Jurnal Sains Kesihatan Malaysia 23 (1) 2025: 81-89
DOI : http://dx.doi.org/10.17576/JSKM-2025-2301-01

From Skulls to Faces: Unveiling the Secrets of Identity with 3D Facial Reconstruction

(Daripada Rangka ke Wajah: Menyingkap Rahsia Identiti dengan Rekonstruksi Wajah 3D)

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Abstract

3D facial reconstruction is a technique in forensic science used to create images of unidentified individuals based on skeletal remains, aiding investigations and forming part of forensic anthropology. This technique utilises computer software and anatomical data to create a digital model depicting a likeness of the individual's face. By employing this technology, forensic investigators can obtain valuable facial characteristics that aid in identification, such as ethnicity, age, and potential distinguishing features. This article will further discuss the development of 2D to 3D facial reconstruction and its working principles. Additionally, the impact of cosmetic surgery on the accuracy of reconstruction will also be explored. Lastly, the challenges and limitations of 3D facial reconstruction will be reviewed.

Keywords: 3D facial reconstruction; forensic; software; cosmetic surgery; accuracy; challenges

Abstrak

Rekonstruksi wajah 3D adalah teknik yang digunakan dalam sains forensik untuk membuat imej individu yang tidak dikenali berdasarkan tinggalan rangka. Ia memainkan peranan penting dalam penyiasatan forensik dan antropologi forensik. Teknik ini menggunakan perisian komputer dan data anatomi untuk membuat model digital yang menggambarkan wajah asal seseorang. Dengan menggunakan teknologi ini, penyiasat forensik dapat memperoleh petunjuk visual yang penting untuk mengenal pasti individu yang terlibat dalam kes jenayah atau bencana. Dalam artikel ini, perkembangan rekonstruksi wajah 2D kepada 3D dan prinsip akan dibincangkan. Selain itu, kesan pembedahan kosmetik yang melibatkan pengubahsuaian badan manusia, terutamanya wajah, terhadap ketepatan rekonstruksi juga akan diteroka. Akhirnya, cabaran dan batas teknik ini juga akan diulas.

Kata kunci: Rekonstruksi wajah 3D; sains forensik; perisian; pembedahan kosmetik; ketepatan; cabaran

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INTRODUCTION

Human faces can be reconstructed manually or in a virtual environment (Baldasso et al. 2021). 3D face reconstruction (3DFR) is defined as the process by which an individual's facial image is created using anatomical data and computer technology to generate a digital model depicting a potentially original face based on skeletal remains or facial bone structure. This technique evolves from 2D images to 3D models, which can help overcome challenges associated with recognition tasks. The development of 3D face reconstruction is particularly beneficial in addressing forensic anthropology issues, especially in cases involving mutilated, decomposed, or skeletonised remains (Sangkhro et al. 2018). However, while facial reconstruction can assist in recreating a victim's appearance from the skull, the results must also be corroborated by DNA analysis, dental records, or other valid identification methods (Kundu et al. 2021). In alignment with the study by Baldasso et al. (2021), which provides a comprehensive overview of the application of 3D forensic facial approximation in real-world cases, the authors discuss the advantages and limitations of both manual and virtual methods, emphasizing the potential for incorporating DNA analysis into the reconstruction process. They acknowledge the historical dominance of manual methods (e.g., clay modeling) in forensic facial reconstruction but highlight advancements in virtual techniques that offer greater accuracy and efficiency. Baldasso et al. (2021) suggest that DNA analysis can yield valuable information about an individual's ancestry, which can inform the reconstruction process by suggesting likely facial features. This integration of genetic data enhances the realism and accuracy of reconstructed faces. The article by La Cava et al. (2023) discusses how 3DFR can effectively address challenges in CCTV surveillance, particularly in scenarios involving non-frontal views, unpredictable environments, and uncooperative subjects. Traditional 2D facial recognition methods often struggle with variations in pose, lighting, and distance, leading to inaccurate identifications. However, 3DFR algorithms are designed to reconstruct three-dimensional models of faces from 2D images captured under varying conditions. This is achieved through techniques such as statistical model fitting and deep learning, which incorporate prior knowledge about facial geometry and texture. For instance, using multiple 3DFR algorithms allows for the fusion of complementary information, enhancing recognition capabilities even when images are taken from unconventional angles or in poor lighting. Additionally, these algorithms can adapt to different acquisition settings by utilising data from various distances and camera types, thereby improving robustness against challenges posed by uncooperative subjects or dynamic environments. Overall, integrating 3DFR into surveillance systems facilitates more reliable identity verification by creating detailed 3D facial models that can be matched against reference images such as mugshots or ID photos potentially leading forensic investigations to fruitful conclusions (La Cava et al. 2023).

