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The Doppelgänger effect? A comparative study of forensic facial depiction methods

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ABSTRACT

This study attempted to assess the reproducibility of 2D and 3D forensic methods for facial depiction from skeletal remains (2D sketch, 3D manual, 3D automated, 3D computer-assisted). In a blind study, thirteen practitioners produced fourteen facial depictions, using the same skull model derived from CT data of a living donor, a biological profile and relevant soft tissue data. The facial depictions were compared to the donor subject using three different evaluation methods: 3D geometric, 2D face recognition ranking and familiar resemblance ratings. Five of the 3D facial depictions (all 3D methods) demonstrated a deviation error within $\pm$ 2 mm for $\geq$ 50% of the total face surface. Overall, no single 3D method (manual, computer assisted, automated) produced consistently high results across all three evaluations. 2D comparisons with a facial photograph of the donor were carried out for all the 2D and 3D facial depictions using four freely available face recognition algorithms (Toolpie; Photomyne; Face ++; Amazon). The 2D sketch method produced the highest ranked matches to the donor photograph, with overall ranking in the top six. Only one 3D facial depiction was ranked highly in both the 3D geometric and 2D face recognition comparisons. The majority (67%) of the facial depictions were rated as limited or moderate resemblance by the familiar examiner. Only one 2D facial depiction was rated as strong resemblance, whilst two 2D sketches and two 3D facial depictions were rated as good resemblances by the familiar examiner. The four most geometrically accurate 3D facial depictions were only rated as limited or moderate resemblance to the donor by the familiar examiner. The results suggest that where a consistent facial depiction method is utilised, we can expect relatively consistent metric reliability between practitioners. However, presentation standards for practitioners would greatly enhance the possibility of recognition in forensic scenarios.

1. Introduction

Facial approximation/reconstruction is described as the depiction of the living face of an individual through interpretation of skeletal morphology from human remains. For the purposes of this article the authors will use the term 'facial depiction' to describe all 3D and 2D facial approximation/reconstruction methods. The accuracy and reproducibility of forensic facial depiction techniques continues to be debated and accuracy studies vary in their research design and relevance to forensic application [1–5]. The demands of facial depiction differ somewhat when applied to a forensic or historical case.

In the forensic context, facial depiction is usually attempted when other identification leads have failed and is predicated on producing a facial depiction that would be recognisable to someone familiar with the individual in life. In these cases, facial depiction is not an identification method, but rather an investigative method. It is assumed that creative interpretation by the artist will remain sensitive to the limits of accepted feature prediction standards. 'Success' is generally based on achieving identification in forensic investigation, yet 'success' and 'accuracy' can be mutually exclusive, as other factors may contribute to whether an investigation leads to identification or not, and by their nature, unsuccessful cases cannot be evaluated. In addition, it is unclear what elements of a forensic facial depiction are relevant to familiar recognition and, based on previous research [6], it is possible that correct facial morphology is not the most important factor for successful identification. Current psychology literature suggests that we process faces

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holistically, rather than by individual features; and that we process internal and external features of familiar and unfamiliar faces differently [7]. That is to say, we are as able to recognise someone we know well by their external features (ears, hair etc.) as we are by their internal features. For someone we have not seen before, or we have just met, our focus reads external features of the face. Barring alternation through surgery, temporary disguise, disease, lifestyle or aging over time, our internal features are relative constants, whereas an external feature like hair, or contextual factors like lighting, can radically alter physical appearance. Some practitioner guidelines for presentation have been published [8], consolidating factors and principles gleaned from a wide-range of face-based studies.

Currently, practitioners use a range of facial depiction techniques that can broadly be grouped as either 2D or 3D, and then further specified as either manual, computer-assisted and automated [9]. Further, practitioners may employ one or more methods whether working two- or three- dimensionally. Most manual and computer-assisted practitioners utilise anatomical standards and anthropometry, and all methods utilise average soft tissue data [10–14]. All methods rely on the assessment of a biological profile (sex, age, ancestry) and any material found with the remains (clothing, jewellery, hair and so on) may provide additional information (e.g., body mass index, hair colour), which can be included in the final depiction to aid recognition. Several studies have attempted to identify best-practice protocols [15] and others have made a significant contribution in collecting soft tissue data for a wide range of population groups [16–18]. Subjective interpretation is cautioned against [19], and several researchers call for standardisation of soft tissue depth data [20] There has been a shift towards full automation in the 21st century, to try and mitigate subjective interpretation and improve effectiveness. However, automated systems are only as good at making faces as the database from which they are derived [21]. For systems based on clinical imaging databases [22] computer-assisted faces may have closed eyes, imaging artefacts and postural/equipment deformations. These factors can reduce morphological accuracy, decrease recognition and diminish believability (looking like a mask rather than a real face). Automated and practitioner-led methods each have their pros and cons, and these are outlined in the literature [23,24].

