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Development of Craniofacial Superimposition: A Review

Desarrollo de la Superposición Craneofacial: Una Revisión

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SUMMARY: Craniofacial superimposition is a method for identifying individuals by using secondary data in order to identify a target group of persons before a DNA process can be used, or to identify an individual instead of using primary data in cases where DNA, fingerprint or dental records are not found. Craniofacial superimposition has continued to evolve, with various techniques, including computer-assisted and photography techniques, to help the operation be more convenient, faster and reliable. The knowledge of forensic anthropology is applied, with a comparison between anatomical landmarks. The study of developments in craniofacial superimposition using computer-assistance has yielded satisfactory results.

KEY WORDS: Craniofacial superimposition; Skull; Forensic anthropology.

INTRODUCTION

In the legal process regarding management of the deceased, one starts by confirming that the found body has been proven to be a human corpse. It is crucial that the individual's identity be proven, which can be done using various methods, and which can be divided into primary data and secondary data. Primary data can be found on corpses that are in normal condition and have a definite verifiable history. In cases of extreme decomposition where only bones remain, secondary data plays an important role. Secondary data can also be supplied in the form of craniofacial superimposition and facial reconstruction to prove personal identity, with confirmation by genetic testing.

Craniofacial photographic superimposition involves superimposing a skull's image over an antemortem photograph. The theory used to compare the features of the skull to a facial image originated in 1867 by comparing skulls to death masks. The method of craniofacial superimposition was applied for the first time by comparing physical features in order to prove the identity of a skull purported to belong to Oliver Cromwell. Craniofacial superimposition was used to first murdered case to solve 'The Ruxton Case'.

Craniofacial superimposition is currently used to confirm identity in many countries, such as Malaysia, Japan, South Africa and England, for considering various evidence to confirm the death and the identity of a person. Before 1994, image superimposition was difficult and complicated, despite the introduction of video superimposition to help the operation work more easily. Since then, there has been some initiative in the application of computer-assisted craniofacial superimposition by Austin-Smith & Maples (1994).

Copious research has concentrated on improving the reliability and efficiency of craniofacial superimposition using computer-assisted and anatomical knowledge such as Ricci *et al*. (2006), Birngruber *et al*. (2010) and The New Methodologies and Protocols of Forensic Identification by Craniofacial Superimposition (MEPROCS) project. Photographic craniofacial superimposition requires accurate setting of the skull's position relative to the facial image, with adjustments before superimposition. The disadvantages and weaknesses of photographic and/or video superimposition due to the limitations, that the skull cannot be rotated and the stages of alignment and adjustment before

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overlapping are manual, which can cause the results to be inaccurate. These problems were later resolved by applying 3-D images using a 3-D scan or laser scanner.

Anatomical Landmarks of the Skull and Face Related to Craniofacial Superimposition

In each person, there is often a unique structure and position of the various organs on the face that are clearly different.

Craniofacial superimposition and anatomical landmark relationships were used to compare craniometric landmarks and facial landmarks, with corresponding landmarks overlaid, as follows:

Craniometric Landmarks

A bony point in any area of the skull is used for measuring or alignment of the skull. It is also used to define overlapping points in craniofacial superimposition (Table I and Fig. 1A).

Facial Landmarks

A facial point is a point located in any part of the head, while covered by the muscles and skin, which is used in the measuring or alignment of the skull. It is also used to define overlapping points in craniofacial superimposition (Table II and Fig. 1B).

Table I. Craniometric landmarks and definition.

Landmarks	Definition
Glabella (g)	The point between the supraorbital ridges.
Gnathion (gn)	A constructed point midway between the most anterior and most inferior points on the chin.
Gonion (go)	The lateral point at the mandibular angle.
Nasion (n)	The midpoint of the suture between the frontal and the two nasal bones.
Pogonion (pog)	The anterior point in the midline on the mental protuberance.
Zygion (zy)	The lateral point on the zygomatic arch.
Dacryon (d)	The point of junction of sutures between the frontal, maxillary, and lacrimal bones.
Frontomalare temporale (fmt)	The point where the frontozygomatic suture crosses the temporal line.
Nasospinale (ns)	The point between the lower margins of the right and left nasal apertures, intersected by the midsagittal plane.
Prosthion (pr)	The apex of the alveolus in the midline between the maxillary central incisors.

