivalent definition" (e.g., M, V, BR, MH, B, AD, BM, HW, K, P, T, W, and WM) are Howells' sources. The full citations are listed in Howells' bibliography located below, after the instrument descriptions.

Asterion as
The common meeting point of the temporal, parietal, and occipital bones, on either side.

If the meeting point is occupied by a wormian bone (os astericum), extend the lambdoid suture onto its surface, and then extend the other two sutures (temporo-parietal, temporo-occipital) to the first line, finding asterion as the point midway between the intersections if these do not coincide (BM). Use only the part of the last two sutures (ca. 1 cm) which is nearest the point, in finding these directions.

If the lambdoid (or other) suture is complex or composed of wormian bones, trace a pencil line along the center of the area covered by the complexity, as well as can be done, to find the main axis of the suture.

If the sutures gape at this point, leaving an open space, find asterion on the edge of the occipital bone.
Equivalent definitions: BM, M, K, BR

Basion ba
On the anterior border of the foramen magnum, in the midline, at the position pointed to by the

[1] Howells WW. 1973. *Cranial Variation in Man: A Study by Multivariate Analysis of Patterns of Difference Among Recent Human Populations*. Papers of the Peabody Museum of Archaeology and Ethnology, 67. Harvard University, Cambridge Massachusetts.

apex of the triangular surface at the base of either condyle, i.e., the average position from the crests bordering this area. Mark carefully with a pencil.

In the most usual specimen the border of the foramen will have a thickness of 1-2 mm and a rounded edge. The position chosen will be about half way between the inner border directly facing the posterior border (opisthion) and the lowermost point on the border, i.e., between the points usually designated endobasion and hypobasion respectively.
As a practical matter, the point will almost always be the endpoint of the basion-nasion length if the caliper is applied here so as to find a maximum. It will correspond with endobasion only if there is a thin, sharp border to the foramen.

The variation in structure here is considerable: in thickness of the border, and in the presence of a small tubercle or a larger articular surface. In the case of the former, displace basion to one side or the other; in the case of an articular surface, place the point on this, trying to estimate the position from directions above.

To estimate basion in a damaged skull, use a transverse line connecting the posterior limits of the bases of the spinous processes on either side. The elevation of basion in such a case can, however, be only guessed at.

Notes:

1. There is no actual anatomical point "basion," but only a variety of conventions to establish a point at this site. Buxton and Morant (BM) have reviewed the problems involved extensively. The definition used here is meant to correspond with theirs (which I find a little difficult to apply), and at least not to diverge from it; it reads: "the inferior point in that plane of the basi-occipital region bounding the foramen."
2. If basion is to be used for several different measurements, and above all for the establishment of angles and facial triangles, it must without question be not only a unique point but one which can be used in all the measurements intended. This makes most undesirable the acceptance of two separate points (M, V, K), a lower (hypobasion) and a posterior (endobasion) merely for convenience in taking individual measurements, or finding maximum readings in so doing, e.g., basion-bregma height, or basion-prosthion length.

Equivalent definitions: BM

Bregma br

The posterior border of the frontal bone in the median plane.

Normally this is the meeting point of the coronal and sagittal sutures. The latter may diverge from the midline here, however, and should not then be followed. (Metopic sutures should be disregarded.)

More commonly, the coronal suture may project slightly backward in a small point here, from the general smooth curve of the suture on either side; or the two halves of the suture may meet in a short antero-posterior line, i.e., one half may lie forward of the other where they reach the midline. In these and similar cases, the general course of the suture as a whole should be lightly drawn with a pencil, and the bregma established on this. The point should mark the limits of the frontal and parietal segments of the vault generally, not minor sutural variations.

If the coronal suture is nearly obliterated, its course must be established from any remaining traces: if it is completely obliterated, there is nothing to do but estimate the position of bregma.

The sutures may meet with rounded external edges, resulting in a cleft or depression at their junction. Bregma is then to be established "in the air" (BM), i.e., in its correct position but at the level of the general surface of the bone and not, by sinking the caliper point into such a fissure in measuring, below this surface. Some device, such as displacing bregma slightly to one side in the same transverse plane, may be followed.

In any other questionable case where such a choice may be necessary, bregma is considered to be on the frontal bone.

Equivalent definitions: M, BR, K, (BM).

Notes:

Buxton and Morant (BM) reject Martin's recommendation to place bregma in the midline by projecting forward the general course of the sagittal suture, which they consider may be asymmetrical throughout its length; instead they would use the anterior extremity of the sagittal suture even if it does appear to be asymmetrically placed. This conflicts with the aim of finding the essential border of the frontal bone in the median plane.

Dacryon dk

The apex of the lacrimal fossa, as it impinges on the frontal bone. Mark with a pencil point on both sides.

In the ideal well-preserved specimen, the groove will be clearly defined and sharply apexed, the apex corresponding well with the inner wall of the orbit as viewed by sighting. The groove will be bisected by the lacrimo-maxillary suture, which will meet the fronto-lacrimal and fronto-maxillary sutures (the frontal bone) at the groove's apex. The inner border of the orbit, curving down from above, will form a slight promontory overhanging the apex of the groove and just lateral to it. The point determined should be on the frontal bone.

There is much variation from the above pattern: the fossa may be shallow with a broad or ill-de-fined apex; the suture may be obliterated; the lacrimal bone itself may be absent anatomically or lost post mortem. Approximate the point defined above, i.e., the apex, by using, in **order of priority**:

- **(a)** the lacrimal fossa observed from directly above, a view which makes it easy to determine its course and the proper point of its apex;
- **(b)** the promontory on the frontal bone – the best guide when the lacrimal bone is broken out entirely;
- **(c)** the posterior border of the fossa – the point never lies posterior or lateral to it, but may approach it;
- **(d)** the lacrimo-maxillary suture, when the structures are whole but the form of the fossa is shallow and undefined;
- **(e)** there is often a small foramen just at the apex of the fossa, which may be used as a guide, though it is apt to lie slightly mesial to the apex proper.

Notes:

1. Dacryon is traditionally defined as the meeting point of the frontal, maxillary, and lacrimal bones (or of the sutures involved). Such a point is less easy to establish in most skulls than

this would imply, and the definition substituted here is meant to have a more specific basis structurally (the lacrimal fossa), so that a search for it in difficult cases has a guiding principle and does not depend on a sutural configuration which is unreliable in several ways.

2. There is no satisfactory landmark for the inner border of the orbit. Broca (1875) defined and named dacryon for the purpose, but after long general use it was abandoned by both British (B) and French (V) workers in favor of maxillofrontale, defined as the intersection of the fronto-maxillary suture and the anterior lacrimal crest or its penciled extension. In effect this is the upward extension of the lower border of the orbit. In a review of these problems by Piquet (1954) she gives evidence that orbit breadth is less variable when measured from maxillofrontale than when measured from dacryon, and adds, as arguments for using the former, the fragility of the lacrimal bone (which does not affect maxillofrontale) and the propriety of including the lacrimal fossa in the orbit when measuring breadth.

   I have preferred dacryon for the present study for these reasons:
   (a) Maxillofrontale is indeed not difficult to find, and use for purposes of orbital breadth, but in fact in most cases its location is somewhat vague and it is without clear structural meaning as a point.
   (b) Maxillofrontale is, not usually visible so clearly on the orbital margin as diagrams of cranial points (e.g., Martin, fig. 290) might imply; dacryon, as defined here, is more definitely related both to the upper border and the lacrimal fossa, and is closer to the actual margins of the orbit and of the inter-orbital space than is maxillofrontale.
   (c) In addition to wanting a point with a clear anatomical basis, this point is used in measurements in an antero-posterior direction (e.g., dacryon subtense), and not in orbit width only; dacryon is more serviceable for these.

Ectoconchion ek

The intersection of the most anterior surface of the lateral border of the orbit and a line bisecting the orbit along its long axis. Mark both sides with a pencil.

Hold the flat of a pencil lead so that this surface is perpendicular to the median plane of the skull, i.e., tangent to the most anterior curvature of the orbital margin, and use it to draw a line along this crest. Turn the skull so as to be able to sight along the long axis of the orbit, however oblique, and to bisect the orbit visually, with the pencil as a sighting guide. Make a tick with the pencil where this axis appears to intersect the line already made.

Note:

This does not appear to coincide with Martin's point, although it may in many cases where the orbital border is sharp. Martin's definition (p. 621) and diagram clearly refer to the "orbital margin," without reference to the anterior position of this. Here, the point is on the line of the true profile of the orbit, the most anterior crest, and relates to measures of facial flatness as well as to orbital width.

Frontomalare anterior fm:a
The most anterior point on the fronto-malar suture. It may be found with the side of a pencil lead held in the transverse plane.

This is neither the orbital nor the temporal point of the suture (Martin's frontomalare orbitale and temporale respectively), nor is it the line of the orbital border. It is strictly the most anteriorly projecting point, and is used for measurements relating to such projection.

The suture may be, and usually is, quite irregular in its course here. No corrective for this is offered: the point is placed on the suture wherever it may lie.

Lambda la
The apex of the occipital bone at its junction with the parietals, in the midline.

This is normally the meeting of the sagittal and lambdoid sutures, but must be placed in the midline. The ruling principle, as in the case of bregma, is to divide the parietal and occipital segments of the sagittal section of the skull (BM).

There is often an intercalary or apical bone at the site, in which case lambda is to be found by extending the general curving course of each half of the lambdoid suture to their intersections with the midline; if these extensions do not meet the midline in a single point, lambda is halfway between such intersections (BM).

In occasional cases, the apex of the occipital makes an obvious forward excursion along the midline, away from the general course of the suture, and probably resulting from an apical bone joined to the occipital. The same procedure as immediately above is followed.

The lambdoid suture itself may be very complex or composed largely of wormian bones. Trace a pencil line along the center of such an area on each side, to find lambda as above.
Equivalent definitions: BM, BR, (M)

Nasion na
The intersection of the fronto-nasal suture and the median plane. Mark with a pencil.

This does not refer to the internasal suture in any way. If there is irregularity near the midline, rectify the general curve of the fronto-nasal suture with a pencil so as to find the correct level for nasion.

Except for this last, a general rule is to consider nasion as on the frontal bone (BM, V). I.e., if the fronto-nasal suture forms a cleft or gap, locate nasion on the midline just at the angle between the facial and sutural surfaces of the frontal bone itself.
Equivalent definitions: BM, V, M.

Opisthion os
The inferior edge of the posterior border of the foramen magnum in the midline.

The posterior border is virtually always either a sharp edge or one which makes a clear angle between the external surface and the actual border of the foramen.
Equivalent definitions: BM, V (?)

Prosthion pr

The most anteriorly prominent point, in the midline, on the alveolar border, above the septum between the central incisors. Mark with a pencil.

This most anterior point (with the skull erect in a position corresponding to the eye-ear plane) is generally easily seen, but if the bone descends smoothly into the inter-incisor septum, while also continuing to slope forward, find the point in the general line of the border elsewhere along the gum. There is apt to be a thickening or reinforcement of the border slightly below the arcs of exposure of the tooth roots along the row, especially if there has been some slight (not marked) retraction of the edges of the alveoli—this is the level sought for prosthion.

Because of frequent damage, and of ante-mortem loss or avulsion of the incisors, location of prosthion for actual measurement may be difficult, resulting in the need for approximations or estimates of its original position. Sighting along the border on either side of the central region will help.

The point is often slightly recessed between the incisors themselves. If the recession is exceptionally deep, the point should correspond to the center of a more gentle concavity, i.e., about that which would meet the rounded tip of the spreading caliper, so that this may be used directly in measuring basion-prosthion length.

Notes:

1. See note #2 under basion. There can be only one landmark for measuring and defining angles in this region. Prosthion, as here defined, is decidedly more suitable than the inferior tip (alveolar point, alveolare) of the process between the incisors, because natural variation, damage and resorption all affect the latter to a greater degree.
2. Historically, after a period of confusion (P), both the German (M) and the French (V) schools accepted the usage of two points for vertical and horizontal measurements respectively, i.e., hypo-prosthion and exoprosthion (V). The Biometric Laboratory on the other hand recognized the difficulty of two points (P, BM), and selected the lower—alveolar point, or alveolare—as the single point for use. Pearson (P) defined prosthion as the "point in which the geodesic on the anterior surface of the alveolar arch between the midpoints of the anterior faces of the middle incisors at the anterior alveolar border meets the incisive suture," which seems to correspond with the definition here.

Equivalent definition: P.

Stephanion st

The intersection of the coronal suture and the limit of the temporal muscle (the inferior temporal line). Mark with a pencil on both sides.

The temporal line is generally divided before reaching the suture; if not, the upper limit is used. The lower line may follow a mutual course with the suture for a short distance, in which case the posterior end of this course is used. In general, it may help to imagine the point as the end of the inferior temporal line on a detached frontal bone.

In some skulls surface erosion or poor definition make finding the point difficult. Better definition on one side may help on the other. Also, the point usually coincides with the lower end of the pars complicata of the suture, if this is discernible.

Note:

Broca defined stephanion as a region along the suture, ending below where the suture changed from complicated to simple, this point being the one to use in measuring. This usually coincides with stephanion as defined above.
Equivalent definitions: (BR), M, V.

Subspinale ss
The deepest point seen in the profile below the anterior nasal spine.

Practically, this relates to the deepest points found in measuring zygomaxillary subtense and subspinale radius; and one must bear in mind that the point is on the crest, or profile, not in the fissure of the intermaxillary suture.

If the nasal spine is small or eroded, the point is difficult to locate. It should not be placed internal to the outermost limit of the lower border of the aperture.
Equivalent definition: M.

Zygomaxillare anterior zm:a
The intersection of the zygomaxillary suture and the limit of the attachment of the masseter muscle, on the facial surface. Mark with a pencil on both sides.

In very rare cases, and in association with an os japonicum, the suture runs more posteriorly, and over a centimeter lateral to the anterior end of the masseter attachment. It then is apt to be located beyond the angle of the malar; in such cases it is recommended that the point be placed on the facial surface, on the masseter limit, not more than 6-8 mm from the anterior end of the masseter area. If obliteration makes the facial part of the suture difficult to follow, inspection of its course, if present, on the internal surface of the arch may help.

Notes:

1. This is not the point defined by Martin (p. 621) and used by Woo and Morant, which is the lowermost end of the zygomaxillary suture, not facial in position. Such a point is not useful (Woo and Morant to the contrary) for measurements of facial flatness and projection, and the point defined here is that used by Russian anthropologists.
2. A better point for most of the same purposes would probably be the most anterior point on the masseter attachment on the facial surface. It is difficult to see the usefulness of the suture for these purposes. However, such a point has not been used, except approximately by Landauer.