Historically, attempts to assess accuracy have suffered from poor donor data (e.g., cadavers, death masks, low quality ante-mortem images) [25]. Advances in 3D clinical imaging technology have provided novel and detailed ways to evaluate the accuracy of facial depiction methods by utilising living donor material (craniofacial data) and researchers have quantitatively evaluated morphological accuracy using 3D geometric comparison software [26,27]. The superimposition of 3D face models has been studied for identification of the living [28] and results show high matching ability and high repeatability.

Other studies have assessed facial depiction accuracy using qualitative methods, such face pool recognition, resemblance ratings and face recognition software [29–31]. Whilst accuracy studies have been numerous, there has been a lack of evaluation of the reproducibility of facial depiction practice and the variation in facial depiction outcomes. Some previous comparative studies evaluated the use of different tissue depth datasets on the same skull [32–34] rather than practitioner or method variation. A large-scale practitioner comparative study, from the RSFP2005 conference [35,36], was disappointing, as it utilised unidentified remains and therefore, merely evaluated the level of believability of the faces produced. A more recent comparative study [37] utilised CT data from a donor, 2 manual practitioners and 2 computerised systems (FaceIT and ReFace) and compared each facial depiction to the donor face visually and geometrically. This study showed variability in accuracy with 61–76% of the surfaces $\pm$ 5 mm error, and while each depiction demonstrated aspects of the face correctly, inaccuracies were exhibited at the chin area, ears, and nasal region. However, although this study evaluated the level of accuracy of each method, it did not attempt to evaluate the resemblance of the depictions to the donor.

The ideal reproducibility study should set out to compare quantitative morphological accuracy alongside qualitative visual likeness/resemblance, since morphological accuracy and physical likeness may not be directly correlated.

2. Materials and methods

The authors invited a number of experienced practitioners based around the world to participate in a comparative analysis of facial depiction methods. This was a double-blind study, with photographs of the donor face only revealed to researchers and practitioners once all depictions were submitted. Thirteen practitioners from seven countries (UK, USA, Netherlands, South Africa, New Zealand, Hungary, Belgium) took part in the study and fourteen facial depictions were produced using 2D sketch (n = 3), 3D manual (n = 8), 3D computer-assisted (n = 2) and 3D automated (n = 1) methods.

A 3D skull model was produced from DICOM (Computed Tomography) data donated by a living individual (middle-aged US male of European ancestry). This biological profile was supplied to practitioners along with an appropriate set of average soft tissue depths (Helmer, 1984) and instructions to produce a facial depiction (head and neck) without hair or expression (in frontal view if 2D). All thirteen practitioners returned at least one facial depiction, with one practitioner contributing two depictions (2D and 3D). Of these, eleven were 3D (manual, automated and computer-assisted) and three were 2D (manual sketch). Facial depictions were received either as digital images of 2D sketches, 3D scans of sculptures, 3D computer-generated models, or physical sculptures. Physical sculptures were scanned by the authors using a Polhemus Scorpion hand-held laser scanner. Scans were viewed in FastScan and converted to.obj files for use in Geomagic Freeform Modelling Plus.

3. Analysis

The morphological accuracy of each facial depiction was evaluated using two methods: a 3D geometric comparison and a 2D image comparison.

3.1. 3D geometric comparison

The 3D facial depictions were metrically compared to the 3D donor CT model. The CT data for the donor was collected with the donor lying in a supine position, and therefore we can assume that his face shape was affected by gravity. Previous research suggests that postural changes to the face in this position can affect all features of the face, except the nose, and these effects are most marked at the lateral cheeks and jawline [38] and are greater in older (>50 years) than younger (20–30 years) individuals [39]. In addition, the donor CT model demonstrated closed eyes, whilst all but one (O) of the 3D facial depictions demonstrated open eyes. These factors will affect the 3D geometric comparisons and must be considered when interpreting the results, as 3D forensic facial depictions are usually produced with the face in an upright position and with open eyes, to optimise recognition.

The computer-assisted and automated facial depictions were presented as 3D files including the skull model as a separate digital layer. Therefore, these facial depictions could be aligned to the donor CT model in Freeform Modelling Plus using the skull for common registration. The scans of the 3D manual facial depictions were visually aligned to the pegged skull by the researcher using the eyeballs, external auditory meati and nasal root as registration points (see Fig. 1). Once achieved, the 3D manual facial depictions could then be aligned to the donor CT model using the skull for common registration (see Fig. 2).