Biometrics, as defined by the Oxford Dictionary, refers to the automated recognition of individuals based on unique physical characteristics, typically for security purposes. This includes methods like fingerprinting, facial recognition, and iris recognition. While closely linked to individual identification, 3DFR faces several challenges related to performance assessment, forensic analysis, and comprehensibility evaluation. To overcome these limitations, researchers have explored various approaches, including model-based and view-based methods (La Cava et al. 2023). 3DFR involves precisely determining facial landmarks and tissue depth to enable the creation of detailed facial models. A comprehensive database is essential for mapping individual faces and improving the accuracy of 3DFR technology.

While 3DFR is widely used today, this technique still has limitations and challenges. For example, plastic surgeries such as facial feminisation surgeries (FFS) may affect the accuracy of 3DFR results due to changes in landmark positions (Schall et al. 2020). The accuracy of 3DFR must consider various factors.

BACKGROUND

The face is crucial for individual identification; a facial photograph is taken after a body that cannot be recognised is discovered. In cases involving unidentified skulls, the soft tissue of the skull can be recreated or reconstructed using forensic face recognition techniques. 3D Face Reconstruction (3DFR) plays an important role in forensic science and anthropology.

In 1895, a German scientist named Wilhelm His took the first steps in facial reconstruction technology. At that time, scientists like Johann Sebastian Bach and Welcker relied on actual bodies to understand how much soft tissue covered the skull. They would carefully poke specific points on the faces of deceased individuals using a thin needle instead of a sharp blade. This method, known as the "Welcker Facial Reconstruction Technique," helped them measure the average thickness of soft tissue in different areas of the face. This early approach paved the way for more advanced techniques used today (Manna et al. 2023).

In 1946, anthropologist Wilton Maria Krogmann made a significant impact on the field of facial reconstruction with his introduction of five key principles. These principles focused on analysing the relationship between the eyeball and its socket (orbit), the specific shape of the nose tip, the position of the ears, the width of the mouth, and the length of the ears. By incorporating these anatomical considerations, Krogmann's work revolutionized techniques for reconstructing facial soft tissue based on skeletal remains (Manna et al. 2023).

The evolution of facial recognition technology has significantly impacted forensic science, transitioning from early 2D methods to advanced 3D systems. Initially, facial recognition relied on anthropometric techniques in the late 19th century, where facial features were measured and catalogued for identification purposes. The introduction of photographic methods standardised image capture; however, these 2D systems faced limitations under varying conditions, such as non-frontal views and poor lighting (La Cava et al. 2023). By the 1990s, algorithms like Eigenfaces emerged, utilising statistical methods to improve recognition accuracy in controlled environments. Nevertheless, challenges persisted in real-world applications due to factors like pose variability and occlusions. The advent of deep learning and convolutional neural networks in the early 2010s marked a turning point, enhancing the capabilities of 2D recognition systems. Recently, the development of 3D facial recognition has addressed many of these challenges by creating detailed three-dimensional models that are less affected by angle and lighting variations, thereby improving identification accuracy in forensic contexts (Gietzen et al. 2019). This progression underscores a shift toward more robust and reliable facial recognition technologies that are essential for modern forensic investigations.

With advancements in 3D technology, rapid, efficient, and cost-effective computerised facial reconstruction software has been developed. This software mimics manual methods of facial reconstruction. Computerised reconstruction software was first studied at London College University in the 1980s, where a cranial reconstruction procedure was carried out using a laser-like scanner and video camera. The data collected were used to build a library of living subject facial surfaces (Gupta et al. 2015).

