Prediction methods for soft tissue structures in forensic facial reconstruction: A review for reconstruction of nose, eyes, mouth and ears

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Abstract
Facial reconstruction is an art and science in the field of forensics which involves construction of a recognizable face on unknown skull remains. It appears as a, metaphorically speaking “shining beacon of hope” after everything else fails for identification of the remains. Both, 2D and 3D methods of facial reconstruction have been developed for this process. The database of facial soft tissue thickness based on gender, ethnicity and age, at certain bilateral and unilateral anatomical points on skull bones, lay foundation to the process of reanimating the facial profile of a deceased. Several imaging modalities have been used for the collection of this data, in addition to the cadavers and various guidelines have been given for the reconstruction of the soft tissues, however, to construct soft tissue structures like nose, eyes, mouth and ears which take an important position in determination of the facial features is still a tedious task. This process is being researched since a century and multiple guidelines for reconstruction of the soft tissue structures are available. The face plays out based on the method used; hence selection of an appropriate method is vital. This review encompasses the various methods/guidelines derived for the reconstruction of the nose, eyes, mouth and ears of the face. In addition to the traditional methods given by Gerasimov, Krogman, Prokopec and Ubelaker, George, etc. other newer methods have been mentioned. This review also highlights assessment studies performed using the said methods in populations other than the ones they were derived from.

Keywords: Forensic science; facial reconstruction; soft tissue; face; skull.

Introduction

The fascination of human faces has existed since second and third century BC, when the art of making death masks was a rage (1). The dead have always been mysterious, especially those from the past and facial reconstruction has helped to get a step closer to them by its use in anthropology. It has also been used as a tool for recognition in the field of forensic sciences. However, it is generally, opted as the last resort when no other alternative is available (2). This art progressed from wax models to 2D sketching to 3D manual sculpting to 3D computerized facial reconstruction (CFR) in the present era (1). The methods of facial reconstruction included:

1. 2D methods which included sketching and superimposition methods, 2. 3D manual methods which included: Russian method by Gerasimov, American method by Krogman and Manchester method which was a combination of the two, 3. 2D and 3D computerized methods (1) (3).

The skull is like an anlagen for the facial form and contours (4) and though the face is made up of the same structures, no two faces are alike. Variations come in the form of genetics, environmental factors, gender, ethnicity, growth, and congenital anomalies (5). Hence, for a reconstruction, the age, gender and ethnicity should be reflected in the reconstructed face.

Gerasimov developed a reconstruction method based on the anatomy of the facial muscles which later became the Russian/European method. Wilton Krogman developed the American method which relied on average facial soft tissue depth at certain anatomical landmarks. The Manchester method, which is considered the most accurate, was developed by Richard Neave, who combined the former two methods. He used the average soft tissue depths by Krogman but used an anatomical approach for the placement of the facial muscles (1). All these methods were time consuming and quite subjective.

Computerized facial reconstruction was developed due to the need for a flexible, speedy, efficient system with the ability to avoid subjectivity (1). The first computerized facial reconstruction, based on cranial reconstructive surgery, was developed in 1980s. Subsequently, multiple 2D and 3D methods were developed. The 2D methods included utilizing various facial features and contours from a database to form an image over the skull (6). The 3D method consisted virtual sculpting of the face over the skull using devices like haptic feedback or animation software's, the process of which was similar to the manual modeling (6) (7), but there were concerns of subjectivity similar to manual methods (8). The other method employed included warping of a similar facial template from a database over the unidentifiable skull. The advantage of this process included an ability to create plausible head variants (9) (10).

