Investigation of Anatomical Predictors for the Positioning of the Eyeballs, Nasal Wings, Projection of the Lips and Others from the Structure of the Skull

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This chapter aims to present the results of a study carried out with 33 anonymous cone-beam computed tomography (CBCT) scans. The study sought to investigate cranial structures, in average orthogonal (2D) projection, so that they could function as predictors for the dimension of important frontal regions of the face, such as the position of the pupils, central line of the lips (ch-ch), nasal wings and others. , from three-dimensional models of the skull.

Introduction

The face and its proportions have been widely studied for some time. Several approaches propose to determine the ideal relationship between anatomical structures such as the lip, nose and orbit with each other and the exact proportion between bone structures and soft tissues, among these we can mention golden measurements , cephalometrics and other studies already developed.

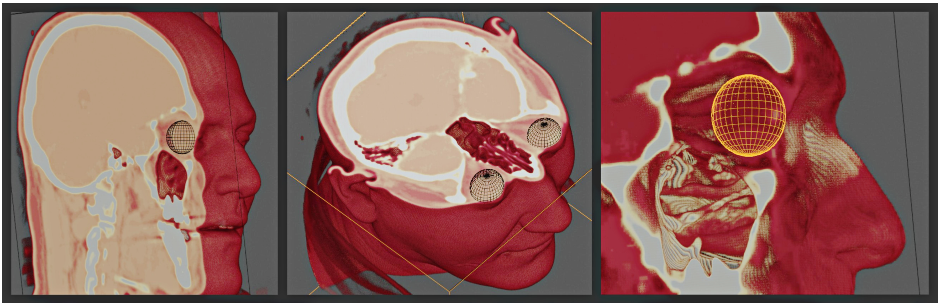
In the field of forensic sciences, it is extremely important to know in depth the morphophysiology of tissues and their three-dimensional positioning on the face so that professionals such as: designers, archaeologists, paleontologists, forensic scientists, among others, can analyze and/or recreate the appearance of humans and other animals accurately. This knowledge is also used in the vast field of surgery and facial prostheses, it is essential to predict the movements to be performed in patients who are candidates for surgical procedures. Procedures that aim to restore function and determine facial harmony, and the sum of these two factors bring the patient a concept of beauty according to the region in which he lives, culture and time he is. Without accurate knowledge of the proportions between the aforementioned structures and the face, it is impossible to reach a satisfactory result. Despite the few clear references between some structures and the skull, the relationship between these and the individual's appearance is very strong. Among these relevant anatomical structures on the face, three stand out and are the target of this study.

Nose : It is found in the center of the face both vertically and horizontally, that is, it is the predominant structure in the middle third of the face. It has the noble function of inhaling the air, filtering it and heating it, preparing it to be received by the lungs. It is a fundamental part of one of the 5 human sensory senses, smell, consisting of bone, cartilage, adipose tissue and skin.

Lips : They are located in the lower third of the face, just below and centralized in relation to the nose. It has numerous functions such as: phonation, suction, promoting the sealing of the mouth between the internal and external environment, assisting in chewing and phonation. They vary in color and thickness according to ancestry, and are structures extremely valued by us human beings with important aesthetic characteristics. It is mainly composed of muscles, glands and covered by mucosa.

orbits: Large cavities that house the eyeball and are made up of parts of several bones of the face and skull that are located in the middle third of the face, one on the right side and one on the left side, separated by the nasal root. In axial view, it has a pyramidal shape, with the base located on the face and visible to the observer and the apex in the intracranial portion. The orbit is the bony framework where some muscles are housed or have their origin such as: extraocular muscles are a group of six extrinsic muscles of the eye. They are: superior rectus, lateral rectus, inferior rectus, medial rectus, superior oblique and inferior oblique. Located inside the orbit, they encircle the eyeball completely, facilitating its movements in various directions and orbicularis oculi muscle that open and close the eyelids.

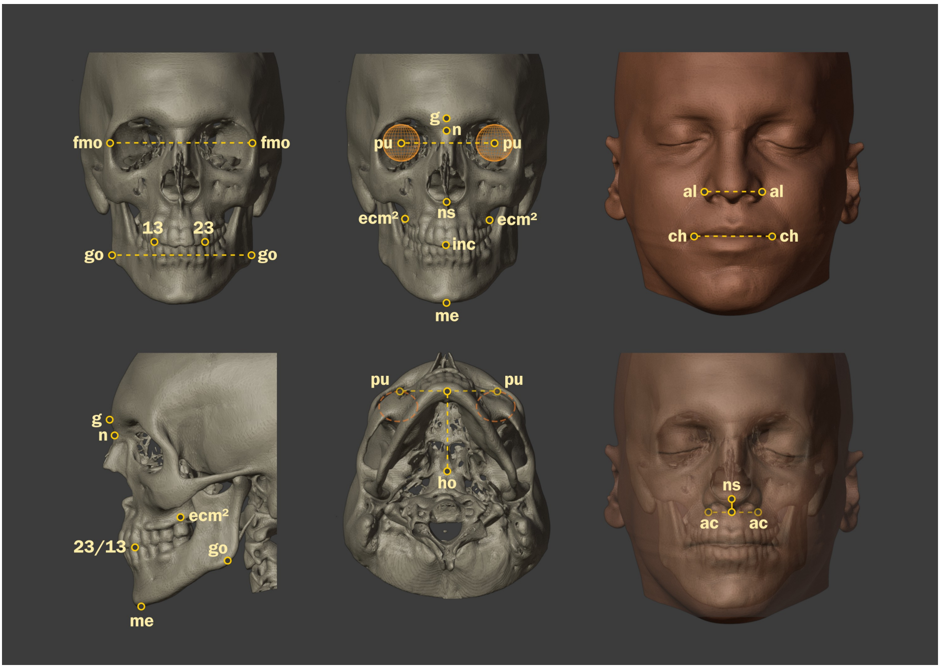
Materials and methods



Screenshots with voxel data eyeball positioning , measurement process and predictive example of facial structures

