Title: Estimation and reconstruction of facial creases based on skull crease morphology

H. Hadi[1] and C. Wilkinson[2].

[1]*School of Health Sciences, Universiti Sains Malaysia, 16150 Kubang Kerian, Kelantan, MALAYSIA*

[2]*Centre for Anatomy and Human Identification (CAHID), University of Dundee, Dundee, DD1 5EH, UNITED KINGDOM*

Correspondence: Helmi Hadi (helmi_mhp@usm.my) Caroline Wilkinson (C.M.Wilkinson@dundee.ac.uk)

Title: Estimation and reconstruction of facial creases based on skull crease morphology

Abstract

This research explores the relationships between the facial creases and the morphology of the underlying skull for supplementary use during forensic facial reconstruction. The correlation between skull morphology and the patterns of facial creases was obtained using the three-dimensional (3D) skull surface scans from William Bass skeletal collection at the University of Tennessee, which also provided the related ante-mortem face photographs. Superimposition of the facial crease patterns seen in a face photograph with the related skull image enabled the visual analysis of the correlation between the crease and the skull morphology. Qualitative analysis indicated that the infraorbital crease follows the outline of the orbit in 52% of the subjects while the nasolabial fold (NLF) relates to the canine fossa in 95% of the subjects. The infraorbital crease and NLF were reconstructed in a blind study using ten 3D surface scan skull models and related face photographs from the Helmer collection available in the Centre for Anatomy and Human Identification, the University of Dundee. Correct prediction was obtained in six specimens (60%). One inconclusive result was due to poor photograph quality and three inaccurate results showed an overestimation of the NLF strength although the location of the crease manifestation was correct.

Keywords: Facial creases; Facial identification; Facial reconstruction; Skull morphology

Introduction

The applied value of utilising the relationship between the skull morphology and face photograph during forensic identification of human remains is well established since the landmark Ruxton case in 1935[16]. However, little research has been reported on the relationship between the creases seen in a face photograph and the underlying skull morphology. Although standards are lacking to categorise wrinkles, furrows and folds[22] which may be interchangeably used along with grooves on the face[7], yet synonymous terminologies such as infraorbital for nasojugal fold [36] or nasojugal groove[5] and nasolabial fold (NLF) for melolabial fold[2,14] or nasomandibular fold[32] or or nose-cheek fold ("smile line")[12] have gained acceptance in forensic anthropology. The NLF is manifested in most individuals face images and is a dynamic structure as it undergoes change during the growth period of an individual migrating to its configuration during adulthood[6]. Thereafter NLF or crease persists as a permanent mark engraved in the skin on a face unless physical deformities intervene and distort it.

In a study of smiling faces in repose by Yousif et al. [44], the NLF angle was characterised by the angle made to the y axis when a line was drawn through the middle of the NLF. The upper margin of the alar notch to the point of intersection with a horizontal line through the lateral commissure was measured as the length of the fold. They[44] mentioned that it was difficult to identify the nasolabial crease from subject's photographs even though they used multiple images from infancy to adulthood at ten year intervals. Uncontrollable lighting and the facial expression in the photographs were the major problems impeding identification of the NLF[44]. A study of the left NLF in a photo-anthropometry study of facial features on Black South African population[33] revealed that in their sample 76.5% did not reveal NLF[33], 9% had a long NLF with the rest having a short fold[33]. The lack of fold or the difficulty in diagnosing the fold in the above study may possibly be due to the prevalence of maxillary prognathism characterised by protrusion in faces and skulls[33]. It is also unclear why the left NLF alone was utilised for the above research instead of considering the NLF creases on both sides of the face. It is seen that NLF is commonly included as an observable feature in studies relating to face photographs[19].

While a majority of researchers used CT scans to scan the orbits and maxillae of living subjects[13,20,21,24,28,30,31,45], some have used MRI to measure the soft tissue thickness in the NLF[17]. In as much as conventional MRI and CT scans require the subjects to lie down, it is possible that the measurements recorded are influenced by the sagging of the skin due to lying posture wherein, the fat and skin of the face would be displaced due to the gravity acting posteriorly to the face. To simulate the effects of erect posture as in real life scenario where gravity is directed downwards on the face, [17] devised a support to the face while subjects lay ventrally. Although their study explored the histological constitutions of the NLF and not the hard tissue relationship to NLF.