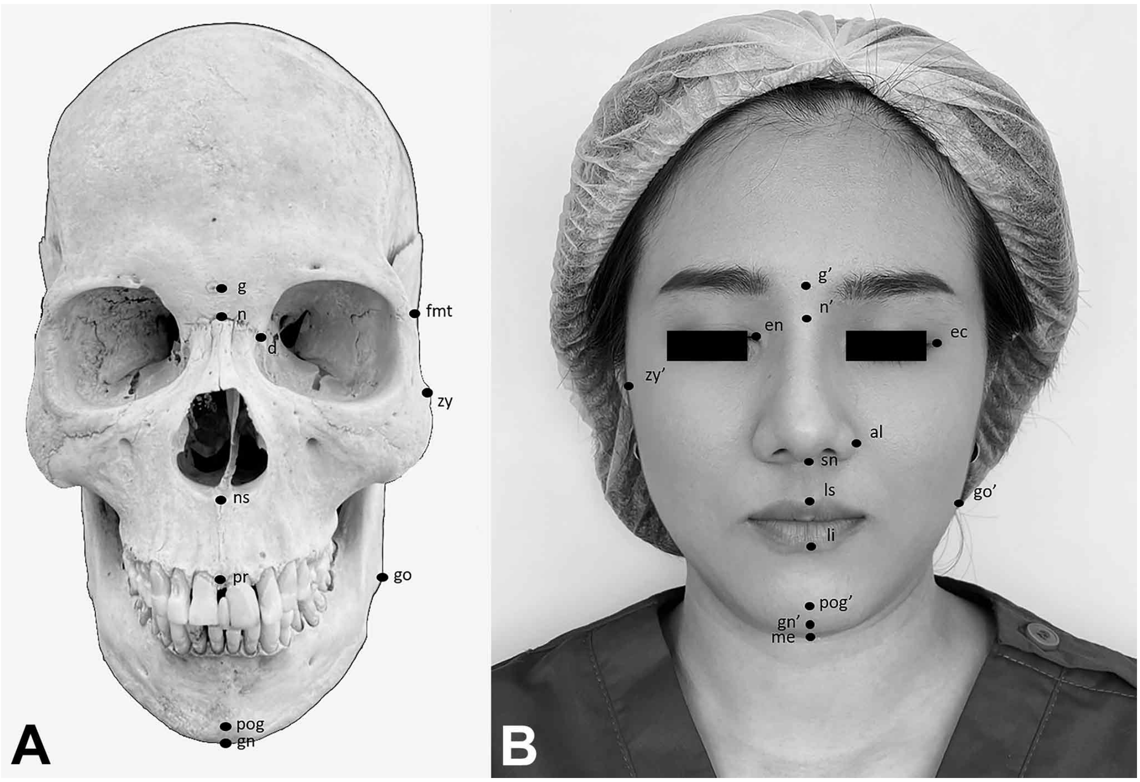

Fig. 1. A) Craniometric landmarks for craniofacial superimposition. B) Facial landmarks for craniofacial superimposition.

Table II. Facial landmarks and definition.

Landmarks	Definition
Glabella (g’)	The point between the eyebrows.
Gnathion (gn’)	The point on the chin midway between the Pogonion (pog’) and Menton (Me).
Gonion (go’)	The lateral point at the mandibular angle.
Nasion (n’)	In the midline, the point of maximum concavity between the nose and forehead.
Pogonion (pog’)	The anterior point of the chin.
Zygion (zy’)	The lateral point of the cheeks (zygomaticomalar) region.
Alare (al)	The lateral point on the alar contour.
Ectocanthion (ec)	The point at the outer commissure of the palpebral fissure.
Endocanthion (en)	The point at the inner commissure of the palpebral fissure.
Menton (me)	The lowest point on the midsagittal plane of the chin.
Labiale inferius (li)	The midpoint on the vermilion line of the lower lip.
Labiale superius (ls)	The midpoint on the vermilion line of the upper lip.
Subnasale (sn)	The midpoint of the lower border of the nasal septum where it meets the upper lip.
Tragion (t)	Point in the notch just above the tragus of the ear.

