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KEY WORDS

computerised
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EDUCATION BOX

Forensic facial reconstruction aims to recreate the appearance of an individual, to allow recognition by a family member or close friend. Recognition may then lead to identification.

Computer modelling facial reconstruction systems produce a three-dimensional model, employing virtual clay rather than actual clay.

Many computer-based facial reconstruction systems have not been assessed for reliability or reproducibility and levels of accuracy are unknown.

This computerized three-dimensional system can be applied easily and reliably to forensic identification investigations.

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A blind accuracy assessment of computer-modelled forensic facial reconstruction using Computed Tomography data from live subjects

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ABSTRACT

A computer modelling system for facial reconstruction has been developed that employs a touch-based application to create anatomically accurate facial models focusing on skeletal detail. This paper discusses the advantages and disadvantages of the system and illustrates its accuracy and reliability with a blind study using CT data of living individuals.

Three-dimensional models of the skulls of two White North American adults (one male, one female) were imported into the computer system. Facial reconstructions were produced by two practitioners following the Manchester method.

Two posters were produced, each including a face pool of five surface model images and the facial reconstruction. The face pool related to the sex, age and ethnic group of the target individual and included the surface model image of the target individual. Fifty-two volunteers were asked to choose the face from the face pool that most resembled each reconstruction. Both reconstructions received majority percentage hit rates that were at least 50% greater than any other face in the pool. The combined percentage hit rate was 50% above chance (70%).

A quantitative comparison of the facial morphology between the facial reconstructions and the CT scan models of the subjects was carried out using Rapidform™ 2004 PP2 – RF4. The

majority of the surfaces of the facial reconstructions showed less than 2.5mm error and 90% of the male face and 75% of the female face showed less than 5mm error. Many of the differences between the facial reconstructions and the facial scans were probably due to positional effects caused during the CT scanning procedure, especially on the female subject who had a fatter face than the male subject. The areas of most facial reconstruction error were at the ears and nasal tip.

Forensic facial reconstruction is employed in human identification investigations, and is primarily utilised when the police do not have any clues as to the identity of the individual. The ultimate aim of facial reconstruction is to recreate an in vivo countenance of an individual that sufficiently resembles the deceased person to allow recognition by a family member or close friend. In forensic situations the recognition may lead to positive identification via other evidence, such as dental record or DNA analysis. There are many existing forensic facial reconstruction techniques currently in use, and the established approaches include two-dimensional[1], three-dimensional manual[2 3 4] and three-dimensional computer-based [5 6 7]. These three approaches can be further divided into techniques that follow the anatomy of the head and neck [1 2 5 6] and those that rely upon anthropometry [3 4 7].

The three-dimensional manual techniques have been developed over the last 120 years, and consequently there have been a number of studies into the reliability and accuracy of these techniques. The early 20th century development of facial reconstruction methods led to the comparison of facial reconstructions with death masks or cadaver photographs, and these studies produced somewhat confusing results. Studies by Von Eggeling [8], Stadmuller [9] and Kollman [10] compared reconstructions with death masks and found little or no resemblance between the reconstructions and the death masks (although one of the reconstructions in Von Eggeling's study appears reasonably successful (see fig 1)). Stadmuller concluded that this technique provided only an approximation of a basic head type. In contrast, Krogman [11] compared the reconstruction of a middle-aged Black American man with a photograph of the cadaver and the reconstruction was considered to be recognizable, even with metrical errors at the bipalpebral breadth (-13mm) and bigonial points (+10.5mm). In 1940 Gerasimov [3] carried out an extensive experiment using 12 cadavers and claimed that *"the results exceeded* *even my expectations. All the twelve heads were so true to life that their identity with the relevant photographs was undoubted."*