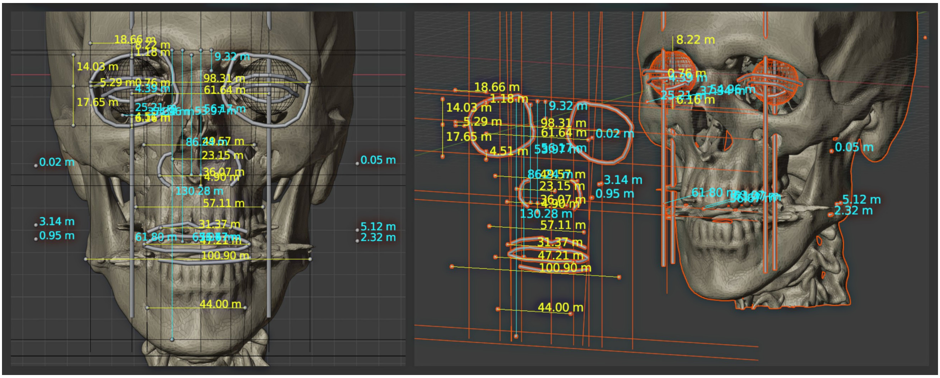
The work included 33 helical tomography (CT-Scan) and cone beam (CBCT) scans that were reconstructed in the Blender 3D environment using the OrtogOnBlender add-on [A18] . The work is part of a project approved by the CEP-UFU (CAAE: 52592021.3.0000.5152) that aims at digital forensic facial reconstruction techniques from computed tomography. As the sample consisted of anonymous tests in its own database, no human being was exposed to radiation for research purposes.

Initially, three meshes were automatically reconstructed: soft tissue, bone and teeth [A19] , using the pre-configured database, which is activated according to the tomography model. Mesh reconstruction uses the *hounsfield* scale (*threshold*) with a single value and generates a model in the scale of 1 Blender Unit = 1 mm, suitable for 3D printing and compatible with that used by medical biomodels. Due to the limitation of mesh reconstruction, which does not include a satisfactory automatic segmentation of the eyeball, the authors chose to reconstruct the *voxel data* [A21]of the tomography, in order to visualize this structure (Fig. 1). All planes (axial, coronal and sagittal) as well as the volume interactive visualization elements (Voxel_Boolean) were parented to the Bones mesh, corresponding to the reconstructed skull. The maneuver allowed the interface operator to align the skull to the Frankfurt plane, while all other elements, including the soft tissue already "parented", that is, following the changes in positioning and rotation that are attributed to the skull. Once the scene is pre-configured, with the meshes and voxel data aligned to the Frankfurt plane, the operator positioned a sphere at the eyeball location, making small changes to the scale of the axes, in order to adapt the model to the volume. corresponding. In order for the sphere to fit the desired volume,*voxel* , in order to make small adjustments until the alignment matches.



Points and distances used in the chapter

All points used in the present chapter (Fig. 2) followed the publication **A standardized nomenclature for craniofacial and facial anthropometry** by Caple and Stephan 2016 [A4] . Small spheres were positioned in orthogonal planes (2D) on different axes, at the desired measurement points (Fig. 3). The Measureittool was used to survey the spaces. To verify the predictive capacity of cranial dimensions for the structures that are the target of this work, the correlations between the following linear measurements and the actual position of the anatomical points sought were tested.



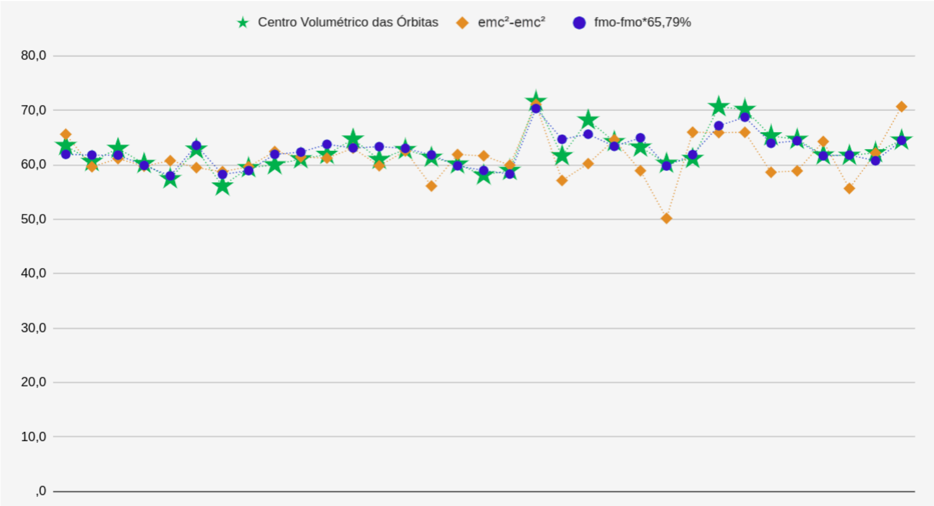
Measurement process and predictive example of facial structures

Results

Eyeball Positioning

For the positioning of the eyeball in the orbit, the three displacement axes were approached: X, Y and Z, in view of the structural complexity and the great variation, mainly in the Y axis.