In Freeform Modelling Plus, the donor CT model was cropped to three planes superiorly, posteriorly and inferiorly. Once aligned, each 3D facial depiction was cropped to the same planes as the donor model. Therefore, each the 3D model consisted of 3 flat sides and a facial

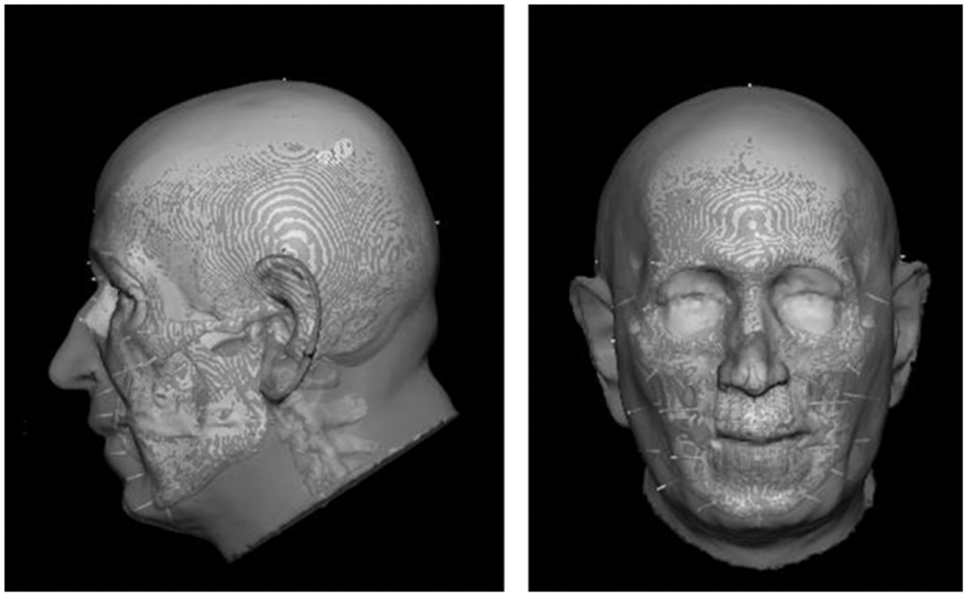

Fig. 1. Screenshots of a 3D facial depiction (C) aligned with the pegged skull.

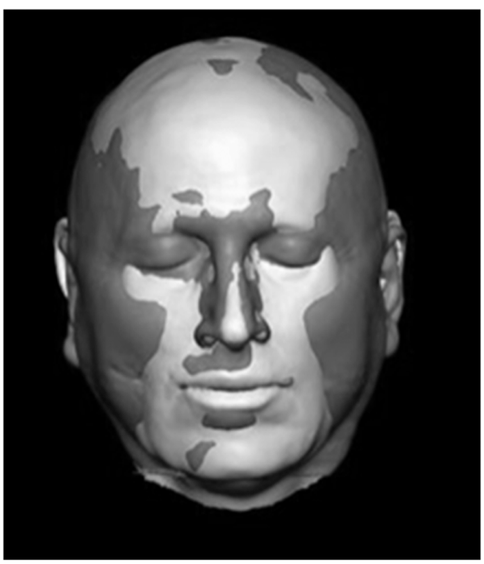

Fig. 2. Screenshots of a 3D facial depiction (F - light) aligned to the donor CT model (dark).

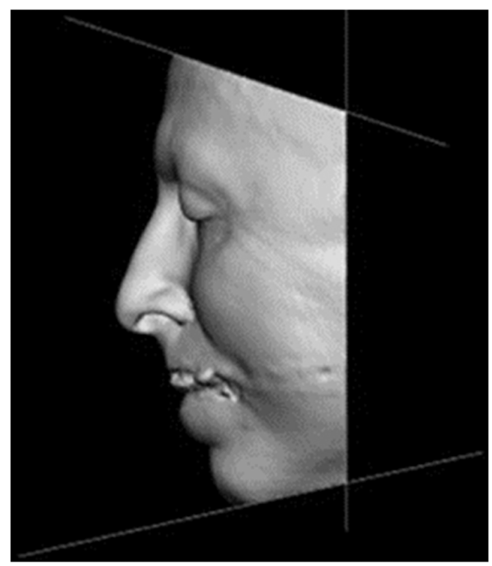

Fig. 3. Screenshot of 3D donor model cropped to planes.

surface, rendering the entire dataset more practically comparable (see Fig. 3).

The 3D geometric comparison was carried out using Geomagic Qualify 2013 software, which compares two 3D surfaces using shell-to-shell deviation maps. The geometric accuracy of each facial depiction was assessed by mapping its deviation (error measurement) from the surface of the donor CT model and calculating the percentage of the surface of the facial depiction that demonstrated a maximum deviation (error) of ± 2 mm. The flat planes were excluded from the surface comparison so that only the facial surfaces were compared.

3.2. 2D facial image comparison

A facial depiction image dataset (see Fig. 4) was created including frontal views of the fourteen facial depictions on black backgrounds, and a frontal photograph of the donor (see Fig. 5) was compared to the facial depiction image dataset. The black and white, frontal photograph of the donor demonstrated a non-smiling face with a beard. Facial hair will reduce the ability to accurately locate landmarks around the mouth and jawline.