Equivalent definition: AD.

Zygoorbitale zo
The intersection of the orbital margin and the zygomaxillary suture. Mark with a pencil.

Since the orbital border is usually softly rounded here, the point should be found midway between the facial and orbital surfaces.

A small process of the malar may extend several millimeters mesially from the rest of the bone just here, pushing the suture and point well inward along the orbital margin, and increasing the measurement of malar length by the length of this sliver. As a convention, the point is never placed mesial to the plane of the medial border of the infraorbital foramen.

Equivalent definitions: K, W.

MEASUREMENT DEFINITIONS

Many of the precise instructions assume a right handed worker; a left handed one will have to fend for himself.

Glabello-occipital length GOL Ia
Greatest length, from the glabellar region, in the median sagittal plane.

Rest the skull with the base up facing the observer, which makes sighting the midplane easier. Place the left caliper point in the glabellar region in the midline and move the right point along the occiput in the midline for the maximum reading. On finding this, move the left point up and down slightly to make sure the reading is maximum.

Synonyms:

M	Grösste Hirnschädellänge	1
B	Greatest glabello-occipital length	L (see note 4)
V	Maximum length	
MH	Longueur maxima du crane	1 (see note 3)

Notes:

1. The anterior point must be confined to the glabellar, supraorbital region. In occasional female skulls with vertical foreheads and little or no glabellar protrusion, moving the anterior point up the frontal bone will give readings higher than the glabellar region itself, which nevertheless can be determined with little difficulty.
2. The external occipital protuberance (inion) may be so well developed that the maximum length lies at this point, though such cases are uncommon and are confined to particular populations. This length is not accepted as measuring the contour, or actual cranial length, unless it forms part of a broad nuchal crest development. In almost every case a secondary but true maximum may be found higher on the occiput, and this should be used. If it cannot be found, and the inion is still clearly a special development, approximate the contour of the bone and/or the crest in this area, discounting the protuberance itself, and make the best estimate of length accordingly. The most likely site for measurement in such cases may be the notch in the midline directly above the downward curve usually taken by the nuchal crest here (see under occipital subtense).
3. This is the maximum length of the Monaco Agreement but, contrary to the specific statement of that document, Hrdlicka asserted that it intended to disregard the median plane, so that his own definition differs. The practice of Hrdlicka, also of Vallois, of holding the caliper in one hand, near the hinge, to manipulate it, is not preferred here, as allowing less control by the fingers.
4. The Biometric Laboratory usage has evidently been to observe the median plane, though this is not explicit. The Frankfort Agreement, from which it was drawn, gives for Grösste Länge, "gr. L: von der Mitte zwischen den Arcus superciliares bis zu dem am meisten vorragenden Punkt des Hinterhauptes." Fawcett's early (1902) list gives for L: "greatest length, from glabella to the most projecting point at the back of the skull."

Macdonnell (1904) reports that he closely followed Miss Fawcett, and gives a similar definition, as do most subsequent writers, even Pearson in his 1928 article on the Egyptian E series, in which he dwelt at some length on the great importance of standardization.

However, Morant in 1927 and in further papers as late as 1937 specified the median plane (as does Trevor 1950), noting that L was therefore different from the Monaco maximum length, which did not specify this plane (which the Monaco Agreement in fact does specify). Finally, there is in the Duckworth Laboratory a notebook evidentally (sic) drawn up by Evelyn Thomson to record and control the work being done on the Egyptian E series (it is dated May,1907), which contains the following:

> Greatest length from glabella to the occiput. (L). Measurement taken exactly similar to Macdonnell. Care must be used, that this measurement is taken in the median plane, and this is best assured by having the skull facing you.

It thus seems clear that actual practice in the Biometric Laboratory was always to use the midplane.

This is not a trivial point, especially since maximum length has been a universally taken measurement. Small asymmetries will make the "most distant" or "most projecting" point further from glabella than any in the midline. And such differences will also cause a photographic profile of a skull to give a greater reading than the midline maximum.

For various reasons, although agreement with a photographic measurement would be desirable, the midplane measurement is to be preferred. Only by using it can length in a slightly asymmetrical skull be assumed to give the best approximation to a symmetrical one (no safe assumption in any case). And since other measurements (such as lengths of occipital, and angles) also follow the midplane, this measurement best coordinates with them.

Nasio-Occipital length NOL Ia
Greatest cranial length in the median sagittal plane, measured from nasion.

With the skull in position as for glabello-occipital length, place the left caliper point at nasion, sighting to be certain that the point, especially if blunt, is properly aligned with nasion. Move the right point along the occiput in the midline for the maximum reading.

Synonym:
M Hirnschädellänge von Nasion aus. 1d

Note:
See Note 2 under Glabello-occipital length.

Basion-nasion length BNL Ia
Direct length between nasion and basion.

With the skull in position as for glabello-occipital length, place the caliper points at, or align them carefully with, nasion (left point) and basion (right point).

Synonyms:
≈ M Schädelbasislänge 5
≈ B Length of skull base LB
≈ V Nasion-basion length
≈ MH Diamètre naso-basilaire 9

Notes:
1. As Martin notes, if the caliper end is not sufficiently pointed, it may not reach nasion in a deeply notched nasal root. In such a case the accuracy of the measurement can be checked by using one of the other instruments with sharp points.
2. The measurements noted above as approximate synonyms probably coincide in practice with this one, as normally finding basion at the maximum distance from nasion, where my definition would also usually find it.

Basion-bregma height BBH Ia
Distance from bregma to basion, as defined.

Rest the skull on the occiput, with its right side facing the observer. Place the left caliper point at bregma, and find basion carefully with the right.

Synonyms:
(B Basio-bregmatic height H' insofar as the BM definition of basion is followed.)
(This is not the same as Martin #17, which like many others uses hypobasion, to give a maximum diameter.)

Notes:
1. Do not sink the left point into any cleft which may exist at the coronal suture; the measurement should be to the general contour of the skull at bregma, and if there is a depression, the point is to be placed before (or behind) it in the midline. Bregma is on the frontal bone, when any question arises.
2. Since basion has usually been defined as two points depending on the measurement, with hypobasion used for basion-bregma height, there are no exact equivalents for the measurement described above. The following are approximate equivalents, which will sometimes give the same reading as in the above measurement, but will usually exceed it and never fall short of it: M Basion-Bregma Höhe 17; BR Diamètre vertical basilo-bregmatique; V Basion-bregma height. For MH, basion is apparently endobasion, so that Hauteur basilo-bregmatique, 4a, may coincide but if not, it will be less.

Maximum cranial breadth XCB Ia
The maximum cranial breadth perpendicular to the median sagittal plane (above the supramastoid crests).

Rest the skull on its base, with the occiput facing the observer. Use free ring finger and little finger at the mastoid region to be sure caliper points are symmetrically placed. Try first to find the maximum on the parietals; if it must be found on the temporals, be certain to avoid the supramastoid crests completely.

Synonyms:

M	Grösste Hirnschädelbreite	8
V	Maximum breadth	
H	Maximum breadth	3

Notes:

1. If, as is often the case, slight warping has separated the temporal squamata from the parietals, an allowance must be estimated if the measurement must be made on the temporals.
2. The Biometriec Laboratory version of B is defined by Morant (1937) as being "the maximum transverse diameter on the parietal bones" and thus as differing from the Monaco Agreement, H3, “maximum breadth above the mastoids and roots of zygomae" (although in another place Morant (1928) equates B with Martin's 8, which is the same as MH,3). Some other lists in Biometrika similarly indicate that the measurement is to be made on the parietals only—see also Trevor 1950—and Miss Thomson's 1907 notebook likewise says: "The measure should not be made upon the edges of the lower bones which sometimes are warped, & give a false maximum."

Maximum frontal breadth XFB Ia
The maximum breadth at the coronal suture, perpendicular to the median plane.

Rest the skull on its base, with the face toward observer. Apply the caliper points to the coronal suture on either side being sure that they are symmetrically placed, and find the maximum at any level. The measurement may be thought of as if it were finding the maximum external breadth of an isolated frontal bone.

Synonyms:

M	Grösste Stirnbreite	10
B	Maximum frontal breadth	B”
V	Maximum frontal breadth	
MH	Largeur frontale maxima	6

Notes:

1. The measurement cannot be less than the bistephanic breadth, a useful check.
2. If the suture is obliterated in the temporal fossa, its course must be estimated from what indications remain.

Bistephanic breadth STB IIa
Breadth between the intersections, on either side, of the coronal suture and the inferior temporal line marking the origin of the temporal muscle (the stephanion points).

In a large majority of cases the uppermost limit of the temporal origin (the fascia) can be distinguished from a lower line. Follow the latter (or the former if no distinction can be made) and mark with a pencil its intersection with the coronal suture. Line and suture may follow a common course for a short distance, in which case the point (stephanion) lies at the posterior end of this course. With the skull in position as for maximum frontal breadth, measure between the marked stephania.

Synonym:
M Stephanienbreite 10b

Notes:
1. The breadth may coincide with the maximum frontal breadth but is otherwise necessarily less.
2. Surface erosion or indistinctness may make determination of the points difficult. If it is found on one side, the principle of symmetry may help locate it on the other. It also generally corresponds with the lower limit of the pars complicata of the suture, where this can be defined.

Bizygomatic breadth ZYB IIa
The maximum breadth across the zygomatic arches, wherever found, perpendicular to the median plane.

With the skull resting on the occiput with the base toward the observer, place the flat arms of the calipers on the zygomatic arches at their broadest point, making sure that the caliper is vertical to the median plane. Move it very slightly to assure a maximum reading.
Synonyms:
M Jochbogenbreite 45
B Zygomatic breadth J
V Bizygomatic breadth
MH Diamètre bizygomatique 8

Note:
If one arch is broken, make the best approximate reading by placing the caliper in position and estimating the original projection of the damaged arch. Then take a reading from the midline of the skull (palatine suture, vomer, basion) to the good arch, and double this. If the two readings agree closely, write an estimated figure followed by "?". If damage is such that this check is not feasible but an estimate seems good, write this with "??". If both sides are badly damaged, make the best guess followed by "???".

Biauricular breadth AUB IIa
The least exterior breadth across the roots of the zygomatic processes, wherever found.

With the skull resting on the occiput and with the base toward the observer, measure to the outside of the roots of the zygomatic process at their deepest incurvature, generally slightly anterior to the meatus, with the sharp points of the caliper.

Synonym:
M (Biauricularbreite) IIb

Notes:
1. This measurement makes no reference to standard landmarks of the ear region, e.g., porion or auriculare. It is an external basal breadth. It is the biauricular used by Landauer 1963, but is not the same as that used by the author in a recent study (1966), which employed

auriculare as a landmark (Martin #11). Accurate determination of this proved difficult and time consuming, to no visible purpose. The biauricular used here is simple, accurate on repetition, and anatomically sound.

2. The measurement is specifically different from those using other endpoints, e.g., M Biauricularbreite 11; or B Bi-auricular B = BR Diamètre biauriculaire = M IIa, all these being taken to Broca's points sus-auriculaires, which are on the temporal above the zygomatic roots.

Minimum cranial breadth WCB IIa
The breadth across the sphenoid at the base of the temporal fossa, at the infratemporal crests.

With a pencil lead, held at 45º to the vertical, find the infratemporal crest (actually poorly defined) which divides the temporal from the basal surface of the sphenoid, trying to draw a flattisc curve which leaves the varying small crests and tubercles in this region on the inferior side of the line. The deepest (most medial) point of the curve should still be on the temporal surface. With the skull base up and occiput facing the observer, measure the least distance between these lines with the sharp points of the calipers.

It may help to sight from the inner limit of the glenoid fossa toward the orbital fissure, at the zygomaxillary junction.

Synonym:
M Kleinste Schädelbreite 14

Notes:

1. If the pterygoid processes are large, the longest arms of the caliper may be used. If the skull must be measured with the mandible fixed in place, the spreading calipers Ia must be used, though this is awkward.
2. In male skulls there is more frequently a well-developed tubercle projecting downward near the anterior end, and most mesial part, of the infratemporal crest. Draw the line on the lateral surface of this tubercle, but definitely on its "flat" part, i.e., in the temporal fossa.

Biasterionic breadth ASB IIa
Direct measurement from one asterion to the other.

With the skull resting on the frontal region, occiput facing the observer, measure the distance from one asterion to the other with the sharp points of the caliper.

Synonyms:
M Grösste Hinterhauptsbreite 12
B Chord, asterion R to asterios L Biasterionic-B

Notes:

1. If the sutures gape somewhat at this point, measure at the edge of the occipital bone; it is meant to be a measure of the breadth of the occipital in this region.
2. If there is a wormian bone (os astericum) at the point, use the procedure of Buxton and Morant; extend all three sutures on its surface, and mark the lambdoid extension midway between its intersection with the extensions of the other two.

3. If there is simply no area of complex suturation, find the central point of this as well as possible.

Basion-prosthion length BPL IIa (or Ia)
The facial length from prosthion to basion, as defined.

With the skull resting base upward, face to the left, measure between previously marked prosthion and basion with the points of the caliper. If the incisors are present, it will usually be necessary to use the spreading calipers instead.

Synonyms:

M	Gesichtslänge	40
V	Basion-prosthion height (sic)	
MH	Diamètre alvéolo-basilaire	10

Notes:
1. This differs from any measurement which uses the alveolar tip (alveolare), or the endobasion.
2. In the common case of incisor loss or other damage to the anterior alveolar border, it may be necessary to estimate the measurement by gauging the missing portion to find an imaginary prosthion.
3. Note that the previously marked prosthion should be used. This should not be the same as the lowest point of the alveolar border seen in this view of the skull.

Nasion-prosthion height NPH IIa
Upper facial height from nasion to prosthion, as defined.

Measure with the skull face up, base to the right, between previously marked landmarks.

Notes:
1. In the case of damage to the area of prosthion, an estimate must be made by visually prolonging the thickened rim of the alveolar border between lateral teeth to the point of the estimated original midline profile. Use of the flat arms for sighting, rather than the pointed arms, may facilitate this estimate. Record the degree of uncertainty with question marks.
2. See definition of prosthion. Most corresponding measurements are made from nasion to "prosthion" = hypoprosthion = alveolar point = alveolare, e.g., M Obergesichtshöhe 48; B Upper face height G'H; V Height of upper face; MH Diamètre naso-alvéolaire 12. These are all equivalent, and all different from nasion-prosthion height as defined here.

Nasal height NLH IIa
The average height from nasion to the lowest point on the border of the nasal aperture on either side.

With the skull face up, base to the right, measure the above distance on each side and strike an average to the nearest whole millimeter. A correct figure is greatly facilitated by a dial or vernier caliper.