A Brief History of Craniofacial Superimposition

In the history of craniofacial superimposition from past, methods have been developed by various researchers. Craniofacial photographic superimposition involves superimposing a skull image over an antemortem photograph. Welcker (1867), who compared skull measurements to death masks, originally used the theory to compare the features of the skull to the face in 1867.

Pearson & Morant (1934) applied the method for the first time in order to prove that it was actually Oliver Cromwell's skull, by comparing a photograph of a prisoner with a photograph of the skull. Therefore, tracings were made between photographic portraits and the photograph of the skull until they finally overlapped.

Glaister & Brash (1937) used the technique of craniofacial superimposition to solve a real-life case known as ‘The Ruxton Case’. In this case, craniofacial superimposition used a life-sized enlargement of an antemortem photograph and full scale was used. For comparison, the nasion and prosthion were used as reference points, and salient features of each photograph were outlined and then compared using superimposition.

Gordon & Drennan (1948) applied a machine-made projected drawing of a reconstructed skull to overlap with a life-size photograph of the victim, which was made to confirm the person's identity by comparing the bone fragment. A mechanical projection of part of the skull was applied and overlaid on the outline of the head, and that showed a significant match of transverse dimensions of the head.

Cocks (1971) introduced craniofacial superimposition to identify a person with an incomplete skull from a murder case by using knowledge of anatomical landmarks to construct a pattern of triangles, and then using for comparison.

Since 1971, United States Armed Forces Central Identification Laboratory in Hawaii has been used craniofacial superimposition system by Furue. Furue developed the theory of craniofacial superimposition, mainly by creating a superimposition imaging system. The system uses the distance between the subject and camera to make more efficient use of craniofacial superimposition (Taylor & Brown, 1998).

Helmer & Gruner (1977a,b) in Germany, and Brown *et al*. (1978) from Australia, initiated video superimposition to overcome some of the disadvantages of photographic superimposition. This technique has shown greater accuracy to correspond with the position of the face in the photograph, and consists of a real-time craniofacial superimposition that uses the rotation of the skull.

Klonaris & Furue (1980) applied the superimposition method to compare maxillary fragments with dental radiographs. The antemortem radiograph was enlarged to be a reverse-contrast transparent radiograph. The superimposition method was then used for a comparison process using transparency images that were placed over a photograph of the maxillary fragment.

Thomas *et al*. (1987) superimposed a projected image for printing comparisons by enlarging the image from a passport to the actual size and adjusting it to a vertical surface. A transparent photograph of the skull was projected onto the enlarged passport image in a similar orientation.

Nickerson *et al*. (1991) instigated comparison in which the size and shape of the skull was also added. A complex digital method was applied by computing selected data from four landmarks: the glabella, nasion, subnasale and ectocanthion. Computer software was then used to alignment of three-dimensional skull images to two-dimensional facial images in the re-scaling processes for matching.

Ubelaker & Scammell (1992) solved a case by using computer-assisted photographic craniofacial superimposition, which resulted in a positive identification. Before the operation, the skull was screened, based on the missing woman's personal data.

Austin-Smith & Maples (1994) proposed a way to make craniofacial superimposition more reliable through technology using the application of computer software, but which still adheres to the principles of superimposition.

Craniofacial Photographic Superimposition

During the process of craniofacial photographic superimposition using the overlapping of skull and facial images. The first step is to prepare the skull in order to obtain a high-quality cranial image that can be assessed with clarity, by applying a knowledge of photography in order to set the proper lens distance from the skull and the appropriate amount of light. This affects the quality of the photograph.

In the second step, the angle and plane of the skull must be consistent with the original face image. In order to obtain a skull image with the closest perspective and size for comparison, adequate knowledge and techniques in both photo manipulation and anthropology need to be used in order to enhance the placement of the skull and ensure that it is more complete.

