University of Wollongong

Research Online

Faculty of Science, Medicine and Health -
Papers: part A

Faculty of Science, Medicine and Health

1-1-2014

Facial approximation of 'Angel': case specific methodological review

Susan Hayes

University of Wollongong, suehayes@uow.edu.au

Follow this and additional works at: <https://ro.uow.edu.au/smhpapers>

Part of the [Medicine and Health Sciences Commons](#), and the [Social and Behavioral Sciences Commons](#)

Recommended Citation

Hayes, Susan, "Facial approximation of 'Angel': case specific methodological review" (2014). *Faculty of Science, Medicine and Health - Papers: part A*. 1544.
<https://ro.uow.edu.au/smhpapers/1544>

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

Facial approximation of 'Angel': case specific methodological review

Abstract

A forensic facial approximation is typically undertaken to generate further leads to identity of the deceased, and over the past ten years there has been a considerable increase in the number of verified relationships concerning the skull and likely facial appearance. This paper describes the evidence and methods used to approximate the face and facial features of a young woman whose remains were found in the Belanglo State Forest (New South Wales, Australia) in August 2010. A review of methodologically analogous forensic facial approximations (i.e. involving some degree of manual manipulation to achieve the results), and published in international academic journals since 2000, indicates that it is common for methodological description to be minimal. Furthermore, what information is provided clearly shows a surprisingly enduring preference for applying 'legacy' skull-soft tissue relationships, despite most of these recommendations having been proven invalid.

Keywords

Facial approximation, methods, identification, facial reconstruction, CAS

Disciplines

Medicine and Health Sciences | Social and Behavioral Sciences

Publication Details

Hayes, S. (2014). Facial approximation of 'Angel': case specific methodological review. *Forensic Science International*, 237 e30-e41.

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/260016409>

Facial approximation of 'Angel': Case specific methodological review

Article in *Forensic science international* · April 2014

DOI: 10.1016/j.forsciint.2013.12.039

CITATIONS

10

READS

249

1 author:

[Susan Hayes](#)

University of Wollongong

47 PUBLICATIONS 103 CITATIONS

[SEE PROFILE](#)

Some of the authors of this publication are also working on these related projects:

Public science [View project](#)

Accepted Manuscript

Title: Facial approximation of 'Angel': Case specific methodological review

Author: Susan Hayes

PII: S0379-0738(14)00009-7
DOI: <http://dx.doi.org/doi:10.1016/j.forsciint.2013.12.039>
Reference: FSI 7469

To appear in: *FSI*

Received date: 29-8-2013
Revised date: 11-11-2013
Accepted date: 30-12-2013

Please cite this article as: S. Hayes, Facial approximation of 'Angel': Case specific methodological review, *Forensic Science International* (2014), <http://dx.doi.org/10.1016/j.forsciint.2013.12.039>

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Acknowledgements

The author is grateful for the support of the New South Wales Police, who approved this paper prior to submission (and in particular Detective Sergeant Tim Attwood from the NSW Police Force Homicide Squad), the extensive input of all of the police officers, forensic specialists and consultants who have worked on this case since 2010, the willingness of the Australian media to report the results, and those many individuals who have provided possible leads. The author also appreciates the positive feedback and insightful suggestions provided by the Reviewers.

Title Page

Facial approximation of ‘Angel’: Case specific methodological review

Susan Hayes, PhD¹

¹*Faculty of Science, Medicine and Health, University of Wollongong*

Address for correspondence:

Dr Susan Hayes, Research Fellow
Centre for Archaeological Science
Faculty of Science, Medicine and Health
University of Wollongong
New South Wales Australia 2522

E: susan_hayes@uow.edu.au

T: +61249281556

Abstract

A forensic facial approximation is typically undertaken to generate further leads to identity of the deceased, and over the past ten years there has been a considerable increase in the number of verified relationships concerning the skull and likely facial appearance. This paper describes the evidence and methods used to approximate the face and facial features of a young woman whose remains were found in the Belanglo State Forest (New South Wales, Australia) in August 2010. A review of methodologically analogous forensic facial approximations (i.e. involving some degree of manual manipulation to achieve the results), and published in international academic journals since 2000, indicates that it is common for methodological description to be minimal. Furthermore, what information is provided clearly shows a surprisingly enduring preference for applying ‘legacy’ skull-soft tissue relationships, despite most of these recommendations having been proven invalid.

Keywords: facial approximation, methods, identification, facial reconstruction

Over the past ten years there has been a considerable increase in the number of verified relationships concerning how the skull relates to the surface appearance of the face. As a consequence many earlier recommendations, particularly those of Gerasimov, Neave and Krogman [1-4], are either able to be applied with greater confidence, or, as is most often the case, have been found to be invalid. This paper describes the 2D computer-graphic approach used to approximate the facial appearance of a young woman whose remains were found in Belanglo State Forest, Australia, in 2010. Rather than gloss the methodology and/or present the results as a *fait accompli*, each aspect is justified through reference to relevant peer reviewed research and published recommendations. Within this justification is also discussion as to why a particular method was considered preferable, as well as, where relevant, feature-specific verified relationships published after this approximation was undertaken in 2011. This expanded methodological explanation is particularly important given, as will be discussed, a review of methodologically similar forensic facial approximations published in international academic journals since 2000 [5-15] shows a marked tendency for minimal explanation as to how the facial features were accomplished, and strongly indicates that many of the invalidated recommendations regarding undertaking a facial approximation continue to be the tools of choice.

On Sunday, 29th August 2010 a group of trail bike riders alerted police to skeletal remains they had discovered in dense bushland in Belanglo, a small plantation forest located approximately halfway between Canberra and Sydney. Analysis undertaken at the Department of Forensic Medicine (Glebe, Sydney) indicated that the remains, which included the skull, pelvis, limb bones and lengths of hair, likely belonged to a European female (15-25 years), and that time since death was estimated to be between six months and ten years prior to discovery (i.e. 2000 – early 2010). Examination of the scene by police officers found a t-

shirt near the skeletal remains, and a graphic reconstruction of the garment was undertaken due to its distinct motif (Figure 1). The t-shirt is short sleeved featuring the word 'Angelic' in pink text, depicts a rose and a heart with angel wings, and had been available for sale in New South Wales and other parts of Australia from the early to mid 2000s. The t-shirt label indicates it is a size 10, which in Australia is equivalent to 'small'. Media releases initially outlining the discovery of the remains, and later an image of the reconstructed t-shirt (which led to this young woman being referred to in the media as 'Angel'), generated leads to identification from the Australian public. Unfortunately, neither these, nor a search of missing persons' databases, resulted in identification.

In response to the initial inquiry from the New South Wales Police Force Homicide Squad, an earlier paper describing the initial application of this computer-graphic facial approximation approach [16] was forwarded to the relevant officers. This was so the police officers were able to be more informed as to what was involved, what was likely to be required, and what the possible options may be. It was subsequently agreed that 2D digital photographs would form the basis of the approximate likeness, and that the results would incorporate a hair-style referencing the remains. It was also agreed that the process would be as collaborative as practically possible, including the police officers as well as forensic specialists, and that the basis for undertaking the approximation was applied research and available, in due course, for academic publication (subject to approval prior to submission). This approximation was commenced on 29th August 2011, exactly a year after the remains were first discovered.

Methods and Results

One of the advantages of undertaking a computer-graphic facial approximation is that application of the methods can constitute illustrations of the results, and therefore these are

presented in tandem with the descriptions of the methods applied. Following a brief overview outlining the general context of the research, the approximation process is presented in the following sequence: articulation of the mandible and orthogonal image capture, soft tissue depth application, underlying anatomy, feature identification (eyes, nose, mouth, ears), overall facial shape and indices, and surface appearance. This is, however, an artificial division of the actual process; all aspects of the head and face are, to some extent, inter-related. Following this there is an overview of the reporting and media release, as without such coverage a facial approximation is unable to facilitate identification, and after this, the methods used to identify the literature comprising the review.

General Context

The remains of the skull, teeth and hair were examined, measured and photographed *in situ* within the main examination room of the Glebe Department of Forensic Medicine (DOFM). This took four days, and all participants were gloved and gowned throughout. In addition to access to the relevant forensic analyses and reports, this period also involved discussions with the DOFM Chief Forensic Pathologist, consulting Forensic Odontologist and consulting Forensic Anthropologist, all of whom had undertaken the analyses of the remains in 2010 and concluded that this individual was likely Caucasoid (hereafter European population affinity), 15-25 years of age, and female.