With the establishment of different theoretical approaches and the development of facial reconstruction protocols, accuracy analysis became more quantitative and less subjective. The use of cadaver comparisons was challenged due to postmortem facial appearance changes, and so comparison with live subjects was considered. In the USA, Snow and his colleagues[12] produced two reconstructions of a young white male and an elderly white female. Posters were constructed using the clay reconstructions and a face pool of seven individuals, and volunteers were asked to select the individual who most resembled the reconstruction. The female scored 11% above chance (25%) correct identification and the male 54% above chance (68%). The female result was poor, even taking into account the age difference between the photograph and the individual at death (25 years), but the male result suggested a significant potential for this technique. A double-blind study by Helmer and his colleagues[13] used two practitioners who each reconstructed 12 skulls, and three examiners who assessed the resemblance using a rating scale (where 1=no, 2=slight, 3=approx, 4=close and 5=strong resemblance). Comparison of the reconstructions with each other showed 50% approximate resemblance as the mean rating, and comparison of the reconstructions with photographs of the individuals showed 42% slight resemblance as the mean rating. Wilkinson and Whittaker's[14] accuracy study of five female juvenile skulls showed more promising results. They employed photographic face pool identification and all five reconstructions were correctly identified as the most frequently chosen face from the face pool, with a mean hit rate of 34% above chance (44%). The volunteers also rated the reconstructions as a mean close resemblance to the individuals, on the five-point rating scale. Wilkinson and Whittaker concluded that it was possible to create a good likeness of an individual. In contrast, Stephan and Henneberg[15] used 37 assessors to identify 16 reconstructions and found that only one of sixteen facial reconstructions was identified at a significant hit rate above chance. They recorded an overall mean hit rate of 19% below chance (6%), which is a markedly lower result than all other similar studies.

Over the last decade various systems have been developed to produce facial reconstructions using computer software, with the aim of increasing the levels of flexibility, efficiency and speed. The first computer system to be developed for forensic purposes was produced by Moss and his colleagues[5] at University College London and was based upon techniques used for cranial reconstructive surgery. An automated laser line scanner and video camera was used to produce surface data from the skull, and this was then displayed as a fully shaded 3-D surface. Tissue depth markers were placed at a number of surface sites on the skull and an average face was then chosen (dependent upon the sex, age and ethnic group of the skull), which was "morphed" to fit the skull[16] . Additional facial features could then be added to the face, such as open eyes, hair, facial hair, etc. These additions provided a more realistic appearance to the face to enhance any recognition. Since this early work many other computer systems have been developed, which also rely heavily upon pre-existing facial templates and average morphology [6 17 18]. These systems create multiple variations for each skull, but they impose a very specific set of facial characteristics onto the facial reconstruction, in that the resulting face will ultimately resemble the sample face. More recently virtual sculpture has been utilized to mimic the three-dimensional manual method of facial reconstruction [7]. The computer modelling system produces a sculptural three-dimensional model following a similar method to the manual technique, employing virtual clay rather than actual clay. These systems endeavour to interpret the contours between landmarks rather than laying a face over the landmarks. A number of two-dimensional computerised facial reconstruction systems have also developed [19 20 21], employing facial composites to produce a face over an image of the skull. Facial contours and features are chosen from an image library, dependant upon the skeletal structure or cephalometrics. A variety of software exists and all produce realistic photographic quality images, usually from a frontal view only.

In forensic investigations the computer-generated facial reconstructions that are presented to the public vary in appearance, dependant upon the particular case, the police requirements and practitioner protocol. Some practitioners present the reconstruction with estimated hair, skin colour and eye colour by painting or wrapping a texture map around the model, whilst others present the face without the addition of estimated details as a neutral coloured, non-realistic model.

However, very few of these computer-based facial reconstruction systems have passed through rigorous scientific assessment, and levels of accuracy are unknown. Many systems illustrate accuracy by exhibiting examples of successful forensic casework, but it must be noted that this in no way ensures quality or reliability. Reliance upon such assessment is flawed, since only the successful cases are included and no account is taken of unsuccessful cases.