The final step should produce a photograph of a skull that compares with the facial image. It would take a specialist, who could make the necessary decisions regarding the process, without any technology to assist in that decision. In the landmark comparison of the face and skull made by McKenna *et al*. (1984), eye orbits, the nasal aperture and ears openings were used.

Craniofacial Video Superimposition

Video superimposition was developed by Brown *et al*. (1978), who suggested that an operational system should consist of two video cameras in combination with a TV display, along with integration with electronics. One camera will focus on a live photo and another camera will focus on the skull. The overlay is then displayed on a screen mounted in a video superimposition system.

The craniofacial video superimposition method has advantages over superimposition that uses photographs as in the past, because it can reduce various problems within the imaging system. Working steps are similar to photographic superimposition, which requires anthropological knowledge to improve the performance of the images that are to be overlapped in the video superimposition. As well, a mechanism to fade the image without loss of image quality has also been added.

In the process of deciding on the desired overlapping result of skulls and photographs using the video superimposition method, this remains the domain of experts with knowledge of anthropology in identifying craniofacial superimposition.

Computer-assisted Craniofacial Superimposition

In the continuous development of technology regarding craniofacial superimposition for identification, a computer application has been applied to the operation. This can be divided into 3 types: Computer-assisted photographic craniofacial superimposition, Computer-assisted video craniofacial superimposition, and Computer-assisted 3D approaches to craniofacial superimposition.

Computer-assisted Photographic Craniofacial Superimposition

Bilge *et al*. (2003): Craniofacial superimposition was used for identification with other authentication methods. In this study, it was done using Corel Draw and Adobe Photoshop, with the face and skull resized to match, while using a semi-transparent technique. With a photo of the skull and face overlaid, the researchers then tested it using skull geometry such as the vertical central bilatero zygomatic, biforamen infraorbitale, nasal axis and bimaxillary canine ridges. This method has shown good results and resulted in positive identifications.

Ghosh & Sinha (2005): Craniofacial superimposition was used for identification of individuals using SPAN and ESPAN programs. Craniofacial superimposition was performed using extended symmetry perceiving adaptive neuronet (ESPAN), and perceiving adaptive neuronet symmetry (SPAN). They performed the superimposition of face and skull images, and then compared them in the frontal view to gain symmetry using an artificial neural network method. The results show that

SPAN and ESPAN integration showed matching results, with continuity of the picture as well.

Al-Amad *et al*. (2006): Craniofacial superimposition was used to identify three individual cases. This was performed in Adobe Photoshop using a method of adjusting the skull and facial dimensions to a similar size and angle. Then they were overlapped in semi-transparent images and the operator made a decision. The results gave positive identification in all three cases. However, the researcher opined that if distinctive tooth features or dental records were used in the craniofacial superimposition, it could greatly increase reliability and provide help in making a good decision.

Ricci *et al*. (2006): This paper studied craniofacial superimposition of faces and X-ray images by using anatomical landmarks for overlay analysis. The results indicate that, from the sum of distances, facial landmarks and bony landmarks provide the least valuable data. This experiment showed that if the owner of the face and skull images are the same owner, the sum of distances will be at its lowest number.

Srisinghasongkram *et al*. (2019): Craniofacial superimposition was comparing edge detection methods and calculating the overlapping points with mathematical methods. The results were compared between the skull of the deceased and a random skull. As a result, it was determined that if the skull and facial image were of the same person there would be more overlaps, as the overlaps would show up at 1,000 or more points.

Computer-assisted Video Craniofacial Superimposition

Bajnoczky & Kiralyfalvi (1995): Video superimposition was developed through computing with a computational matrix method that compares the overlapping points of individual anatomical landmarks. This research is used for false positive identifications.

Yoshino *et al*. (1995): The cases of video superimposition were made for comparison by the experts, which resulted in 35 of the 52 cases in the form of a positive identification. However, this research study had a limitation in the photography, in that only one view could be used in some people. This made it difficult to overlap and compare some images.