Articulation and 2D photography

Some of the teeth had become loose post-mortem, and these were relocated in their corresponding sockets by the DOFM Forensic Odontologists, who also identified best fit for bite. Articulation of the mandible to the cranium involved strips of poster putty being placed at the temporo-mandibular joint and between the molars to simulate the articular disc and

freeway space as is commonly recommended [17, 18]. For this approximation the freeway space is approximately 2.5mm, which is within the average range (2-4mm) verified by Johnson *et al.*'s [19] study of young, living, dentate European adults (N=79, 19-23 years). The skull was then mounted onto a purpose-built skull stand and orientated in the Frankfurt Horizontal Plane (FHP) referring to the left auditory meatus and left inferior orbital rim.

The articulated and orientated skull was digitally photographed with the assistance of officers from the Sydney Crime Scene Section using a Nikon D200 mounted on a tripod and from a distance of 2m (which was the maximum distance enabled by the examination room). For both the frontal and lateral views the nasion was used as the central focus point and a vertical scale was positioned at the coronal and sagittal midlines. The images were uploaded into Adobe Photoshop CS2 to check for camera distortion, and once an orthogonal frontal/lateral pair had been identified (referencing horizontal and vertical measures of the skull as well as the scale) these were used for the subsequent approximation. Given the ambient conditions it took just under one day to achieve satisfactorily clear, high resolution and orthogonal images.

The images were scaled to life-size in Adobe Photoshop CS2, and using a graphics tablet an outline trace layer, detailing the shapes of the cranium and mandible in both the frontal and left lateral orientations, was achieved at 400% magnification (Figure 3). This occurred while directly referencing the remains to ensure that the outlines captured shape, and not tonal variations such as discoloration due to weathering. A methodological advantage of producing this outline trace is that it requires an extended period of concentrated focus on the morphology of the bones, both with regards to general shape and specific details, such as the location of craniofacial landmarks and indications of muscle attachments. It also enables subsequent publication of the skull in situations where, out of respect for the deceased (which

also occurs in an archaeological context [16]) and in accordance with police protocols, publication of actual images of the skeletal remains is not desirable.

Soft Tissue Depths (STDs)

The STDs applied in this approximation (Table 1, Figure 3) are taken from the weighted means calculated by Stephan and Simpson [20], and positioned at the angles recommended by George [21]. Stephan and Simpson [20] closely analysed 66 existing STD studies, and found a number of inconsistencies such as subjective assignment of age, body weight and population affinity, a lack of standardisation in landmark definitions and identification, and errors in data set reproductions. From the studies where this was able to be reported, Stephan and Simpson found a typical measurement error rate of 10%, which, together with the impact of other variables (e.g. which methods were used, variations in applied landmark identification), results in what they estimate to be a conservative error rate of >2mm.

Examining 55 of the more reliable existing STD studies, Stephan and Simpson identified 25 landmarks with sufficient similarity in definition to make them comparable. This comparison found that what method was applied, the year of publication, and the population affinity, age and sex of the measured, had little practical value as the conservative STD error rate was always greater than the differences arising from these variables. Therefore, Stephan and Simpson pooled the collected STD data, and calculated the total weighted mean for each landmark. The result is a data set of STDs that are more robust than any of the individual studies (for each landmark the average is 3250 individuals, range 545-6786), and is applicable across sex, age and population affinity.

Only a subset of Stephan and Simpson's [20] weighted means have been used for this facial approximation, due to the soft tissue depths being applied to the orthogonal images and not

the skull itself. This ‘hands-off’ approach removes the necessity of applying adhesive, such as sticky wax, directly onto the skull, and thereby avoids further bone contamination. A digital approach also allows for more precise measurement and angulation than manually cutting and attaching physical depth markers. Digital application, however, imposes a restriction in that only lateral sagittal and frontal coronal soft tissue depths are able to be applied with confidence. However, as this is a 2D facial approximation, analysis is concentrated on the lateral and frontal orientations, and therefore the sagittal and coronal landmarks are the most informative.

Underlying Anatomy

Each of the facial muscles applied in this facial approximation (Figure 4) were built as separate layers in Adobe CS2 Photoshop, working from the deep to surface muscles, and warped onto the skull following the shape, density and attachment locations identified and described in research predating this case [16, 22]. Subsequent applications (e.g. [23]) include modification to the depressor labii inferioris to more closely agree with Standring [24]. This revision has, however, a negligible impact on mouth and chin shape in the frontal view.

Two facial muscles which contribute to outer face shape are the temporalis and masseter. Stephan and Devine [25] note that the temporalis does not fill out the fossa bordered by the zygomatic arch, but contains two fatty components: the deep buccal fat pad and the superficial temporal fat pad. Their cadaveric analyses (N=19: 9M, 10F, 58-97 years) found the superficial temporal fat pad impacts on shape in producing a bulge superior to the zygomatic arch. In the cadavers Stephan and Devine dissected this bulge was found to form either a single (n=5) or double peak (n=5). It is likely that a 3D facial approximation would be compromised if it did not account for the superficial temporal fat pad, but in a 2D facial

approximation the impact of this bulge is subtle (Figure 4), and in this instance in the final result the surface appearance at the temples is not visible (Figure 2).

While the temporalis impacts on upper face shape, the masseter affects lower face shape. The masseter is comprised of three distinct layers (superficial, middle and deep) [24], but only the superficial part is represented in this facial approximation (Figure 4). Stephan conducted a review of literature regarding the masseter [26], and in addition to noting its anatomical composition and attachment patterns, reports that the size of the masseter is sexually dimorphic, affected by edentulousness, and that facial height, width and gonial angles are more reliably related to size.

As is also observed in these studies of the temporalis [25] and masseter [26], anatomical illustrations differ considerably across popular forensic recommendations (e.g. [3, 17, 27]). However, representations differ also across the more reputable anatomical references (e.g. [24, 28-31]). Although these anatomical differences are mostly related to the individual depicted, the medium of depiction, and the degree of stylisation in the illustration, it is also the case that the presence of some anatomical features, such as the number of zygomatic muscles and the shape of the parotid gland, can vary considerably between individuals [24]. Therefore, although a facial approximation can include some aspects of individual difference in underlying anatomical features based on attachment patterns (when present), estimation of these features is unavoidably highly approximate.

Facial Features: Eyes

Examination of the remains shows the orbits to be fairly symmetrical (R: 28.9mm x 35.6mm; L: 28.7mm x 34.5mm), with the right orbit being located slightly lower on the face relative to

the FHP (which references the left orbital rim). The recommended average eyeball diameter within the popular forensic recommendations is 26mm [3] and 25mm [17, 27], though the ocular anatomist, Wolff [32] records the average human eyeball as 23mm in height and 23.5mm in width. This approximation uses an average eyeball diameter of 24mm, closer to Wolff's recommendation. This diameter, however, is an underestimation, as a recent analysis [33] of a large number of CT scans (N=375: 204M, 171F; 18-95 years) results in an average eyeball height and width of 24.3mm and 24.6mm respectively.

A further legacy forensic recommendation is that the eyeball sits centrally within the orbit [4, 34]. Over sixty years ago Wolff [32] noted that the human eyeball is displaced from the orbital centre, and this is further supported by more recent cadaveric studies [35, 36] which found that, on average, the eyeball is displaced 1.4 mm superiorly and 2.3 mm laterally. For this approximation the eyeball is positioned approximately 1mm lateral, and 1mm superior, to the centre of the orbits. This location is less than the results of the cadaveric studies, particularly laterally, as it appeared to result in too wide a mouth (relative to the medial iris and infraorbital foramen as is discussed below) – and as the authors themselves note, their cadaveric research is based on a small number of significantly older individuals. However, the recent ocular study of CT scan data mentioned above [33], but published after this approximation was undertaken, indicates these findings regarding orbital displacement are broadly applicable to an adult population.

With regards to location of the canthi, Stephan and Donaldson [35] find the endocanthion is, on average, located within the lacrimal fossa approximately 12mm below the nasion. For this facial approximation examination of the remains showed the right medial canthial tendon to be still present within the lacrimal fossa at approximately 11.5mm below the nasion, though

this may not correspond to the exact antemortem location due to taphonomic processes.

Stephan and Donaldson [35] also verify the legacy recommendation that the tendon of the lateral canthus corresponds to the location of the malar tubercle on the lateral orbital wall [37], but for this approximation these were too indistinct to refer to with confidence. Instead the exocanthion is located in accordance with Stephan and Donaldson's [35] recorded average of 7.9mm below the frontozygomatic suture, which is somewhat less than the legacy forensic recommendation of 9.5mm for females [37].