This paper aims to thoroughly assess an existing computer-based facial reconstruction system in a blind study of live subjects utilizing face pool identification to assess resemblance.

METHOD

This project utilised “virtual” sculpture (Freeform Plus software) employing a system (Sensable Technology’s PHANTOM and CONCEPT desktops) that incorporates haptic feedback and a technique and database developed by Wilkinson[7]. This is a touch-based application of three-dimensional design and allows an intuitive interaction with the digital world. The system is run from a Dual 800 mhz Pentium Processor with 1GB RAM, Windows 2000, 1024 x 768 resolution display and NVIDIA Quadro4 900XGL graphics card. Two practitioners were involved in this research; one with twelve years (CW) and one with two years (CR) experience and training in forensic facial reconstruction.

Computed Tomography (CT) data from two live individuals were supplied by the Federal Bureau of Investigation (FBI). U.S. federal government and FBI policies require that all research involving human subjects be reviewed annually by an Institutional Review Board (IRB). Prior to collection of the CT scans, the proposed research was approved by the FBI IRB and, where applicable, by each IRB from the medical facilities where the collections occurred. Each subject was required to read and sign an informed consent form prior to participating in this study. The subjects were a White North American male and female, both aged 20-29 years. The DICOM data were converted to STL files of skeletal data and skin surface data at the Centre for Product Design & Development Research (PDR) at University of Wales Institute, Cardiff, using MIMICS software. The STL files were supplied on CD ROM and the skin surface models were kept on CD in a secure environment to preserve the blind nature of this experiment. The skin surface models were not viewed by the practitioners until after completion of the facial reconstructions.

The skull model was imported into Freeform Plus as an STL file (see fig 2). Tissue depth pegs were attached to the surface of the skull at the appropriate anatomical sites using a computerized measuring tool (with 0.001mm accuracy) in a similar way to the manual method. The points were determined by the tissue data set employed (male and female White North American data[22]). The anatomical points were identified by the practitioner and fine alterations in peg rotation were performed at the skull surface.

Pre-existing eyeball shapes (25mm diameter with 11mm iris diameter) were placed in the orbits at the appropriate position and depth. A bank of pre-modelled facial muscles was utilised[7] containing sixteen facial muscles and the parotid glands. Each muscle was imported and placed onto the skull, altering the shape and size by utilising three-dimensional deformation tools. In this way each muscle was customised to fit the new skull. Within the data bank were also a number of ears and noses, produced from surface scans, which could be imported and placed onto each facial model. These features were then further customised to relate to the bony structure of the skull. The facial features were sculpted and developed following the Manchester method of facial reconstruction[23] (see fig 3). The final sculptural stage was the addition of a skin layer over the muscle structure. This followed the shape that the facial anatomy had already defined whilst adding the appropriate subcutaneous fat and skin layers.

When the facial reconstructions were complete, the skin surface models were displayed. Frontal and profile views of each reconstruction were saved as jpg files. The skin surface models of the target male and female provided by the FBI and individuals (four male and four female) supplied by the University Dental Hospital at Cardiff from laser scan data were imported into Freeform Plus as STL files. Frontal and profile views were created for each head to produce the face pools. Since the laser scan models did not include the back of the head and all of the ears, the faces of these subjects were attached to the back of the head and ears of the target individual, in Freeform Plus, to create full head models that were consistent throughout the face pools. All subjects in the face pool were white and of comparable age range. Two posters were then created that included a face pool and images of the facial reconstruction for the white male and white female data (see figs 4 & 5).

Fifty-two adult volunteers were shown the two posters, one-by-one, and asked to choose the face from the face pool that most resembled the facial reconstruction. The order of poster presentation was varied randomly between volunteers. Hit rates (x%) were calculated as the percentage of correct identifications, and since a hit rate of 20% would be produced by chance, the hit rate above chance was calculated as x% - 20%.
The results were analysed using the SPSS statistical package.