2D AND 3D FACIAL RECONSTRUCTION

Facial reconstruction techniques can be categorised into 2D and 3D methods. 2D facial reconstruction involves creating frontal and lateral profile views of an individual based on visual or sketched images. Mugshot photographs can provide valuable information for this process. Researchers have attempted to develop 3D reconstructions from 2D mugshot images, primarily focusing on facial shape reconstruction and limited rotation angles of the image typically not exceeding seventy degrees. Additionally, these techniques often rely on traditional baseline face-matching algorithms (Liang et al. 2020).

There are two main types of facial identification used during investigations: circumstantial identification and positive identification. Circumstantial identification occurs when an individual's characteristics, such as age, sex, ancestry, and stature, match those of unidentified skeletal remains. This method helps narrow down potential identities but is not conclusive on its own. In contrast, positive identification involves matching distinctive biological traits—such as unique dental features or previous fractures—with skeletal remains. For positive identification, the skeletal remains must also be confirmed against valid forms of identification, like dental records or DNA (Singh 2022).

Another method is superimposition, though it remains infrequently used, primarily because it requires prior knowledge of the identity specifically related to the skeletal remains. Superimposition involves carefully overlaying known antemortem photographs onto X-ray images of skulls, enabling investigators to assess the structural alignment of features. While not a definitive method of identification, superimposition is a valuable tool in forensic investigations (Singh 2022). Table 1 presents key differences between 2D and 3D facial reconstruction techniques.

While superimposition helps verify identities by overlaying known photographs on X-ray images of skulls, it is not as definitive as more advanced methods. These sophisticated approaches use anatomical and morphometric features to create realistic facial representations. The process often involves two main methods: automated techniques and modeling (Kundu et al. 2021). Automated methods rely on data such as anthropometric measurements, skeletal characteristics, and pre-existing facial templates stored in databases. Software analyses this data to generate a possible facial structure that matches the specific skull. In contrast, modeling methods use 3D animation software to virtually sculpt a face onto the digital skull model, allowing for greater customization and detail based on the expertise of forensic artists.

Forensic identification methods are generally categorised into three types based on the imagery used: 2D-based, quasi-3D, and 3D-based techniques (Zeng et al. 2020). The 2D-based methods use only two-dimensional images, like photographs, to extract identifying features. Quasi-3D methods enhance these 2D images by adding some depth and texture, creating images that lie between 2D and 3D. 3D-based methods, on the other hand, capture full three-dimensional details of an object's shape and size. Laser scanning, a non-invasive and accurate 3D technique, is commonly used in forensics. There are two types of laser scanning methods: time-of-flight and phase-based. Time-of-flight measures how long it takes a laser pulse to travel to an object and back, while phase-based scanning analyses wave shifts after reflection, offering higher precision but at a slower pace. Another useful technique, structured light scanning, projects patterns of light onto objects and records the distortions to reconstruct shapes. Additionally, stereo photogrammetry uses multiple images taken from slightly different angles to capture depth, mimicking how human vision perceives depth. This technique is versatile and can integrate a range of imaging technologies (Zeng et al. 2020).

Researchers are constantly developing new methods for 3DFR. One approach involves using 3D Morphable Face Models (3DMMs), which are digital templates of human faces that can be manipulated to create likenesses based on available information. Software like FaceGen allows for generating realistic 3D faces; however, earlier versions lacked details such as expressions, hair, and skin texture. Researchers are working to overcome these limitations to create increasingly accurate and detailed facial reconstructions (Lium et al. 2021).