Maximum eyeball protrusion has, traditionally, been taken to correspond to a line connecting the superior and inferior anterior orbital rims [4]. Two studies have found this legacy recommendation to be incorrect. A review of published exophthalmometric measures [38], which included an MRI study (n=79), found average eyeball protrusion to exceed the legacy recommendation by 3.7mm, and a later examination of MRI scans [39] (N=39: 11M, 28F; 60-90yrs), resulted in a similar level of greater eyeball protrusion (3.8mm). For this approximation the projection of the right lateral eyeball is taken to be 3.8mm beyond a line connecting the orbital rims (Figure 3).

Other recommendations used here for approximating the eyes include an average iris diameter of 10-12mm [40], and an iris colour that is a neutral greyscale shade, and therefore possibly capable of being perceived as a range of hues [17]. It is also possible that the crease of the upper lid and the suggestion of the shape of the eyebrows may follow the shape of the superior orbital rim [37], though these relationships are as yet unverified by modern methods. A somewhat verified relationship regarding the eyebrows does, however, exist. Stephan [41] measured eyebrow placement and found that for 70-80% of the young adults studied (N=128: 54M, 74F, 18-30 years), the eyebrow peak is located between the medial border of the iris

and the exocanthion, and that, overall, the peak is located 2.7mm lateral to the medial border of the iris. However, given the standard deviations are very high Stephan does not recommend this as a valid guideline for a facial approximation, except in a very general sense. For this approximation the eyebrow follows the general shape of the superior orbital rim, the peak is rendered fairly indistinct, and in the final result only the left eyebrow peak is visible, located just lateral to the medial iris (Figure 2). Although, as stated, the relationship of the eyebrow to the orbital rim is unverified, a face perception study finds that while an absence of eyebrows deleteriously impacts on familiar face recognition, even a highly stylised indication of eyebrow in the region of the brow ridge restores recognisability [42]. This suggests that an unverified approximate location is better than none.

Facial Features: Nose

Lateral nasal projection for this approximation was calculated using the algorithms derived by Rynn *et al.* [43], whose research findings also add verification to a number of Gerasimov's recommendations for approximating nasal shapes [1, 2]. Because, in this instance, the most anterior part of the nasal spine is possibly missing (which is a common occurrence given the delicacy and location of this feature), the height nasion-acanthion was taken as an approximate mean value within an arc of possible nasal spine tip locations ($\pm 0.5\text{mm}$), and lateral nasal dimensions were calculated as follows:

- $[(\text{rhinion-subnasale } 32.6\text{mm}) * 0.83] - 3.5 = 23.5\text{mm}$ anterior projection from the nasion-prosthion plane (valid for all populations studied)
- $[(\text{nasion-acanthion } 46\text{mm}) * 0.9] - 2 = 39.4\text{mm}$ vertical projection parallel to the nasion-prosthion plane (valid for all populations studied)
- $[(\text{nasion-subnasale } 49.7\text{mm}) * 0.74] + 3.5 = 40.3\text{mm}$ nasal length from the soft tissue nasion to nasal tip (valid for European populations only)

- $[(\text{nasion-subnasale } 49.7\text{mm}) * 0.63] + 17 = 48.3\text{mm}$ nasal height from the soft tissue nasion to subnasal (valid for female European populations only)
- $[(\text{rhinion-subnasale } 32.6\text{mm}) * 0.5] + 1.5 = 18\text{mm}$ nasal depth from the nasal tip to soft tissue subnasal (valid for female European populations only).

Rynn *et al.*'s [43] findings are derived from CT scans and cephalograms ($N=139$, <50 years), and also show that maximum nasal aperture width is approximately $\frac{3}{5}$ the width of the fleshed nose, which in this instance results in a maximum nasal width of 33mm. This finding is particularly useful as an earlier study [44] only tested this relationship with 'white' ($n=73$) and 'black' ($n=109$) males, and found that while the $\frac{3}{5}$ rule was statistically valid for 'blacks', this did not hold true for 'whites'. Other relationships verified by Rynn *et al.* [43] are that (i) the maximum extent of the ala is approximately 6mm beyond the most posterior point on the lateral wall of the nasal aperture, (ii) maximum ala height corresponds, approximately, to the crista conchalis on the lateral wall of nasal aperture, (iii) maximum ala depth is 4mm beneath the lowest point on the curve of the lateral aperture border; (iv) the shape of the alar groove generally corresponds with the lateral curve of the aperture, and, (v) as a general rule, 'angular' nasal apertures tend to have a pointed or angled nasal tip, and 'rounded' apertures, rounded tips.

For this approximation, and in other applications of this method [16, 22, 23], Rynn *et al.*'s [43] relationships relating to the shape of the lateral walls of the nasal aperture and the shapes of the nasal wings and tip are taken much more literally than the authors likely intended. This is because to approximate a more general relationship would require a speculative morphological modification, and a literal interpretation removes the need for such speculation. A further point is that this approximation uses the general direction of the

anterior nasal spine to approximate nasal tip location, as per Gerasimov's 'two tangent' method [1, 2], and as applied by Rynn *et al.* [43]. It transpires, however, that this is a common misunderstanding resulting from a mistranslation. Gerasimov's method actually involves the direction of the nasal aperture base, lateral to the nasal spine [45], and not the anterior nasal spine itself.

Overall the results of this approximation suggest this young woman likely had a straight nose with a relatively wide base, a slight degree of undulation in the nasal profile, and fairly high, and long, nasal wings. Because the canine fossae are fairly deep (R:9.2mm; L:7.8mm) then it may be that the naso-labial folds were reasonably marked at the start of the nasal wings [37], but this relationship is as yet unverified. The shape of the nasal tip may also be related to the shape of the nasal spine [17] but again, this relationship is yet to be reliably tested. There is also some suggestion by the shape of the lateral borders of the nasal aperture, and the position of the vomer (though this could be a taphonomic artefact), that the left nasal chamber is slightly wider than the right.

Facial Features: Mouth

Unfortunately the upper and lower central incisors were lost post-mortem and not recovered from the scene. Therefore, to approximate the angle of the upper central incisors a probe was positioned within the centre of the left upper incisor socket (in accordance with previous research [16] and with the agreement of the DOFM Forensic Odontologist). The resulting angle of the probe (Figure 3, lateral) suggests normal anterior occlusion for a female of European population affinity.

Another popular forensic recommendation is that mouth width is, for European populations, equivalent to interpupillary width [4]. This has been invalidated [46, 47]. However, two metric relationships for calculating mouth width have been derived from living populations. One includes interpupillary width $((\text{intercanine width}) + 0.57 * [(\text{interpupillary width}) - (\text{intercanine width})])$ [46]), which is dependent on an accurate location of the eyeball/iris within the orbits, and one showing intercanine width is approximately 75% mouth width [48]. For this approximation these calculations are necessarily highly approximate, as the upper left canine was also not recovered from the scene. However, using an estimated intercanine width of 36.3mm, both of these algorithms produce similar results (48.3mm and 48.4mm respectively).

A further verified skeletal relationship, which is very useful for approximations involving postmortem tooth loss, as in the case here, involves the location of the infraorbital and mental foramen. Stephan and Murphy [49] conducted a cadaveric study and added further verification to earlier research by Song *et al.* [50] who found that mouth corners tend to be located on the same vertical plane as the inferior orbital foramen, and that the mental foramen is, on average, approximately 20mm from the oral fissure [50]. For this approximation the inferior orbital foramen also aligns with the medial edge of the iris, which has been found to work moderately well to estimate mouth width in living European subjects [46]. To allow for a slightly wider mouth, given the estimated intercanine width suggests this may well be the case, and that the eyeballs have been positioned 1.3mm less laterally than the research recommends (see above, and refer [35, 36]), the visible mouth corners radiate slightly out from the width indicated by the foramen/medial iris in the rendering of the surface appearance (Figure 2).

The oral fissure is popularly understood to lie approximately $\frac{3}{4}$ down the length of the upper central incisors [17], which is close to the anatomical location of slightly superior to the incisal edges of the anterior maxillary teeth [24]. In this instance, the oral fissure was approximated in reference to the edge the upper left lateral incisor, which is the only anterior maxillary tooth remaining. As can be seen (Figure 3, frontal), the right and left mental foramen are asymmetrically located, but both right and left distances between the foramina and this approximate location for the oral fissure (R:22mm; L:19mm) are within the range identified by Song *et al.* [50] (mean 20.9mm, *s* 3.8mm).