In addition a quantitative comparison of the facial morphology between the facial reconstructions and the facial scans of the identified individuals was carried out using reverse modelling software Rapidform™ 2004 PP2 (@ INUS Technology Inc, Seoul, Korea) – RF4 for analysis. This software provides nine different three-dimensional work activities and together allows high quality polygon meshes, accurate freeform Non-Uniform Rationale B-Spline (NURBS) surfaces and geometrically perfect solid models to be created. RF4 generates data as absolute mean shell deviations, standard deviations of the errors during shell overlaps, maximum and minimum range maps, histogram plots and finally colour maps. Within RF4, a shell-to-shell deviation map may be computed and automatically produced. The results include the maximum and minimum range of shell deviations, the average distance between the two shells and the standard deviation. This function was used to statistically analyze the differences between the facial reconstruction and the facial scan of the target individual.

RESULTS

For both reconstructions the target individual received the majority of hits, and Goodness of Fit Chi-squared tests showed that these results were significantly ($p<0.001$) different from chance. The combined hit rate was 70%, which was 50% above chance (see table 1). Both reconstructions received hit rates at least 50% greater than any other face in the pools. Only one other face in both face pools received a hit rate more than chance and this was only 1% above chance. There was no significant difference between the results of the two reconstructions (69% white male and 71% white female).

The shell-to-shell absolute deviation maps created in Rapidform™ 2004 PP2 – RF4 (see fig 6) for the white male showed that 61.5% aligned within an error less than 2.6mm. The largest areas of error (>5mm) were at the nasal tip, portions of the ears and the temple region. Errors between 2.6 - 5.2mm occurred at the upper and lower cheeks, right forehead and left side of the mouth. The most accurate areas of the face were at the nose, chin, mouth, eyes and left forehead.

The signed deviation maps for the white male (see fig 7) showed that most of the face (60%) deviated no more than +/- 2.5mm. The right forehead, upper and lower cheeks and some of the nasal tip on the facial reconstruction were between 2.5 - 5mm more prominent, and the right temple, upper cheek, portions of the ears and the nasal tip were more than 5mm more prominent than the facial scan. The inferior border of the alae, left side of the mouth, mental protruberance and side of the head of the facial reconstruction were between 2.8 – 5.4mm less prominent, and parts of the neck were more than 5.4mm less prominent than the facial scan.

The shell-to-shell absolute deviation maps created in Rapidform™ 2004 PP2 – RF4 (see fig 8) for the white female showed that 53.8% aligned within an error less than 2.6mm. The largest areas of error (>5mm) were at the upper lip, nasal alae, ears and lower cheeks. Errors between 2.6 - 5.2mm occurred at the side of the head, eyes, lower lip and chin. The most accurate areas of the face were at the nose, chin, upper mouth, upper cheeks and cranium.

The signed deviation maps for the white female (see fig 9) showed that most of the face (51.8%) deviated no more than +/- 2.5mm. The nasal alae and lower cheeks were between 3-8mm more prominent, and the upper lip and ears had areas that were more than 8mm more prominent than the facial scan. The temples and chin of the facial reconstruction were between 2.5 – 5 mm less prominent, and no areas of the face were more than 5mm less prominent than the facial scan.

DISCUSSION

Only a few studies have used face pool identification for the assessment of the accuracy of facial reconstruction, with varying degrees of success, and the hit rates of this study are markedly higher than all the previous studies. Snow et al [12] produced an average hit rate of 33% above chance, Wilkinson and Whittaker[14] recorded 34% above chance, Van Rensburg [24] produced 19% above chance and Stephan and Henneberg [15] recorded 19% below chance. There are no similar accuracy studies of computer-based facial reconstruction with which to compare these results. These results suggest that the computer-based facial reconstructions were closer in likeness to the individuals than in previous studies.