Cadaver dissections have been carried out to find the relationship between the muscle structures and the NLF for cosmetic purposes[3,23,27,34,35,43], focusing on the muscles contributing to the fold[3,29] and the types of NLFs[29,46].

Three studies, all relying on cadaver dissection, have attempted to classify the angle of the NLF[29,35,46]. While [35] classify the shape of the NLF as being concave, straight or convex, no graphical representation of the shapes was included in their research. The lack of demonstrative models to standardise the classes has led to inconsistency in the classification[29,46]. Both studies agree with [35] that the nasolabial crease is either concave, straight or convex, but the classification of ‘convex’ and ‘concave’ is opposite in these studies. The research by [46] was conducted earlier compared to [29]. In dissections made on

50 hemifacial cadavers, convex type NLF was reported as the highest manifesting (60%) followed by straight (30%) and convex (10%). Short and extended creases by length were more frequent, 38% and 42% respectively while the continuous type scored at 20%[29]. Lesser manifestation of continuous crease length may be because its manifestation restricted to very aged individuals where the skin tissue is already lax. The classification “continuous” may be a NLF which has extended into the mandibular fold ((refer Figure 1 in[18]. The state of the cadaver tissue due to embalming could also affect the skin morphology[37,38].

Fedosyutkin and Nainys [12] place the origin of the NLF originates at the upper edge of the alar margin above the maxillary first molar and consider the prominence of the fold to depend on the depth of the canine fossa, the angle of horizontal profiling, the protrusion of the frontal surface of the cheekbones, and the availability of teeth[12]. The canine fossa is considered shallow if it is less than 3 mm, moderate if less than 6 mm and deep if 6 mm or more[12]. The NLF is more prominent when the canine fossa is deep and when the midface profile is strong[12]. The NLF is also prominent in edentulous individuals[12]. Gerasimov [15], mentions that the upper part of the fold is formed by the concavity of the levator muscles and that the depth of the canine fossa is correlated with the depth of the fold in the midportion and is terminated at the central portion of the Levator Anguli Oris muscle[15]. He also states that the fold starts from the edge of the nasal alae above the crista conchalis, continues along the canine fossa and terminates at the projection of the second molar[15]. The NLF is directed inwards towards the lower jaw[15]. In young individuals, the fold is shapeless with little outline and increases as a person gets older[15]. Figure 1 shows an example of the location of the NLF on a living individual.

The suggested anatomical guidelines to reconstruct the fold include to determine the curves and depths of the fold and the probability of a secondary lateral (buccal) crease[42]. While Changes in BMI do not affect the tissue thickness at the NLF region in adults[8], the morphology of the NLF was found to change dramatically by up to 6 mm based on the emotions shown on the face[41]. .

Crease classification for this research follows a modified version of the [9] face crease classification based on observations on crease resilience on post-mortem cadavers[18]. In this research, ante-mortem face photographs of individuals with known 3D skull data from The William Bass skeletal are compared and studied to identify the correlation between the creases in the face images and the skull morphology. A blind study was also conducted to reconstruct NLF creases based on skull images in the Helmer collection and to compare the results with the corresponding known face photograph also available in that collection to verify is the possibility to construct creases on any given skull as done during facial reconstruction.

Materials and methods

Part A: Qualitative crease analysis

Eighty three photographs from The William Bass skeletal collection of the University of Tennessee collection available at the Centre for Anatomy and Human Identification (CAHID) were utilised for this study. The collection includes 3D surface scans, photographs of the skulls and related ante-mortem face photographs. Only those ante-mortem photographs deemed to be of acceptable quality and view were selected.

The ante-mortem face images were utilised for producing facial tracings in Adobe® Photoshop® CS3[1] with a Wacom Intuos 3 tablet on a Viglen desktop computer. Lines indicating the crease tracings were marked in blue colour. A template for increasing image darkness was created in Photoshop to increase the shadow effect on images so that creases were more visible. Once tracings were produced, the template was removed facilitating better visual contrast between the images and the crease tracings. The creases present on the selected face photographs were tabulated in excel files for further comparison.