Synonyms:

B	Nasal height	NH
(≈ M	Nasenhöhe	55)
(≈ V	Nasal height)	
(≈ MH	Nasal height	13)

Notes:

1. The lower border of the aperture is well defined in most populations. It is not always the most anterior edge, but the beginning of the actual floor of the nasal cavity. **It is not the forward border, of any prenasal gutter or fossa.** If the border is gently sloping, determine the floor of the cavity as well as possible by sighting, and make a pencil mark, being aided by any sign of a border originating from the septum, not the lateral edges. In brief, this is the height of the functional nasal structure, not taking account of special variations of the most anterior part of the opening.
2. This is not quite the same as a measurement made to nasospinale, i.e., the intersection with the midplane of a line joining the two subnasal points defined above (as in M Nasenhöhe 55; V Nasal height). The readings obtained should be virtually identical but the one used here measures one side of a narrow isosceles triangle, of which the other measurements cited are the bisector. Note that, for MH, the Monaco Agreement uses nasospinale while Hrdlicka himself says "measure to base of spine, or separately to each subnasal point and record the mean," two quite different techniques (the second of which is followed here), both of which differ from the Monaco Agreement and Hrdlicka's translation thereof.

Orbit height, left OBH IIb

The height between the upper and lower borders of the orbit, perpendicular to the long axis of the orbit and bisecting it.

With the skull upside down and facing the observer, use the inside calipers to measure between the borders - this is an inside measurement. Bisect the orbit visually, referring to its own axes, not to the planes of the skull.

Synonyms:

M	Orbitalhöhe	52
B	Greatest height of orbit	O2L
V	Orbital height	
MH	Hauteur orbitaire	

Notes:

1. Substitute the right orbit if both diameters cannot be taken on the left. While there are apt to be constant differences between the two orbits, this is the best means of estimating the diameters of the left orbit.
2. The height should be taken at the midpoint of the long axis; if there is a deep notching just here in the lower border (as is common in some populations) move the measurement very slightly medialward.

Orbit breadth, left OBB IIb
Breadth from ectoconchion to dacryon, as defined, approximating the longitudinal axis which bisects the orbit into equal upper and lower parts.

With the skull upside down and facing the observer, use the inside calipers to measure between the points, of which ectoconchion at least should always be marked.

Synonym:
B Orbital breadth from dacryon O'_1 (?)

Notes:
1. See Note #1 under orbit height.
2. This differs from any measurement in which ectoconchion is not located as here (e.g. M 51a).
3. The measurement is taken to be synonymous with that of the Biometric Laboratory on the assumption that ectoconchion is defined in the same way (the most anterior point on the lateral border of the orbit-see Trevor). Other orbital breadths are made to an ectoconchion apparently placed at the rim of the orbit itself (e.g., M 51a) or are measured from maxillofrontale.

Bijugal breadth JUB IIa
The external breadth across the malars at the jugalia, i.e., at the deepest points in the curvature between the frontal and temporal process of the malars.

The jugalia should be noted carefully, and preferably marked. With the skull right side up and facing slightly up, place the sharp edges of the flat caliper arms against the curve of the malar at the correct point on either side. The measurement, however, is external, i.e., to lateral points, if these differ from jugale as defined by authors.

Synonym:
M Hinterer jochbeinbreite 45(1)

Notes:
1. This measurement should at first be repeated several times on each skull, until consistency is attained in locating the observed point correctly with the calipers. Canting the calipers slightly up from a horizontal plane (relative to the skull) will help in applying the edges correctly.
2. The measurement is a particularly good example of those in which the positioning of the skull (it can be taken readily with the skull base up or base down) and the application of the instrument can give errors, or divergences between workers, having nothing to do with the definition of the measurement or the understanding of it. This is the reason for the precise description of the skull position in all these definitions. However, high consistency nevertheless results from careful attention to the points used. In early work it is likely that the measurement will be underestimated.

Nasal breadth NLB IIa
The distance between the anterior edges of the nasal aperture at its widest extent.

Use the sharp points of the caliper, and remember that this is not an inside measurement.

Synonyms:

M	Nasenbreite	54
B	Nasal breadth	NB
V	Nasal breadth	
MH	Largeur du nez	14

Palate breadth MAB IIa
The greatest breadth across the alveolar borders, wherever found, perpendicular to the median plane.

With the skull base up, apply the flat arms of the calipers to the bone of the alveolar border to find the maximum reading, being sure the arms are parallel to the midline.

Synonyms:

M	Maxilloalveolarbreite	61
V	Maxilloalveolar breadth	
MH	Largeur du bord alvéolaire supérieur	18

Notes:

1. Measure to the bone, not the teeth, unless the roots are exposed at the widest point.
2. If there is some obvious special growth on one side, make allowance.
3. In cases of damage or tooth loss, estimate as well as possible by the method used for bizygomatic. Make the best estimate directly by visual reconstruction, and check by measuring from the good side to the midline and doubling. Indicate the probable reliability of the estimate with question marks.

Mastoid height MDH IIa
The length of the mastoid process below, and perpendicular to, the eye-ear plane, in the vertical plane.

With the skull lying on its right side and facing the observer, place the calibrated bar of the caliper just behind the process on the left side, so that the fixed arm is tangent to the upper border of the auditory meatus and pointing (by visual sighting) to the lowest point on the border of the orbit. The calibrated bar should be perpendicular to the eye-ear plane of the skull (i.e., approximately level in the position given), not following the axis of the process itself, in either plane; sighting across the flat measuring surface of the fixed arm should indicate whether it is in fact level with the upper edge of the meatus. Move the measuring arm until it is level with the tip of the process, using the flat surface of the arm once more as control to sight across the tip of the process and, where possible, to the tip of the opposite process as well. This entails a slight shift of eye position for sighting while holding the caliper firm.

Repeat for the other side, reversing the caliper. Average the two sides to the nearest millimeter. If the discrepancy between them is 3 or 4 mm, repeat as a check.

Notes:

1. The upper edge of the meatus should be the limit of the shadowed, deep portion. If a previous worker has marked porion on the skull, it should be found to correspond well with this.
2. This is the same measurement as that used by Giles and Elliot 1963, though the technique is slightly different. Giles and Elliot based theirs on the measurement of Keen 1950, which, however, differs in not referring to the eye-ear plane, either in finding the upper level or in orienting the instrument, since it is made along the process itself.
3. An alternative and possibly better measurement would be to measure (also by sighting) from the deepest point of the glenoid fossa and at right angles to the line of the top of the zygomatic root.
4. For references to other methods of measuring mastoid dimensions, including length, see Vallois 1969.

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Vallois, H.V. 1969. Le temporal néanderthalien H 27 de La Quina. Étude anthropologique. *L'Anthropologie*, 73: 365-400, 525-544.

Mastoid width MDB IIa

Width of the mastoid process at its base, through its transverse axis.

Measure from the incisura mastoidea, or digastric groove, to a corresponding level on the external surface of the process, transversely with reference to the process itself, not with reference to the skull. Where the digastric groove is not the obvious inner limit, because of irregularities in the formation of the process, measure from the base of the main body of the latter. Average the two sides to the nearest millimeter.

Notes:

1. This is an attempt to get a measure of the bulk of the process independent of the length as measured with reference to the eye-ear plane, since this length is affected by features of placement of the process and not by size alone. The difficulty of finding consistent landmarks for the width, especially at its internal point, makes this an unsatisfactory measurement.
2. The measurement was adopted because Schaefer (1961) reported a marked sexual dimorphism in it, making it useful for sexing remains from cremations. Schaefer defines it merely as "von der Incisura mastoidea bis zur Aussenkante der Mastoidfortsätze."

Bibliography:

Schaefer, U. 1961. *Grenzen und Möglichkeiten der anthropologischen Untersuchung von Leichenbränden*. Bericht über den V. Internationalen Kongress für Vor-und Frühgeschichte, Hamburg 1958: 717-724.

Bimaxillary breadth ZMB IIIa
The breadth across the maxillae, from one zygomaxillare anterior to the other.

With the skull face up, set each arm of the coordinate caliper on zygomaxillare anterior, and set screw firmly.

Synonym:
AD zygomaxillary breadth

Note:
This is not the same, though it is close to, other midfacial or maxillary breadths which use the previously defined zygomaxillare, i.e., the lowermost edge of the zygomaxillary suture, which is not the facial surface. It differs from M 46 and B GB.

Bimaxillary subtense SSS IIIa
The projection or subtense from subspinale to the bimaxillary breadth.

With the caliper in position for bimaxillary chord, lower the coordinate arm to subspinale and set the screw for reading.

Synonym:
AD (zygomaxillary subtense)

Notes:
1. If the nasal spine is small or eroded, location of subspinale may be difficult and somewhat arbitrary. This is unusual.
2. The point of the caliper is not to be lowered into the intermaxillary suture, if this is open. The measurement is to the profile of the subnasal region here, and should be made on the sharp edge to one side of the suture whenever necessary.

Bifrontal breadth FMB IIIa
The breadth across the frontal bone between frontomalare anterior on each side, i.e., the most anterior point on the fronto-malar suture.

With the skull face up, set each arm of the coordinate caliper on the designated points, and set the screw firmly.

Notes:
1. The fronto-malar suture varies in position and may wander rather widely on the surface, but nevertheless is used to determine the point. If there is any question, because of breakage or an open suture, the measure is to be taken on the frontal bone, this being what it is meant to measure.
2. This differs from both M Obergesichtsbreite 43, measured to the external points on the suture (frontomalare temporale), and WM Internal bi-orbital breadth IOW (=M Innere orbitale Gesichtsbreite 43(1)), measured to the inner suture points frontomalare orbitale).

Nasio-frontal subtense NAS IIIa
The subtense from nasion to the bifrontal breadth.

With the calipers in position for bifrontal breadth, lower the coordinate arm to nasion, and set the screw firmly.

Note:
Do not let the point sink into an open nasofrontal suture; find nasion on the frontal bone just at the angle of its facial and sutural edges. This subtense and the bifrontal breadth relate to the frontal bone.

Biorbital breadth EKB IIIc
The breadth across the orbits from ectoconchion to ectoconchion.

With the skull face up, place the points on ectoconchion, previously marked on either side, and set the screws firmly.

Note:
Ectoconchion is here defined as lying on the most anterior surface of the orbital border, and the caliper points rest on this crest of the convexity for this and the next measurement. The breadth differs from any using a more medial position for ectoconchion—cf. Martin, p. 621 and diagram, p. 656.

Dacryon subtense DKS IIIc
The mean subtense from dacryon (average of two sides) to the biorbital breadth.

With the caliper points in position for biorbital breadth (i.e., resting on the ectoconchia); lower the coordinate arm to the level of dacryon on the right side and read; repeat on the left side, and use the average to the nearest whole millimeter. (It is easier to read this measurement first, before removing the instrument to read biorbital breadth.) Repeat if there is discrepancy or uncertainty.

Notes:
1. This is a difficult measurement, because of the nature of dacryon (which should be marked), and because of the ease with which the lateral points slip off the ectoconchion. It requires practice in manipulation.
2. If the caliper has a coordinate arm pointed on one side (e.g., IIIa), the dacryon should be measured on one side; and then the skull should be pivoted 180º, so that the vertex faces the observer, and the caliper repositioned to measure the other side.
3. The measurement is read to the nearest whole millimeter; in spite of its small scale it cannot be made with such precision as to justify reading to 1/10 mm.

Interorbital breadth DKB IIIc
The breadth across the nasal space from dacryon to dacryon.

With the skull face up, place the lateral points on the dacryon, with particular attention to the antero-posterior location of these. Hold the instrument in such a way that it can also be kept in position for measuring the naso-dacryal subtense, and set the screw.

Synonyms:

Pearson	Nasodacryal chord	DC
M	Zwischenaugenbreite	49a

Note:
This is also a taxing measurement because of the difficulty of locating and maintaining the points on dacryon while also measuring the subtense and avoiding damage to delicate lacrimal bones. Measuring breadth and subtense is a joint operation.

Naso-dacryal subtense NDS IIIc
The subtense from the deepest point in the profile of the nasal bones to the interorbital breadth.

With the caliper in position for interorbital breadth, lower the coordinate arm to the deepest point in the nasal profile, i.e., onto the most convex point in the transverse section at the most concave point in the profile, and not into the internasal suture. Read to the nearest whole millimeter.

Synonym:

Pearson	Nasodacryal subtense

Notes:

1. Because of the difficulty of placing the lateral points very precisely, reading to 1/10 mm is not justified.
2. This subtense and the dacryon subtense will sum approximately to a subtense from the nasal saddle to the biorbital breadth, if this is measured, since they represent two components in the projection of the nasal bridge from the line of the orbital margins, one being a subtense from dacryon, the other a subtense to dacryon. They will not necessarily sum exactly to this total subtense because of approximations to whole millimeters (and other errors); and will in fact tend to be less, since they are in parallel but separate planes on which the projection of the total subtense is smaller than the direct measurement.

Simotic chord (Least nasal breadth) WNB IIIc
The minimum transverse breadth across the two nasal bones, or chord between the naso-maxillary sutures at their closest approach.

Read to 1/10 mm.

Synonyms:

WM	Simotic chord	SC
M	Kleinste Breite der Nasenbeine	57

Notes:

1. The measurement is between the naso-maxillary sutures, i.e., never above the fronto-nasal suture, if there is a rectangular upward extension of the nasalia here.
2. Martin notes that the position will be high if the naso-maxillary sutures are nearly parallel, but much lower if they are hourglass form. Measurement must be made wherever the minimum distance lies, though some consideration should be given to the general course of the sutures in the not uncommon case of sudden inward excursions of one suture.
3. The simotic measurements were originally introduced by Mérejkowsky 1882, and named by Pearson (Benington 1912: 316).
4. In a few populations (Eskimos) the nasalia may not reach the frontal bone, but pinch out; or they may be absent entirely. In such a case there is nothing to do but take a measurement lower down, or measure the structure which substitutes; zero measurements cannot be allowed.
5. A possible improvement on this measurement and the next: to use the deepest point of the nasal saddle, not the point of least nasal breadth. The two may coincide much of the time.

Simotic subtense SIS IIIc
The subtense from the nasal bridge to the simotic chord, i.e., from the highest point in the transverse section which is at the deepest point in the nasal profile.

With the caliper in position for simotic chord, lower the coordinate arm to the most prominent point or ridge (i.e., not into the internasal suture) on the nasalia, while the instrument is tilted so as to find the generally lowest projection of the bones with relation to the chord. Read to 1/10 mm.