Positioning on the X Axis (Horizontal Position)



Comparative graph between the real measurements and the projections of the volumetric center of the orbits on the X axis

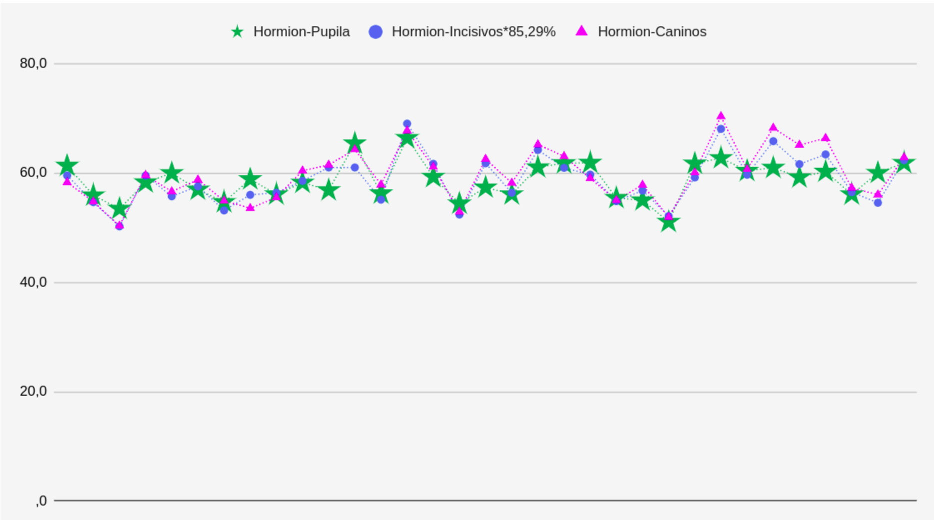
Initially, the distance between the frontomalar orbital point (fmo) and the volumetric center of the orbit (orthogonal, only on the X axis) was measured. The average orthogonal frontal distance was 16.41 mm with a standard deviation of 1.06 mm. Another way to arrive at the distance between the centers of the eyeballs is to measure the space (only on the X axis) between the frontomalar orbital points (fmo-fmo) and multiply by 0.6579 (corresponding to 65.79%), with deviation default of 1.52. This was the best match found between the projections.

There is also the possibility of projecting the center of the eyes from teeth 16 and 26 (also orthogonal, only on the X axis), with a standard deviation of 4.09, a projection with a lower degree of precision in relation to the fmo-fmo space. , but very useful in the case of missing a part of the maxilla, so that it can be projected from the previous data, that is, in the absence of maxillary volume, the average space of 16.41 mm can be used or the 65.79% of the fmo-fmo to project the position emc²-emc² (bone crest in the cervical of the teeth).

Positioning on the Z Axis (Height)

Once the positioning of the eyeball on the X-axis is estimated, a line cutting through the upper edge of the orbit can be drawn. From the intersection of the vertical line drawn and the edge of the orbit, the center of the eyeball on the Z axis will be at an average of 15.46 mm below it, with a standard deviation of 1.50.

Positioning on the Y Axis



Comparative graph between the real measurements and the projections of the volumetric center of the orbits on the Z axis

An approach using the average of the measured values can be traced from a cut (clipping border) made in the middle of the eyeball already positioned on the X and Z axes, thanks to the cut it is possible to see the position of the globe in relation to the edge lower orbital bone. From the limit of the outer edge of the orbit a vertical line is drawn and the mean of the limit position of the pupil is 5.59 mm, with a standard deviation of 2.51.

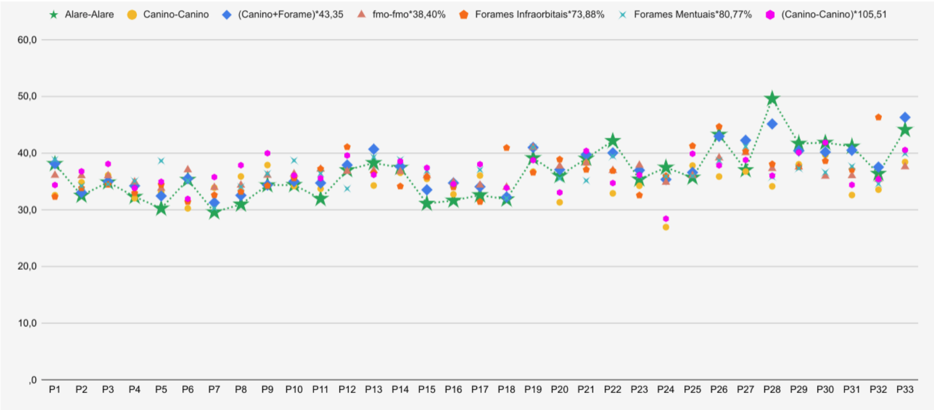
Another way to know the pupil position is to measure the distance (orthogonal, on the Y axis only) between the hormion (ho) and the incisors (inc) and multiply by 0.8529 (or 85.29%), with standard deviation of 3.94. The result will be the distance from the pupil to the hormone. In the absence of this structure, in the case of incomplete or digitized skulls with missing areas, one way to know the position of the pupil is to observe the face from the side (X axis) and draw a vertical line from the base of the canine. Although with a lower precision than the projection by the hormion previously discussed, there is a high chance that the pupil will be there, with a standard deviation of 3.04.

Given the variation in the data, a good approach is to cross the projection by the mean with the inc-ho or by the projection with the canine, always taking into account the standard deviation.

Frontal Stroke of the Nose Wings

The frontal tracing of the nose wings complements the lateral tracing, presented in the chapter Complementary Nasal Projection System in Forensic Facial Reconstructions/Approaches, since it is focused on the most anterior part of that structure.

Wing-Wing (Al-Al)



Comparative graph between the real measurements and the projections of the nasal wings

Five approaches were studied for the limit width of the nasal wings (al-al), initially the general average of the distance, whose result was 36.55 mm with a standard deviation of 4.62.