In the earlier times, cadavers were used to gather data for average facial soft tissue thickness (1) but with the advent of technology, imaging modalities like radiographs, CT, MRI, USG and CBCT have been found to been useful for the determination of average soft tissue depths (11). So, a soft tissue depth database assisted in facial reconstruction to achieve average skin thickness but what about the soft tissue structures of the face like nose, ears, eyes and mouth? The majority of these structures are made up of cartilage and soft tissues, most of which decompose quickly leaving little behind (4). Additionally, the skull offers little information about these appendages. Hence, reconstructing them becomes a challenge. A separate set of guidelines were developed for their reconstruction. However, multiple guidelines were given by different authors, studies performed in different population made it difficult to generalize. This review deals with these prediction methods or guidelines for all the four structures as well as the assessment studies performed for them which might assist in the selection of most acceptably accurate technique of reconstruction.

The Nose

The nose is an important part of the face and provides a distinctive demeanor to an individual. Its central position, shape, size and symmetry play an essential role in determination of the facial appearance and also facial convexity (5). The nose was one of the structures which were highly studied due to its contribution to the facial outlook. Prediction guidelines given by Gerasimov, Krogman, George, Prokopec and Ubelaker and Macho were some of the older methods for nasal prediction.

Gerasimov (1971) pioneer in the development of the Russian/ European method, gave the two tangent method (One from the last one third of the nasal bone and other the continuation of the anterior nasal spine; meeting point of both determined the nasal tip) which was considered the most popular method of nasal morphology prediction (12) (13) (14). He also stated that the profile of the nose could be determined by the lateral border of piriform aperture (15).

Wilton Krogman, on the other hand, gave a method where the soft tissue of nasal width could be predicted from the width of the bony nasal aperture that is, addition of 10 mm to the maximum width of nasal aperture for Caucasians and 16 mm for Negroids (16). Also stated that, the pronasale position could be predicted by measuring the length of anterior nasal spine from the vomer maxillary junction till the tip of the anterior nasal spine (acanthion), which would then be tripled and added to the average soft tissue depth at the mid philtrum (16).

The Macho method developed in 1986 was based on regression equations developed using seven bony cranial landmarks (height of piriform aperture from rhinion to the anterior nasal spine, height of bony nose from nasion to anterior nasal spine, distance from the sellanasion plane till the most prominent point on the nasal bones, height of the most prominent point on the nasal bones from the nasion, height of the rhinion and the angle between anterior nasal spine-nasion plane and anterior nasal spine-rhinion plane) and they were correlated to the nasal soft tissue to corroborate regression equations for nasal length, nasal height and nasal depth (17). The effect of age on the nasal morphology was also studied and concluded that nasal height and length can be predicted from the bony landmarks but nasal depth and thickness of soft tissue were influenced by age (17).

The George method given in 1987 was based on the aesthetic methods of facial surgery given by Goode. It stated that the nasal projection/pronasale position was a proportion of the distance drawn from the nasion to point A, which was 60.5% in males and 56% in females. This distance was projected on a line parallel to the Frankfurt horizontal plane, from a point along the nasion-point A plane at the height of a point located midway along inferior slope of anterior nasal spine. A line perpendicular to the Frankfurt horizontal plane was drawn to mark the position of the nose projection predicted (18) (19).

Prokopec and Ubelaker in 2002 gave a detailed description of a method for nose projection which was initially proposed by Gerasimov to determine the profile of the nose. It included a line drawn from rhinion (line B) which was parallel to the nasion-prosthion plane with the nasal aperture being subsequently divided into seven equidistant segments along the line. The distance from the line B till the lateral surface of the aperture was measured and replicated anteriorly. Gerasimov was of the opinion that this demonstrated the nasal cartilage in profile, thus 2 mm was added to all for the skin depth and by connecting all the points the nasal profile was determined (18) (19).

Stephen et al. in 2003, tested accuracy of pronasale/ nasal projection determination on 59 lateral cephalograms of Australians of European extraction and concluded that Gerasimov methods were subjective, imprecise and also tended to overestimate the nasal projection. Krogman's method also performed poorly which could also be attributed to difficulty of detecting the vomer maxillary junction in radiographs. To overcome this, Stephen et al. developed a variation of the technique which involved measuring the length of anterior nasal spine from the lateral border of aperture rather than the vomer maxillary junction. Though there was no scientific basis for this variation, it performed better than the original method by Krogman. The George method outperformed all the other three methods for predicting nasal projection among Australians. Stephen et al. also derived his own set of regression equations for nasal prediction through this study (18).