Table 1 Key Differences between 2D and 3D Facial Reconstruction Techniques

Key differences	2D	3D
Dimensionality	These methods involve creating flat representations of the face, such as sketches or photographs. They rely on frontal and lateral views to reconstruct facial features, often using antemortem images and soft tissue depth estimates (Liang et al. 2020). For example, superimposition techniques overlay known photographs onto X-rays of skulls to assess matches (Singh, 2022)	In contrast, 3D facial reconstruction creates volumetric models that represent the face in three dimensions. This approach captures more complex facial features and contours, allowing for a more accurate representation of the individual's appearance (Gietzen et al. 2019)
Methodology	These methods often require manual artistry and are limited by the information available in two dimensions. They may incorporate traditional algorithms for matching facial features but struggle with variations in pose and lighting (La Cava et al. 2023). The accuracy of these methods can be compromised by occlusions and the lack of depth information	3D reconstruction utilizes advanced technologies such as multi-view imaging, laser scanning, or photogrammetry to gather data from multiple angles. This allows for a more comprehensive capture of facial morphology, including depth and texture. Recent advancements include automated systems that enhance accuracy by reducing human error and subjectivity (Gupta et al. 2015)
Applications	Primarily used in cases where quick visual approximations are needed, such as in initial identification efforts. They are often less reliable for forensic purposes due to their inherent limitations (Singh 2022)	These methods are increasingly favoured in forensic science for their ability to create detailed reconstructions that can be used in legal settings. They allow for repeated modifications and can produce multiple views of the same face efficiently (Manna et al. 2023). The integration of computerized systems has made these techniques more accessible and practical for real-world applications
Accuracy and details	Generally provide less accurate representations due to their reliance on flat images, which can lead to misinterpretations of facial features (Anas et al. 2019)	Offer higher accuracy by capturing the full geometry of the face, including subtle variations in contours and textures. Studies have shown that measurements taken using 3D methods are significantly more reliable than those obtained from 2D techniques (Anas et al. 2019)

PRINCIPLES

In forensic science, facial recognition techniques are crucial for identifying unknown individuals from skeletal remains. These techniques can be categorised into 2D and 3D methods, each with distinct principles and applications. 2D facial recognition involves creating frontal and lateral views of a face based on visual or sketched images, often utilising mugshot photographs for reference. This method relies on traditional algorithms that match facial features but is limited by its inability to capture depth and variations in pose or lighting. For instance, superimposition techniques overlay known photographs onto X-rays of skulls to assess matches, although this method is not definitive and primarily serves as a supplementary tool in forensic investigations (Singh 2022). The reliance on 2D images can lead to inaccuracies due to occlusions and the lack of depth information (Liang et al. 2020).

In contrast, 3D facial recognition (3DFR) provides a more robust framework by reconstructing three-dimensional models from multiple 2D images or video data. This approach captures complex facial features and contours, allowing for more accurate representations of an individual's appearance. 3DFR algorithms use various strategies such as statistical model fitting, photometric stereo, or deep learning to enhance recognition capabilities, particularly in unconstrained environments where subjects may not present their faces frontally (Gietzen et al. 2019). The integration of 3D technology has improved the accuracy of identifications by accommodating variations in angle and lighting, making it particularly useful in forensic contexts where traditional methods may fail (La Cava et al. 2023).

3DFR can be achieved through two main methods: Traditional manual sculpting and modern computer-based techniques. Manual methods involve painstakingly sculpting facial features from clay or wax onto a replica skull, relying on demographic data and artistic skill (Sangkhro et al. 2018). However, this is a time-consuming process and can't directly determine details from the skull alone. In contrast, computer-based 3DFR utilises a laser scanner or camera to capture a digital skull image (Miranda et al. 2018). The software then analyses facial template databases, average tissue depth information, and specific population data to create a digital reconstruction. While faster and working directly with the skull, this method might have limitations in accurately reflecting the intricate relationship between soft tissues and the underlying skull structure (Sangkhro et al. 2018).

3DMM was first employed by Han and Jain in the 3DFR method. It is a statistical object model separating shape from appearance variation. The 3D face is reconstructed by shaping from the frontal face image, refining the face based on landmarks, and lastly mapping the texture from the frontal face image to reconstruct the 3D face shape (Liang et al. 2020). Deep learning-based reconstruction involves 3D generative adversarial networks (3DGANs) and 3D convolutional neural networks (3DCNN), and it is time-consuming. 3DMM is a powerful tool for creating realistic and customisable 3D faces. They work by combining a large dataset of real faces into a single model that can be manipulated to create new, unique faces. This is done by adjusting the model's parameters, such as shape and expression. 3DMMs have become increasingly popular in recent years due to their ability to generate high-quality, photorealistic faces for various applications, including computer graphics, facial recognition, and virtual reality (Sharma & Kumar 2022). The article by Carew et al. (2019) investigates the accuracy of 3D modelling and 3D printing in forensic anthropology. They focus on the reconstruction of evidence, specifically facial features. The authors found that 3D modelling and 3D printing can be effective tools in creating accurate and detailed facial reconstructions. However, the accuracy of the results depends on various factors, such as the quality of the input data and the expertise of the forensic anthropologist. Overall, the study highlights the potential of 3D technology in assisting forensic investigations (Carew et al. 2019).