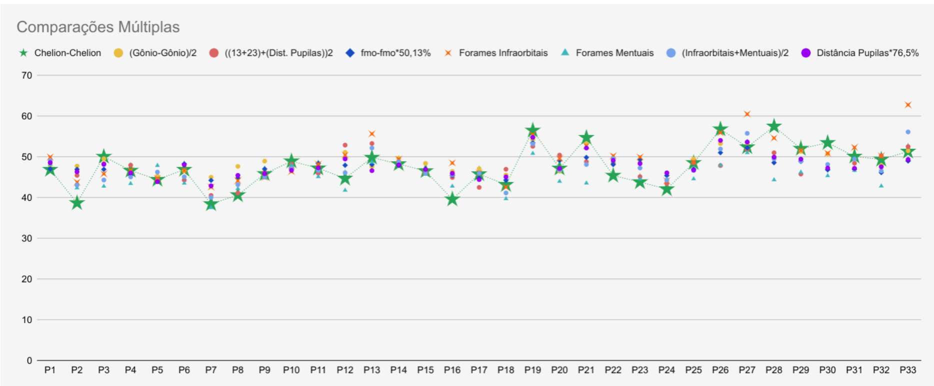
The best projection from other anatomical data was the one in which the distance between the canines plus the distance between the infraorbital foramina are added together and the total is multiplied by 0.4335 (or 43.35%), with standard deviation of 4.21. Such a projection was the closest to the real distances. In the absence of the mandible or mental foramina data, another possible projection is the one that uses the space between the infraorbital foramina, multiplying it by 0.7388 (or 73.88%) with a standard deviation of 6.10. In the absence of the mandible or part of the maxilla, another approach is the one that multiplies the fmo-fmo space by 0.384 (or 38.40%), with a standard deviation of 4.12.

There are still two other possibilities, but both are not recommended, due to the large discrepancy in relation to those presented above. One uses two projections from the distance between the canines multiplied by 1.0551 (or 105.51%), with a standard deviation of 14.53. The other is to multiply the space between the mental foramina by 0.8077 (or 80.77%), with a standard deviation of 9.07.

Nasospilane-Alar Curvature Point

The distance between the nasospinale marker (ns) and the alar curvature point (ac) is, on average, 4.51 mm with a standard deviation of 2.05. In order to design a more harmonious structure, it is essential to follow the projection provided by the lateral outline of the nose, discussed in the aforementioned chapter.

Frontal Tracing of the Mouth



Comparison chart between actual measurements and mouth projection

The *chelion-chelion line*(ch-ch) mean was 47.70 mm with a standard deviation of 5. The projection that proved to be the most promising was the one in which the distance from the infraorbital foramina was added, plus the distance from the mental foramina, dividing the result by two. Another promising approach was to use the distance between the gonia (maximum orthogonal frontal limit) divided by two. In the absence of the mandible and even part of the maxilla, the ch-ch distance can be obtained by multiplying the fmo-fmo distance by 0.5013 (or 50.13%) with a standard deviation of 4.02. A more subjective projection, as it is based on a positioning with one of the elements approximate, is the one that uses the sum of the distance between the pupils, plus the distance between teeth 13 and 23 (canines), dividing the result by 2. Using a similar approach and equally approximate, you can multiply the distance between the pupils by 0.6579 (or 65.79%), with a standard deviation of 1.52. There is also the possibility of using the direct projection of the infraorbital foramina and, with less precision, the projection of the mental foramina.

Heads up

The study of the present chapter only addressed the chelion-chelion distance, ignoring the height of the lips, however, at least with the sample used, the height of the incisors was consistent with the height of the lips in young individuals.

Other Projections

In forensic facial approximation work, especially in the archaeological field, it is common for some parts of the skull to be absent, mostly the mandible itself. Although the dimensions of the mandible are difficult to project, the study sought to approach this and other distances from available regions in the skull structure.

Glabela (Bone) and Lower Regions

Glabela-Nasoespinale

The mean distance between the glabella and the nasospinale point was 59.58 mm with a standard deviation of 2.75. The projection can be made by multiplying the fmo-fmo distance by 0.6276 (or 62.76%) with a standard deviation of 3.35.

Glabella - Incisors

The mean distance between the glabella and the incisors (teeth 11 and 21) was 88.95 mm with a standard deviation of 3.06. The projection can be made by multiplying the fmo-fmo distance by 0.9375 (or 93.75%) with a standard deviation of 5.10.

Glabella - Ment (Bone)

The mean distance between the glabella and the chin was 125.91 mm with a standard deviation of 6.11. The projection can be made by multiplying the fmo-fmo distance by 1.3265 (or 132.65%) with a standard deviation of 7.62.

Nasion (Bone) and Lower Regions

Nasion-Nasoespinale

The mean distance between the nasion and the nasospinale point was 49.05 mm with a standard deviation of 2.86. The projection can be made by multiplying the fmo-fmo distance by 0.5165 (or 51.65%) with a standard deviation of 3.095.

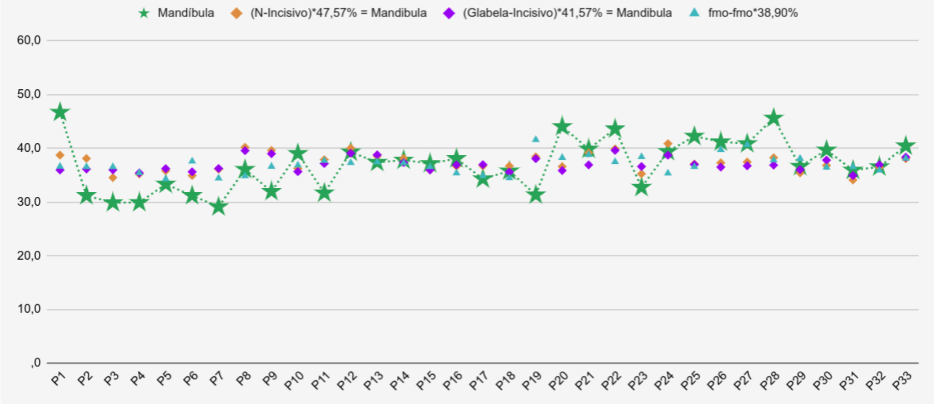
Nasion - Incisors

The mean distance between the nasion and the incisors (teeth 11 and 21) was 78.42 mm with a standard deviation of 3.65. The projection can be made by multiplying the fmo-fmo distance by 0.8264 (or 82.64%) with a standard deviation of 5.06.