Calculation of the heights of the vermilion followed research undertaken on living subjects (N=95) [47], which derived the following formulae for adults of European population affinity:

$$\text{upper vermilion height} = [(0.6 * \text{upper central incisor height}) + 0.4]$$

$$\text{lower vermilion height} = [(0.4 * \text{lower central incisor height}) + 5.5].$$

However, and again because of the absence of the central incisors, vermilion heights were estimated for this approximation referring to the upper and lower height averages also reported in this study (5.8mm and 8.7mm).

Other recommendations used for approximating the shape of the mouth include a suggestion that the shape of the vermilion border may possibly be related to the shape of the alveolar border [47]. In this case neither the canines nor the central incisors predominate and therefore both the upper and lower vermilion borders were approximated as fairly flat. Philtral width is understood to possibly correspond to the distance between the centres of the maxillary central incisors [37], but here philtral width was estimated using the centre of the upper central incisor sockets.

Facial features: Ears

For this approximation the tragus is located in relation to the external auditory meatus [29], and ear height (58mm) is taken to be closely equivalent to the anthropometrically verified average soft tissue distance subnasale-menton [51]. Recommendations within the forensic literature involve a relationship between ear morphology and the shape of the mastoid process/angle of the ramus [2, 37], however recent research shows these relationships are statistically invalid [52]. As can be seen, ear shape is minimally approximated here (Figure 4) and not visible in the image released to the media (Figure 2).

Head Shape, Cranial and Facial Indices

Overall, this young woman's skull is fairly symmetrical, with the right hemiface tending to display slightly larger measures and angles than the left. The Cranial Index is 73.8 (dolicocephalic head form) which according to Enlow and Hans [53] is often associated with a long/narrow and possibly protrusive face – which is not the finding here. Overall facial shape, however, is largely determined by the coronal arc of the cranium together with the height of the mandibular ramus and angle of the gonion. In this instance, head shape is comprised of an oval upper head culminating in a short/square jaw. Unverified recommendations are that gonial angles of less than 125° (in this case R: 110.9° ; L: 110.7°) coupled with a wide and low coronoid process is indicative of a round or rectangular lower face shape [37]. As can be seen (Figure 4), the shape of the upper head is approximated closely following the shape of the underlying bone, approximately 5mm superior to the bone from the superior temporal lines (in accordance with the average soft tissue depths for the vertex). This is unrealistic, as the surface of the skin is likely smoother than this

representation, but smoothing the flesh would involve an unnecessary element of speculation given head hair is to be added to the final result (Figure 2).

In order to provide an overall description of this young woman's possible facial appearance, facial indices (Table 2) were determined for overall face shape and the features, with reference to those provided by George [54]. These indices were calculated from the surface landmarks, and not their bony orientations, as these differ according to the angle of the soft tissue depth (refer Figure 2, in particular lateral view). The facial indices suggest that, relative to the average, this young woman had a wide face, wide jaw, and wide-spaced eyes, a long nose, short upper and lower lip (nose to mouth, and mouth to start of chin), and the suggestion of a high chin.

Surface Appearance

Prior to rendering the surface appearance, photographs of young adult individuals were examined, together with 25 reference images displaying similar facial proportions, face and/or individual feature shapes, and sub-aspects of feature shapes to that suggested by the foregoing. All resulting approximated features were checked against both the technical and anatomical layers (Figures 3 and 4), and an initial draft was forwarded to the NSW police officers for input as to whether the surface appearance appropriately captured the age range as determined by the DOFM forensic consultants (15-25 years). The initial appearance was considered to suggest a face that was too old (appearing more towards mid-20s), and therefore the surface skin was reworked referring to some younger reference images and the overall level of tonal shading was reduced. The surface appearance was then rendered to be further indistinct using a composite layer incorporating both the Texture Grain and Film Grain Adobe Photoshop CS2 filters. As has been argued for previous archaeological facial

approximations of anatomically modern humans [16, 22, 55, 56], it is important to render the surface appearance with some degree of 'sketchiness'. This is not just because of the approximate nature of the results, but also because a less precise image may also allow for a broader interpretation of the applied methods, which are, after all, for the most part statistical averages. However, whether this is actually the case is as yet unverified.

The remains of the hair were measured and photographed at the DOFM using a Nikon D200, and the hair lengths were found to fall into the following clusters: 22 and 23cm; 12, 13 and 14cm; 7.5 and 8cm. Because these lengths suggest a hair style, it was agreed that consultation with a hairdresser was both appropriate and desirable. The hairdresser, who at the time had over thirty years' full time professional experience in both Australia and the United Kingdom, was advised that this related to a case which occurred sometime during 2000-2010, and was shown photographs of the hair. The hairdresser was also supplied with a summary sheet displaying overall face shape (hairdressing training literature advocates particular styles for different facial shapes [57]), the range of hair lengths, and tonal variation as indicated using the Adobe Photoshop CS2 eyedropper tool (Figure 5).

The advice following this consultation was that given the appearance of the hair mass (dense), texture (coarse), shape (straight), and the range of lengths, the style which best accorded with the remains and was the most popular during the period for both teenagers and young women was a choppily layered style that included a long and large side fringe. The hairdresser supplied an image best illustrating the style, and this was applied to the approximation but warped, 'coloured' and retextured within Adobe Photoshop CS2. This consultation was beneficial, not just because an experience-based style was able to be associated with the remains of hair, but also because two assumptions to do with hair style

and hair morphology were found to be potentially misleading. These were that, for this style at least, the maximum lengths of hair would have originated at the nape, and not the vertex, and that while the remains of hair appear wavy, the hairdresser's experience was that all hair, including straight hair, has a tendency to curl after it has been removed from the head. A further point is that after the final result had been submitted (see below), a review of Australian missing persons images published on the internet was undertaken to see whether this hair style was common during the decade. Although this review did show that most of the young women tended to be depicted with a less styled appearance, a young Finnish exchange student who went temporarily missing in March 2011 [58] was found to display a similar hair style – and, indeed, similar facial proportions.

There has been an indication that a facial approximation is better identified without head hair [6], but this could be due to this study involving recognition by participants unfamiliar with the deceased. Face recognition research suggests that while unfamiliar face recognition (as in face matching trials) uses similarity of hair style to identify an unknown individual, this does not hold for familiar face recognition (i.e. friends, family and colleagues) [59]. However, a more recent study has also found that hairlessness improves recognition of a facial approximation, which in this instance was performed on a CT scan of a living subject, and the recognition tests involved a pool of familiar assessors [60]. There are, however, underlying methodological issues associated with this study, and the companion paper describing how the facial appearance was achieved is one of the articles critically evaluated in the literature review below.

Report and Media Release

On 26th September 2011 a report of the methods (including Figures 3-5, Tables 1 and 2) and initial result (Figure 6) was forwarded to the police officers and the forensic team for their response, and as a consequence the facial approximation was further modified to adjust the tonal values of the lower vermillion and lip, give greater exposure to the right cheek and jaw line, and lighten the overall hair shade. The modified result was forwarded to the team on 12th October, and accepted as a final result on 17th October 2011 (Figure 2).

To maximise public exposure (i.e. avoiding Australian public and school holiday periods) the image was released by the NSW Police on Friday, 2nd December 2011, which attracted national television, radio and newspaper coverage. As requested, the official release described the image as a “facial approximation” (e.g. [61]), rather than the more popular term, “facial reconstruction”. As has been convincingly argued elsewhere [18, 21, 62, 63], referring to the process and results as a “facial reconstruction” is not desirable. This is because firstly, within medico-dental and archaeological science ‘facial reconstruction’ is restoration of the skull following injury and/or taphonomic processes. Secondly, given its dependence on known averages of craniofacial variation, and that some of the legacy recommendations have yet to be verified, facial approximation is a far more accurate description of both the methods and the results. Related to this, there is a further advantage. Because in both the original media release, and in all subsequent coverage, the NSW Police refer to a facial approximation, this has enabled the results to be more clearly, and easily, distinguished in the public eye from popular fiction, where a ‘forensic facial reconstruction’ is achieved somewhat miraculously.

In the intervening period since the initial release the image continues to be intermittently broadcast in the media (newspapers, magazines, television), and continues to evoke new

leads to identification. Although to date there have been over 130 new leads generated, these have yet to prove successful. The role of a facial approximation in identification is understood to be largely due to chance circumstances, and unrelated to either the accuracy or quality of the likeness produced [6, 64, 65]. However, as the remains were discovered in Belanglo State Forest, which is indelibly associated with the “back-packer murders” of the early 1990s, it is as yet unknown whether this young woman continues to be unidentified due to the happenstance of international, as well as local, circumstances.