Surface scans of the skulls from the William Bass skeletal collection of the University of Tennessee in FASTSCAN format (*.fsn)[11] were processed in FASTSCAN into an object file format (*.obj) so that it could be manipulated in FreeForm Modeling Plus software ver. 11 [40] on a Intel® Xeon™ 2.66 ghz, 8 GB RAM, Windows XP (64-bit) with NVIDIA® Quadro FX3500 graphics card with a 1920x1200 monitor Viglen computer.

The face photograph with crease tracings was imported onto a plane in FreeForm and the corresponding skull was as an *.obj model. The skull was orientated and resized in FreeForm to match the posture in the face photograph and the skull and face images were superimposed. Once a satisfactory superimposition was obtained, a screenshot of the skull- and face-image was obtained. The crease outline on the face-image was visually compared with the skull morphology for identifying correlations between the face creases and skeletal structure of the skull. Microsoft Live Labs Pivot, an add-on software for Microsoft Excel[25] was utilised to compare crease-to-skull relationships in the superimposed images.

The orientation of the skull (Figure 2-right image) to the face photograph with creases (Figure 2-left image) was combined to produce the centre image (Figure 2) in Photoshop. All the images were then combined further in Photoshop to create one image set (Figure 2). Visual comparison with each image set was carried out with Pivot by Live Labs[25]. The presence of creases and the details of the skull morphology were tabulated.

The left and right maxilla were analysed separately as the skull morphology does not remain symmetrically similar among the left and right side. Aside from the NLF, the infraorbital fold was also reconstructed following the lower border of the orbital border. The strength of the NLF was based on visual assessment of the ante-mortem photograph of the face. Figure 3 shows an example of the NLF classification relied on during this study; weak (Figure 3a) and strong (Figure 3b) . Those creases that were in between were classified as normal.

Part B: Crease Prediction Blind Study

Ten skulls from the Helmer collection at CAHID were utilised for the blind study to test the prediction arrived in the study that used the William Bass skeletal collection. The morphology of the maxilla in the skull-image (or is it canine fossa in the skull-image) and NLF creases in the face-images were categorised based on the shape and crease strength. A 'weak' NLF related with a short and broad maxilla, while a 'normal' NLF related with a normal maxilla while a 'strong' NLF related with a long and slender maxilla in norma frontalis view of the cranium.

Adobe® Photoshop® CS3 was employed to mark the hypothesized region of the nasolabial fold on the skull-images in frontal view. Maxilla morphology was accessed and tabulated based on the classification mentioned previously. Results were then submitted to an external researcher and the face photographs of the ten skulls were released to the researcher for comparison purposes. Results of the blind study are provided in Table 3.

Skulls were orientated relative to the posture in the face photographs were superimposed in Freeform Modelling Plus and screenshots of the final orientation of the skull-images alone was obtained. The locations of the NLF and infraorbital on the face photographs were hypothesised and these crease locations were reconstructed on the orientated skull-image in Photoshop. Reconstructed face creases were marked with blue colour lines while the NLF region on the skull was marked in green colour and the infraorbital on the skull was marked with red colour for ease of comparison.

Results

Part A: Qualitative crease analysis

A summary of the amount of each crease present for all subjects is displayed in Table 1. A figure showcasing the location of each creases on the face is available from previous research[18] Analysis was also conducted using the marked creases on face photographs superimposed with the related skull-image to verify if there is any correlation between the underlying skeletal morphology and facial creases. Correlation includes the presence of grooves on the skeletal morphology on the superimposed images. The results are shown in Table 2.

From Table 2, it could be inferred that the facial crease which followed the online of the skull morphology with highest frequency is the infra orbital crease. The infra orbital crease followed the lower orbit outline in 52% of the individuals followed by other unclassified creases (28%), the vertical glabellar line, transverse nasal line and mental pit (between 20% to 22%). All other creases had lower than 20% correlation. Figure 4 shows the region where the orbital border in a skull-image that correlated with the infra orbital crease on the face photograph follows the skull.