Synonym:
WM Simotic subtense SS

Notes:
1. Woo and Morant counsel marking the "ridge" of the nasal bones in this region with the flat side of a pencil lead.
2. Pearson (1934) was concerned about the geometric effect of any lateral displacement of the highest point from the midline, i.e., the effect on the computed angle; but this hardly seems worth taking account of in view of other comparatively generous sources of error in measures of this small scale.

Malar length, inferior IML IIa
The direct distance from zygomaxillare anterior to the lowest point of the zygo-temporal suture on the external surface, on the left side.

With the skull resting approximately on the right parietal, measure with the pointed arms between the previously marked points. Use the right side if necessary.

Notes:
1. This measures the major part of the extent of the origin of the anterior part of the masseter muscle. It is not the same, however, as the "anterior masseter" of Landauer 1962, used also in Howells 1966. The posterior point (Woo's ZT) coincides closely with the posterior

limit of the masseter attachment which, however, runs anteriorly beyond the zigomaxillary suture about 5 millimeters onto the maxilla. In this study, the measurement has been changed to use the point zygomaxillare anterior, so as to integrate it with other measurements, e.g., bimaxillary breadth and zygomaxillare radius.

2. A full or partial os japonicum (division of the malar by a horizontal suture) was present rarely in most populations. In some cases it appeared to have the effect of shortening and deepening the body of the malar, and especially of displacing the zygo-maxillary suture laterally and posteriorly.

Malar length, maximum XML IIIa
Total direct length of the malar in a diagonal direction, from the lower end of the zygo-temporal suture on the lateral face of the bone, to zygoorbitale, the junction of the zygo-maxillary suture with the lower border of the orbit, on the left side.

With the skull resting on the right side of the occiput and the left frontal region facing the observer, place the fixed point of the calipers at the zygotemporal point (Woo's ZT) and measure to zygoorbitale. Fix the screw. Use the right side if necessary.

Synonym:
Woo Chord of the minimum horizontal arc C

Recent attempts to measure the shape of the malar and the suborbital fossa are:
Ducros A. and J. 1967. Relations de I'os zygomatique. Bull. et Mém. De la Soc. d'Anthrop. de Paris, ser.12, vol. 1: 367-376.
Rideau, Y. 1968. Étude anthropométrique de la fosse sous-orbitaire. Bull. et Mém. De la Soc. d'Anthrop. de Paris, ser. 12, vol. 3: 317-329.

Malar subtense MLS IIIa
The maximum subtense from the convexity of the malar angle to the maximum length of the bone, at the level of the zygomaticofacial foramen, on the left side.

With the caliper in position for maximum malar length, lower the coordinate arm to the most prominent point in the horizontal profile of the malar approximately at the level of the small foramen below the external angle of the orbit (foramen zygomaticofaciale), i.e., without tiling the caliper down to maximize the reading. Use the right side the left is damaged.

Synonym:
Woo Maximum subtense of minimum horizontal arc S

Cheek height WMH IIa
The minimum distance, in any direction, from the lower border of the orbit to the lower margin of the maxilla, mesial to the masseter attachment, on the left side.

Measure with the skull face up, placing the caliper so as to find the minimum in any direction, and being sure to measure with the tips of the points, not their shanks, so as not to displace the axis of measurement. Use the right side if the left is damaged.

Note:
This differs from Martin's "Wangenbeinhöhe", 48(4), which specifies measurement in a vertical direction.

Supraorbital projection SOS IIIa
The maximum projection of the left supraorbital arch between the midline, in the region of glabella or above, and the frontal bone just anterior to the temporal line in its forward part, measured as a subtense to the line defined.

With the skull resting on the right side of the occiput and the left frontal region facing the observer, place the point of the fixed arm on the frontal surface next to the incurvature of the temporal line, and the movable point in the midline near glabella, lowering the coordinate arm to find the highest reading anywhere in the supraorbital area. The lateral points are not specific, but are moved around slightly (keeping the right point in the midline) to maximize the reading. Read to the nearest whole millimeter. Use the right side if the left is damaged.

Notes:
1. Because of the indefinite landmarks used, reading to 1/10 mm is not justified. This appears to be a coarse method for a small measurement, but the results are consistent. If the measure is viewed as an improvement on visual grading, its objectivity and its availability for numerical treatment will be obvious.
2. As a measure of supraorbital development alone it is imperfect, because it also reflects the horizontal convexity of the frontal bone itself. Thus, females with virtually no supraorbital arches will give values of 4 or 5 mm.

Glabella projection GLS IIId
The maximum projection of the midline profile between nasion and supraglabellare (or the point at which the convex profile of the frontal bone changes to join the prominence of the glabellar region), measured as a subtense.

Rest the skull on the right occiput, left side to the observer so that the lower frontal region is in full profile. Set one caliper arm at nasion (not in a cleft of the suture), and move the coordinate arm to a position at the most prominent point in the midline profile and the other lateral arm on the frontal at the lowest point above any part of the glabellar eminence. Read the coordinate arm to the nearest whole millimeter.

Notes:
1. Note # 1 under supraorbital projection applies fully here, although the landmarks are more precise in this case.
2. If the frontal bone descends convexly into the glabellar eminence without a break, the right lateral arm should be placed a sensible distance away from the glabellar eminence, i.e., something over 1 cm. Variations in this placement make very little difference in the measurement obtained.
3. No attempt is made here to define a point "glabella," measuring simply being done from the most prominent point in the profile.

Foramen magnum length FOL IIb
The length from basion to opisthion, as defined.

Measure with the skull base up, using the inside calipers for simplicity, not in order to take an inside measurement.

Notes:
1. The main purpose of this measurement is to complete the outline of the skull, otherwise covered by other measurements.
2. This differs from M Länge des Foramen magnum, 7, because of the different location of basion.

Nasion-bregma chord (Frontal chord) FRC III a
The frontal chord, or direct distance from nasion to bregma, taken in the midplane and at the external surface.

Rest the skull approximately on the right asterion so as to get a good left profile view of the frontal region. Place the points at bregma and nasion as defined, and set the screw.

Synonyms:

M	Mediansagittale Frontalsehne	29
B	Chord nasion to bregma	S_1'
HW	Frontal chord	42 (p. 55)
Woo, J-K.	Frontal chord	(N to B)

Notes:
1. Do not let the points sink into a sutural cleft which may be present at either end point—this is a measure of the external outline of the skull. If necessary, displace the caliper point slightly to a spot on the surface at an equivalent position—
wanderings of the coronal and sagittal suture usually permit such a spot to be found.
2. This measures the essential contribution of the frontal bone to the sagittal section of the vault. Consequently, the placing of nasion and bregma must reflect the general position of the sutures, and not follow minor and very local deviations of these.

Nasion-bregma subtense (Frontal subtense) FRS IIIa
The maximum subtense, at the highest point on the convexity of the frontal bone in the midplane, to the nasion-bregma chord.

With the caliper in position for nasion-bregma chord, move the coordinate point back and forth several times in the sagittal plane, to find a tangent to the curve of the frontal bone at its highest point. Settle the caliper arm here, set the screw, and read.

Synonyms:

HW	Frontal perpendicular	51 (p. 58)
Woo, J-K.	Frontal subtense	(ab)

Nasion-subtense fraction FRF IIIa
The distance along the nasion-bregma chord, recorded from nasion, at which the nasion-bregma, or frontal, subtense falls.

Following the reading of the two previous measurements, this is read from the caliper at the appropriate scale (position of the coordinate arm on the main measuring bar).

Notes:
1. This reading makes possible the computation of the frontal angle, by dividing the chord into two parts at the subtense and thus forming two right triangles of which two sides are known.
2. While the subtense, or height of the frontal curve, can easily be read precisely, its exact location along the chord is often hard to find satisfactorily when the curve is a gentle one, and two readings may differ considerably. This can hardly affect the value of the angle to be computed to a significant extent.

Bregma-lambda chord (Parietal chord) PAC IIIa
The external chord, or direct distance from bregma to lambda, taken in the midplane and at the external surface.

Proceed as for nasion-bregma chord, shifting the position of the skull.

Synonyms:

M	Mediansagittale Parietalsehne	30
B	Chord bregma to lambda	S_2'
HW	Parietal chord	43 (p. 55)

Notes: See notes under nasion-bregma chord.

Bregma-lambda subtense (Parietal subtense) PAS IIIa
The maximum subtense, at the highest point on the convexity of the parietal bones in the midplane, to the bregma-lambda chord.

Proceed as for nasion-bregma subtense, with the caliper in position for bregma-lambda chord. Note, however, that there is a suture to contend with, and do not let the point sink into a cavity created by this.

Synonym:

HW	Parietal perpendicular	52 (p. 58)

Note:
In many populations there is a slight depression along the middle course of the sagittal suture. The maximum curvature of the parietals in the midplane is accordingly not as great as that slightly lateral to it, which will be the curvature seen in a full profile view. This will be reflected in the measured subtense and derived angle, as compared with what might be derived from a photograph or X-ray.

Bregma-subtense fraction PAF IIIa
The distance along the bregma-lambda chord, recorded from bregma, at which the bregma-lambda, or parietal, subtense falls.

Proceed as for nasion-subtense fraction.

Notes: See notes under nasion-subtense fraction.

Lambda-opisthion chord (Occipital chord) OCC IIIa
The external occipital chord, or direct distance from lambda to opisthion taken in the midplane and at the external surface.

Proceed as for nasion-bregma chord, shifting the position of the skull. The movable point must be placed firmly against the posterior border of the foramen magnum and then held in place with the right thumb.

Synonyms:

M	Mediansagittale Occipitalsehne	31
B	Chord lambda to opisthion	S_3'
HW	Occipital chord	44 (pp. 55, 58)

Notes: See notes under nasion-bregma chord.

Lambda-opisthion subtense (Occipital subtense) OCS IIIa
The maximum subtense, at the most prominent point on the basic contour of the occipital bone in the midplane.

Proceed as for nasion-bregma subtense, with the caliper in position for lambda-opisthion chord.

Synonym:

HW	Occipital perpendicular	53 (p. 58)

Note:

If there is a moderately well-developed but rounded nuchal crest forming part of the general contour and profile of the bone, this should be included if the subtense falls here. If, however, a central elevation or the inion stands out prominently, this should be discounted by placing the point in the notch directly above the midline downward curve of inion and crest. This is most likely to be at the level of the actual apex of curvature of the bone itself, and level with the highest point of the curved lines or the torus on either side. In any case the proper point for the subtense—the apex of curvature—is likely to be above the inion, either in this depression or higher.

This is a deliberate but perhaps not entirely satisfactory step to keep a local development here from giving a highly dislocated rendering of the actual angulation of the occipital bone. Often, however, the maximum subtense reading lies well above even a prominent inion, and the problem arises in only a few populations anyhow.

Lambda-subtense fraction OCF IIIa
The distance along the lambda-opisthion chord, recorded from lambda, at which the lambda-opisthion, or occipital, subtense falls.

Proceed as for nasion-subtense fraction.

Notes:
See notes under Nasion-subtense fraction.
See note under Lambda-opisthion subtense.

Vertex radius VRR IIIb
The perpendicular to the transmeatal axis from the most distant point on the parietals (including bregma or lambda), wherever found.

With the skull resting on the lower occiput, face to the observer; insert the plugs of the radiometer gently and simultaneously into the meatus on either side, until they are snugly in place without forcing. Move the coordinate arm back and forth sagittally, but not necessarily in the midline, to find the maximum reading.

Notes:
1. The term "radius" in these measurements implies "radius from the transmeatal axis," as found by the radiometer, IIIb, or a similar instrument. This instrument will find no other series of radii, nor does it seem likely that any other such set of radii from a transverse axis can be measured directly on the skull. See Martin, p. 669.
2. The coordinate arm reads only to 135 mm. In the occasional case where the measurement is greater, read the excess, along the coordinate arm, from this point to the actual measurement with the inside calipers, IIc, and add to 135.

Nasion radius NAR IIIb
The perpendicular to the transmeatal axis from nasion.

With the skull face up, insert the ear plugs in the meatus, as for vertex radius, and measure to nasion.

Note:
For the radii to the face, the skull should be repositioned and the plugs reinserted after vertex radius, as a safety measure.

Subspinale radius SSR IIIb
The perpendicular to the transmeatal axis from subspinale.

Proceed as for nasion radius.

Note:
Subspinale, as with bimaxillary subtense, is a profile point, not to be measured in a sutural fissure.

Prosthion radius PRR IIIb
The perpendicular to the transmeatal axis from prosthion.

Proceed as for nasion radius.

Notes: See notes #2 and #3 under basion-prosthion length.

Dacryon radius DKR IIIb
The perpendicular to the transmeatal axis from the left dacryon.

Proceed as for nasion radius, measuring to the left dacryon.

Note:
If the left dacryon, or any point involved in the next five measurements, is in such shape that a better reading may be had on the right side for all points, shift to that side for the entire series. It is more important to preserve the relative degrees of projection of each point among the set on one side than to get the left measurement when it is available.

Zygoorbitable radius ZOR IIIb
The perpendicular to the transmeatal axis from the left zygoorbitale.

Proceed as for nasion radius.

Note: See note under dacryon radius.

Frontomalare radius FMR IIIb
The perpendicular to the transmeatal axis from the left frontomalare anterior.

Proceed as for nasion radius.

Note: See note under dacryon radius.

Ectoconchion radius EKR IIIb
The perpendicular to the transmeatal axis from the left ectoconchion.

Proceed as for nasion radius.

Note: See note under dacryon radius.

Zygomaxillare radius ZMR IIIb
The perpendicular to the transmeatal axis from the left zygomaxillare anterior.

Proceed as for nasion radius.

Molar alveolus radius AVR IIIb
The perpendicular to the transmeatal axis from the most anterior point on the alveolus of the left first molar.

Proceed as for nasion radius.

Notes:

1. See note under dacryon radius.
2. This is an attempt to relate the molar row to the facial projection generally. If there is resorption or damage to the alveolar border, an estimate of its original extent must be made. Where most teeth are missing, be certain that the correct alveolus is being used by counting from the midline.
3. Because measurement to the right side is especially difficult, this measurement should be given extra weight in deciding whether or not to shift to the right side where damage makes some estimation necessary on either side.

INSTRUMENTS

These are given Roman numerals, so that they may be referred to specifically in measurement definitions without possibility of confusion with the Arabic numerals used by Martin or others to identify measurements. No attempt has been made to follow Martin's own numbering system for instruments, because:

1. The above possibility of confusion exists
2. Few instruments used here were designated formally by him, and vice versa
3. Martin was inconsistent in his numbering, having one set of numbers for instruments used on the living subject, some of which numbers were applied to different instruments used in osteology.

Ia Spreading caliper

The standard spreading calipers, Hermann, GPM (Gneupel), etc. As Martin points out, for craniology relatively pointed ends are needed.