Rynn and Wilkinson in 2006 studied analysed all the six techniques i.e. Gera simov, Krogman, George, Prokopec and Ubelaker, Macho and Stephen techniques among Caucasoid skulls and found Gerasimov's technique to be quite accurate and the best performing out of all the six though the George method also was deemed useful for determination of nasal projection in Frankfort horizontal plane. To note was that they determined the pronasale position with reference to nasal spine line rather than the Frankfurt horizontal plane. Krogman technique underestimated the nasal projection by a significant amount whereas Macho method overestimated the height and depth for both the genders and length for the male gender by significant amount. Prokepec and Ubelaker method also performed poorly and Rynn and Wilkinson were of the opinion that it did not take into account the asymmetry of the lateral nasal bones (19).

Regression equations given by Stephen et al. in 2003 were able to predict a pronasale in the females quite accurately, however, no correlation was found between the craniometrics parameters and nasal projection for males among the Caucasoid skulls. However, the method was complex as it required multiple measurements (nasal bone angle as measured from nasion to rhinion; tip of nasal spine to lateral aperture border at base; rhinion to most posterior point of aperture border, measured perpendicular to nasion/prosthionplane; nasal spine angle from Frankfort horizontal plane; distance of point halfway along inferior slope of nasal spine from nasion) and was not exactly preferred (19).

With the use of computed tomography imaging modality, data of 79 North Americans (upto 50 years of age) of varied ancestry augmented by 60 lateral cephalograms of European ancestry, six regression equations for the nasal prediction were developed in 2009 known as the Rynn method. The Rynn method was quite simple and practical in a way that it included using only three measurements from defined bony landmarks (nasion to subspinale; nasion to acanthion (tip of ANS) and rhinion to subspinale) which were easily reproducible in both 2D and 3D methods for the nasal prediction (15).

This was assessed by Mala in 2013 along with Stephen method, in 86 lateral cephalograms of central Europe ancestry, found Rynn method to be better than Stephen method overall. However, both the methods underestimated the nasal projection by small amounts. It was also noted that Stephen method predicted anterior nasal projection in females quite accurately while Rynn method had better results with the male gender (20). Rynn method also proved to be accurate enough for the Scottish sub-adult population, but, for Indonesian adults the error was quite high. Scottish population falling under the same broad category of Caucasians could have attributed for favorable results as the Rynn method was developed from the same. As the already published methods was found to be inaccurate for the Indonesian population, Sarilita et al. derived its own set of regression equations for the population (21). Similarly, Rynn method was recalibrated for the Turkish population in 2019 by Bulut et al. as it underestimated all the nasal dimensions (13). Utsuno et al. derived regression equations for nasal tip prediction among Japanese population and compared the same to the Rynn method. They stated the reported differences could have been attributed to the difference in population used for derivation (22).

Lee et al. in 2014 took advantage of 3D imaging technique of CBCT and developed regression equations for the prediction of positions of pronasale, subnasale and ala in the anteroposterior, mediolateral, and inferosuperior position using four bony landmarks, namely nasion, rhinion, anterior nasal spine and most lateral point on the nasal cavity. The measurements were all done either point to plane or plane to plane and it was noted that the antero-posterior position of the pronasale, subnasale, and ala demonstrated statistically significant correlation with the nasal bone projection and nasal bone angle and the mediolateral position of the ala correlated significantly with the nasal width (23). Ridel et al. in 2018 used a similar method to Lee et al. and gave regression equations for nasal prediction and determined that the nasal height and the nasal bone length significantly predicted the pronasale, subnasale and alare positions, while the nasal bone projection predicted the subnasale position in black and white South Africans and also, the pronasale position in white South Africans (24).