Literature Review

Papers identified for this literature review were sourced on 10th August 2013 through the international academic research databases, *Web of Science* and *Scopus*. This search was for the period 2000-2013 inclusive, using the topic search terms ‘forensic’ + ‘facial reconstruction’ OR ‘facial approximation’, and refined so that only peer reviewed articles (and not conference proceedings) were displayed. This produced over 100 results for each search, which were then further refined by only retaining those publications that included undertaking a facial approximation using methods which are analogous to those described in this paper. That is, involving some degree of manual manipulation to achieve the final result, whether in 3D, 2D, or virtually, using 3D and/or 2D computer graphics, and excluding those publications describing computerised facial approximations that are methodologically fully automated (e.g.[66]).

This search resulted in 15 articles, which were further refined as the facial approximations contained in two research papers [60, 67] were already reported in earlier publications, and of the three articles indexed in *Scopus*, but not *Web of Science* [14, 68, 69], one publication was only available in Spanish [69], and another could not be located in any academic journal

database [68]. Of the eleven remaining journal articles constituting this review, only one publication [6] includes an actual case – that is, a facial approximation undertaken for the purposes of actual forensic identification. The remaining publications describe facial approximations undertaken as a laboratory exercise, and applied to unique skulls sourced from past forensic cases, cadavers, anatomical collections, and living individuals. These articles are summarised, with specific attention to the methods cited to achieve an approximate facial appearance, in Table 3. As there is often, for various reasons, a significant period between when the research article was submitted for peer review and the actual date of publication, these papers are listed according to their date of submission (which thereby reasonably limits expectations as to how much the facial approximation practitioner was likely to know regarding verified skull/soft tissue relationships).

Discussion

This paper presents the methods used to approximate the facial appearance of a young woman whose remains were found in Belanglo State Forest, New South Wales (NSW) in August 2010. The approximation was commenced on 29th August 2011, and the results, together with a methodological report, was submitted to the NSW Police, the Head of Forensic Medicine (Glebe, NSW), the Forensic Odontologist and Forensic Anthropologist on 26th September, 2011, and resubmitted with refinements on 14th October 2011. The image was released to the media on 2nd December 2011, and since this initial release has assisted in producing over 130 new individual leads. At the time of writing, however, none have proven identification. Naturally, it would be far preferable to present this case after this young woman has been identified. It is, however, possible that this may never happen, and furthermore, to only present results that are accompanied by a successful identification has been criticised as self-aggrandising [62]. A further point is that this facial approximation is

essentially a hypothesis based on the evidence available at the time, and other interpretations, of both the skull and the methods, are both possible and justifiable.

Since 2000 only one actual forensic facial approximation [6] has been listed in the *Web Of Science* and *Scopus* indexed academic journals (however it is likely that forensic cases are presented in the two papers unable to be reviewed [68, 69]). This forensic case was undertaken in 1999 (five years before the paper was submitted for publication) and the individual was identified both by other means and before the facial approximation could be released to the media. All of the other papers (n=10) are laboratory-based exercises [5, 7-15]. As can be seen (Table 3) the time scale for achieving the facial approximations reviewed is 1999-2012, and there is a reasonable level of international representation (Australia, Brazil, France, Korea, The Netherlands, UK and USA), with Carl Stephan being the most frequently published author (n=4), though only in the earlier papers does he himself carry out the approximations of the individuals depicted.

Within the eleven papers reviewed the facial approximations are based on skulls attained through a range of different means: past forensic cases with antemortem images of the deceased (n=4), an anonymous skull (n=1), photographed and then defleshed cadavers (n=1), existent medical CT scans of living individuals (n=4), and somewhat disturbingly, cone beam CT scans taken from student volunteers (n=1).

Most of the laboratory-based facial approximations reviewed were undertaken to assess recognition and/or accuracy, and the only actual forensic case is similarly embedded within these concerns (n=10). There is also a frequent interest in exploring the results achieved by different practitioners, different soft tissue depths, and different media (n=7), and in some

papers these foci (accuracy/recognisability and methodological variation) are combined.

There is a marked preference for undertaking a 3D facial approximation using clay ($n=8$); 2D manual drawing methods are only used on two occasions. Virtual facial approximations are fairly frequent ($n=5$), but vary between relatively simple warping methods to a haptic application of virtual 3D clay. Images accompanying the methods reviewed are most often an illustration of the final result and an antemortem image of the individual approximated ($n=7$), though some papers also include the skull and soft tissue depths ($n=5$), and, if applied, the underlying anatomy ($n=5$). Two publications contain no images of the facial approximations whatsoever [8, 9].

Given the focus of these studies is predominantly a concern with accuracy (how close the result matches images of the approximated individual), and/or manipulating some of the variables by which the approximation was undertaken, then it would be reasonable to expect that the methodology used to carry out these approximations would be presented in some detail, and moreover, that these methods would show a high level of engagement with published verified skull-soft tissue relationships. Surprisingly, this is not the case.

Most of the articles reviewed include at least one citation concerning the soft tissue depths applied, and as can be seen (Table 3) the most popular is Helmer's ultrasound study followed by Rhine and Moore's cadaveric results, both of which are derived from a comparatively small number of individuals further divided by age, sex, and body mass. None apply Stephan and Simpson's [20] weighted means, but most of the facial approximations reviewed were accomplished prior to their publication in 2008.

How the facial features were achieved is less well accounted for. Interestingly, the most detailed facial approximation methods section occurs in the earliest paper reviewed [5], which is also the only paper that includes an illustration of the actual method used to approximate a facial feature (lateral nasal projection). A moderate level of justification is also present in three subsequent publications including the same co-author, who is also responsible for publishing the one and only actual forensic facial approximation [6, 7, 10]. For the remaining papers (n=8) the methods sections are considerably less informative regarding how the facial approximations were achieved. Some of the methodological justifications are eclectic [9], contradictory [12], many are fairly minimal [8, 11, 13-15], and in one paper the entirety is covered by a single sentence: “[t]he American method was used to create the facial reconstructions”, with no supporting citation as to which American this may refer to [11]. In two of the articles reviewed, the facial approximation practitioners are also authors of popular forensic texts, and therefore it is to an extent understandable that in both articles these popular texts constitute the sole methodological reference for the facial features [15, 27].

It is understandable that research conducted prior to publication of validated skull-soft tissue relationships would rely on the available recommendations of the time, and there is a tendency for many of the methods reviewed to cite the popular recommendations provided by Neave in 1997 [3] and Taylor in 2001 [17], both of whom are highly experienced forensic practitioners and without a doubt both produce very effective results. It is likely, however, that it is their extensive experience that contributes to this success, as for the most part their methodological recommendations are those which have since been proven invalid. Verified recommendations for approximating the eyes and eyebrows have been in existence since 2002 [38, 41], with further verified relationships regarding the eyes and mouth appearing in

2003 [39, 46-48]. Eight of the eleven publications reviewed here were submitted for publication after 2004, but only three facial approximations include application of some of these verified relationships [7, 10, 14]. Furthermore, and somewhat inexplicably, an approximation submitted for publication in 2010 [12] directly references two validated relationships by Wilkinson and colleagues for approximating the eyes [39] and mouth [47] in the methodology section, but the approximations of these features are described according to invalidated legacy recommendations.

Were the papers reviewed only tangentially concerned with facial approximation as it is applied in a forensic context, then the scarcity of methodological explanation and the enduring preference for applying invalidated methods would not really be of concern. However, all of the papers reviewed are explicitly positioned as presenting research findings that will advance this field, and furthermore, nearly all of these findings are addressing issues of facial approximation accuracy. It is hard to understand, therefore, quite why there is what appears to be a marked disengagement with the methodological research which has been undertaken within the field, and/or an unwillingness to explain what methods have been applied, and in particular how the facial features (e.g. eyes, nose, mouth, ears) were achieved. Perhaps these issues are related, but either way, it is arguable that research findings submitted for publication after 2004 that are based on facial approximations using invalidated skull-soft tissue relationships are presenting 'accuracy' findings predicated on unnecessarily unreliable premises.

Conclusion

The method used for this facial approximation of a young woman whose remains were found in Belanglo State Forest in 2011 is computer graphic, based on 2D orthogonal images of the

skull and incorporating an anatomical build-up within soft tissue depths. The main advantages of this approach are that it (i) facilitates collaborative input from the police as well as forensic specialists; (ii) involves minimal contact with the remains, thereby avoiding potential damage and further contamination; (iii) uses readily available technologies that are both affordable and easily transportable for working *in situ* with the remains; and, (iv) is evidence-based. That is, is methodologically transparent, with each aspect of the process able to be clearly justified through reference to a comparative wealth of verified skull/soft tissue relationships.