2D image comparisons were carried out between the donor face and each facial depiction using four freely available face recognition algorithms (Toolpie[1]; Photomyne[2]; Face ++[3]; Amazon[4]). Each software delivers a percentage match between two faces. Two different facial images of the donor (one smiling and one non-smiling) were also compared to each other using each face recognition software.

The likeness/resemblance to the donor of each facial depiction was also evaluated using qualitative familiar face assessment:

[1] https://www.toolpie.com/
[2] https://photomyne.com/
[3] https://www.faceplusplus.com/
[4] https://aws.amazon.com/rekognition/the-facts-on-facial-recognition-with-artificial-intelligence/

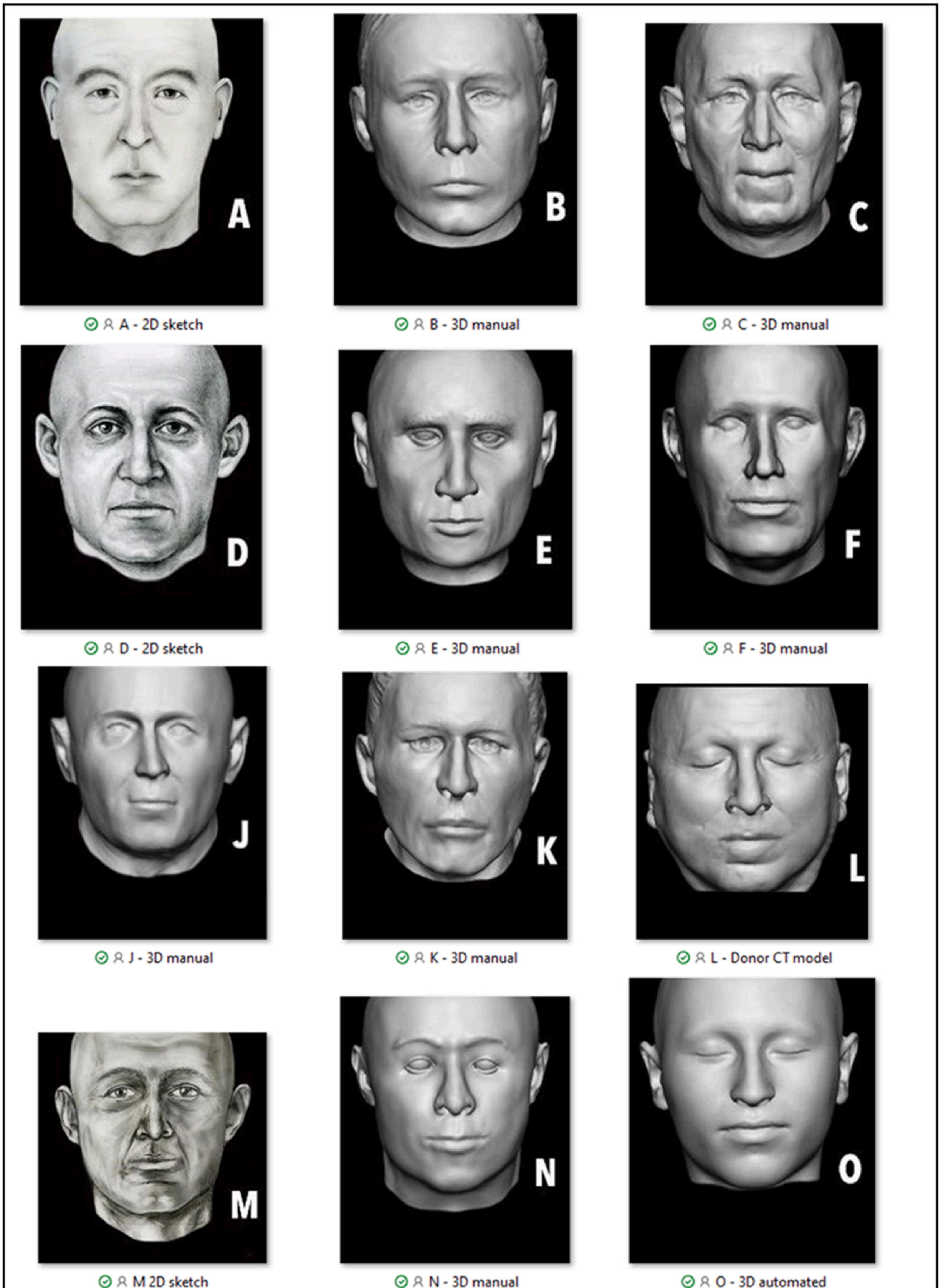

Fig. 4. The facial depiction image dataset, including the donor CT model (L).