Davy Jows et al. demonstrated that at a 60 degree tilt of the head, the contour of the tip of the nose is the same as that of the superior nasal aperture, i.e. the pronasale and the rhinion tend to overlap, except for patients with snub noses. They opined that this method could be an easy and practical method for testing the accuracy of nasal reconstruction (25).

Tedeschi-Oliveira et al. and Strapasson et al. both attempted to relate the skeletal landmarks for nasal morphology prediction in Brazilian population. Tedeschi-Oliveira et al. analysed 600 lateral cephalograms and demonstrated that the Rhinion-Pronasale-Prosthion angle, when kept at 90 degree gives an approximate position of the pronasale with a maximum error of 3 mm (26). Strapasson et al. in 2017 found a correlation between the nasal width and the upper width of the piriform aperture. A multiple linear equation was derived: 23.77 + (c-c x 0.42) + 3.31 (for male individuals) and the male nose was found to be 3.72 mm on an average wider than the female nose. [c-c: upper piriform width].

29.56 + (b-b x 0.26) + 3.41 (for male subjects)—1.18 (for long face type subjects) + (age x 0.06) was the equation given for derivation of the nasal width from the lower width of piriform aperture. It was also concluded that the differences between the average nasal width and the mean distance between the alar insertion points were 14.73 mm for males and 12.74 mm for females. Hence, it was possible to determine the position of the ala insertion points based on the nasal width (27).

Strapasson et al. validated these derivations in 2019 on 246 Brazilian individuals and concluded it to be adequate to predict the nasal width for forensic facial reconstruction. Also, it was determined that an association exists between the facial type and the nasal profile (28).

While all these studies were done on adults, Allam et al. in 2018, specifically derived regression equations for predicting nasal soft tissue through skeletal parameters in children and concluded that children's nasal skeletal parameters predicted the soft tissue quite well (5).

Through these studies, it could be noted that ancestry held an important influence above the nasal morphology. Caucasoid are found to have straight nasal fossa, projected anterior nasal spine, straight nose, while Negroid tends to present wide nasal fossa, wide nose and Mongoloid tends to present with small anterior nasal spine and straight nasal profile (28) (29). Gerasimov's, George's methods obtained good results for Caucasoid population, Krogman's technique worked for the North Americans (29). Tedeschi-Oliveira and Strapasson methods were developed and tested only on Brazilians (26) (27) (28). Rynn method also gave better results for Caucasians (15) (20) (21) (22). Along with ancestry, age and gender also played an important role. It was noted that on average, males had larger nasal external volume and area and wider nasal width than females and the nasal volume area increased significantly from childhood to old age (30). Also, though regression equations can be accurate for the population they have been derived from, they do not work well with sample of other population)19). Also, more studies for prediction of nasal width are required as majority of these studies analysed only the nasal projection or pronasale position (29).

The Eyes

The eyes are a vital component of the mid face and similar to the nose, multiple rules for its position were mentioned. The eyeball was said to occupy the anterior portion of the orbital cavity and accounted for one-fifth of the volume placed slightly laterally and towards the upper sides and a line drawn from the superior and inferior orbital margins would just touch the cornea(31). Also, the line joining the medial and lateral margins was said to have one third of the eyeball anterior to it (32). But, Krogman was of the opinion that the apex of the cornea was at the center of two bisecting lines from the medial to lateral and superior to inferior margins and the a tangent to the superior and inferior margins limit the outer portion of the cornea (33). However, the position was made out to be 2mm closer to the medial wall than lateral in palpation studies (34). For the profile placement, Fedosyutkin and Nainys (1993) were of the opinion that protrusion of the eyeball was dependent on the thickness of the superior orbital rim (12).