The criteria used for reconstructing the NLF in a face-image using the morphology of the maxillary zone in a skull-image are illustrated in Figure 5. In order to predict the location of the crease, the following rules must be fulfilled:

a) The crease originates from the alae landmark *(al)* region of the nose (next to the nostrils) following the most lateral points of the nasal aperture in transverse plane and the distance of the ridge (orange line in Figure 5) on the maxilla bone. The nearest distance between the ridge on the maxilla bone and the nasal aperture is the origins of the crease.

b) The crease continues on the maxilla bone laterally adjacent to the last molar and the nearest concave border of the maxilla bone nearest to the aperture. The crease is nearer to the last molar in a neutral face position (a-b border in Figure 5).

c) In a smiling or laughing pose the crease is situated further laterally. The crease rarely goes higher than the a-c border in Figure 5 and is the most concave outline of the maxilla bone border.

The orange line in Figure 5 is the depth of the ridge present on the maxillae. The ridge is easier located in 3D where there is a marked difference in the height of the surface between the medial side of the ridge and lateral part of the canine fossa. The green area shows the probable region where the crease is located with the blue line at (a) indicating the nearest distance between the beginning of the ridge and the alae border in a face-image . The depth and length of the nasolabial crease cannot be predicted using this hypothesis as the comparison here is based on 2D images. The crease is detected in 95% of photographs based on this hypothesis.

Only four out of the 83 subjects do not fall under the above hypothesis that prescribes point of origin of NLF (a). Among the two such subjects, the origin of the right NLF crease is higher than the blue line marking. From the hypothesis, the right crease should appear slightly lower similar in level to the left crease on each subject. While the reason for the above difference is not known, it is possible that minor asymmetries in bone morphology that remain undetected during visual inspection may still influence the appearance of the crease in the face-image leading to asymmetries.

Qualitative analysis of the face photograph-skull pairs from the William Bass skeletal collection showed that a weak NLF crease related to a skull morphology revealing a broad maxilla and limited indent on the canine fossa region. In norma frontalis, the maxilla border between the zygomatic bone and the upper teeth appeared broader in nature compared to a normal and dolichocephalic skull which has a taller and narrower maxilla bone. For a maxilla that related with a weak crease, the demarcation border between the maxilla at the foramen and the maxilla canine fossa was not clearly visible. The skull also appears more brachycephalic. In contrast, a skull which related to a face with a marked NLF exhibited deep (depressed) canine fossa and the border between the zygomatic bone and the upper dentition was narrow. In norma frontalis, the skull appeareddolichocephalic. Also, the border between the canine fossa and the other parts of the maxilla was seen clearly defined. A skull that related to a face-image with normal crease depth exhibited a morphology which was between those described for the skull that related with weak and marked creases in face-images. Examples of the different maxillary regions are shown in Figure 6.

Part B: Crease Prediction Blind Study

The results of the blind study NLF reconstruction on the Helmer skull collection indicated that the NLF reconstruction was correct in 60% instances, incorrect in 30% instances with 10% inconclusive wherein the face photograph was of poor quality in which NLF could not be detected. Each maxilla was assessed separately based on the morphology in Figure 6. A weak maxilla corresponds to a shallow canine fossa while a strong maxilla corresponds to a deep canine fossa as indicated by (LMT and RMT in

Table 3). The crease strength (LCS and RCS) was related to the type of maxilla morphology (LMT and RMT). Six of the ten results from the blind study were correctly reconstructed (Table 3). Correct reconstruction was also obtained for individual crease strength on the same skull when there is a difference in the left and right maxilla morphology. Three incorrect reconstructions were obtained for skulls C, G and M. Inconclusive identification was obtained for Skull H due to poor quality of the face-image in which the NLF crease markings were only visible after enhancing the image in Photoshop. Hence the results skull H were not included since the modified face-image could may skew the overall result. Some of the face-images for skulls B, F, G, K, L and M were three-quarter view to the right and only creases on the left side of the face could be seen. Creases which could not be seen were not marked on the angled skull or the face photographs.