Fig. 5. The non-smiling facial photograph of the donor.

3.3. Resemblance assessment

The facial depiction dataset (including the donor CT model) was sent to an examiner who was very familiar with the facial appearance of the donor. A familiar examiner was utilised in order to replicate a typical forensic scenario where the target recognisers are family members and/or friends of the deceased. The examiner scored each facial depiction according to a six-tier rating system:

0 = no resemblance.
1 = limited resemblance.
2 = moderate resemblance.
3 = good resemblance.
4 = strong resemblance.
5 = very strong resemblance.

4. Results

4.1. 3D Geometric comparison

Five 3D facial depictions (B, F, H, N, O) showed at least 50% of the surface with ± 2 mm deviation from the donor CT model (see Fig. 6 and Table 1). Of these, three were produced using a manual method, one using a computer-assisted method and one using an automated system. All 3D facial depictions demonstrated the highest accuracy at the forehead, cheek and chin regions. The mouth area and sides of the face demonstrated the most error for the majority of 3D facial depictions.

4.2. 2D Face Recognition Comparison

All facial depictions were compared to the non-smiling donor photograph using four different (Toolpie, Photomyne, Amazon, Face ++) face recognition systems that produced a percentage match to the donor and a ranking from best to worst (1−15) match. An overall ranking was calculated for each facial depiction as an average of the four face recognition system rankings (see Table 1).

Each face recognition system matched the non-smiling donor photograph to itself by > 97%, and the smiling donor photograph to the non-smiling donor photograph by > 83%. The donor CT model was ranked the overall highest match to the donor photograph and two facial depictions (D, M – both 2D sketches) received the same or greater match percentage than the donor CT model.

No facial depiction was matched to the donor at more than 54% by any face recognition system. The Amazon face recognition system consistently matched the facial depictions to the donor at a lower rate (0−22) than the other face recognition systems, rating only the CT donor model (L) at more than 1% match to the donor (22%).

The 2D sketches (A, D, M) and three 3D facial depictions (C, J, N) were ranked the overall highest matches to the donor photograph using the 2D face recognition systems. Only one 3D facial depiction (N) was ranked highly in both the 3D geometric and 2D face recognition comparisons.

4.3. Resemblance assessment

The examiner did not rate any of the facial depiction dataset (including the donor CT model) at the highest and lowest resemblance tier (see Table 1). The donor's own CT model was only rated as limited resemblance to the donor by the familiar examiner. Only one 2D sketch (D) was rated as strong resemblance and this depiction also ranked highly (#2) in the 2D face recognition comparison. Two 2D sketches (A, M) and two 3D facial depictions (H, J) were rated as good resemblances, and three of these (A, J, M) also ranked highly in the 2D face recognition comparisons. The majority (67%) of the facial depictions were rated as limited or moderate resemblance. One 3D facial depictions (H - manual) with low geometric error was rated as a good resemblance, and one 3D facial depiction (J – manual) with high geometric error was rated as a good resemblance. The four most geometrically accurate 3D facial depictions were only rated as limited or moderate resemblance to the donor.

5. Discussion

The facial depiction image database demonstrated variation with respect to individual facial features and, in some cases, face shape. This is similar to other comparative studies where practitioners demonstrated varying degrees of sculptural ability, anatomical modelling and facial feature prediction [32–34].

Five (45%) of the 3D depictions recorded the majority of their facial surface with ± 2 mm error when compared to the donor CT model, and no 3D depiction recorded less than a third of its surface at ± 2 mm error when compared to the donor CT model. This suggests that the 3D facial depictions ranged around moderate morphological accuracy, and that facial depiction methods are more reproducible than demonstrated in the other quantitative comparative study [34], where the facial depictions deviated from the donor face at more than double this level (± 5 mm).

Most 3D facial depictions demonstrated an underestimation of tissue at the lateral cheeks and an overestimation around the mouth, and this is likely due to postural changes to the donor's face in the CT scanner. This result was also seen in the previous quantitative comparative study [34] where CT scan data from a supine donor was also utilised.

Most 3D facial depictions demonstrated higher error at the eyes due to the closed eyes on the donor CT model. However, the 3D automated system produced a facial depiction (O) with closed eyes demonstrating low error in this region. The 3D automated facial depiction (O) demonstrated the lowest deviation error to the donor CT model. The database on which this system was designed was derived from CT data of living donors, so this facial depiction is likely to be least affected by the postural changes associated with a supine position. However, when compared to the donor photograph this facial depiction (O) performed poorly (#9) and was also rated as only limited resemblance to the donor by the familiar examiner.

One 3D facial depiction (N) was ranked highly in both 3D geometric and 2D face recognition comparisons, but this was also only rated as limited resemblance by the familiar examiner. The donor CT model ranked the highest in both 3D geometric and 2D face recognition comparisons, but this was also only rated as limited resemblance by the familiar examiner. These results highlight the challenges associated with clinical image data and the complex correlation between craniofacial morphology and resemblance.