References

- [1] Gerasimov MM. *The Face Finder*. Philadelphia: J.B. Lippincott; 1971.
- [2] Gerasimov MM. *The Reconstruction of the Face from the Basic Structure of the Skull*. Moscow: Nauka; 1955.
- [3] Prag J, Neave R. *Making Faces: Using Forensic and Archaeological Evidence*. London: British Museum Press; 1997.
- [4] Krogman WM, Iscan MY. *The Human Skeleton in Forensic Medicine*. 2nd edition ed. Springfield: Charles C Thomas; 1986.
- [5] Stephan CN, Henneberg M. Building faces from dry skulls: are they recognized above chance rates? *J Forensic Sci*. 2001;46:432-40.
- [6] Stephan CN, Henneberg M. Recognition by forensic facial approximation: case specific examples and empirical tests. *Forensic Sci Int*. 2006;156:182-91.
- [7] Stephan CN, Arthur RS. Assessing facial approximation accuracy: how do resemblance ratings of disparate faces compare to recognition tests? *Forensic Sci Int*. 2006;159, Supplement:S159-S63.
- [8] Starbuck JM, Ward RE. The affect of tissue depth variation on craniofacial reconstructions. *Forensic Sci Int*. 2007;172:130-6.
- [9] Quatrehomme G, Balaguer T, Staccini P, Alunni-Perret V. Assessment of the accuracy of three-dimensional manual craniofacial reconstruction: a series of 25 controlled cases. *Int J Legal Med*. 2007;121:469-75.
- [10] Stephan CN, Cicolini J. Measuring the accuracy of facial approximations: a comparative study of resemblance rating and face array methods. *J Forensic Sci*. 2008;53:58-64.
- [11] Fernandes CMS, da Costa Serra M, da Silva JVL, Yoshito Noritomi P, de Sena Pereira FDA, Melani RFH. Tests of one Brazilian facial reconstruction method using three soft tissue depth sets and familiar assessors. *Forensic Sci Int*. 2012;214:211.e1-.e7.
- [12] Lee W-J, Wilkinson CM, Hwang H-S. An accuracy assessment of forensic computerized facial reconstruction employing cone-beam computed tomography from live subjects. *J Forensic Sci*. 2012;57:318-27.
- [13] Decker S, Ford J, Davy-Jow S, Faraut P, Neville W, Hilbelink D. Who is this person? a comparison study of current three-dimensional facial approximation methods. *Forensic Sci Int*. 2013;229:161.e1-.e8.
- [14] Wilkinson C, Rynn C, Peters H, Taister M, Kau CH, Richmond S. A blind accuracy assessment of computer-modeled forensic facial reconstruction using computed tomography data from live subjects. *Forensic Science, Medicine, and Pathology*. 2006;2:179-87.
- [15] van der Wal KG, Neave RA, van der Biezen JJ, van der Kuijl B. Facial reconstruction on the abnormal skull model of a living patient. *Cleft Palate–Craniofacial Journal*. 2001;38:317-22.
- [16] Hayes S, Buckley H, Bradley R, Milne N, Dennison J. Approximating the face of 'Aunt': a question of likeness. *Journal of Archaeological Method and Theory*. 2012;19:306-21.
- [17] Taylor KT. *Forensic Art and Illustration*. Boca Raton: CRC Press; 2001.
- [18] Reichs KJ, Craig E. Facial approximation: procedures and pitfalls. In: Reichs KJ, editor. *Forensic Osteology: Advances in the Identification of Human Remains*. 2nd ed. Springfield: Charles C Thomas; 1998. p. 491-513.
- [19] Johnson A, Wildgoose D, Wood D. The determination of freeway space using two different methods. *J Oral Rehabil*. 2002;29:1010-3.

- [20] Stephan CN, Simpson EK. Facial soft tissue depths in craniofacial identification (part 1): an analytical review of the published adult data. *J Forensic Sci.* 2008;53:1257-72.
- [21] George RM. Anatomical and artistic guidelines for forensic facial reconstruction. In: Iscan MY, Helmer RP, editors. *Forensic Analysis of the Skull: Craniofacial Analysis, Reconstruction, and Identification*. New York: Wiley-Liss; 1993. p. 215-27.
- [22] Hayes S. A man from San Juan: facial approximation within anthropology (Un hombre de San Juan: aproximación facial dentro de la antropología). *Revista Argentina de Antropología Biológica.* 2011;13:71-81.
- [23] Hayes S, Sutikna T, Morwood M. Faces of *Homo floresiensis* (LB1). *Journal of Archaeological Science.* 2013;40:4400-10.
- [24] Standring S. *Gray's Anatomy: The Anatomical Basis of Clinical Practice*. Elsevier; 2008.
- [25] Stephan CN, Devine M. The superficial temporal fat pad and its ramifications for temporalis muscle construction in facial approximation. *Forensic Sci Int.* 2009;191:70-9.
- [26] Stephan CN. The human masseter muscle and its biological correlates: a review of published data pertinent to face prediction. *Forensic Sci Int.* 2010;201:153-9.
- [27] Wilkinson C. *Forensic Facial Reconstruction*. Cambridge: Cambridge University Press; 2004.
- [28] Warwick R, Williams P. *Gray's Anatomy*. 35 ed. Edinburgh: Longman; 1973.
- [29] Romanes GJ. *Cunningham's Manual of Practical Anatomy. Volume 3: Head and neck and brain*. 15th ed. Oxford: Oxford University Press; 1986.
- [30] Paff GH. *Anatomy of the Head and Neck*. Philadelphia: W.B. Saunders; 1973.
- [31] Grant JCB. *An Atlas of Anatomy*. Baltimore: Williams and Wilkins; 1943.
- [32] Wolff E. *The Anatomy of the Eye and Orbit*. 3rd ed. London: H.K. Lewis; 1948.
- [33] Guyomarc'h P, Dutailly B, Couture C, Coqueugniot H. Anatomical placement of the human eyeball in the orbit - validation using CT Scans of living adults and prediction for facial approximation. *J Forensic Sci.* 2012:1271-5.
- [34] Gatliff BP, Snow CC. From skull to visage. *J Biocommun.* 1979;6:27-30.
- [35] Stephan C, Davidson PL. The placement of the human eyeball and canthi in craniofacial identification. *J Forensic Sci.* 2008;53:612-9.
- [36] Stephan CN, Huang AJR, Davidson PL. Further evidence on the anatomical placement of the human eyeball for facial approximation and craniofacial superimposition. *J Forensic Sci.* 2009;54:267-9.
- [37] Fedosyutkin B, Nainys J. The relationship of skull morphology to facial features. In: Iscan MY, Helmer RP, editors. *Forensic Analysis of the Skull: Craniofacial Analysis, Reconstruction, and Identification*. New York: Wiley-Liss; 1993. p. 119-213.
- [38] Stephan CN. Facial approximation: globe projection guideline falsified by exophthalmometry literature. *J Forensic Sci.* 2002;47:730-5.
- [39] Wilkinson C, Mautner S, A. Measurement of eyeball protrusion and its application in facial reconstruction. *J Forensic Sci.* 2003;48:12-6.
- [40] Larrabee W, Makielski K. *Surgical Anatomy of the Face*. New York: Raven; 1993.
- [41] Stephan CN. Position of superciliare in relation to the lateral iris: testing a suggested facial approximation guideline. *Forensic Sci Int.* 2002:29-33.
- [42] White M. Removing eyebrows impairs recognition of famous faces, or doesn't, depending on how the eyebrows are removed. *Perception.* 2004;33:1215-20.
- [43] Rynn C, Wilkinson M, Peters H. Prediction of nasal morphology from the skull. *Forensic Science, Medicine and Pathology.* 2010;6:20.
- [44] Hoffman BE, McConathy DA, Coward M, Saddler L. Relationship between the priform aperture and interalar nasal widths in adult males. *J Forensic Sci.* 1991;36:1152-61.