IIa Sliding caliper, dial—Helios

Helios 6" caliper with adjustable dial (reading to 1/20 millimeter), RUR 1068 C. Should be ordered fitted with needles in short arms and standard long arms; then modified as follows: blunt the needles slightly; bevel the edges of the long arms slightly and grind the ends of these down to flattish points. Remember that, as with other calipers, the exact measurement is between the inside surfaces of the points.

This caliper is easy to use, is extremely accurate, and prevents reading errors far better than the standard (since the arm reads in whole centimeters and the dial to numbered millimeters).

IIb Sliding caliper, small, inside

Central Scientific Co. 6" calipers, with vernier reading to 1/10 mm. Smaller than standard but useful for smaller measurements and objects. Smaller jaws for inside measurements; larger jaws must be reground to form sharper tips.

IIIa Coordinate caliper

The standard form, e.g., GPM #12, with straight arms (cf. Martin, fig. 271). The instrument supplied by GPM is light and accurate.

IIIb Coordinate caliper—radiometer

This is the large Aichel caliper (see Martin, p. 592), supplied by GPM as #13. It is converted into a radiometer, for reading distances from the transmeatal axis, by having the ends fitted with shoes carrying bullet-shaped points (i.e., parabolic in longitudinal cross section) increasing to a maximum diameter of 4 mm. These can be inserted into the meatus in such a way as to turn easily while being firmly fixed, so as automatically to find the center of the largest circle which will fit the meatus in a plane parallel to the median plane of the skull. These points are made so that their mutual central axis is the zero reading for the coordinate arm.

IIIc Coordinate caliper—simometer

This is made on a design shown me by. G. Debets, in which the jaws are turned in near their extremities, so that the two points of the lateral arms and that of the coordinate arm may all meet at a single zero point (see Alekseev and Debets 1964, p. 23). Both measuring bars are supplied with vernier scales for reading to 1/10 mm, for fine readings of projections of the nasal bones. (The standard coordinate caliper, IIIa, with straight arms, cannot be used in this way.) The calipers may be used for all measurements of facial projection as well. Cost of construction about $130.

IIId Coordinate caliper—palatometer

In this small caliper both of the lateral arms are movable, being extended by screws on either side of the central housing which also carries the coordinate arm. Readings are not reliable if either lateral arm is extended beyond the point at which its non-working end is flush with the housing.

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Appendix 4: Measurement Abbreviations and Landmark Types

From Howells (1973), FORDISC Help File (2017), and 3Skull (2014):

CRANIUM			
ABBR	**MEASUREMENT**	**ABBR**	**MEASUREMENT**
BPL	Basion-Prosthion Length	XFB	Maximum Frontal Breadth
NPH	Nasion-Prosthion Height	STB	Bi-Stephanic Breadth
UFHT	Upper Facial Height	STS	Stephanic Subtense
SSR	Subspinale Radius	NOL	Nasio-Occipital Length
SSS	Zygomaxillary Subtense	GOL	Maximum Cranial Length (Glabello-Occipital Length)
NLB	Nasal Breadth	GLS	Glabella Projection
NLH	Nasal Height	FRC	Frontal Chord
MOW	Mid-Orbital Width	PAC	Parietal Chord
IML	Malar Length Inferior	BBH	Basion-Bregma Height
XML	Malar Length Maximum	OCC	Occipital Chord
OBH	Orbital Height	ASB	Bi-Asterionic Breadth
WMH	Cheek Height Minimum	XCB	Maximum Cranial Breadth
OBB	Orbital Breadth	radii NAR	Nasion Radius
EKB	Bi-Orbital Breadth	BRR	Bregma Radius
DKB	Inter-Orbital Breadth	MDH	Mastoid Height
WNB	Simotic Chord	AUB	Bi-Auricular Breadth
ZYB	Bi-Zygomatic Breadth	FOL	Foramen Magnum Length
ZMB	Bi-Maxillary Breadth	BNL	Cranial Base Length
JUB	Bi-Jugal Breadth	FOB	Foramen Magnum Breadth
UFBR	Upper Facial Breadth	MAL	Maximum Alveolar Length
FMB	Bi-Frontal Breadth	MAB	Maximum Alveolar Breadth
NAS	Nasio-Frontal Subtense	AVR	Molar 1 Alveolus Radius
WFB	Minimum Frontal Breadth		
MANDIBLE			
XRL	Maximum Ramus Length	GOG	Bi-Gonial Breadth
MAN	Mandibular Angle	BCB	Bi-Condylar Breadth
GNI	Chin Height	WRB	Minimum Ramus Breadth
HMF	Body Height at Mental Foramen	CDL	Bi-Condylar Breadth
TMF	Body Thickness at Mental Foramen	MLN	Mandibular Length
Calculated: Do Not Digitize			
SIS	Simotic Subtense	PAF	Parietal Fraction
SIA	Simotic Angle	PAS	Parietal Subtense
NDS	Naso-Dacryal Subtense	VRR	Vertex Radius
NDA	Naso-Dacryal Angle	GOL	Glabello-Occipital Length
MLS	Malar Subtense	OCF	Occipital Fraction
FRF	Frontal Fraction	OCS	Occipital Subtense
FRS	Frontal Subtense		
ARCS			
FRA	Frontal Arc	MAA	Malar Arc
PAA	Parietal Arc	NAA	Nasal Arc
OCA	Occipital Arc		

Landmark Types
Type definitions from Bookstein (1991) and Slice (2005):

Type I: discrete juxtaposition of tissues (i.e., intersection of multiple sutures)

Type II: maximum curvature of a structure (i.e., tip of a tooth, tip of a bony process that may be a muscle attachment site)

Type III: external points, defined with respect to another more distant structure (i.e., points delimiting maximum length or breadth of a structure)

Landmark	Reported Type[1]	Reported Type[2]	Reported Type[3]	Reported Type[4]
Asterion	Type I			
Bregma	Type I			
Dacryon	Type I			
Infradentale	Type I	Type II		
Krotaphion	Type I			
Lambda	Type I			
Nasale Inferius	Type I		Type II	
Nasale Superius	Type I			
Nasion	Type I			
Sphenofrontale				Type I
Staurion	Type I			
Stephanion	Type I			
Zygomaxillare	Type I	Type III		Type II
Basion	Type II			
Condylion Laterale	Type II	Type III		
Condylion Mediale	Type II	Type III		
Coronion	Type II			
Ectoconchion	Type II			
FOB Point	Type II			
Gnathion	Type II	Type III		
Gonion	Type II			
Hormion	Type II	Type I		
Inf Mandibular Notch Point	Type II			
Jugale	Type II			
Marginal Process Lateral	Type II			
Mastoideale	Type II			
Opisthion	Type II			
Pogonion	Type II	Type III		
Prosthion Howells (estimated)	Type II			
Prosthion Martin (ACTUAL)	Type II			
Radiculare	Type II			
Subspinale	Type II			
Sup Condyle	Type II			
Supraglabellare	Type II			
Zygoorbitale	Type II			
Zygotemporale Inferior	Type II			

Zygotemporale Superior	Type II			
Landmark	**Reported Type[1]**	**Reported Type[2]**	**Reported Type[3]**	**Reported Type[4]**
Alare	Type III			
Alveolon	Type III	Type II		
Cheek Height Inferior Point	Type III			
Cheek Height Superior Point	Type III			
Euryon	Type III			
Frontomalare Anterior	Type III			
Frontomalare Temporale	Type III			
Frontotemporale	Type III	Type II		
Glabella	Type III	Type II		
HMF Inferior Point	Type III			
HMF Superior Point	Type III			
Lower Orbital Border	Type III			
M1 Anterior Point	Type III			
Mandibular Angle Base	Type III			
Maximum Frontal Point	Type III			
Most Inferior Nasal Border	Type III		Type II	
Nasomaxillary Suture Pinch	Type III			
Porion	Type III	Type II		
Radiometer Point	Type III			
Sphenion	Type III	Type I		
Sup Condyle Post	Type III			
TMF Buccal Point	Type III			
Upper Orbital Border	Type III			
WRB Anterior Point	Type III			
WRB Posterior Point	Type III			
Zygion	Type III			

[1] Sholts et al. (2011) and Ross and Williams (2008)
[2] Caple and Stephan (2016)
[3] Algee-Hewitt and Wheat (2016)
[4] Spradley (personal communication)

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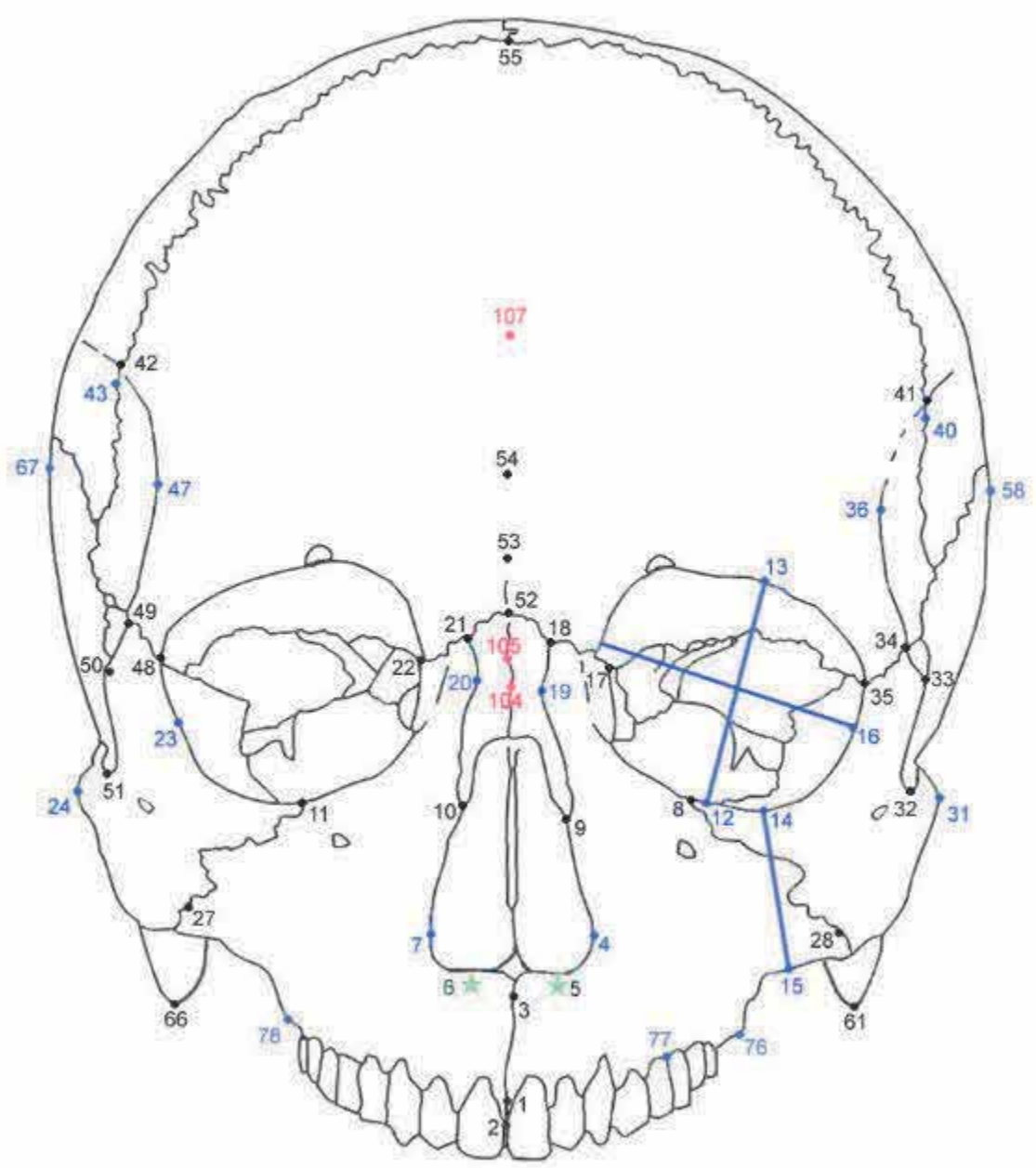
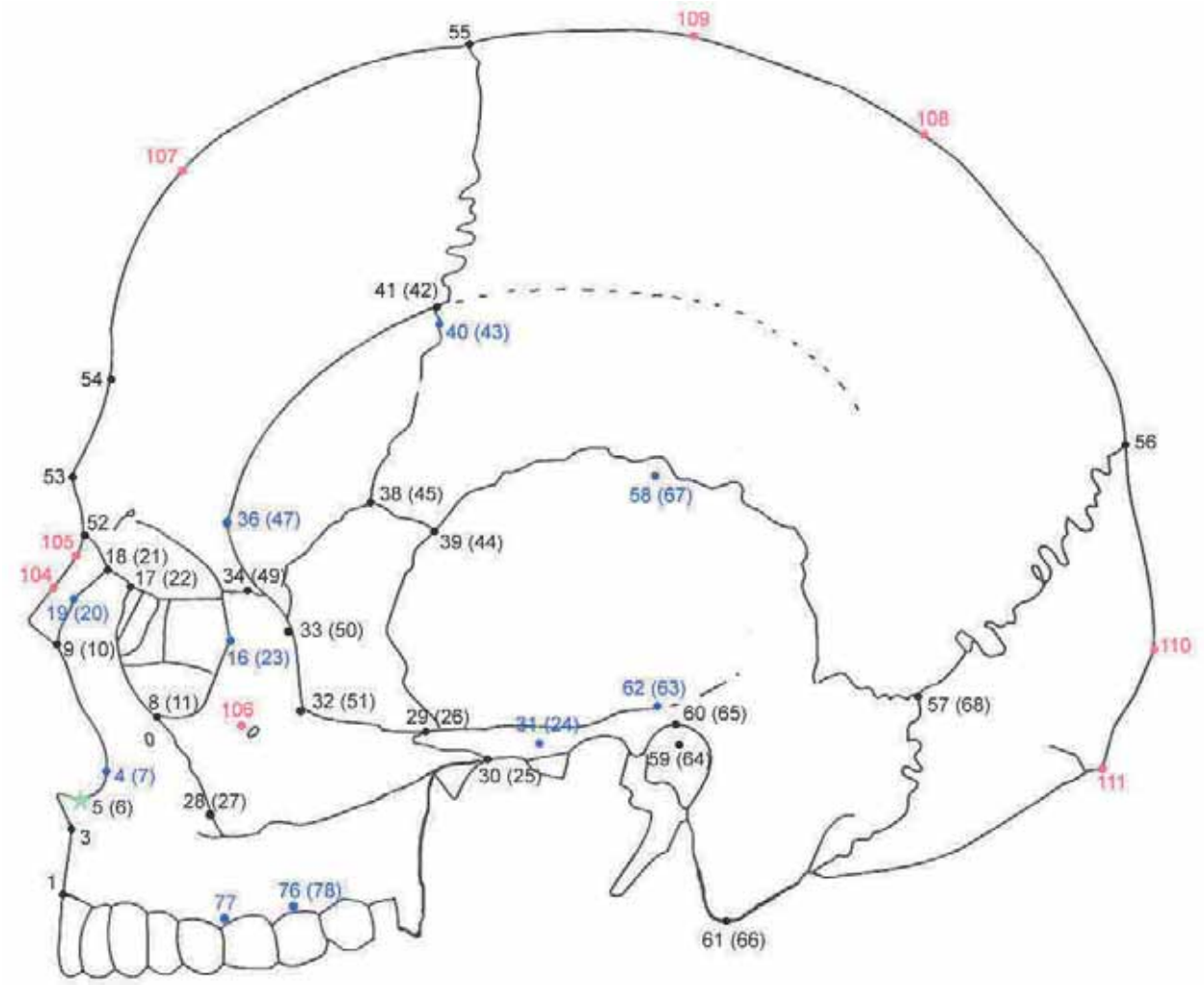
Appendix 5: Illustrations for Osteometric Landmark and Arc Locations