Discussion

A majority of the creases which appear on the face photograph have little relationship to the morphology of the underlying skull as the basis of the formation of the crease. A comparison between Table 1 and Table 2 shows that even though the NLF was a more observable crease, it could not be related to the skull morphology in all instances.. Based on the results in Table 2, it could be said that the infra orbital crease was the most common crease detected on the ante-mortem photographs based on skeletal morphology at 52%. Figure 4 shows the outline of the infraorbital border of the maxilla bone where the crease follows the outline. This is followed by unclassified creases were detected in 28% of the subjects followed by the vertical glabellar line, transverse nasal line and mental pit. The correlation between skull morphology and facial creases could not be established for the formation of other creases such as the horizontal forehead lines, mandibular folds and corner of the mouth lines despite such creases being quite frequently observed (at between 36% to 46% on the face . Adobe® Photoshop® has been utilised previously in skull to photo superimposition[4].

Poor quality of face-images was one of the reasons for failure to obtain positive correlation with skull morphology. Marked indentations that were found on the vertical glabellar line in eight skulls, though uncommon among most skulls, were found to relate with deep glabellar creases in face-images. The above inference needs further study since the vertical glabellar line, like most other facial creases, is dictated by muscle morphology rather than skull morphology.

Even though the NLF was the most detectable crease (95%) on the face photograph (Table 1), it could not be related to any specific morphological variation in the outline of the maxillary bone. Based on the hypothesis for the formation of the NLF (Figure 5,) 95% of the crease formation could be explained for in the William Bass skeletal collection. However, the extent of the marked nature of the NLF was found related to the skull morphology. The qualitative findings on the skull (Figure 6) suggested that a skull which has a shallow canine fossa correlates to a weak NLF in a face-image while a deep canine fossa in a skull suggests a marked NLF in a face-image. The hypothesis on the strength of the canine fossa depth (Figure 5) when tested using related face-image and skull image pairs from the Helmer collection, indicated correct identification in six out of ten skulls (Table 3). The three incorrect crease strength identification were due to underestimation (Table 3). From the demographic data of the Helmer collection, two of the skulls (Skull C and G) had youthful appearance. Skull C was between 15 and 20 years old while skull G was between 30 to 40 years old. Skull M, which had an age of around 40 to 50 years old, appears to have a long and slender maxilla though the crease appeared to be of normal strength. Underestimation of NLF crease strength for youthful faces was expected as the skin firmness on young individuals may mask the presence of a NLF despite the skull morphology revealing a long and slender maxilla suggesting a deep NLF. It has to be noted that due to the limited availability of face photograph-skull database of the Helmer collection the theory on the above relatedness could not be tested further. Furthermore, time lapse between recording the ante-mortem photograph and the death of the subject was also not known. When the above time lapse is greater, the depiction of the creases in a face-image may not be truly representative of the morphology of the skull which would have aged further, a factor that may explain the incorrect identification in the Helmer collection. It should also be noted that some of the images were of poor quality which could also affect the crease classification.

Reaching acceptable relationship between NLFcrease classified using a face-image and the morphology in a skull-image requires prior knowledge on, time at which the face-image was recorded as well as the time of death in order to correct for the underestimation of crease strength on the face photograph. The face-image related to skull C did not reveal any creases at all even though the maxilla in the skull was long and slender. Reconstructing of the NLF on the ten Helmer skulls showed that the face-images of individuals below 30 years of age may either not reveal classifiable creases or may reveal very faint creases due to skin elasticity even though the related skull-image may reveal morphology suggestive of stronger creases, the latter being attributable to death after further aging. The hypothesized region of the fold occurrence[26] could only account for creases up to the end of maxillary region between the ectomalare and the maxillozygion border. If the individual has saggy skin or is edentulous the crease will continue past the maxilla region into the mandibular region and in severe cases such creases may combine with the mandibular folds to create one continuous crease line.

Those creases that do not combine with the mandibular folds terminates in the region around the corner of the mouth where the upper and lower lips meet.

The hypothesized NLF crease region works well for skull-images in fronta normalis as it does not require consideration of tissue thickness allowances. The concurring result obtained during the blind study is also seen to support the above proposition. The left NLF crease region of skulls B, F, K and L were outside the hypothesized region as the region is reconstructed on the maxilla without taking into account the tissue thickness. Acceptable NLF crease reconstruction were obtained when using skulls A, E and H as the face photograph was almost frontal view. The above proposition is also seen applicable for the accuracy of the infraorbital crease.