Nasion - Mento (Bone)

The mean distance between the nasion and the chin was 115.38 mm with a standard deviation of 7.04. The projection can be made by multiplying the fmo-fmo distance by 1.2154 (or 121.54%) with a standard deviation of 8.11.

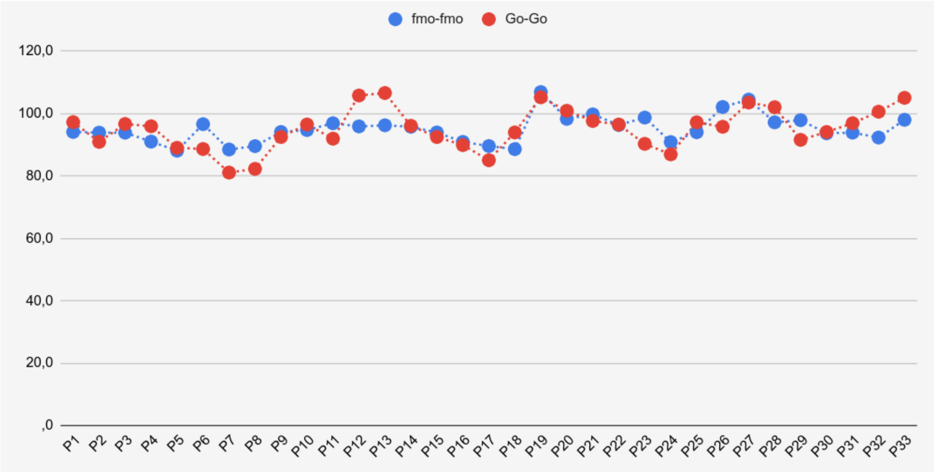
Jaw



Comparative graphic between the real measurements and the projection of the mandible

For the dimension of the mandible, the space between the incisors (11 and 21) and the chin (bone) was used. The mean distance was 36.96 mm with a standard deviation of 4.46. An approximation can be made by multiplying the distance between the glabella and the incisor by 0.4157 (or 41.57%), with a standard deviation of 5.33. Still in the vertical approach, there is also the possibility of multiplying the space between the nasion and the incisor by 0.4712 (or 47.12%), with a standard deviation of 5.56. If any part is missing in the vertical context, the fmo-fmo distance can be multiplied by 0.389 (or 38.90%), with a standard deviation of 4.83.

Gonia and Orbit Limits



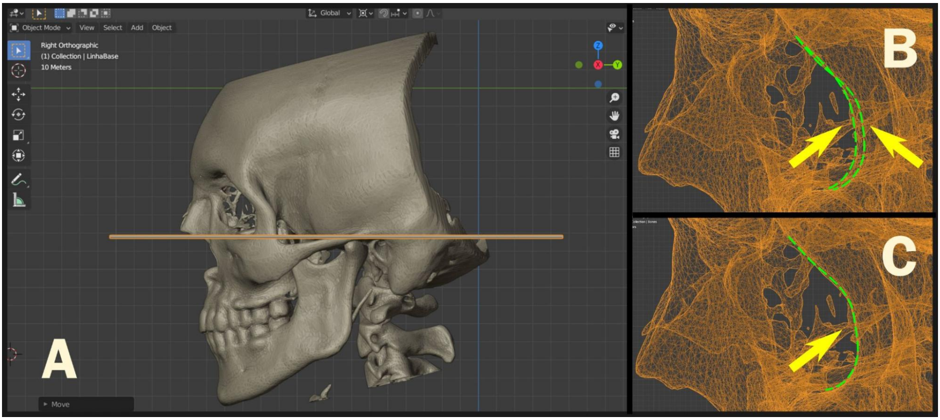
Comparison chart between fmo-fmo and go-go real measurements

The study found a significant relationship between gonia and orbit boundaries, providing a basis for projecting both of them in the case of missing regions.

Protocol Proposal for Frontal Face Traces

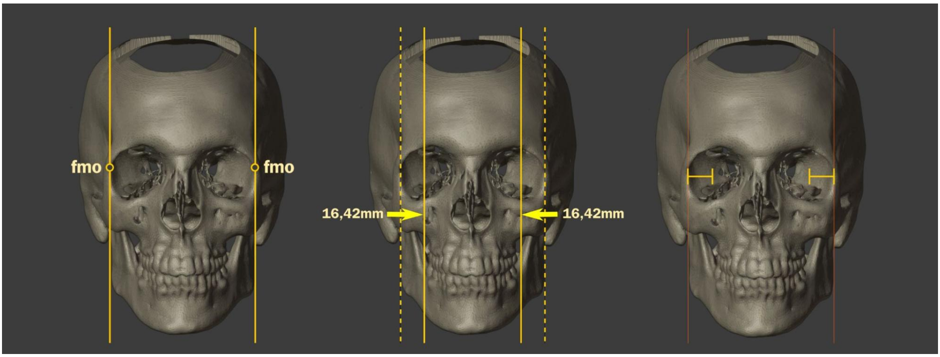
Heads up

The instructions that will be given below are oriented to advanced users of OrtogOnBlender.