- [45] Ullrich H, Stephan C. On Gerasimov's plastic facial reconstruction technique: new insights to facilitate repeatability. *J Forensic Sci.* 2011;56:470-4.
- [46] Stephan CN. Facial approximation: an evaluation of mouth-width determination. *Am J Phys Anthropol.* 2003;121:48-57.
- [47] Wilkinson C, Motwani M, Chaing E. The relationship between the soft tissues and the skeletal detail of the mouth. *J Forensic Sci.* 2003;48:728-32.
- [48] Stephan C, Henneberg M. Predicting mouth width from inter-canine width-a 75% rule. *J Forensic Sci.* 2003;48:725-7.
- [49] Stephan C, Murphy S. Mouth width prediction in craniofacial identification: cadaver tests of four recent methods, including two techniques for edentulous skulls. *J Forensic Odontostomatol.* 2008;27:2-7.
- [50] Song W-C, Kim S-H, Paik D-J, Han S-H. Location of the infraorbital and mental foramen with reference to the soft-tissue landmarks. *Plastic and reconstructive surgery (1963).* 2007;120:1343-7.
- [51] Farkas LG, Munro IR. *Anthropometric Facial Proportions in Medicine.* Springfield: Charles C Thomas; 1987.
- [52] Guyomarc'h P, Stephan CN. The validity of ear prediction guidelines used in facial approximation. *J Forensic Sci.* 2012:1427-41.
- [53] Enlow DH, Hans MG. *Essentials of Facial Growth.* Philadelphia: WB Saunders; 1996.
- [54] George RM. *Facial Geometry: Graphic Facial Analysis for Forensic Artists.* Springfield Illinois: Charles C Thomas; 2007.
- [55] Hayes S, Taylor RG, Paterson A. Forensic facial approximation: an overview of current methods used at the Victorian Institute of Forensic Medicine/Victoria Police Criminal Identification Squad. *The Journal of Forensic Odonto-Stomatology.* 2005;23:45-50.
- [56] Hayes S, Valentin F, Buckley H, Spriggs M, Bedford S. Faces of the Teouma Lapita people: art, accuracy and facial approximation. *Leonardo.* 2009;42:284-5.
- [57] Cole M. *Theory and Application Hairdressing Science.* Kensington, NSW: NSW University Press; 1979.
- [58] AAP. Search halted for missing Finnish exchange student. *Sydney Morning Herald.* Sydney: Fairfax Media; 2011.
- [59] Shepherd J, Davies G, Ellis H. Studies of cue saliency. In: Davies G, Ellis H, Shepherd J, editors. *Perceiving and Remembering Faces.* London: Academic Press; 1981. p. 105-31.
- [60] Fernandes CMS, Pereira FDAdS, da Silva JVL, Serra MdC. Is characterizing the digital forensic facial reconstruction with hair necessary? a familiar assessors' analysis. *Forensic Sci Int.* 2013;211.e1-e7.
- [61] Morri M. Police release woman's face after human bones were found in Belanglo State Forest *The Daily Telegraph.* Sydney: News Limited; 2011. p. <http://www.news.com.au/national-news/police-release-womans-face-after-human-bones-were-found-in-belanglo-state-forest/story-e6frfkvr-1226212134175>.
- [62] Stephan CN. Anthropological facial 'reconstruction' - recognizing the fallacies, 'unembracing' the errors, and realizing method limits. *Sci Justice.* 2003;43:193-200.
- [63] Taylor RG, Angel C. Facial reconstruction and approximation. In: Clement JG, Ranson DL, editors. *Craniofacial Identification in Forensic Medicine.* London: Arnold; 1998. p. 177-86.
- [64] Clement JG, Thomas CDL, Taylor RG, Craig PJG, Ismaniati N, Sheridan CS, et al. The dilemma of the forensic artist. *First International Conference on Forensic Human Identification.* London1999.
- [65] Stephan C. Facial approximation: a review of the current state of play for archaeologists. *International Journal of Osteoarchaeology.* 2005;15:298-302.

- [66] Claes P, Vandermeulen D, De Greef S, Willems G, Clement JG, Suetens P. Bayesian estimation of optimal craniofacial reconstructions. *Forensic Sci Int.* 2010;201:146-52.
- [67] Stephan CN, Cicolini J. The reproducibility of facial approximation accuracy results generated from photo-spread tests. *Forensic Sci Int.* 2010;201:133-7.
- [68] Mattoo KA, Budhiraja V. 3-dimensional facial reconstruction utilising clay. *Indian Journal of Forensic Medicine & Toxicology.* 2011;5:35-7.
- [69] Serrulla F, Gómez M. Aplicaciones de la técnica de aproximación facial forense en la identificación humana individual. *Cuadernos de Medicina Forense.* 2008;291-307.
- [70] Stewart TD. Identification by the skeletal structures. *Gradwohl's Legal Medicine 2nd ed* Camps, FE, ed Bristol: Wright. 1968:123-54.
- [71] Ubelaker DH, O'Donnell G. Computer-assisted facial reproduction. *J Forensic Sci.* 1992;37:155-62.
- [72] Perper JA, Patterson GT, Backner JS. Face imaging reconstructive morphography: a new method for physiognomic reconstruction. *The American Journal of Forensic Medicine and Pathology.* 1988;9:126-38.
- [73] Helmer R. Schadelidentifizierung durch elektronische bildmischung; zugleich beitr zur konstitutionsbiometrie U Dickermessung d Gesichtsweichteile. Heidelberg: Kriminalistik-Verlag; 1984.
- [74] Gatliff BP. Facial sculpture on the skull for identification. *The American Journal of Forensic Medicine and Pathology.* 1984;5:327-32.
- [75] George RM. The lateral craniographic method of facial reconstruction. *J Forensic Sci.* 1987;32:1305-30.
- [76] Caldwell MC. New questions (and some answers) on the facial reproduction techniques. In: Reichs KJ, editor. *Forensic Osteology: Advances in the Identification of Human Remains.* Springfield: Charles C Thomas; 1986. p. 229-55.
- [77] Angel J. Restoration of head and face for identification. 30th Annual Meeting of the American Academy of Forensic Sciences, 20–25 February. St. Louis, MO 1978.
- [78] Stewart T. The points of attachment of the palpebral ligaments: their use in facial reconstructions on the skull. *J Forensic Sci.* 1983;28:858-63.
- [79] Krogman W. *The Human Skeleton in Forensic Medicine.* Springfield: CC Thomas. 1962.
- [80] Manhein MH, Listi GA, Barsley RE, Musselman R, Barrow NE, Ubelaker DH. In vivo facial tissue depth measurements for children and adults. *J Forensic Sci.* 2000;45:48.
- [81] Wilkinson C. Virtual sculpture as a method of computerized facial reconstruction. *Proceedings of the 1st International Conference on Reconstruction of Soft Facial Parts.* Potsdam, Germany 2003. p. 59-63.
- [82] Taylor R, Craig P. The wisdom of bones: facial approximation on the skull. *Computer-graphic Facial Reconstruction: Access Online via Elsevier;* 2005. p. 34-56.
- [83] Farkas L, Forrest C, Litsas L. Revision of neoclassical facial canons in young adult Afro-Americans. *Aesthetic Plast Surg.* 2000;24:179-84.
- [84] Moore CE. A problem in human variation: the facial tissue thicknesses of Caucasoids, Negroids, and Mongoloids. Albuquerque: University of New Mexico; 1981.
- [85] Rhine JS, Moore CE, Weston J. *Facial Reproduction: Tables of facial tissue thicknesses of American Caucasoids in forensic anthropology;* Maxwell Museum of Anthropology, The University of New Mexico; 1982.
- [86] Quatrehomme G. *Reconstruction faciale: intérêt anthropologique et médico-légal;* University of Bordeaux I; 2000.
- [87] Macho GA. An appraisal of plastic reconstruction of the external nose. *J Forensic Sci.* 1986;31:1391-403.