Tissue depth measurement is used to study the relationship between soft facial tissues and the underlying skull (Sangkhro et al. 2018). The article by Gietzen et al. (2019) introduces an innovative method for automatic forensic facial reconstruction that leverages dense statistics of soft tissue thickness (FSTT), significantly reducing reliance on manual artistry and anthropological input. This automated process enhances the accuracy and efficiency of generating facial approximations from skeletal remains, validated against existing datasets to ensure realistic outcomes. The methodology begins with a 3D model of the skull, which is standardised through a parametric skull model. It then utilizes statistical data on soft tissue thickness from a diverse population to estimate facial features based on the underlying skull structure. The final output is a digital 3D facial reconstruction, providing a reliable representation of the individual before death, thus improving the applicability of facial reconstructions in forensic investigations where time and accuracy are paramount (Gietzen et al. 2019).

Facial soft-tissue depth varies with different ethnic groups and regions of the face. The morphology, position, and colour of the eyes, the shape and profile of the nose and mouth, and certain dynamic features like the distribution of adipose tissue, are distinctive to everyone (Nilendu & Johnson 2023). Thus, the average thickness of the soft tissue is used for reconstruction (Stanciu et al. 2020). Soft tissue depth tables are usually used in combination with a large database of face templates. CT images are used to reconstruct 3D cranial and facial models (Lee et al. 2020). Data segmentation involves identifying the bone and soft tissues on stacked 2D grey-level images. Then 3D mesh models of the skull and face are generated from segmented 2D slices (Buhan & Nardoni 2018). Tissue depths determine the displacement between facial and skull landmarks. Their combination shapes the reconstructed face, crucial for fidelity and directly affects reconstruction error (Liang et al. 2024). Average soft tissue depth tables demonstrate the relationship between skull ancestry and the distribution of facial soft tissue (Jong 2022).

Murjani et al. (2020) reviewed various approaches for reconstructing facial soft tissues, including nasal features (position, shape, size, and symmetry), eyes, mouth, and ears. For nasal tip prediction: Gerasimov's method uses the intersection of nasal bone and anterior nasal spine projection, Krogman's method is based on bony nasal aperture width, Macho's method utilizing cranial landmark regression equations, and George's method is inspired by facial aesthetics and nasion-point A distance proportions (males: 60.5%, females: 56%). Bulut et al. (2019) also emphasised the importance of age and sex in nasal reconstruction, with males exhibiting larger nasal structures and both volume and area increasing significantly from childhood to old age (Bulut et al. 2019).

For eye placement, the traditional method centering the eyeball was challenged by Stephen who reported a 4mm underestimation of the anterior globe, aligning with observations by Wilkinson and Mautner Similarly, the location of the medial and lateral canthi varied among authors, with Wilder suggesting the lacrimal fossa and malar tubercle, respectively, while others reported discrepancies (Murjani et al. 2020).

Mouth reconstruction methods considered factors like the upper jaw's alveolar part, dental arch width, tooth size and shape, and occlusion (Gerasimov). Krogman's rule approximated mouth width to the interpupillary distance or canine-premolar width Stephen and Henneberg proposed a 75% rule based on the inter-canine distance. Notably, Babacan et al. (2020) introduced equations utilizing computed tomography (CT) data to predict lip morphology (Babacan et al. 2020).

Regarding ear reconstruction, Gerasimov proposed aligning the ear angle with the jawline, a view supported by Broadbent and Matthews. Additionally, they linked earlobe attachment to the direction of mastoid processes. However, the morphology, position, and surface characteristics of the mastoid process, despite being considered by Gerasimov, Fedosyutkin, Nainvs and Jordanov, were deemed unreliable predictors by Guyomarc'h and Stephan (Murjani et al. 2020).

There are three types of soft tissue depth methods: the mixed method relies on soft tissue depth indexes and anatomical knowledge; the American method relies on soft tissue depth indexes and the Russian method focuses on anatomical details of the face. All of them have fundamental stages. Firstly, analysis of the skull in terms of sex, age, and race. Secondly, the selection of an adequate tissue depth index to cover the flesh. Thirdly, the selection of facial characteristics (Delgado 2020).