(Image courtesy of: HCIFS)

Color Key for Appendix 5

- Landmarks that should be marked prior to placing cranium on tri-column stand
- Calculated landmarks--no need to digitize
- Landmarks that can be marked prior to placing on the stand, but not necessary
- ★ **Inferior nasal aperture points**: PLEASE READ DEFINITION. Taken on the internal surface of the aperture if possible, or on the anterior surface if internal surface is not accessible
- Landmarks that are taken on the mandibulometer or work surface, not directly on the bone



(Image courtesy of: HCIFS)

Color Key for Appendix 5

- Landmarks that should be marked prior to placing cranium on tri-column stand
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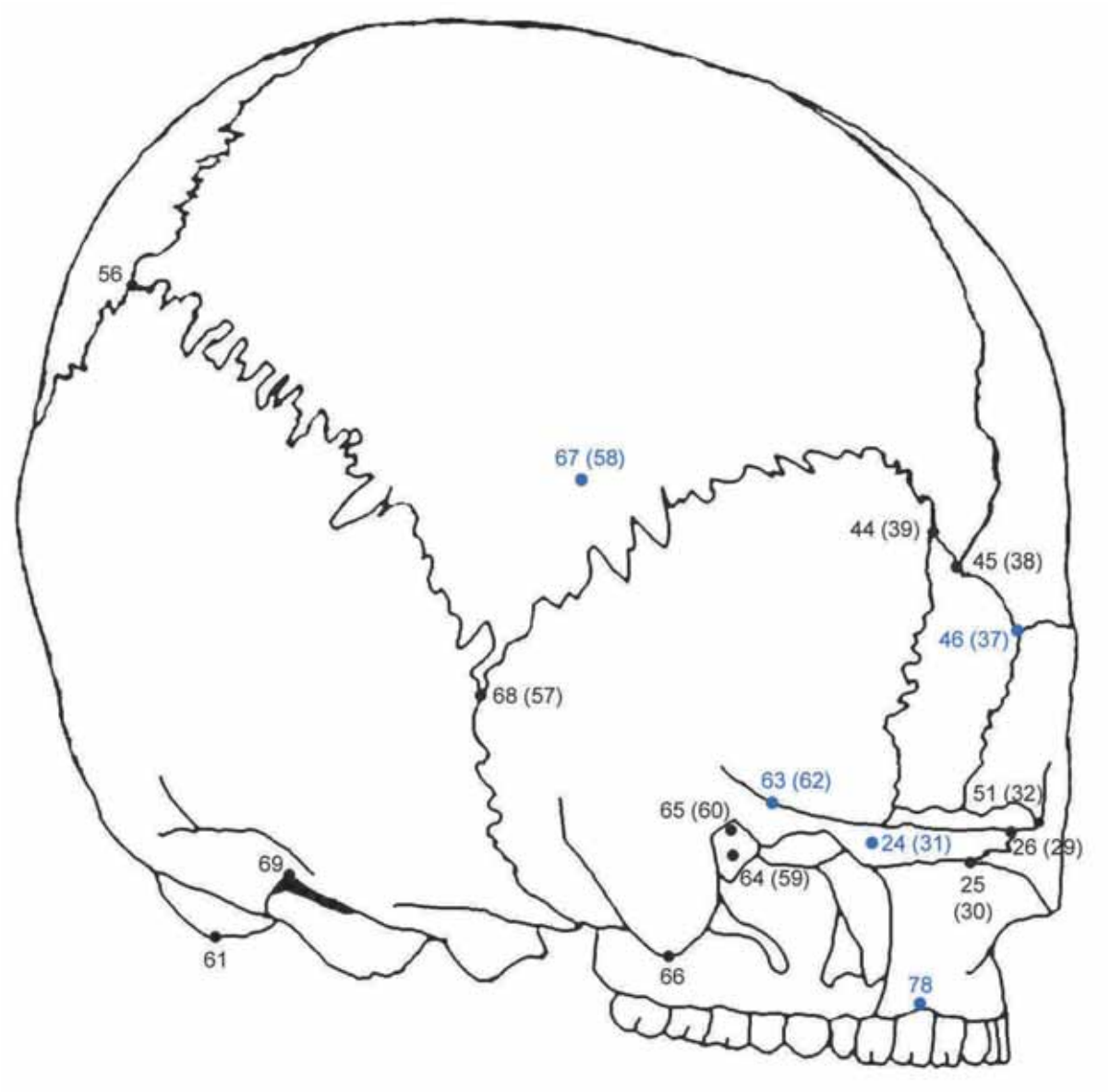
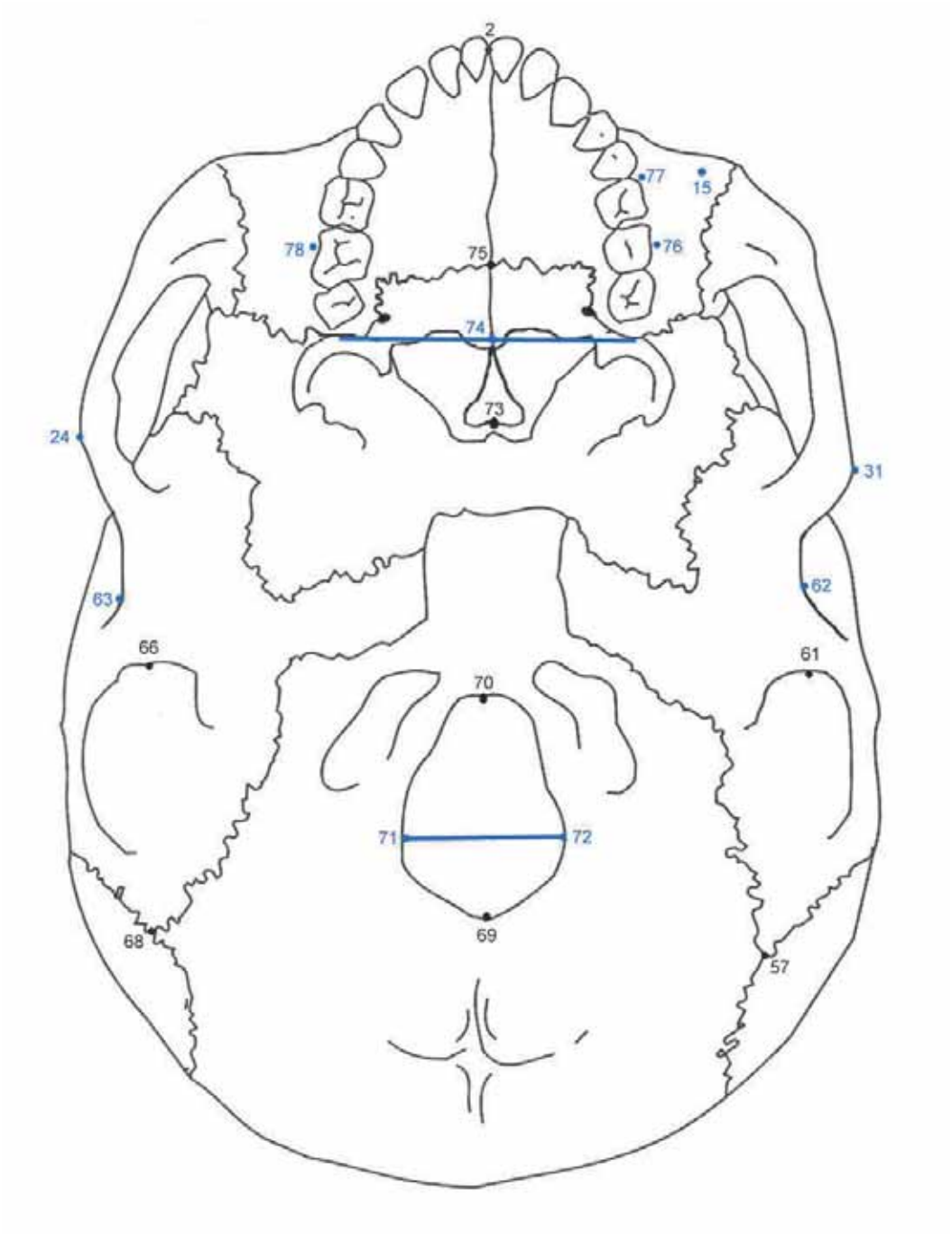
- ★ **Inferior nasal aperture points**: PLEASE READ DEFINITION. Taken on the internal surface of the aperture if possible, or on the anterior surface if internal surface is not accessible
- Landmarks that are taken on the mandibulometer or work surface, not directly on the bone



(Image courtesy of: Julie Fleischman and HCIFS)

Color Key for Appendix 5

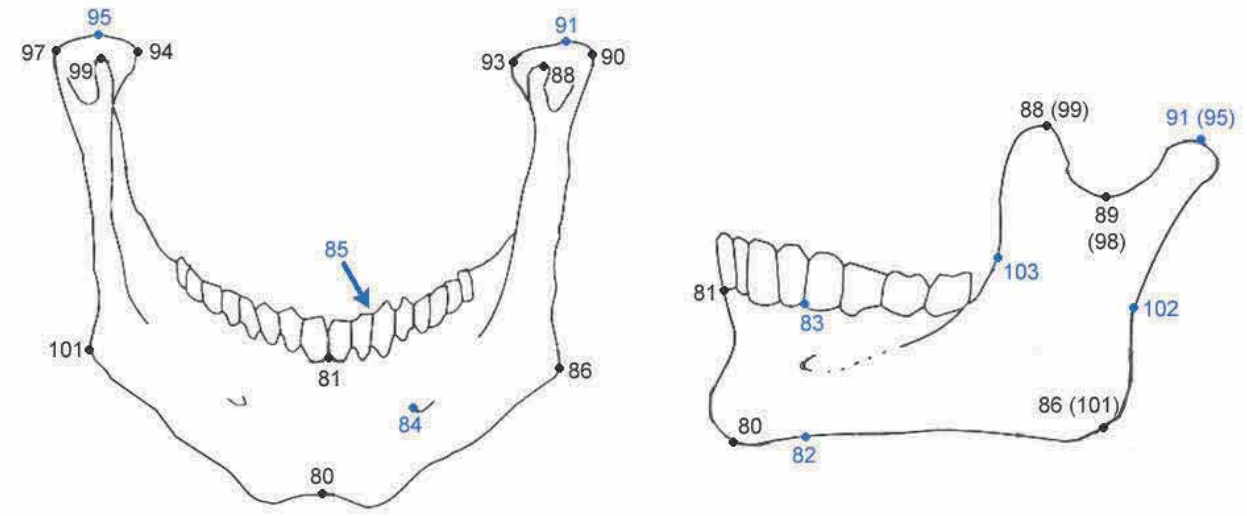
- Landmarks that should be marked prior to placing cranium on tri-column stand
- Calculated landmarks--no need to digitize
- Landmarks that can be marked prior to placing on the stand, but not necessary
- ★ **Inferior nasal aperture points**: PLEASE READ DEFINITION. Taken on the internal surface of the aperture if possible, or on the anterior surface if internal surface is not accessible
- Landmarks that are taken on the mandibulometer or work surface, not directly on the bone



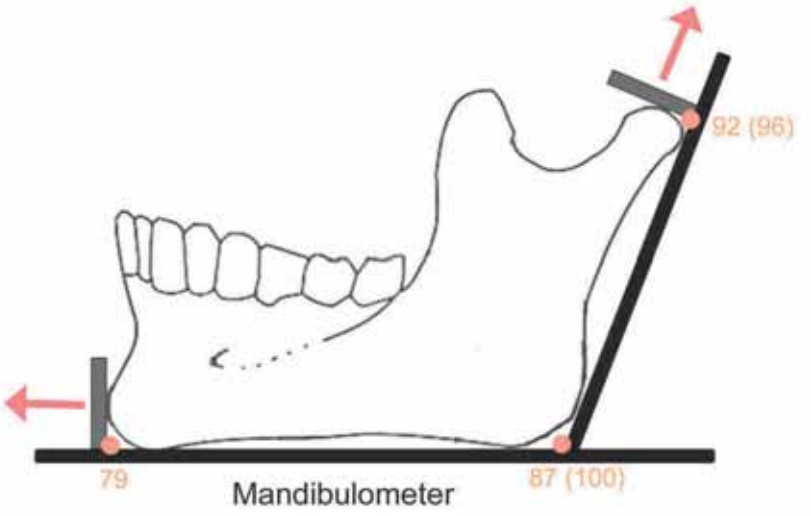
(Image courtesy of: HCIFS)

Color Key for Appendix 5

- Landmarks that should be marked prior to placing cranium on tri-column stand
- Calculated landmarks--no need to digitize
- Landmarks that can be marked prior to placing on the stand, but not necessary
- **Inferior nasal aperture points**: PLEASE READ DEFINITION. Taken on the internal surface of the aperture if possible, or on the anterior surface if internal surface is not accessible
- Landmarks that are taken on the mandibulometer or work surface, not directly on the bone



(Images courtesy of: HCIFS)



Note: After the mandible is positioned in the mandibulometer, pull back the horizontal and vertical sliding plates (arrows) so the digitizer stylus can reach the horizontal and vertical boards of the mandibulometer to capture the points.