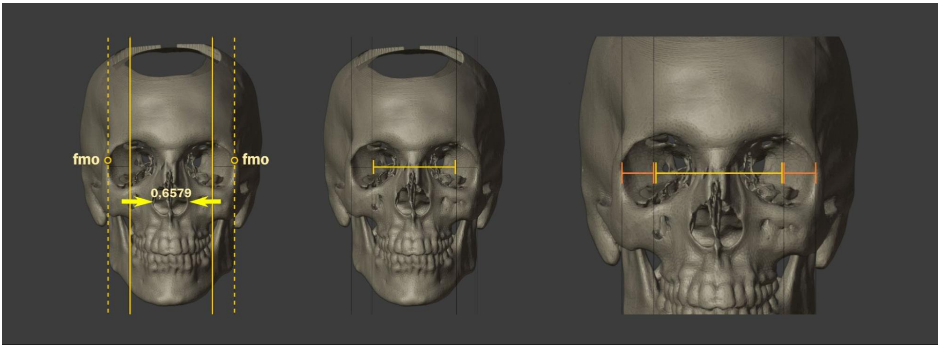
Alignment of the skull to the Frankfurt plane with correction of rotation in the orbits

Initially, it is necessary to import the skull and position it in the Frankfurt plane (Fig. 10, A), manually or with the tools available for this task in OrtogOnBlender. As the approximation work is aimed at the frontal portion of the face, it is a good practice to be aware of a possible misalignment of the orbits (Fig. 10, B) and, if this occurs, make the correction in the Z axis, so that the two line up as best as possible (Fig. 10, C).



Projection of the axis of the eyeballs by the mean on the X axis

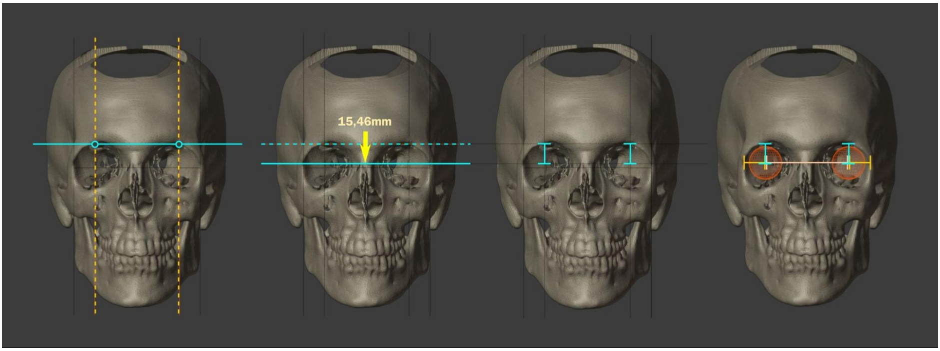
Starting from the top of the skull, the first step may be to project the center of the eyeball. Initially, the user can add two vertical lines (Vertical Center Line from OrtogOnBlender) passing through the fmo point on each side (Fig. 11 on the left) and copy them, shifting the one on the left by 16.40 positively on the X axis (Shift+D, X , 16.42, Enter) and the one on the right negatively on the same X axis (Shift+D, X, -16.42, Enter) (Fig. 11 center). Once the lines are positioned, the user can resize them in Z (S, Ctrl+D, X, 16.42, Enter and move the mouse until reaching the desired dimension), in order to compose a graph with constrainers (Fig. 11 to right). A suggestion to create such an effect is to join the lines with Ctrl+J, enter edit mode and access the Subdivide command, with the F3 key. After creating the two new vertices,*edge*) is created as a point between the vertices.



Projection of the axis of the eyeballs by the fmo-fmo distance

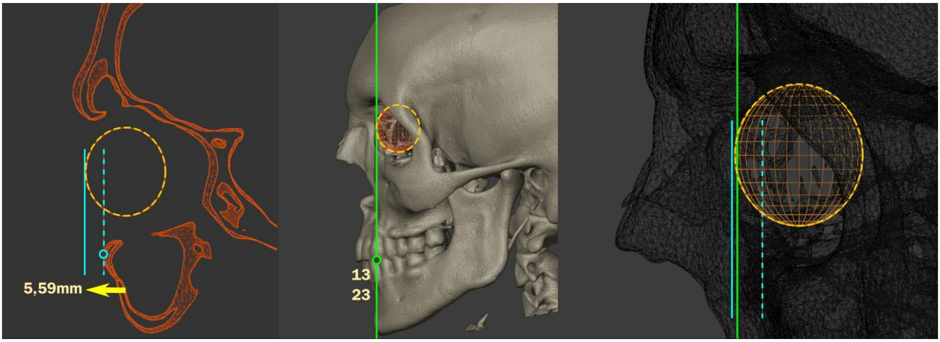
To reinforce the alignment, using a proportion-based approach, the user can select the lines that pass through the fmo points, created earlier, copy them, merge them with Ctrl+J, enter edit mode, to force centering of the transformation and reduce the scale on the X axis to reach 65.79% of the original space (S, X, 0.6579, Enter)

(Fig. 12 on the left). Then proceed with the visual configuration of the space marker (Fig. 12 at the center) and at the end two projections will be available to the user, one based on the average and the other on the proportion (Fig. 12 on the right).



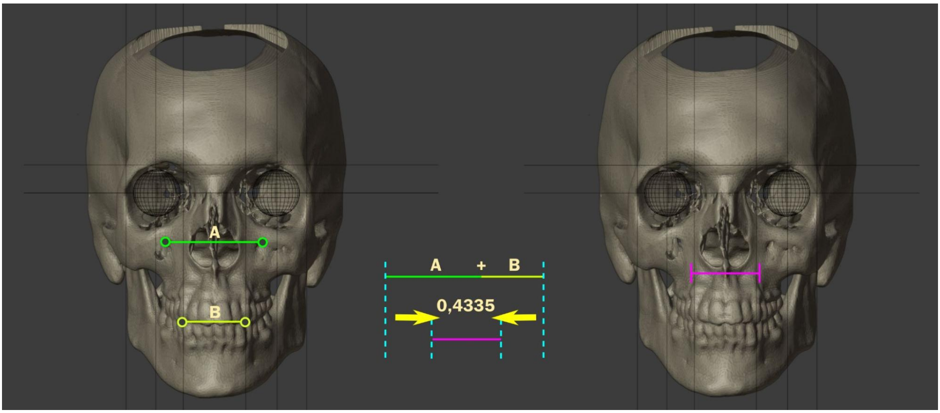
Projection of the axis of the eyeballs by the mean on the Z axis