Yoshino *et al*. (1997): A mathematical process was applied to craniofacial superimposition in the form of video superimposition by comparing the edges of the images using a Polynomial function on the curvature of a skull with thin skin. The comparison method used 10 points on the curvature and a sine-cosine spectra graph for harmonics. This method assumes that they are the same person, as the points on the curve and the height of the graph are approximately the same, which are the results that showed up in positive identifications.

Birngruber *et al*. (2010): A video superimposition was done with Photoshop and Afloat, where the skull floats over the facial image in a semi-transparent image. The expert then decides, based on the image overlay. This method is used for positive identification operations.

Computer-assisted 3D Approaches to Craniofacial Superimposition

Shahrom *et al*. (1996): A laser scanner was used to create a three-dimensional image of the skull, but the resulting image still had a sharpness problem. This research gives an incentive to use 3D imaging to make craniofacial superimposition in order to reduce various problems with the placement of the skull and other various complications.

Santamaría *et al*. (2007): Image registration was applied in this study with Scatter search (SS) for 3-D pair-wise range IR to the skull. By creating a 3-D skull image with a laser scanner for reconstruction of an incomplete skull, it solves alignment problems that are difficult to overcome craniofacial superimposition that uses photographic and video means.

Ibáñez *et al*. (2008): Image registration was used for craniofacial superimposition by using a real code genetic algorithm that uses fuzzy sets with anatomical landmarks. In this work, 3-D skull images were aligned into facial photographs to solve the complexities of traditional craniofacial superimposition. This research study was used in both positive cases and negative cases. The results can be used as a guideline for the development of positive identification using craniofacial superimposition.

Santamaría *et al*. (2009): Image registration was applied in craniofacial superimposition by using the Covariance Matrix Adaptation Evolution Strategy (CMA-ES). This approach uses fuzzy sets and anatomical landmarks in the craniofacial superimposition. This research study was performed in five female missing person cases. The satisfactory results could serve as a guide for the development of positive identification.

Ballerini *et al*. (2009):Image registration was applied to craniofacial superimposition by using a real code genetic algorithm (RCGA) and fuzzy sets combined with important anatomical landmarks to perform craniofacial superimposition. This approach compares with the binary code genetic algorithm (BCGA). As a result, the BCGA is more effective, but difficult due to its complexity. The RCGA should be developed as a guideline for the development of positive identification.

Ibáñez *et al*. (2009): A comparison of alignment efficiency and image overlapping was conducted with anatomical landmarks using image registration with three approaches: BCGA, RCGA and CMA-ES in the form of positive identification with different postures. The results revealed Fitness analysis, MSE, MAX and expert comparisons. The CMA-ES produced the best results for visualization of the complex.

Ibáñez *et al*. (2011): The CMA-ES was developed and conducted in three case studies with three postures to compare efficacy as measured by Area-deviation-error. The appropriate landmarks that differ in each case were defined, including Crisp, weighted and fuzzy landmarks. This research shows that the fuzzy-evolutionary-based had the smallest value in the frontal posture. The results showed that the Area-deviation-error of automatic fuzzy-evolutionary-based is still much less than with other methods.

Ibáñez *et al*. (2012a): Comparisons were made between the SS and the CMA-ES in real-world identification cases in order to test whether the SS could be processed faster and more robustly solve craniofacial superimposition problems. It demonstrated that SS has accurate and robust performance.

Ibáñez *et al*. (2012b): A Cooperative co-evolutionary genetic algorithm (CCGA) was applied to make craniofacial superimposition. Crisp fitness function and fuzzy sets were used to solve problems from previous research. This enables one to be more accurate in the alignment and overlapping of anatomical landmarks, as well as make it possible to process other populations. This research was comparing the efficiency of the RCGA, CMA-ES and CCGA from Area-deviation-error values. The results showed that the CCGA was the best and the least time consuming.

Campomanes-Alvarez *et al*. (2015): Craniofacial superimposition was developed by analyzing the consistency between bony and facial chin outlines. This research used a Spatial relation along with a Shape similarity approach to compare the curvature and shape of the chin. The results showed that these approaches were effective in females, but in males there was still a lot of discrepancy.