APPLICATION – FEMALE SKULL IN GUAR KEPAH, MALAYSIA

In 2017, the Centre of Global Archaeological Research (CGAR) discovered skeletal remains and labelled them as GKph2017. In this research, the skeleton was discovered with both hands flexed to the chest, indicating it was likely laid in a semi-flexed position. Most upper body parts are intact, although some bones, such as the carpal, metacarpal, and upper right lateral incisor, are missing. The orientation of the skeleton was northwest to southeast, lying on the right side with the face facing southwest. The gender of GKph2017 was determined through non-metric cranial morphology analysis and Walker's score system, focusing on specific landmarks in the cranium, due to the absence of lower abdominal parts. In the sexing scoring system, GKph2017 was assigned 8/18 (0.4), indicating a female gender. In this study, the intracranial volume is 1330mL, comparable to modern humans, which averages 1328mL. GKph2017 is the sole Guar Kepah skeleton in Malaysia, with limited access to the stored material in Leiden. Analysis of the remains suggests that the ancient Guar Kepah people belonged to the Melanesoid group (Abdullah et al. 2022).

LIMITATION AND CHALLENGES OF 3DFR

Biological profile (BP) involves the examination of the skeletal remains to identify characteristics and traits that help determine the individual's identity. The biological profile includes sex, age, stature, injuries, pathologies, and ancestry (Jong 2022). For sex estimation, measurements of hands, feet, and extremities corresponding to upper, lower, and ling bones belong to morphometric measurements. Morphological measurements include foundation in the sexual dimorphism (skull and pelvis area). Based on the article by Mesejo et al. (2020), the GP (Geometric Projection) and TW2 (Two-Way 2D) methods are two distinct approaches used in the context of skeleton-based forensic human identification. The GP method involves using geometric principles to project 3D skeletal data onto a 2D plane, allowing for the analysis and identification of skeletal remains. This technique takes advantage of the spatial relationships between different anatomical landmarks on the skeleton. By creating a geometric model that represents these relationships, forensic experts can extract features that are critical for identification purposes. The GP method is particularly useful in scenarios where only partial skeletal remains are available, as it can enhance the visibility of key features that may aid in matching with known individuals.

The TW2 method, on the other hand, focuses on a two-dimensional approach that utilizes images from multiple angles to reconstruct a more comprehensive view of the skeletal structure. This method captures variations in perspective and allows for a more detailed analysis of skeletal features. By employing image processing techniques, the TW2 method can enhance the quality of 2D images, facilitating better comparisons with existing databases of known individuals. This approach is beneficial in forensic investigations where high-quality images of skeletal remains are available, as it maximizes the information extracted from these images. In summary, both methods leverage different aspects of geometric analysis and image processing to improve the forensic identification of skeletal remains. The GP method emphasizes geometric relationships in a 3D context, while the TW2 method enhances 2D imaging techniques to provide a more detailed analysis (Mesejo et al. 2020).

Facial landmarks are specific key points on the human face, such as the eyes, nose, and mouth. They are utilized for calculating anthropometric measurements. The number of extracted facial landmarks varies depending on the application (Vu et al. 2022). In the study of (Ferková et al. 2020), the authors stated that face generation by using landmarks. Firstly, they take the input image annotated with landmarks, secondly, depth images were chosen from the FIDENTIS database based on age estimation and gender, thirdly planar meshes were generated and lastly the depth from chosen depth images to each vertex of the mesh. The FIDENTIS 3D Face Database is a collection of 3D facial scans from over 2,400 people, primarily European. It includes basic information about each person scanned. The database is useful for researchers in areas like facial recognition technology, forensics, and studies on how faces change over time (Urbanová et al. 2018).