However, the results of this study may be more successful, because the surface scan models in the face pools were very similar in appearance to the facial reconstructions, and the volunteers were forced to compare morphology when attempting to identify the target from the face pool without becoming distracted by skin tones or textures. Bruce and her colleagues [25] considered how texture and tone affect facial recognition using three-dimensional models created from laser-scans of faces. A photographic face pool of 4 males was set up and the volunteer attempted to choose the individual that the scan represented. Despite the fact that the scan represented a face of exactly the same proportions, shape and size as the target individual, the overall hit rate was only 26% above chance. This study suggests that people find it difficult to compare faces depicting inconsistent information (ie. shape alone compared with photographs) and perhaps the present study produced higher hit rates due to the simplicity of the comparison. However, the facial reconstructions would still need to be accurate in morphology to the identified individual.

Problems with the recognition of unfamiliar faces have also been studied by Bruce and her colleagues [26]. They investigated matching of unfamiliar target faces from high quality video stills against photographic arrays. The target faces were shown as frontal-neutral, frontal-smiling and three-quarter views, whilst the array faces were all shown as frontal views. The overall correct hit rates were only 60% (frontal-neutral), 64% (frontal-smiling) and 61% (three-quarter) above chance, despite the fact that the target photograph was taken on the same day as the array photographs. These results are only slightly higher than those produced in this facial reconstruction study, which suggests that the reconstructions are good likenesses.

It is possible that the target faces were distinctive and significantly different from the other faces in the face pool, and that this caused the high hit rates in this study. Therefore, ten volunteers viewed the face pools independently (and without the facial reconstruction images) and were asked if any of the faces stood out from the face pool. None of the volunteers chose the target face from the white male pool, and 60% thought the faces were all similar. This suggests that the high hit rate for the male facial reconstruction had nothing to do with distinctive features. However, 80% of volunteers chose the target face from the white female face pool. This suggested that the target female face was different to the other faces in the female face pool. When questioned, the volunteers stated that the target face was wider and/or had a more distinctive nose that the other faces. This may have contributed to the high hit rate for this reconstruction, but the facial reconstruction would still have had to have matched the target face in those distinctive features.

The shell-to-shell deviation maps created in Rapidform™ 2004 PP2 – RF4 suggested that the majority of both facial reconstructions showed less than 2.5mm error to the facial scan. Both reconstructions had fuller cheeks, more prominent upper lips and ear pattern errors and these differences may be due to the positional effects caused by the subject when the CT scans were taken[27]. Gravity causes the cheek and mouth areas of the face to sag downwards when the subject lies on his/her back, and since the facial tissue depth data used in the facial reconstruction were measured with the subjects sitting upright, the facial reconstruction will inevitably show fuller cheeks and a less taut mouth. The pillow on which the subject lay during the CT scanning procedure also caused some neck, ear and head tissue distortion, which may explain the differences seen between the facial reconstructions and the facial scans at these areas.

The nasal tip and ears of the male reconstruction and the nasal alae and ears of the female reconstruction showed large errors and these features have traditionally been problematic for facial reconstruction practitioners. The nasal tip shape is very difficult to determine from the skeletal detail due to its connection to the nasal cartilages rather than the bone, and we are not, as yet, able to accurately determine the morphology of this area. Similarly ear shape cannot be determined from skeletal morphology with any degree of reliability, although position and lobe shape appeared accurate.

The more prominent area on the male facial reconstruction at the right temple cannot easily be explained and may be due to some asymmetry in the facial tissues of the subject, since this side of the head appears flatter than the left side on the three-dimensional facial scan model. Study of the subject photograph suggested an injury at this site.

Finally, the practitioners had varying levels of experience, and yet produced facial reconstructions of similar resemblance to the target individuals, although the less experienced practitioner did take more time to finish his reconstruction. This suggests that the computer-based reconstruction system was easy to learn with good reliability and reproducibility.