Overall, no single 3D method (manual, computer assisted, automated) produced consistently high results across all three evaluations (3D geometric, 2D face recognition, familiar resemblance).

It is worth noting that the 2D facial depictions (unlike the 3D facial

Fig. 6. Geometric deviation maps comparing each 3D facial depiction with the donor CT model. Green and yellow areas/Paler areas = ± 2 mm deviation error; blue and red areas/Darker areas = ± > 5 mm deviation error.

depictions) were presented with skin/hair textures (these details cannot be predicted from skeletal remains), and research [6] shows that people respond more positively to textured faces, creating a bias towards 2D sketches due to their innate ability to appear more 'realistic'. This is demonstrated in these results, as all the 2D sketches recorded consistently high 2D face recognition rankings and resemblance ratings.

The use of a familiar examiner mitigated the confusing effect of the beard on the donor images, as the examiner was very familiar with the donor's face in multiple different scenarios and presentations. This would be similar to a forensic investigation where the recognition targets are family and friends.

Whilst the number of donor data in this study was limited (n = 1), the number of practitioners was large (n = 13) and a variety of modes of production (n = 4) and evaluation (n = 3) were considered. The inclusion of experience practitioners was key to this research, as previous comparative studies had utilised inexperienced practitioners or an

Table 1
Summary of facial depiction evaluation as compared to the donor using 3D geometric analysis, 2D face recognition (FR) match and familiar resemblance assessment.

Facial depiction	Method	±2 mm 3D surface error (%/rank)	Toolpie FR match (%/rank)	Photomyne FR match (%/rank)	Amazon FR match (%/rank)	Face + + FR match (%/rank)	Overall 2D FR match rank	Resemblance Assessment
A	2D sketch		28/6 =	30/4 =	0.6/3 =	36/9	6 =	3-good
B	3D manual	50/4 =	20/11 =	6/11	0/14 =	27/13	12 =	1-limited
C	3D manual	45/8	30/5	28/7	0.8/2	42/5	5	2-some
D	2D sketch		43/1	38/1	0.2/8 =	54/1	2 =	4-strong
E	3D manual	35/12	9/15	0/12 =	0/14 =	26/14	14	2-some
F	3D manual	55/3	28/6 =	20/9	0.1/11 =	35/10	10	2-some
G	3D computer	37/11	20/11 =	16/10	0.1/11 =	34/11	11	2-some
H	3D manual	50/4 =	20/11 =	27/8	0.3/6 =	39/7 =	9	3-good
I	3D computer	49/7	21/10	0/12 =	0.1/11 =	21/15	12 =	1-limited
J	3D manual	42/9	39/3 =	29/6	0.6/3 =	47/4	4	3-good
K	3D manual	41/10	39/3 =	0/12 =	0.5/5	39/7 =	8	1-limited
L	donor CT model	100/1	40/2	34/2 =	22/1	53/2	1	1-limited
M	2D sketch		28/6 =	34/2 =	0.2/8 =	49/3	2 =	3-good
N	3D computer	50/4 =	28/6 =	33/4 =	0.2/8 =	33/12	6 =	1-limited
O	3D automated	59/2	17/14	0/12 =	0.3/6 =	41/6	9	1-limited
1	Donor neutral		100	100	100	97		
2	Donor smiling		90	83	100	88		

unknown donor [35–37], therefore, the researchers prioritised the contribution of the practitioners over the number of donor data. The limited donor sample may mean that this study is not wholly representative of the forensic application of facial depiction, and further comparative studies would be valuable.

6. Conclusion

This study appears to be the first large-scale comparative study where three different assessment protocols were utilised to compare the facial depictions across practitioners, across modes and to the donor face.

The results suggest that where a consistent method and application of soft tissue data is utilised, we can expect relatively consistent metric reliability between practitioners.

However, a visual assessment of the facial depictions reveals significant differences in the interpretation of facial features and, in some cases overall face shape, across the group.

The addition of textures, such as hair, skin detail, open eyes and facial hair, has a significant effect on the resemblance of a facial depiction to a living individual leading to enhanced face recognition ranking and resemblance ratings for the 2D sketches. These results suggest that practitioner presentation standards would greatly enhance the possibility of recognition in forensic scenarios. Suggested presentation guidance includes:

1. Open eyes with realistic iris presentation.
2. Addition of textures (skin detail, hair, facial hair, etc.) to a 2D image of the 3D model – multiple versions or blurred external textures may be preferable where these details are unknown.
3. Include eyebrows.
4. Orthogonal frontal view with head in FHP - additional views may be presented where characteristic features are present.