The most commonly used technique utilized for placement of eyeball was centered on the central position of the eyeball and lateral projection accounted for the tangent from the superior and inferior orbital margins. However, the lateral projection method was disapproved by Stephen when he discovered an underestimation of the anterior globe by 4mm on average (35). This was also in accordance to the study performed by Wilkinson and Mautner that the eyeball protrusion was 3.8 mm ahead of the tangent and that the globe should be positioned such that it touches the iris rather than the cornea (12). Stephen et al., (36) (37) Guyomarc'h et al (38). concluded similar results as earlier anatomic observations that the eyeball is placed in superior lateral position rather than centrally whereas Kim et al. found the eyeball to be placed inferiolaterally (39). Mala and Veleminska studied three methods: "tangent to the cornea", "tangent to the iris" and the orbital height method given by Guyomarc'h and found Guyomarc'h method to be the best to predict the eyeball protrusion. This method slightly overestimated the eyeball position while "tangent to iris" method slightly underestimated the position. "Tangent to the cornea" on the other hand significantly underestimated the position of the eyeball (40).

Wilder stated that the position of the medial canthus was at the lacrimal fossa and that of the lateral canthus was at the malar tubercle (12).The position of lateral canthus at the malar tubercle was widely accepted, however, the distance from the orbital rims varied for different authors (34). Another opinion was that the lateral canthus is 5-7 mm medial to the orbital margin and 1 cm from the frontozygomatic suture (32). Angel placed the medial canthus 2mm lateral to the medial wall and lateral canthus 3-4 mm medial to the lateral wall (36). Couly 1976 placed the lateral canthus at a distance of 8-10 mm inside the lateral wall of the orbit (41) while for Stephen et al medial canthus was 4.8 mm and lateral canthus 4.5mm from the medial and lateral wall respectively (36). Fedosyutkin and Nainys (1993) stated that the length of the eye fissure was 60--80 per cent of the width of the orbit (12). Regression equations were given by Kim et al. for the calculation of position of the canthi (39). In Caucasians, the lateral canthus was found to be 2 mm higher than the medial canthus, which gave the palpebral fissure an inferiomedial slope which was more prominent in Mongoloids (32). Fedosyutkin and Nainys (1993) stated that the eyebrows and the eyelids could be predicted from the supraorbital rim (12) (34). Earlier studies as well as the recent ones have stated a superiolateral positioning of the eyeball rather than central and based on the recent studies, the tangent to the cornea underestimated the lateral projection of the eyeball. However, the canthus positions differed for different authors.

The Mouth

The mouth majorly consisting of soft tissues, the skeletal parameters do not provide much information for its reconstruction. However, Gerasimov opined that the alveolar portion of the upper jaw, width of the dental arch, size and shape of the teeth and their occlusion can assist in determination of the morphology of the mouth and the height of the enamel of the incisors could determine the thickness of the lips. He emphasized on racial differences based on the presence of prognathism of the jaws (14). Krogman's rule of thumb gave the width of the mouth to be approximately equivalent to the interpupillary distance or the distance between the lines at the junctions of canine and first premolar on each side (33). Prag and Neave (1997) stated that the mouth width is equal to the distance between the medial borders of the iris (42). Stephen in 2003 studied the three methods (two given by Krogman and one by the Prag and Neave) among Australians and concluded that the method given by Prag and Neave was the most accurate out of the three, though, it also underestimated the width by around 2 mm. A new guideline was derived which was found to be highly accurate, described the mouth width as canine width plus 57% of the total distance between the lateral canine borders and the pupil centers on each side (42). Stephen and Henneberg suggested a 75% rule where the intercanine distance was 75% of the mouth width. They stated that this method was better as it relied on reproducible hard tissue landmarks (43). Wilkinson found a correlation between lip thickness and teeth height and derived linear equations for both Europeans and Asians/Indians. Fedosyutkin and Nainys (1993) stated that the philtrum width was equal to the distance between the midpoints of the upper central incisors (12). There was gender differences with males demonstrating a larger lip width, thickness, and volume than females (44). Houlton et al. in 2019 studied Stephen and Henneberg 75% rule and Fedosyutkin and Nainys method to determine the philtrum width in South African population. They found that the philtrum width was underestimated with this method (could be attributed to the difference in population the methods were derived from) and it correlated more accurately with central-lateral incisor junction. They derived regression equations for determination of mouth and philtrum width and concluded a better result with the regression equations than the original two methods (44). Babacan et al. in 2020 derived 14 equations for lip predicting lip morphometry using computed tomography. They also noted that the mouth width and the width of the philtrum was more in males than in females (45).