This computer facial reconstruction system can be applied easily and reliably to forensic identification investigations. The laser scan or CT data are easy to prepare and import and it is not necessary for the practitioner to be geographically near the crime scene. This system could also incorporate preserved soft tissue data from CT scans and allow the practitioner more accurate and reliable methods of post-mortem depiction.

CONCLUSIONS

These results suggest that this computerized modelling system for facial reconstruction, following an anatomical method, will produce a recognizable individual, with good levels of reliability and accuracy. Further studies may require laser scans of the subjects rather than CT scans for surface morphology, as the effects of gravity or the pillows and straps used during the CT scanning procedure caused problems during the morphological assessments and made many of the facial features incomparable.

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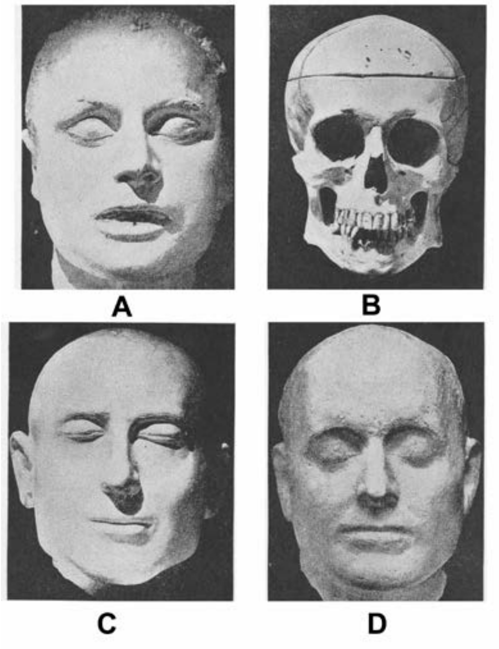

Fig 1: Accuracy study produced by Von Eggeling (1913).
A = Death mask, B = skull, C & D = facial reconstructions
After: *Personal Identification* (Wilder & Wentworth, 1918).

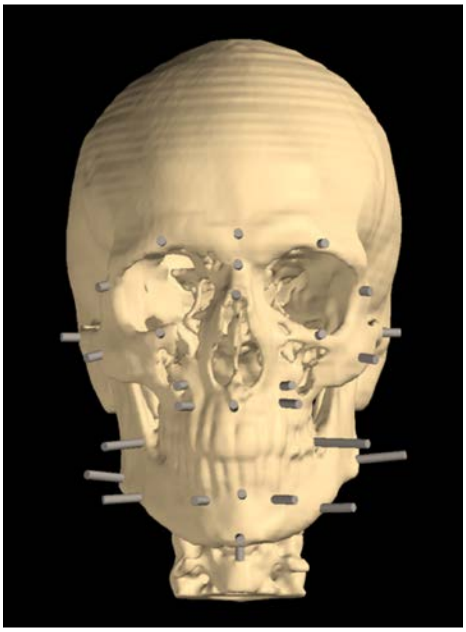

Fig 2: Three-dimensional skull model with tissue depth pegs attached.

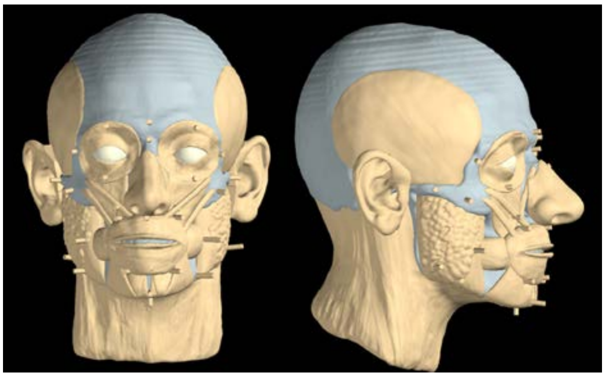

Fig 3: Anatomical model of the face produced by computerised facial reconstruction system.