Once the projection on the X axis has been established, the next step is to proceed with it on the Z axis. To do so, it is necessary to create a horizontal line (Horizontal Center Line) at the intersection of the orbit edge with the center of the pupil on the X axis (Fig. 13 on the left). This second point is nothing more than the one projected earlier. Once the horizontal line is positioned, a copy is made and shifted by 15.46 mm on the Z axis (Shift+D, Z, -15.46, Enter) (Fig. 13, center left). With the projections in the X and Z axes established, the user can add the eyeball and center it using the traced visual elements as a parameter (Fig. 13 on the right).



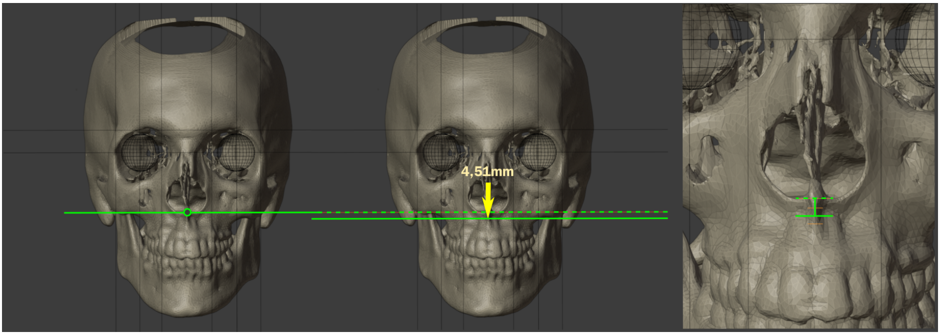
Projection of the axis of the eyeballs through the media and canines on the Y axis

For positioning on the Y axis, the user can use two of the most practical projections available, the first tracing a line from the edge of the orbit edge and shifting 5.59mm positively on the Y axis (Fig. 14 on the left) and the second tracing a line from the related canine to the orbit side, may be 13 or 23 (Fig. 14, center). If there is a good match between the two, the user can position the eyeball at the center of the two projections (Fig. 14, right).



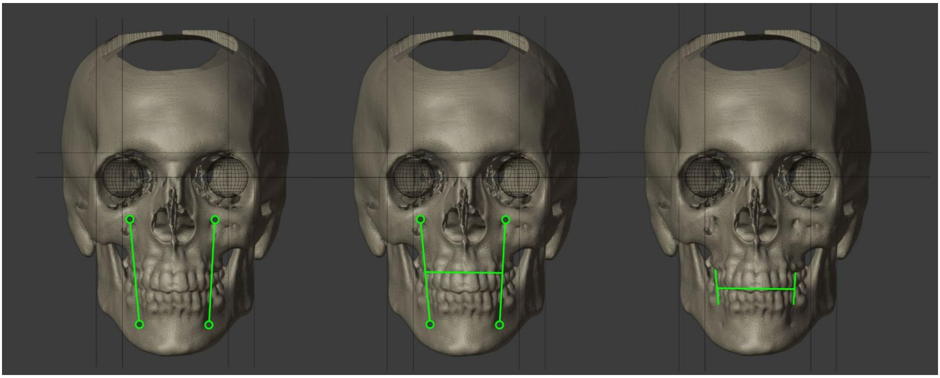
Projection of the limits of the nasal wings on the X axis

The limit of the nasal wings can be traced by adding two distances, the one between the infraorbital foramina and the canine (Fig. 15 on the left), and then resizing it to 43.35% of the original dimension on the X axis (Fig. . 15 to the center). The limiter can be positioned just below the nasospinal opening and corrected posterior to the lower limit of the alar width.



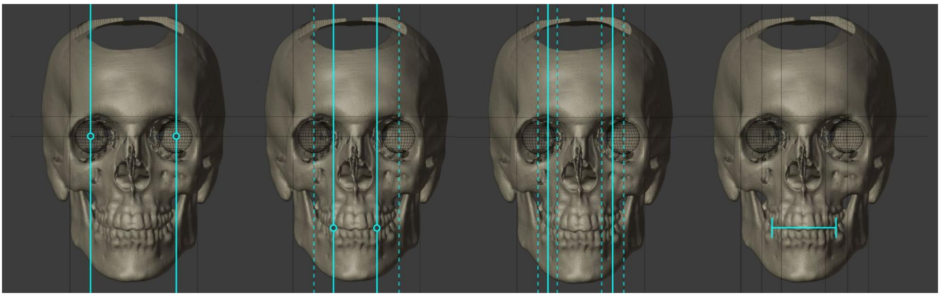
Projection of the limits of the nasal wings on the X axis

The lower limit of the nasal wings can be traced from a line positioned at the *nasospinale* point (Fig. 16 on the left), which will be copied and shifted 4.51 mm negatively on the Z axis (Fig. 16 at the center). If the user is interested, the lines corresponding to the standard deviation can be drawn in order to complement the projection data (Fig. 16 on the right, orange dashes).