In the study of (Singh et al. 2023), "Top 100 most beautiful women" lists are used. The study aimed to determine the common features shared by the female faces and their correlation to their racial demographics. Models based upon principal component analysis (PCA) of 3DMMs produced by deep convoluted neural networks (GANs). Neutral poses in positions frontal, left oblique, right oblique, left lateral, and right lateral were downloaded. 3DMM was trained to produce 3D reconstructions from 2D photographs while GAN was used to generate texture output. Generally, East Asian populations, Chinese and Korean had wider and shorter noses than Caucasians. The white population had narrower faces than Asians. African Americans exhibited shorter, wider noses as well as narrower jaws than Caucasians and Koreans. Malaysian Chinese and Malaysian Malay had different upper, middle, and total face height measurements, and Malaysian Chinese and Malaysian Indian had different upper and middle facial heights as well as interzygion distance. The study showed that even if a particular face shares common features with its assigned racial demographic, it also displays distinct facial proportions compared to the general population.

Rhinoplasty is a well-known procedure in cosmetic surgery because the nose is considered the most attractive part of the human face. It is believed to enhance facial beauty according to *feng shui* in some Asian cultures. Additionally, reconstructing damaged nasal passages is necessary to improve communication among specific patients (Vu et al. 2022). For trans and gender-diverse individuals, physical descriptions, including biological sex, may not align with their social identity. This can delay and complicate identification. Some trans individuals undergo physical changes to better reflect their gender. Facial feminisation surgeries (FFS) involve reducing the forehead size, rhinoplasty, brow lifting, and chin reduction for smaller facial features. FFS was expected to impact the outcome of metric cranial sex assessment, potentially complicating the already challenging process of assessing sex from the skull. It is hypothesised that comparing cranial metric, morphological, and pelvic assessments should accurately determine sex and gender in forensics. Morphological analysis of a male-to-female (MTF) skull after FFS should reveal evidence of surgical modifications, such as screws and pins. These may include horizontal pins/screws above the nasal bones, screws on the chin's anterior superior portion where bone has been reattached, missing parts of the gonial angles where bone has been shaved off, and evidence of bone tapering along the lateral mandibular body near the gonial angles (Schall et al. 2020).

There are differences in biological male and female skulls: brow and nasal bone are more prominent in males, a larger mastoid process in males, and gonial flare causes a taller and angular jaw present in males. Integrating knowledge from gender and sociological studies into forensic practices can mitigate limitations associated with anatomical variations (Vieira et al. 2021).

MOVING FORWARD

The relationship between facial reconstruction and forensic science involves several approaches, each with limitations. Facial reconstruction often adopts a holistic method, but it is generally highly inaccurate. It relies on facial landmarks to measure distances and proportions between features, which are subject to subjective estimations and unpredictable factors. Techniques like superimposition are commonly used but can be challenging in uncontrolled scenarios. Additionally, morphological comparisons can lead to examiner bias or errors, highlighting the complexities and limitations of facial reconstruction in forensic applications (La Cava et al. 2023). Although 3DFR is an effective technology in facial reconstruction, however, it still needs to address numerous challenges. The challenges of 3DFR involve lips reconstruction, teeth and tongue capturing, eyes and eyelids capturing, hairstyle, and complete head (Sharma & Kumar 2022).

Two enhancement approaches have been established: the model-based approach and the view-based approach. The model-based approach utilizes a probe image to generate a frontal face view through 3DFR; it is suitable for real-world scenarios and has a low computational cost. The view-based approach focuses on forensic mugshot images. It was established in 2008, as a multilevel variation minimization approach that required landmarks. For example, focus on the eyes, eyebrows, nose, and lips and point between them (La Cava et al. 2023).

In the study of (Stephan et al. 2019), the authors stated an overview of the latest developments in facial imaging. Facial approximation builds a face based on an unidentified skull which involves 2D, 3D, and computerized sculpting of the face, however, relies on the thickness of facial soft tissue. For the photographic superimposition, it compared the anatomy of a skull to an ante-mortem face using a photographic overlay. Age progression/regression provided an image of a person's facial appearance either before or after their last known appearance. Facial depiction removed distracting details from post-mortem facial images so that faces could be displayed in a sanitized format to the public and family members while molecular photofitting was used to estimate facial appearance from a person's DNA.

CONCLUSION

Advancements in both 2D and 3D facial reconstruction techniques are shaping the future of forensic applications. These innovative technologies enhance the effectiveness and reliability of identifying individuals from skeletal remains. By carefully considering the principles behind each method, researchers are driving progress in the field, uncovering hidden identities behind faceless remains.

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