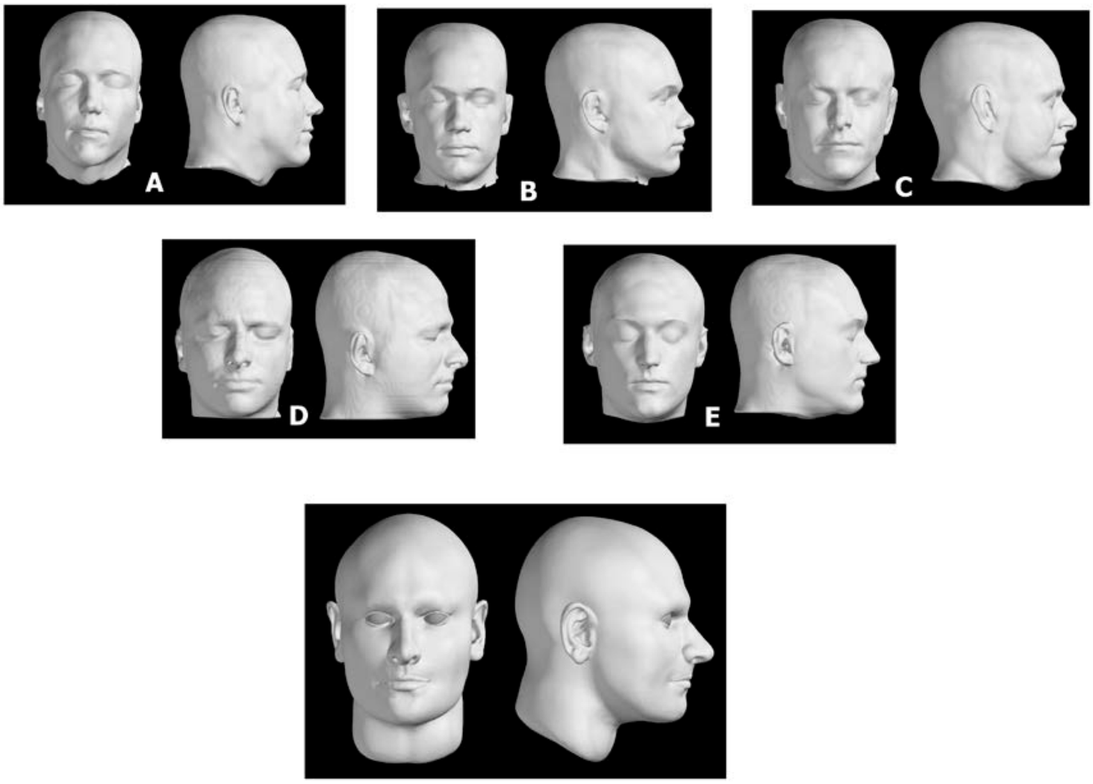

Fig 4: Poster of the white male face pool (A-E) and the facial reconstruction.