The relationship between metric accuracy and visual resemblance continues to be a challenge for this field. The most faithful face shape is not necessarily the most effective, and the character of individual features and the overall texture of the face can have an alarmingly strong effect upon recognition. Further research is necessary to determine the optimal presentation methods for forensic facial depictions.

CRediT authorship contribution statement

Kathryn Smith: Conceptualization, Methodology, Contributor as participant, Evaluation, Writing- Reviewing and Editing. Caroline Wilkinson: Co-design, Evaluation, Writing- Original draft preparation, Writing- Reviewing and Editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] C.M. Wilkinson, Forensic Facial Depiction, Cambridge University Press, Cambridge, 2004.
[2] J. Prag, R.A.H. Neave, Making Faces, British Museum Press, London, 1999.
[3] C.M. Wilkinson, Facial depiction – anatomical art or artistic anatomy? J. Anat. 216 (2010) 235–250, https://doi.org/10.1111/j.1469-7580.2009.01182.x.
[4] W.D. Haglund, D.T. Reay, Use of facial depiction techniques in identification of Green River serial murder victims, Am. J. Forensic Med. Pathol. 12. 2 (1991) 132.
[5] C.N. Stephan, M. Henneberg, Building faces from dry skulls: are they recognized above chance rates? J. Forensic Sci. 46 (3) (2001) 432–440.
[6] V. Bruce, P. Healey, M. Burton, T. Doyle, A. Coombes, A. Linney, Recognising facial surfaces, Perception 20 (6) (1991) 755–769.
[7] R.A. Johnston, A.J. Edmonds, Familiar and unfamiliar face recognition: a review, Memory 17 (5) (2009) 577–596, https://doi.org/10.1080/0965821090297696.
[8] S. Davy-Jow, The devil is in the details: a synthesis of psychology of facial perception and its applications in forensic facial depiction, Sci. Justice 53 (2013) 230–235, https://doi.org/10.1016/j.scijus.2013.01.004.
[9] C.M. Wilkinson, Computerized forensic facial depiction: a review of current systems, Forensic Sci., Med., Pathol. V1–3 (2005), https://doi.org/10.1385/Forensic Sci. Med. Pathol, 1:3:173.
[10] M.M. Gerasimov, The Face Finder, Hutchinson, London, 1971.
[11] K.T. Taylor, Forensic Art and Illustration, CRC, Boca Raton, 2001.
[12] C.C. Snow, B.P. Gatliff, K.C. McWilliams, Depiction of facial features from the skull: an evaluation of its usefulness in forensic anthropology, Am. J. Phys. Anthr. 33 (1970) 221–228.