The quality of the face photographs of the Helmer collection also proved an issue during this study. Superimposition of the face-images and the skull-images indicated that some of the face-images may have camera distortion. Earlier research on perspective distortion[10,39] indicate that distortion is unavoidable among the face-images used in this research as it is possible that many of these face-images had been photographed with lens-object distances that are less than 12 m as facial image photography at greater than 12 m distance is indeed rare[39]. Freeform Modelling Plus allows a perspective view in order to correct for close-up images of the subject but the extent of such correction that Freeform Modelling Plus allows appears too much compared to the distortion in face photographs. While superimposition of the skulls reveal that a degree of perspective correction was needed, the facilities to reach the appropriate correction for best superimposition are not available in Freeform Modelling Plus.

Limitations

The uncontrolled nature of the posture in the face-images obtained from the available face photographs, photograph quality, the time difference between the time at which the photograph was taken, time of death and unknown demographic details of the subject such as age, diet, skin elasticity and facial hair are factors that can potentially influence the result of the reconstruction reported in this research. Perspective distortion in the face photograph is unavoidable due to the nature of the face images which were donated by the next of kin. Problematic images such as those revealing poor quality, angles that are oblique or obstruction of features were excluded during this research. FreeForm Modelling Plus has a function to correct for perspective distortion, however the degree of correction employed is fixed. Crease reconstruction works best on skull-images in frontal view as variation in the appearance of skin thicknesses when the face is rotated away from the frontal view could not be accounted for. The hypothesized region works only for NLF crease reconstruction up to the end of the maxilla border. Creases which extend further pass this border could not be accounted for.

Conclusion

Reconstruction of facial creases using the morphology of skull-images in norma frontalis indicate that the creases that can be reconstructed with higher confidence are the infra orbital crease followed by the vertical glabellar line, transverse nasal line and mental pit. From the face photograph-skull pairs, studied, it is inferred that the 95% of the NLF in face-images could be placed within the postulated region. However, reconstruction of the NLF based on the above postulation yielded only 60% correct results due to the limitations of the Helmer collection. The finding of this research that the morphology in a skull-image in norma frontalis offers clue to reconstruct the infra orbital crease and the

NLF in face-images would prove useful as an aid for forensic practitioners involved in reconstructing faces using skulls.

References

1. Adobe®. Adobe® Photoshop® CS3. CS3 ed.: Adobe Systems Incorporated; 2007.
2. Bagal A, Dahiya R, Tsai V and Adamson PA. Clinical experience with polymethylmethacrylate microspheres (Artecoll) for soft-tissue augmentation: a retrospective review. Archives of Facial Plastic Surgery. 2007;9(4):275-280. Available from http://www.ncbi.nlm.nih.gov/pubmed/17638763 doi 10.1001/archfaci.9.4.275
3. Barton FE, Jr. and Gyimesi IM. Anatomy of the nasolabial fold. Plastic and reconstructive surgery. 1997;100(5):1276-1280. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=9326792
4. Bilge Y, Kedici PS, Alakoc YD, Ulkuer KU and Ilkyaz YY. The identification of a dismembered human body: a multidisciplinary approach. Forensic Science International. 2003;137(2-3):141-146. Available from http://www.ncbi.nlm.nih.gov/pubmed/14609649
5. Camp MC, Wong WW, Filip Z, Carter CS and Gupta SC. A quantitative analysis of periorbital aging with three-dimensional surface imaging. Journal of Plastic, Reconstructive & Aesthetic Surgery. 2011;64(2):148-154. Available from http://www.ncbi.nlm.nih.gov/pubmed/20547117 doi 10.1016/j.bjps.2010.04.037
6. Clement J and Ranson DL. Craniofacial identification in forensic medicine. Hodder Arnold; 1998.
7. Collins. Collins Dictionary. In: The American Heritage® Dictionary of the English Language, Fourth Edition. 4th ed.: Houghton Mifflin Company http://www.thefreedictionary.com Accessed On: 17 May 2013; 2009.
8. De Greef S, Vandermeulen D, Claes P, Suetens P and Willems G. The influence of sex, age and body mass index on facial soft tissue depths. Forensic Science, Medicine and Pathology. 2009;5(2):60-65. Available from http://www.ncbi.nlm.nih.gov/pubmed/19437147 doi 10.1007/s12024-009-9085-9
9. Dunn KW and Harrison RK. Naming of parts: a presentation of facial surface anatomical terms. British journal of plastic surgery. 1997;50(8):584-589. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=9613399
10. Eliasova H and Krsek P. Superimposition and projective transformation of 3D object. Forensic Science International. 2007;167(2-3):146-153. Available from http://www.ncbi.nlm.nih.gov/pubmed/16884880 doi 10.1016/j.forsciint.2006.06.062
11. Polhemus Fastscan: Polhemus; [Updated March 2005
12. Fedosyutkin BA and Nainys JV. The relationship of skull morphology to facial features. In: Forensic Analysis of the Skull: John Wiley & Sons; 1993, p. 199-214.
13. Furuta M. Measurement of orbital volume by computed tomography: especially on the growth of the orbit. Japanese journal of ophthalmology. 2001;45(6):600-606. Available from