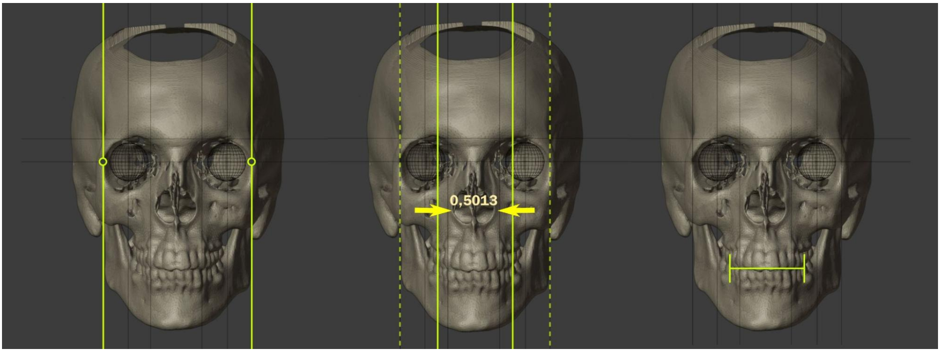
Boundary ch-ch on the X axis by the mean of the foramina

In the frontal projection of the mouth (*chelion-chelion*), the most robust tracing is the one resulting from the average between the distances of the infraorbital foramina and the mental foramina (Fig. 17 on the left). A horizontal line can be drawn from the subdivision of the two verticals (infraorbital-mental) discussed earlier (Fig. 17 in the center).



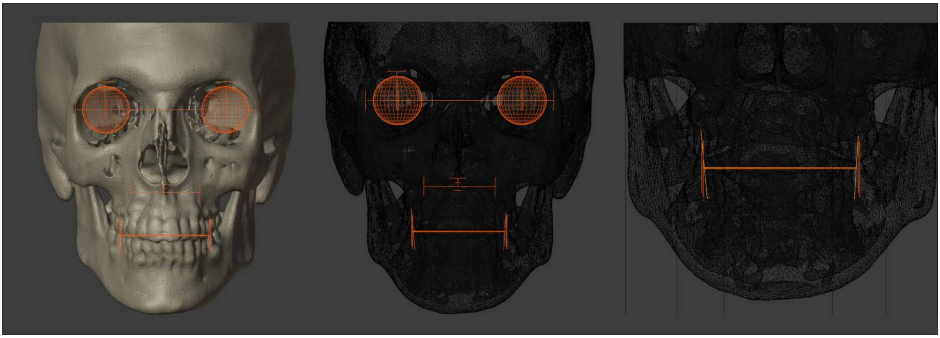
X-axis ch-ch limit by averaging the eyeball and canine distances

In order to complement the data and once the eyeballs have been added to the scene, another projection can be made from an average between the center lines of the eyeballs and the canines (Fig. 18).



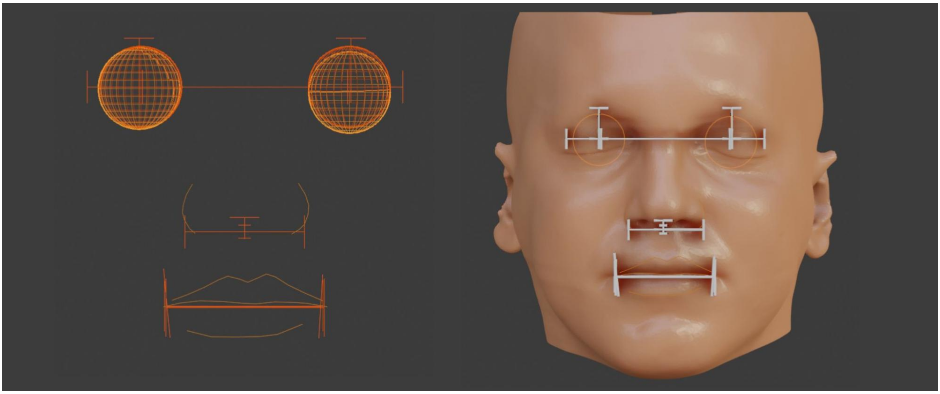
Bound ch-ch on the X axis by percentage of fmo-fmo distance

Another approach with good compatibility is the one that uses the space of 50.13% between the *right and left fmo* points (Fig. 19).



superimposed facial projections

All projections performed provide the user with a clear idea of the potential location of the frontal elements to be reconstructed. As in the example presented here, most of the CT scans studied generate convergent results, even though the approach is different (Fig. 20).



Comparison between projections and real facial elements

Using a tomography that is not part of the sample, when comparing the projections (in dark orange) with the real structures (in light orange), it is noted that the proposed methodology significantly coincided with them (Fig. 21 on the left). When comparing, in frontal view, the projections of the structures with the soft tissue mesh, it is confirmed that the parameters are within the expected range (Fig. 21 on the right). In the case of the lips, there seems to be an error in the extremities, however, there are indications of characteristics of this structure that provide a simple explanation for this situation.

Ch-ch stitches with open and closed lips

The study sought to position the ch-ch points at the structural limit of the lip opening. However, depending on the age of the individual (or other factors), at the time the lips are closed, there may be a tendency for the expression mark to enhance and the final line to be significantly larger than the actual opening (see the dark spots on the Fig. 22).

Discussion and Conclusion

The present study aimed to evaluate several linear distances with important facial structures for forensic facial reconstruction. Despite a small sample in relation to the population, it provided the establishment of promising predictive references for orbital positioning, mouth size and nose characteristics. Knowing that facial reconstruction is a technique based on approximation of facial characteristics, based on population averages, the high correlation index between the estimates encourages putting the proposed technique into practice, favoring further research on the method and anticipated benefits for facial reconstruction work. *The reference of the fmo* points is highlightedwhich is extremely useful, since it was surprisingly related to all investigated structures. More than that, it is an easily identifiable and highly reproducible anatomical reference. The possibility of adding predictive references was observed, reducing the error margins of each method. With this research, a new perspective of studies was opened, with promising results for facial reconstruction in forensic or archaeological contexts. Using the methodology presented, it is possible to position the eyeball, the alar width and the width of the lips in an easy and enhanced way by the tools of OrtogOnBlender.

Thanks

To Dr. Davi Sandes Sobral, who provided the tomography used in the didactic demonstration of the projection of structures from the skull. To the INDOR radiological institute for promoting scientific advancement through computed tomography.