- [88] Yoshino M, Seta S. Skull-photo superimposition. *Encyclopedia of Forensic Sciences*. 2000;2:807-15.
- [89] Aulsebrook W. Facial tissue thickness in facial reconstruction. *Encyclopedia of forensic sciences Academic Press, San Diego*. 2000:779-88.
- [90] Rogers SL. *Personal Identification from Human Remains*. Springfield, IL: Charles C. Thomas; 1987.
- [91] Rhine J, Moore C. *Reproduction tables of facial tissue thicknesses of American Caucasoids. Forensic Anthropology, Maxwell Technical Series I*. 1984.
- [92] Santos W. *Mensuracao de tecidos moles da face de brasileiros vivos em imagens multiplanares de Ressonancia Magnetica Nuclear (RMN) para fins medico-legais*. Ribeirao Preto: Universidade de Sao Paulo 2008.
- [93] Tedeschi-Oliveira SV. *Avaliação de medidas da espessura dos tecidos moles da face em uma amostra populacional atendida na Seção Técnica de Verificação de Óbitos do município de Guarulhos - São Paulo; Evaluation of facial soft-tissue thicknesses in a population attended by the Seção Técnica de Verificação de Óbitos of the city the Guarulhos-São Paulo [PhD]: Universidade de São Paulo; 2008.*
- [94] Lebedinskaya GV, Balueva TS, Veselovskaya EV. Principles of facial reconstruction. In: Iscan MY, Helmer RP, editors. *Forensic Analysis of the Skull: Craniofacial Analysis, Reconstruction, and Identification*. New York: Wiley-Liss; 1993. p. 183-98.
- [95] Tian S, Nishida Y, Isberg B, Lennerstrand G. MRI measurements of normal extraocular muscles and other orbital structures. *Graefes Arch Clin Exp Ophthalmol*. 2000;238:393-404.
- [96] Davy S, Gilbert T, Schofield D, Evison M. Forensic facial reconstruction using computer modeling software. In: Clement J, Marks M, editors. *Computer-graphic Facial Reconstruction*. Burlington, MA: Elsevier; 2005. p. 183-96.
- [97] Tu P, Book R, Liu X, Krahnstoever N, Adrian C, Williams P. Automatic face recognition from skeletal remains. *IEEE Conference on Computer Vision and Pattern Recognition: IEEE*; 2007. p. 1-7.
- [98] Domaracki M, Stephan CN. Facial soft tissue thicknesses in Australian adult cadavers. *J Forensic Sci*. 2006;51:5-10.

Figure 3

Table 1: Soft tissue depths (from Stephan and Simpson [21]).

Median points	Total Weighted Mean (mm)
Lateral view	
vertex	5
glabella	5.5
nasion	6.5
midnasal	4
rhinion	3
subnasale	13
midphiltrum	11.5
prosthion	11.5
lower lip	13
labiomentale	11
pogonion	11.5
gnathion	8.5
menton	7
Frontal view	
zygomatic	6
mid-ramus	17.5

Table 2: Facial indices (from George [55]).

	Index	Normal Range	Implication
Facial Length Index (nasion-menton/bizygomatic breadth)	81.09	81.50-90.86	Tending towards a wide face
Madibulo-Facial Index (bigonial width/bizygomatic width)	80.12	65.90-74.30	A wide jaw
Intercanthal Index (endocanthal width/exacanthal width)	40.49	34.30-38.40	Wide-spaced eyes
Nasal Length Index (nasion-subnasale/nasion-menton)	46.88	41.60-46.00	Tending towards a long nose
Nasal Width Index (ala-ala/nasion-subnasion)	65.34	59.30-69.40	Within normal range
Labial Index (lip height/lip width)	33	Europeans to 34.9	Approximated within normal range*
Upper Lip Length Index (subnasale-stomion/subnasale-menton)	25.48	28.50-33.70	A short upper lip (nose to mouth)
Lower Lip Length Index (stomion-labiamentale/subnasale-menton)	23.99	24.30-28.70	A short lower lip (mouth to start of chin)
Chin Height Index (labiamentale-menton/subnasale-menton)	50.61	41.20-47.60	A high chin

**This feature was not able to be calculated from the central incisors as these were lost post-mortem, and therefore lip heights and mouth width are highly approximate.*

Table 3: Forensic facial approximation journal articles reviewed¹ (2000-present, organised by date of submission).

Research Paper (year of publication)	Date Submitted	Country	Skull Context	Primary Focus of Research	Methods of Facial Approximation Used:			STD source	Sources Cited for Approximating Features
					Medium	Images	Approach		
Stephan & Henneberg (2001) [5]	10/1999	Australia	4 x past forensic cases	Method comparison for recognition	Clay Drawing Digital	One individual skull and four results	3D Stewart [70] 3D Neave [3] 2D drawing (uncited) 2D warping [71, 72]	Helmer [73]	Krogman [4], Gatliff [74], Neave [3], Neave personal communication, George [75], Feodosyutkin & Nainys [38], Caldwell [76], Angel [77], Stewart [78], Gerasimov [1]
van der Wal, Neave <i>et al</i> (2001) [16]	12/1999	The Netherlands & UK	1 x 3D print of CT scan of a living individual	Accuracy	Clay	Skull, STDs/underlying anatomy, final result, antemortem image	3D Neave [3]	None cited	Neave [3]
Stephan & Henneberg (2006) [6]	04/2004 (undertaken in 1999)	Australia	1 x forensic case study	Case study resemblance, recognition	Clay	Results hair, no hair, antemortem image	3D Combination [5]	Helmer [73]	Taylor & Angel [64], Hoffman & McConathy [45], Gatliff [74], Krogman [79], Taylor [18], Neave [3], Farkas & Munro [52]
Starbuck & Ward (2007) [9]	10/2005	USA	1 x skull	STD body mass variation	Clay	None	3D Taylor [18]	Rhine & Moore as reproduced in Taylor [18]	Taylor [18]
Stephan & Arthur (2006) [7]	03/2006	Australia	1 x past forensic case	Novice versus portrait for resemblance, recognition	Clay	Portrait, naive result, antemortem image	3D Neave [3]	Helmer [73]	Neave [3], Stephan [39, 47]
Wilkinson, Rynn <i>et al.</i> (2006)	03/2006	UK & USA	2 x CT scans of living individuals	Accuracy and recognition	Digital	Skull/STDs, underlying anatomy, results, antemortem CT scans	3D Neave [3]	Manhein <i>et al.</i> [80]	Wilkinson [28, 81]
Stephan & Cicolini (2008) [11]	03/2007	Australia	1 x past forensic case	Accuracy, resemblance, recognition	Clay	Skull/STDs, underlying anatomy, final result, antemortem image	3D Neave [3]	Helmer [73]	Taylor & Craig [83], Wilkinson [28], Stephan [39, 47], Wilkinson <i>et al.</i> [40], Stephan & Henneberg [49], George [75], Hoffman & McConathy [45], Gerasimov [1, 2], Feodosyutkin & Nainys [38], Stephan [42], Farkas <i>et al.</i> [84]
Quatrehomme, Balaguer <i>et al.</i> (2007) [10]	09/2006	France	25 x cadavers	Naive, novice, experienced and methodological variation for accuracy	Clay Drawing	None	3D (no method used) 3D (uncited) 2D Lateral [75]	Moore (PhD) [85] Rhine <i>et al.</i> [86] Quatrehomme (PhD) [87]	Krogman [4], Gatliff [35], Macho [88], Quatrehomme (PhD) [87], <i>Encyclopaedia of Forensic Sciences</i> [89, 90], Rogers [91], George [75]
Fernandes, da Costa Serra <i>et al.</i> (2012) [12]	04/2010	Brazil	1 x CT scan of a living individual	STD data comparison and familiar face recognition	Digital	Results x 3 STDs, target face	3D (no citations)	Rhine & Moore [92] Santos (MSc) [93] Tedeschi-Oliveira (PhD) [94]	None
Lee, Wilkinson <i>et al.</i> (2012) [13]	09/2010	Korea & UK	3 x CBCT scans of student volunteers	Accuracy	Digital	Skulls, build up, results, targets	3D Neave [3] and Wilkinson [28]	Lebedinskaya <i>et al.</i> [95]	Neave [3], Krogman [4], Tian <i>et al.</i> [96], Gatliff [74], Wilkinson <i>et al.</i> [40], Gerasimov [2], Angel [77], George [22], Wilkinson <i>et al.</i> [48], Fedosyutkin & Nainys [38]
Decker, Ford <i>et al.</i> (2013) [14]	11/2012	USA & UK	1 x CT scan and 3D print of a living individual	4 x practitioner and methodological variation for accuracy	Clay Digital	Skull (scan and print), build up, results, antemortem image	3D Taylor [18] <i>FaceIT</i> [97] <i>ReFace</i> [98]	Domaracki & Stephan [99] Rhine & Moore as reproduced in Taylor [18] Helmer [73]	Wilkinson [28], Taylor [18]

¹Refer to *Methods: Literature Review* for an explanation of the criteria used for the selection of publications constituting this review

Figure 1: NSW Police graphic reconstruction of the T-shirt found with the remains, which led to the deceased being referred to as 'Angel' in the media (reproduced with permission)

Figure 2: Facial approximation of 'Angel' as released to the media on 2nd December 2011

Figure 3: Frontal and left lateral anthropometric and morphological assessments used in this facial approximation

Figure 4: Frontal anatomical layers used in this facial approximation

Figure 5: Hair information sheet (approximate facial shape, hair lengths, sampled colours)

Figure 6: Draft facial approximation submitted to the NSW Police and forensic team for critical review on 26th September 2011