Tan *et al*. (2016): Research was using a 3-D skull image overlaid with a 2-D facial image. The researchers applied artificial intelligence with global optimization technology for image overlays by using the Quasi-Newton method in which pivot points are defined for the image overlay. The experimental results were obtained between 10 pivot points and 60 pivot points, and showed that more pivot points would better andmore accurate for overlaying the image. It was also shown that the craniofacial superimposition efficacy was more successful in males.

Campomanes-Alvarez *et al*. (2017): This experiment was conducted to determine if the approaches given for Fuzzy set mean error are most suitable to be used in craniofacial superimposition. To determine the distance between facial landmarks and cranial landmarks, they tested nine cases with frontal and lateral perspectives. This experiment demonstrated that Weighted Mean approaches presented the lowest Average Mean error.

Tan *et al*. (2020): This research was a study on 3-D facial reconstruction and 3-D superimposition. In this work, skulls were aligned with SVD or quaternions. Then, an identity comparison was done using Curve registration: an AC B-spline approach to compare the curve characteristics of the jaw line and mandible. The results showed that AC B-spline approaches are more robust, showing the highest accuracy index of 0.803.

Yuvaraj *et al*. (2020): An automatic skull-face overlay and mandible articulation using an AIRS-Genetic algorithm was performed using the Artificial Immune Recognition System (AIRS) model to calculate distances and obtain crisp points. The landmarks on the skull could be identified better. The results showed that overlays with the AIRS model were more satisfactory than a PCA-based overlay and GA-based overlay.

CONCLUSION

The development of craniofacial superimposition has applied the principles of human anatomy and computer engineering to make the analysis more scientific. The goal of these developments is to allow this work to be done more easily and more reliably, in a way that can be explained by mathematical principles.

The trend of the development of computer-assisted craniofacial superimposition shows that the limitations and abilities are different in each model. Computer-assisted photographic craniofacial superimposition is a simple method, exhibiting good image quality for comparing, and the costs of operation are low. The photographic method has inherent difficulty for setting the skull position and capturing the proper perspective in order to be consistent with the facial image. Computer-assisted video craniofacial superimposition is a more convenient operation that can store information from multiple perspectives, but video still has to have proper placement of the skull. This includes the limitation of video files with low quality when they are used for comparing; consequently, it is not popular and has not been further developed. When 3-D visualization technology was introduced to create 3-D skulls. Computer-assisted 3-D approaches to craniofacial superimposition is easy in its operation, and more reliable because of its computer engineering principles, anatomical landmarks have also been included as a key part of its development. However, this method is expensive and always has the limitation of machine resources.

In conclusion, it has been shown that craniofacial superimposition is useful for identifying individuals. Each country should develop a craniofacial superimposition protocol that is consistent and suitable for the working style and resource limitations in their real-world case. Therefore, the author plans to develop craniofacial superimposition in Thailand by applying an artificial intelligence system to superimpose the skull and facial images that includes computer processing. This will result in consistent numerical sequences and promote decision making.

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SRISINGHASONGKRAM, J.; ARUNORAT, J.; SINGSUWAN, P. & MAHAKKANUKRAUH, P. Desarrollo de la superposición craneofacial: una revisión. *Int. J. Morphol., 40(6)*:1552-1559, 2022.

RESUMEN: La superposición craneofacial es un método para identificar individuos mediante el uso de datos secundarios, se utiliza para identificar un grupo objetivo de personas, antes de que se pueda utilizar un proceso de ADN, o para identificar a un individuo en lugar de utilizar datos primarios en los casos en que no se cuenta con registros de ADN, huellas dactilares o dentales. La superposición craneofacial ha seguido evolucionando, con diversas técnicas, incluidas las técnicas fotográficas y asistidas por computador, para ayudar a que la operación sea más conveniente, rápida y confiable. Se aplica el conocimiento de la antropología forense, con una comparación entre hitos anatómicos. El estudio de la evolución de la superposición craneofacial con asistencia informática ha arrojado resultados satisfactorios.

PALABRAS CLAVE: Superposición craneofacial; Cráneo; Antropología Forense.

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