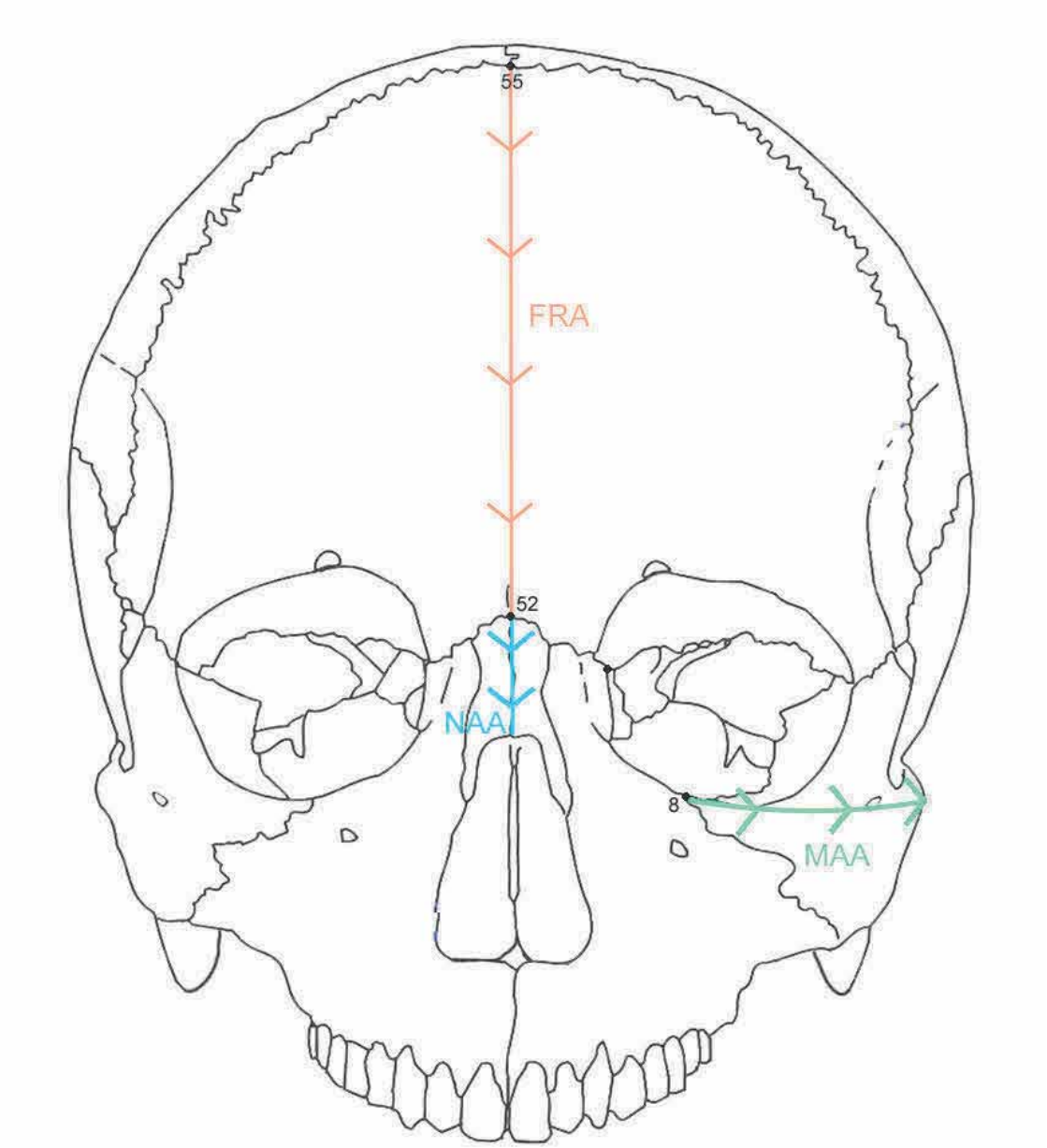
(Image courtesy of: Julie Fleischman and HCIFS)

Color Key for Appendix 5

- Landmarks that should be marked prior to placing cranium on tri-column stand
- Calculated landmarks--no need to digitize
- Landmarks that can be marked prior to placing on the stand, but not necessary
- ★ **Inferior nasal aperture points**: PLEASE READ DEFINITION. Taken on the internal surface of the aperture if possible, or on the anterior surface if internal surface is not accessible
- Landmarks that are taken on the mandibulometer or work surface, not directly on the bone

Arcs to Digitize

Arrows indicate directions the arcs should be traced with the stylus

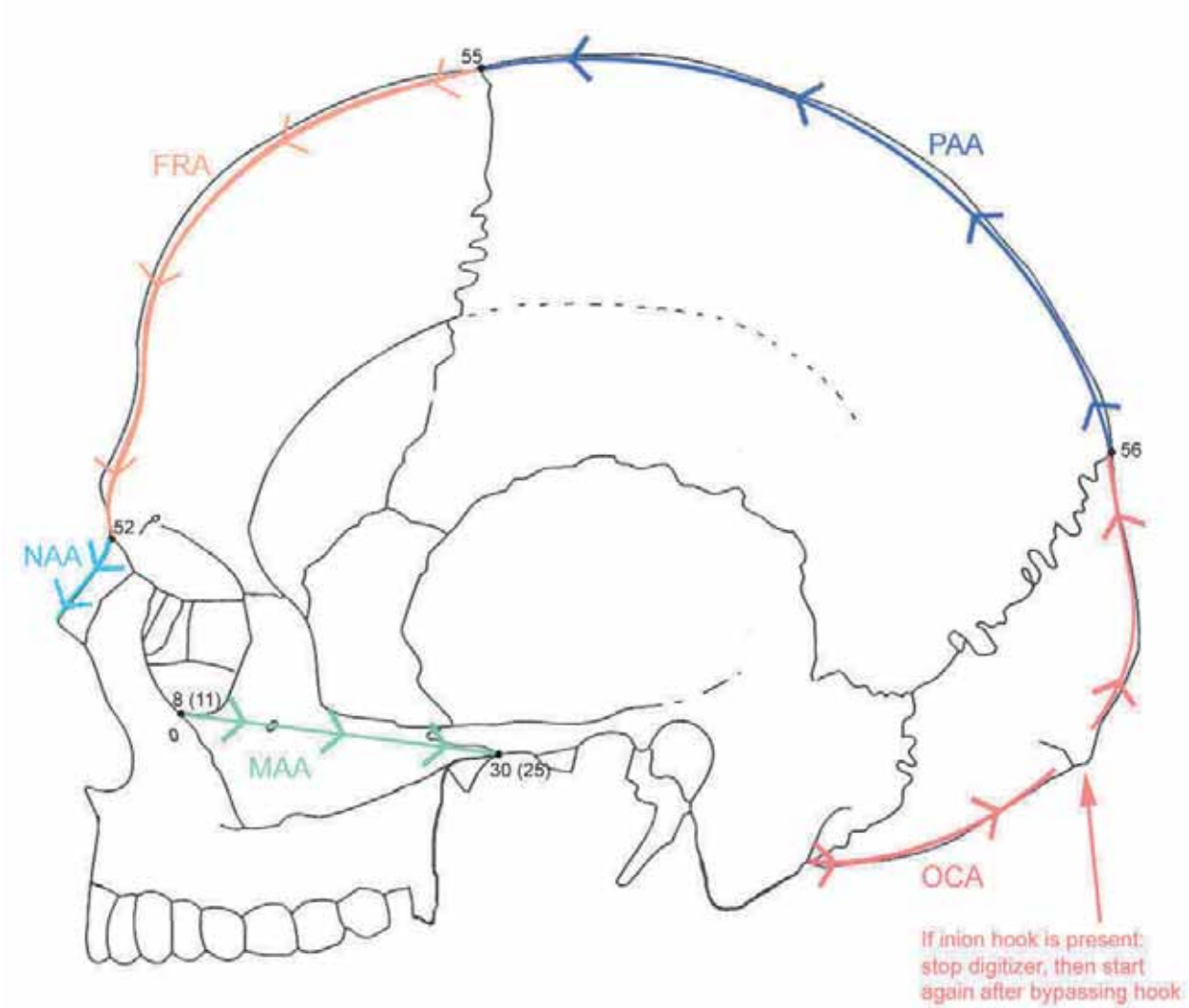


(Image courtesy of: Julie Fleischman and HCIFS)

Note: MAA should be traced at the level of the zygomaticofacial foramen, as depicted in diagrams above and below

Arcs to Digitize

Arrows indicate directions the arcs should be traced with the stylus



(Image courtesy of: Julie Fleischman and HCIFS)

Appendix 6: Figures

Figure 1. Correct and incorrect resting position (AKA Homing position) (Revware Systems 2009, MicroScribe G User Guide).

Figure 2. Positioning an acrylic plate used as an alternative method for digitizing points that replicate those taken on the mandibulometer (Photo courtesy of: Julie Fleischman and HCIFS).

Figure 3. The image on the left demonstrates the correct way to take a bound point with the joint bent intentionally. The image on the right shows the incorrect way to take a bound point in which the stylus and forearm are aligned (Revware Systems 2009).

Figure 4. Lambda point of intersection placement (Photo courtesy of: Julie Fleischman, the Forensic Anthropology Center at Texas State, and the generous willed body donors).

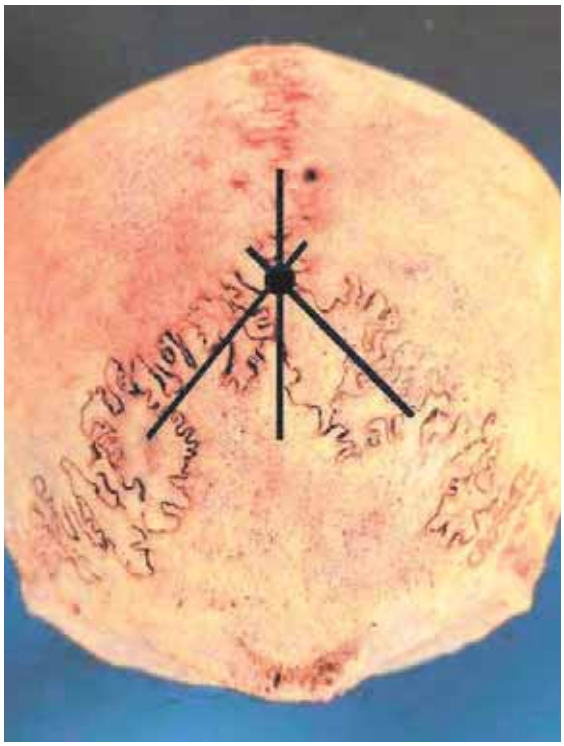


Figure 5. Lambda point of intersection placement (Photo courtesy of: Julie Fleischman, the Forensic Anthropology Center at Texas State, and the generous willed body donors).

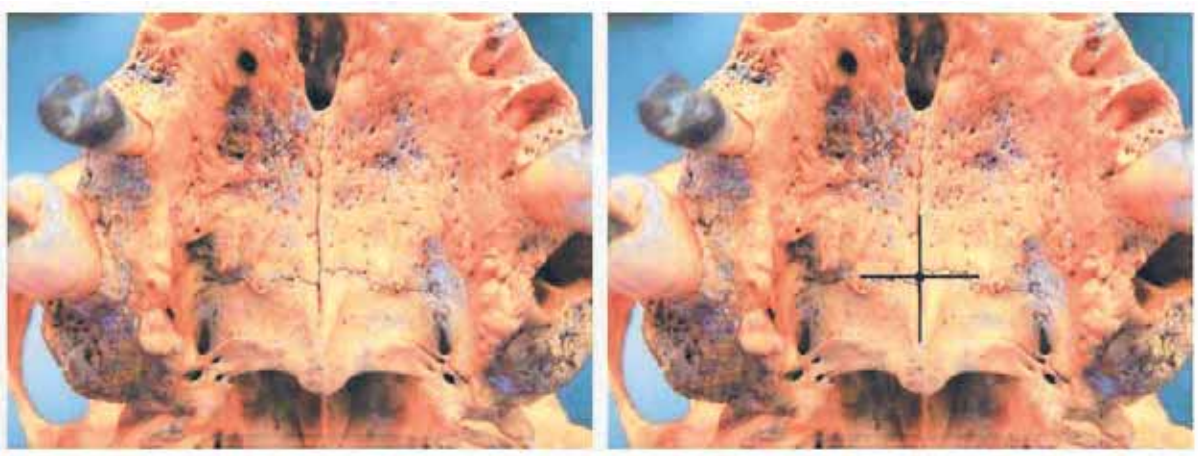


Figure 6. Staurion point of intersection placement (right) (Photos courtesy of: Julie Fleischman, the Forensic Anthropology Center at Texas State, and the generous willed body donors).

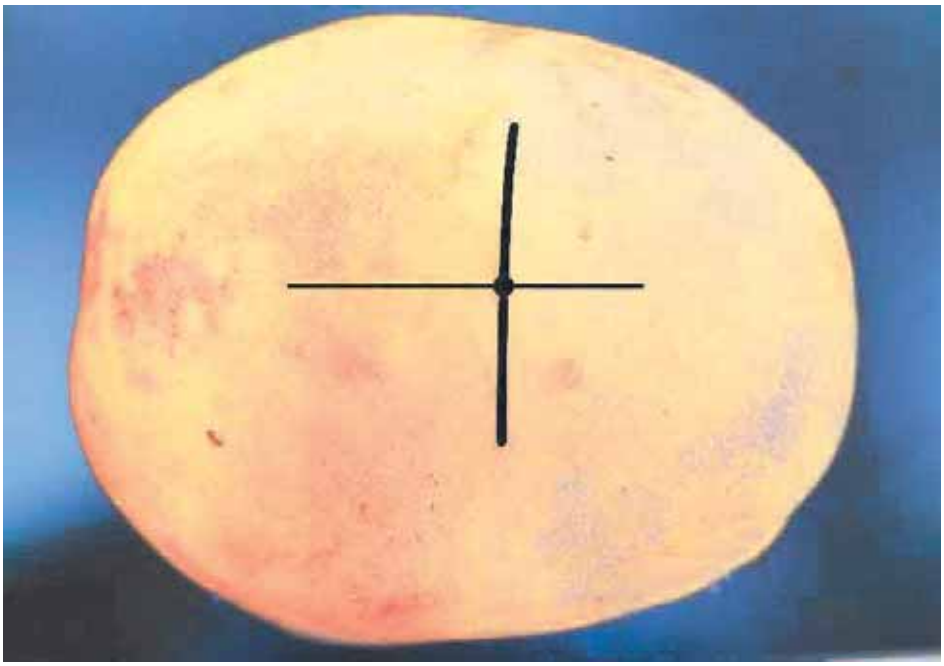


Figure 7. Bregma point of intersection placement (Photo courtesy of: Julie Fleischman, the Forensic Anthropology Center at Texas State, and the generous willed body donors).