The ears

Reconstruction of ears is quite understudied but highly complex considering very little information could be availed from the skull for the same similar to the mouth. Gerasimov was of the opinion that the angle of the ear was parallel to the jaw line (similar direction given by Broadbent and Matthews 1957) (46) and the ear lobe was attached for downward directed mastoid processes and free for forward directed mastoid processes (47). He stated that the temporal bones, the direction, size and shape of auditory meatus, the mastoid process and the direction of the ramus should be taken into account. He also mentioned that a satisfactory method for reconstruction of ear was difficult and that it should be done "intuitively" (14). The earlier studies stated that the long axis of the ears is parallel to that of the nose, however, this theory was soon discarded as it was concluded that the ear is placed at angle of 15-30 degrees (12) (16) (48) . Another theory proposed was that the length of the ear was same as that of the nose height (12) (49) but this was too discarded (49). The ear lobule was at the level of the nasal tip, the superior surface was at the level of eyes and the helix raised up to the level of the eyebrow was the directives given by Broadbent and Matthews (46). Gerasimov, Fedosyutkin and Nainys and Jordanov suggested the morphology, position and surface of the mastoid process could clue in the morphology of the ears (49). Guyomarc'h and Stephan found all these theories to be imprecise for ear prediction and formulated their own regression equations for the same (49). Airan et al. found a correlation between ear length and the mid facial height and suggested that the it can be used for prediction of the ears (50).

Additionally, the structure of the ear was considered unique among individuals and this was what assisted Shekhar to confirm the identification of Veerappan, the sandalwood smuggler, from his remains (51). Rani et al. in 2020, studied the morphology of the external ear among 140 North Indians and opined that such databases could assist in forensic facial reconstruction as well as anthropological research (52).

Though a significant number of studies have been performed to study the relationship of these soft tissues structures to the skull and a number of guidelines have been given, the process of facial reconstruction is still an arduous journey because none of these guidelines could be completely accepted for all individuals due to gender, age and racial differences. Also, the studies for both mouth and ears prediction were heterogeneous and few, making it difficult for selection of a particular method. With ancestry playing a significant role, the difficulty of facial reconstruction increased among individuals descended from different ancestral groups (29). Another important aspect was recognition (29). What is required for forensics is not a statistically accurate reconstruction but rather a reconstruction which bares resemblance to the individual. Many of these studies have calculated the inaccuracies but the resemblance of the reconstruction has been studied only by few.

Conclusion

Facial reconstruction helps in identification in the field of forensic sciences where everything else has failed. This review introduced and discussed the various methods for reconstruction of the nose, eyes, ears and mouth. It also included the various studies to validate the use of these methods on populations different from which they have been derived. This review highlighted the importance of identification of racial, gender and age of the remains for facial reconstruction. But, due to the absence of amicable guidelines for universal application, though multiple studies have been performed till date, more are required owing to the differences in every population, preferably keeping in mind the ability of the reconstruction for recognition. Also, the eyes, ears and mouth had a limited number of studies and more work needs to be performed to analyze these present theories and/or derivation of new guidelines if the existing fails. Along with this, focus should also be given on analyzing the facial changes from childhood to old age which would provide more insight in the facial reconstruction.

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Conflicts of interest

None.

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