[13] Krogman, W.M. and Iscan, M. The Human Skeleton in Forensic Medicine. Thomas, Illinois, 1986.
[14] Mahoney, G. and Wilkinson, C.M. Computer-generated facial depiction. Cpt in: Wilkinson, C. and Rynn, C. (eds.) Craniofacial Identification. Cambridge University Press, Cambridge, 2012.
[15] C.N. Stephan, M. Henneberg, Recognition by forensic facial depiction: case specific examples and empirical tests, Forensic Sci. Int. 156 (2006) 182–191.
[16] C.M.S. Fernandes, M. da Costa Serra, J.V.L. Da Silva, P.Y. Noritomi, F.D.A. de Sena Pereira, R.F.H. Melani, Tests of one Brazilian facial depiction method using three soft tissue depth sets and familiar assessors, Forensic Sci. Int. 214 (2012) 211.e1–211.e7.
[17] S. De Greef, P. Claes, D. Vandermeulen, W. Mollemans, P. Suetens, G. Willems, Large-scale in-vivo Caucasian facial soft tissue thickness database for craniofacial depiction, Forensic Sci. International 159S (2006) S126–S146, https://doi.org/10.1016/j.forsciint.2006.02.034.
[18] D. Cavanagh, M. Steyn, Facial depiction: Soft tissue thickness values for South African black females, Forensic Sci. Int. 206 (2011) 215.e1–215.e7.
[19] C. Stephen, I.S. Penton-Voak, J.G. Clement, M. Henneberg, Ceiling Recognition Limits of Two-Dimensional Facial Depictions Constructed Using Averages, Chapter 11, in: J.G. Clement, M.K. Marks (Eds.), Computer-Graphic Facial Depiction, Elsevier, Massachusetts, 2005, pp. 199–219. Chapter 11.
[20] C.N. Stephan, E.K. Simpson, Facial soft tissue depths in craniofacial identification (part I): an analytical review of the published adult data, J. Forensic Sci. 53 (6) (2008) 1257–1271, https://doi.org/10.1111/j.1556-4029.2008.00852.x.
[21] P. Claes, D. Vandermeulen, S. De Greef, G. Willems, P. Suetens, Craniofacial depiction using a combined statistical model of face shape and soft tissue depths: methodology and validation, Forensic Sci. Int. 159S (2006) S147–S158, https://doi.org/10.1016/j.forsciint.2006.02.035.
[22] J.G. Clement, M.K. Marks, Computer-Graphic Facial Depiction ([Kindle edition]), Elsevier, Massachusetts, 2005.
[23] S. Davy, T. Gilbert, D. Schofield, M. Evison, Forensic facial depiction using computer modeling software. Chapter 10 ([Kindle edition]), in: J.G. Clement, M. K. Marks (Eds.), Computer-Graphic Facial Depiction, Elsevier, Massachusetts, 2005.
[24] R.P. Helmer, S. Rohricht, D. Petersen, F. Mohr, Assessment of the reliability of facial depiction, in: M.Y. Iscan, R.P. Helmer (Eds.), Forensic analysis of the skull, Wiley-Liss, New York, 1993.
[25] Stratomeier, H., Spee, J., Wittwer-Backofen, U. and Bakker, R. Methods of forensic facial reconstruction. Proceedings of 2nd International Conference on Reconstruction of Soft Facial Parts (RSFP), Remagen, Germany, (2005) 19–20.
[26] C.M. Wilkinson, C. Rynn, H. Peters, M. Taister, C.H. Kau, S. Richmond, A blind accuracy assessment of computer-modeled forensic facial depiction using CT data from live subjects, Forensic Sci., Med. Pathol. 2 (3) (2006) 179–187.
[27] W.J. Lee, C.M. Wilkinson, H.S. Hwang, An accuracy assessment of forensic computerized facial depiction employing cone-beam computed tomography from live Subjects, J. Forensic Sci. 57 (2) (2012), https://doi.org/10.1111/j.1556-4029.2011.01971.x.
[28] D. Gibelli, A. Palamenghi, P. Poppa, C. Sforza, C. Cattaneo, D. De Angelis, Improving 3D–3D facial registration methods: Potential role of three-dimensional models in personal identification of the living, Int. J. Leg. Med. 135 (6) (2001) 2501–2507.
[29] C.M. Wilkinson, D.K. Whittaker, Juvenile forensic facial reconstruction—a detailed accuracy study, Proc. 10th Conf. Int. Assoc. Craniofacial Identif. (2002) 11–14.
[30] G. Quatrehomme, T. Balaguer, P. Staccini, V. Alunni-Pettret, Assessment of the accuracy of a three-dimensional manual craniofacial depiction: a series of 25 controlled cases, Int J. Leg. Med 121 (2007) 469–475.
[31] C.M.S. Fernandes, M. da Costa Serra, J.V.L. Da Silva, P.Y. Noritomi, F.D.A. de Sena Pereira, R.F.H. Melani, Tests of one Brazilian facial depiction method using three soft tissue depth sets and familiar assessors, Forensic Sci. Int. 214 (2012) 211.e1–211.e7.
[32] Wilkinson, C.M., Neave, R.A.H. and Smith, D. How important to facial reconstruction are the correct ethnic group tissue depths? In: Proceedings of the 10th meeting of the International Association for Craniofacial Identification (2002, September) 11–14.
[33] D. Nilendu, A. Johnson, Role of soft-tissue thickness on the reproducibility in forensic facial approximation: a comparative case study, Forensic Sci. Int.: Rep. 7 (2023) 100293.
[34] N. Briers, M. Steyn, Re-assessment of South African juvenile facial soft tissue thickness data for craniofacial approximation: a comparative analysis using central tendency statistics, Forensic Sci. Int. 291 (2018) 280–e1.
[35] Bongartz, J., T.M. Buzug, R. Helmer, P. Hering, H. Seitz and C. Tille. 'Introduction to the Comparative Study of Facial Depictions.' Book of Abstracts: 2nd International Conference on Depiction of Soft Facial Parts 2005: 56.
[36] Bongartz, J. and T. Buzug. 'Evaluation of the RSFP 2005 comparative study using facial recognition systems.' Book of Abstracts: 3rd International Conference on Depiction of Soft Facial Parts 2006: 2–3.
[37] S. Decker, J. Ford, S. Davy-Jow, P. Faraut, W. Neville, D. Hilbelink, Who is this person? A comparison study of current three-dimensional facial depiction methods, Forensic Sci. Int. 229 (2013) 161.e1–161.e8.
[38] U. Ozsoy, R. Sekerci, E. Ogut, Effect of sitting, standing, and supine body positions on facial soft tissue: detailed 3D analysis, Int. J. Oral. Maxillofac. Surg. 44 (2015) 1309–1316.
[39] J.W. Park, M. Lee, J. Kim, E. Kim, Quantitative evaluation of facial sagging in different body postures using a three-dimensional imaging technique, J. Cosmet. Dermatol. 20 (8) (2021) 2583–2592, https://doi.org/10.1111/jocd.13880.