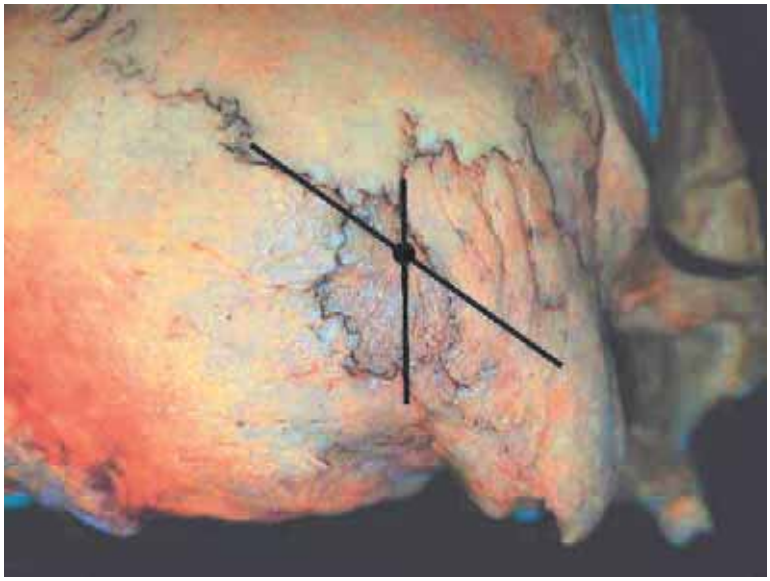


Figure 8. Asterion point of intersection placement (Photo courtesy of: Julie Fleischman, the Forensic Anthropology Center at Texas State, and the generous willed body donors).

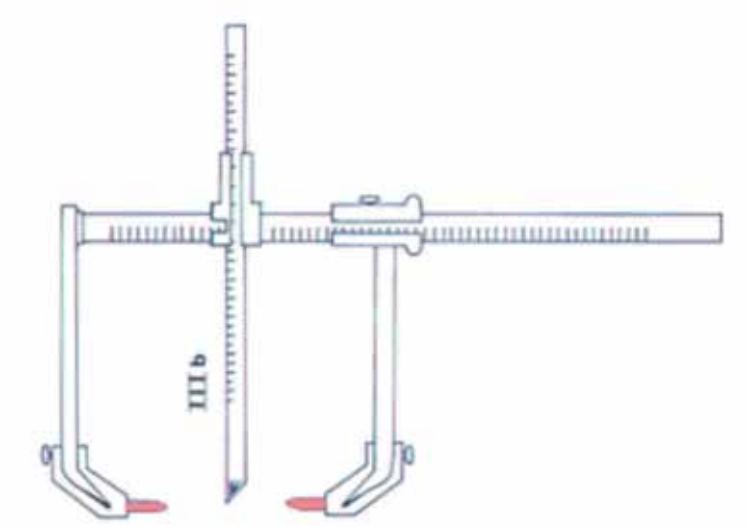


Figure 9. This is a radiometer (coordinate caliper) used for taking radii. The radiometer point is simulating the placement of the probes (in red) in the EAMs. Notice they are parallel and would "float" in the EAMs (Image from: Howells 1973, p. 164).

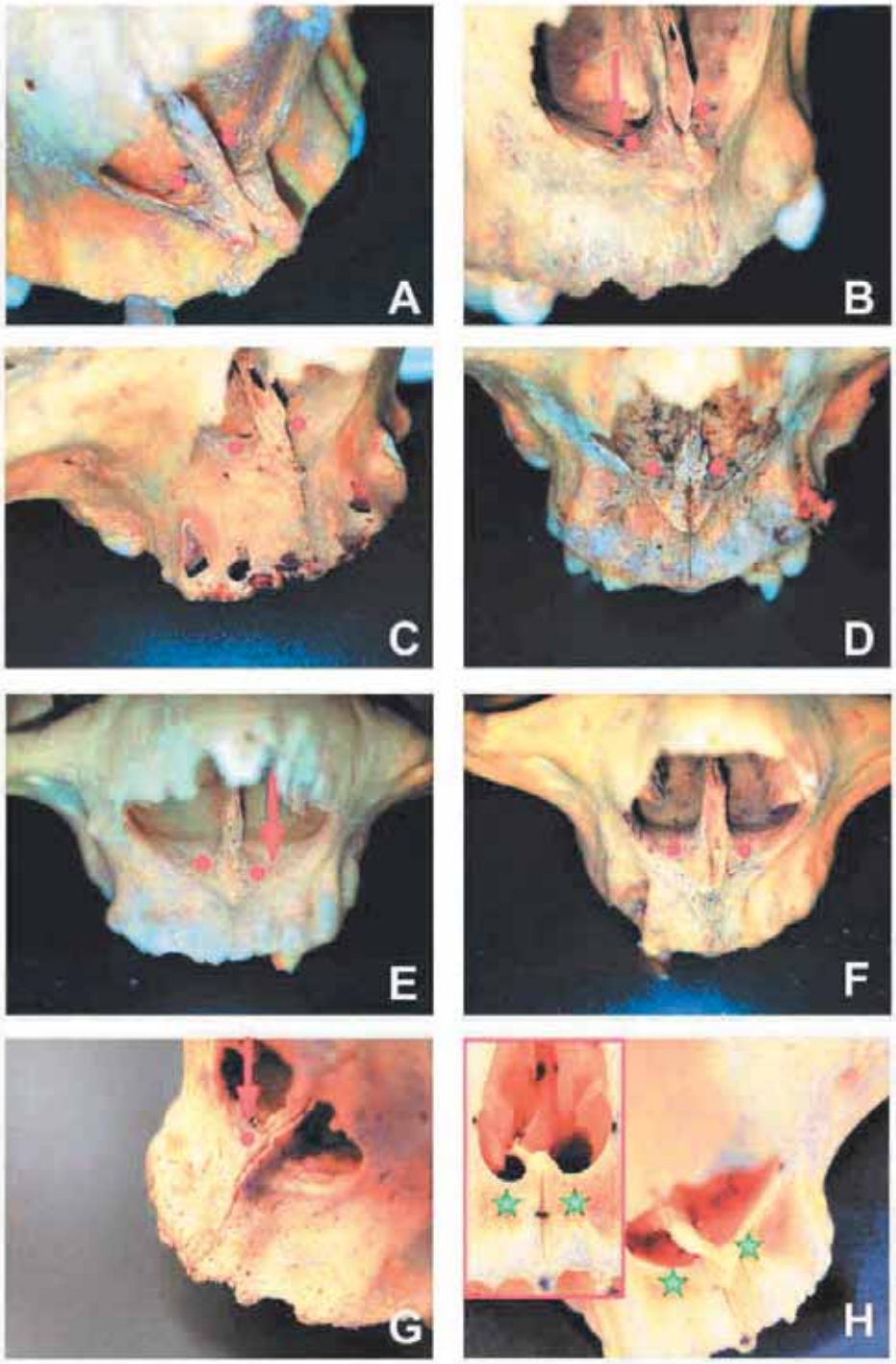


Figure 10. Red dots in images A-G indicate the location of the **Most Inferior Nasal Border** landmarks. This landmark is always taken inside the nasal aperture, even if there is a nasal sill (e.g., A and D), as long as the stylus can reach. In some cases, this landmark is slightly anterior to a ridge of bone on nasal floor (indicated by arrows in B, C, and G). If the stylus cannot be placed into the nasal aperture, approximate the intersection of the nasal floor and the maxilla on the anterior surface of the maxillae (green stars in H) (Photos courtesy of: Julie Fleischman, the Forensic Anthropology Center at Texas State, and the generous willed body donors).

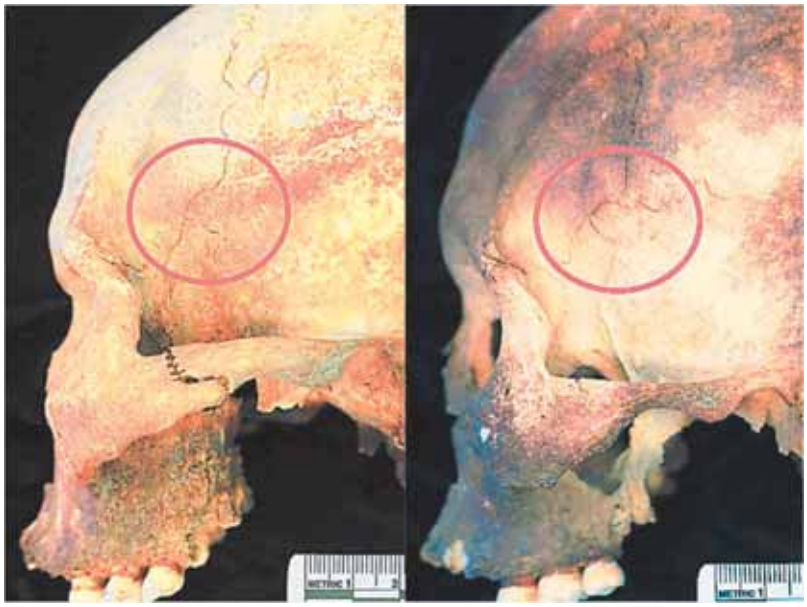


Figure 11. Examples of the frontal-temporal articulation where **Sphenion** cannot be taken (Photos courtesy of: Julie Fleischman and the Choeung Ek Genocidal Center, Phnom Penh).

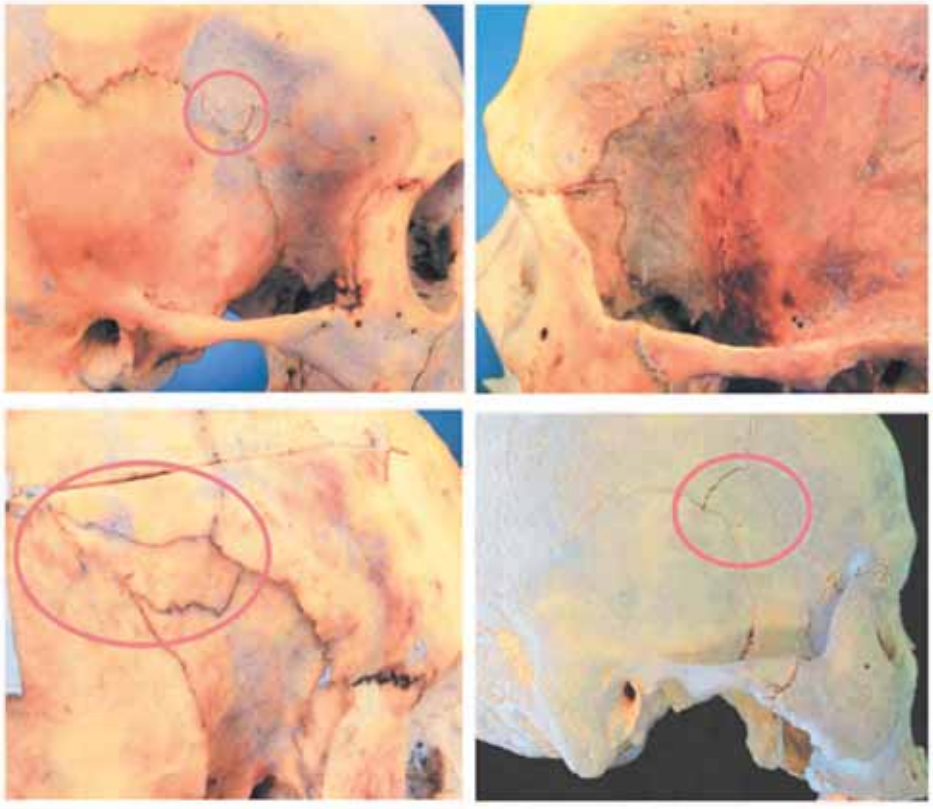


Figure 12. Notch bones: **Krotaphion** cannot be taken (NOTE: neither **Krotaphion** or **Sphenion** can be taken in the bottom two images) (Photo courtesy of: Julie Fleischman, the Forensic Anthropology Center at Texas State, the generous willed body donors, and the Choeung Ek Genocidal Center, Phnom Penh).

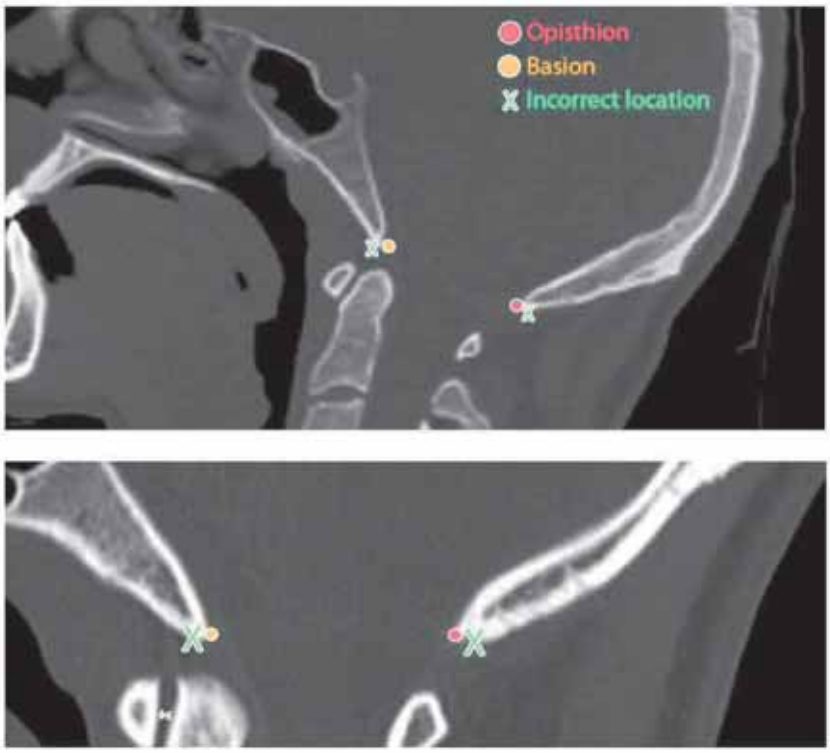


Figure 13. Proper locations of **Basion** (yellow dot) and **Opisthion** (red dot), as seen in a sagittal cross section. Note that the landmarks are not fully endocranial or ectocranial (green Xs), but are on the midpoint of the foramen magnum margins (Modified images courtesy of: Julie Fleischman and HCIFS).

Figure 14. Hormion NOT taken in the anterior deflection, but at posterior margin (Photo courtesy of: Julie Fleischman, the Forensic Anthropology Center at Texas State, and the generous willed body donors).

Figure 15. Location of **M1 Anterior Point** (Photos courtesy of: Julie Fleischman and HCIFS).