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=11754901
14. Gassner HG, Rafii A, Young A, Murakami C, Moe KS and Larrabee WF, Jr. Surgical anatomy of the face: implications for modern face-lift techniques. Archives of Facial Plastic Surgery. 2008;10(1):9-19. Available from http://www.ncbi.nlm.nih.gov/pubmed/18209117 doi 10.1001/archfacial.2007.16
15. Gerasimov MM. The reconstruction of face on the base of structure of skull. 1975 ed.: Translated by: Tshernezky, W. (1975); 1955.
16. Glaister J and Brash JC. Medico-legal Aspects of the Ruxton Case. Edinburgh pp. v-vi, 144-170: E & S Livingstone Ltd; 1937.
17. Gosain AK, Amarante MT, Hyde JS and Yousif NJ. A dynamic analysis of changes in the nasolabial fold using magnetic resonance imaging: implications for facial rejuvenation and facial animation surgery. Plastic and reconstructive surgery. 1996;98(4):622-636. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=8773684
18. Hadi H and Wilkinson C. The post-mortem resilience of facial creases and the possibility for use in identification of the dead. Forensic Science International In press. 2013. Available
19. Işcan MY. Introduction of techniques for photographic comparison: Potential and problems In: Forensic Analysis of the Skull: John Wiley & Sons; 1993, p. 57-70.
20. Johnson DH, Jr., Colman M, Larsson S, Garner OP, Jr. and Hanafee W. Computed tomography in medial maxilla-orbital fractures. Journal of computer assisted tomography. 1984;8(3):416-419. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=6725687
21. Kahn DM and Shaw RB, Jr. Aging of the bony orbit: a three-dimensional computed tomographic study. Aesthetic Surgery Journal. 2008;28(3):258-264. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=19083535
22. Lemperle G, Holmes RE, Cohen SR and Lemperle SM. A classification of facial wrinkles. Plastic and reconstructive surgery. 2001;108(6):1735-1750. Available
23. Lucarelli MJ, Khwarg SI, Lemke BN, Kozel JS and Dortzbach RK. The anatomy of midfacial ptosis. Ophthalmic Plastic & Reconstructive Surgery. 2000;16(1):7-22. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=10674727
24. Mendelson BC, Hartley W, Scott M, McNab A and Granzow JW. Age-related changes of the orbit and midcheek and the implications for facial rejuvenation. Aesthetic Plastic Surgery. 2007;31(5):419-423. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=17486402
25. Microsoft Live Labs Pivot
26. Mohd Hadi Pritam H. Facial Creases in Human Identification Dundee: University of Dundee; 1 October 2012.
27. Owsley JQ. Lifting the malar fat pad for correction of prominent nasolabial folds. Plastic and reconstructive surgery. 1993;91(3):463-474; discussion 475-466. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=8438018

28. Pessa JE, Desvigne LD, Lambros VS, Nimerick J, Sugunan B and Zadoo VP. Changes in ocular globe-to-orbital rim position with age: implications for aesthetic blepharoplasty of the lower eyelids. Aesthetic Plastic Surgery. 1999;23(5):337-342. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=10541847
29. Pessa JE, Zadoo VP, Adrian EK, Jr. and Yuan C. Variability of the midfacial muscles: Analysis of 50 hemifacial cadaver dissections. Journal of the American Society of Plastic Surgeons. 1998;102(6):1888-1893. Available
30. Pessa JE, Zadoo VP, Mutimer KL, Haffner C, Yuan C, DeWitt AI and Garza JR. Relative maxillary retrusion as a natural consequence of aging: combining skeletal and soft-tissue changes into an integrated model of midfacial aging. Plastic and reconstructive surgery. 1998;102(1):205-212. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=9655429
31. Pessa JE, Zadoo VP, Yuan C, Ayedelotte JD, Cuellar FJ, Cochran CS, Mutimer KL and Garza JR. Concertina effect and facial aging: nonlinear aspects of youthfulness and skeletal remodeling, and why, perhaps, infants have jowls. Plastic and reconstructive surgery. 1999;103(2):635-644. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=9950555
32. Robbins LB, Brothers DB and Marshall DM. Anterior SMAS plication for the treatment of prominent nasomandibular folds and restoration of normal cheek contour. Plastic and reconstructive surgery. 1995;96(6):1279-1287; discussion 1288. Available from http://www.ncbi.nlm.nih.gov/pubmed/7480224
33. Roeslofse MM. An analysis of the metrical and morphological features [Thesis]. Pretoria: University of Pretoria; 2006.
34. Rubin LR. The anatomy of the nasolabial fold: the keystone of the smiling mechanism. Plastic and reconstructive surgery. 1999;103(2):687-691; discussion 692-684. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=9950561
35. Rubin LR, Mishriki Y and Lee G. Anatomy of the nasolabial fold: the keystone of the smiling mechanism. Plastic and reconstructive surgery. 1989;83(1):1-10. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=2909048
36. Shaw RB, Jr., Katzel EB, Koltz PF, Yaremchuk MJ, Girotto JA, Kahn DM and Langstein HN. Aging of the facial skeleton: Aesthetic implications and rejuvenation strategies. Plastic and reconstructive surgery. 2011;127(1):374-383. Available from http://www.ncbi.nlm.nih.gov/pubmed/20871486 doi 10.1097/PRS.0b013e3181f95b2d
37. Simpson E and Henneberg M. Variation in soft-tissue thicknesses on the human face and their relation to craniometric dimensions. American journal of physical anthropology. 2002;118(2):121-133. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=12012365
38. Stephan CN. Facial approximation: A review of the current state of play for archeologists. International Journal of Osteoarchealogy. 2005;15:298-302. Available
39. Stephan CN. Perspective distortion in craniofacial superimposition: Logarithmic decay curves mapped mathematically and by practical experiment. Forensic Sci Int.

2015;257:520 e521-528. Available from
http://www.ncbi.nlm.nih.gov/pubmed/26482540 doi 10.1016/j.forsciint.2015.09.009
40. FreeForm Modeling and Modeling Plus System
41. Trotman CA, Stohler CS and Johnston LE, Jr. Measurement of facial soft tissue mobility in man. Cleft Palate-Craniofacial Journal. 1998;35(1):16-25. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=9482219
42. Wilkinson C. Forensic facial reconstruction. First ed.: Cambridge University Press; 2004.
43. Yousif NJ, Gosain A, Matloub HS, Sanger JR, Madiedo G and Larson DL. The nasolabial fold: an anatomic and histologic reappraisal. Plastic and reconstructive surgery. 1994;93(1):60-69. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=8278485
44. Yousif NJ, Gosain A, Sanger JR, Larson DL and Matloub HS. The nasolabial fold: a photogrammetric analysis. Plastic and reconstructive surgery. 1994;93(1):70-77. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=8278486
45. Zadoo VP and Pessa JE. Biological arches and changes to the curvilinear form of the aging maxilla. Plastic and reconstructive surgery. 2000;106(2):460-466; discussion 467-468. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=10946946
46. Zufferey J. Anatomic variations of the nasolabial fold. Plastic and reconstructive surgery. 1992;89(2):225-231; discussion 232-223. Available from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=1732888