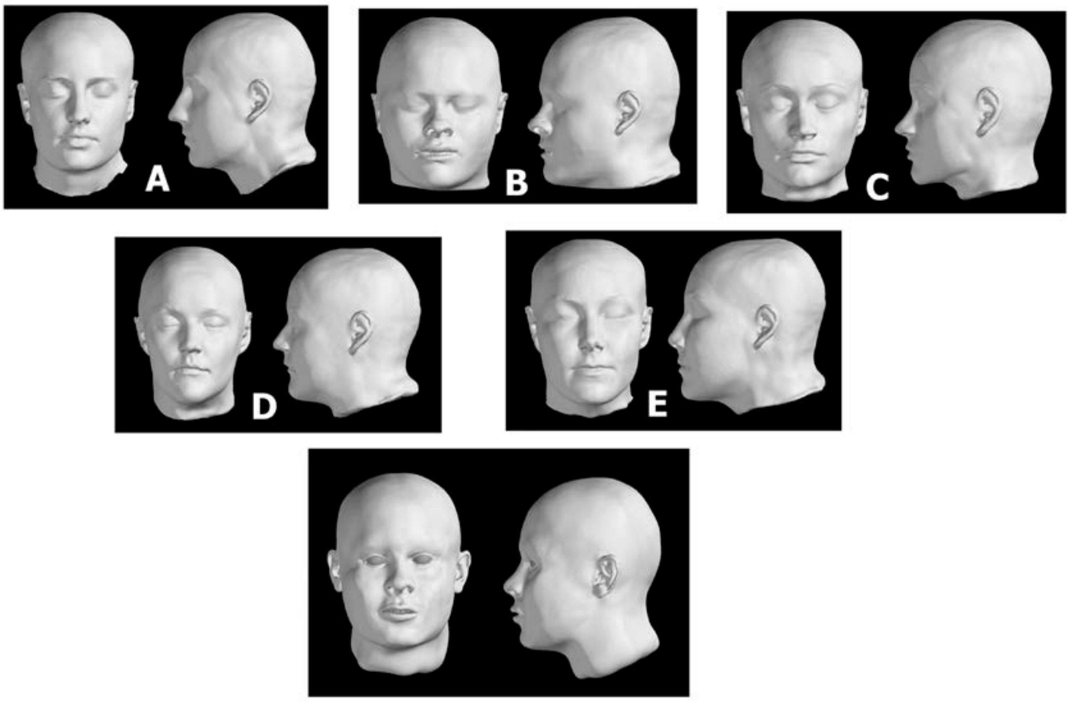

Fig 5: Poster of the white female face pool (A-E) and the facial reconstruction.

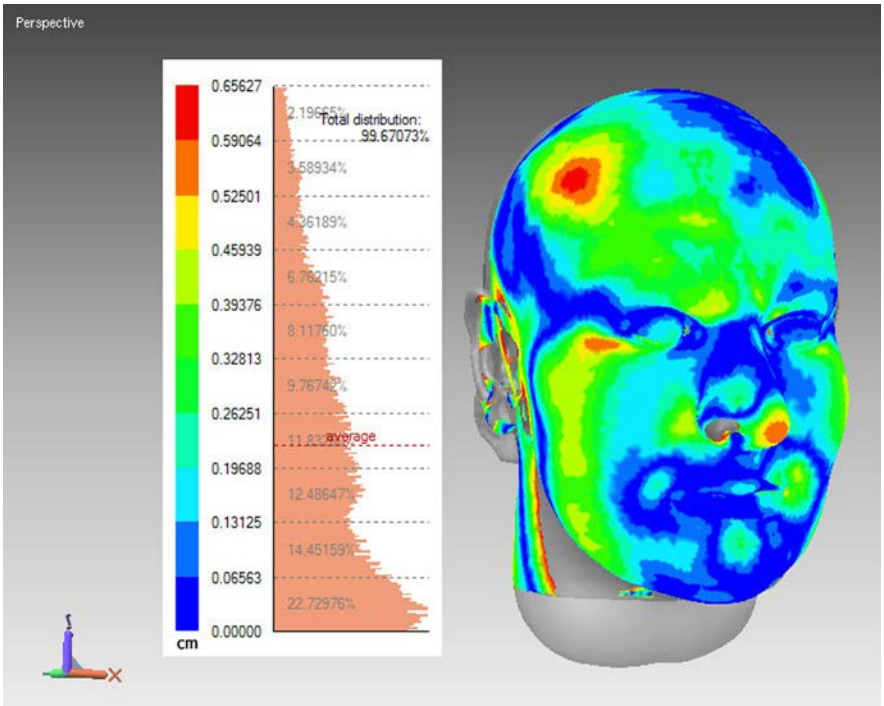

Fig 6: Comparison of the facial reconstruction with the facial scan of the male subject using Rapidform™ 2004 PP2 showing absolute values (cm).

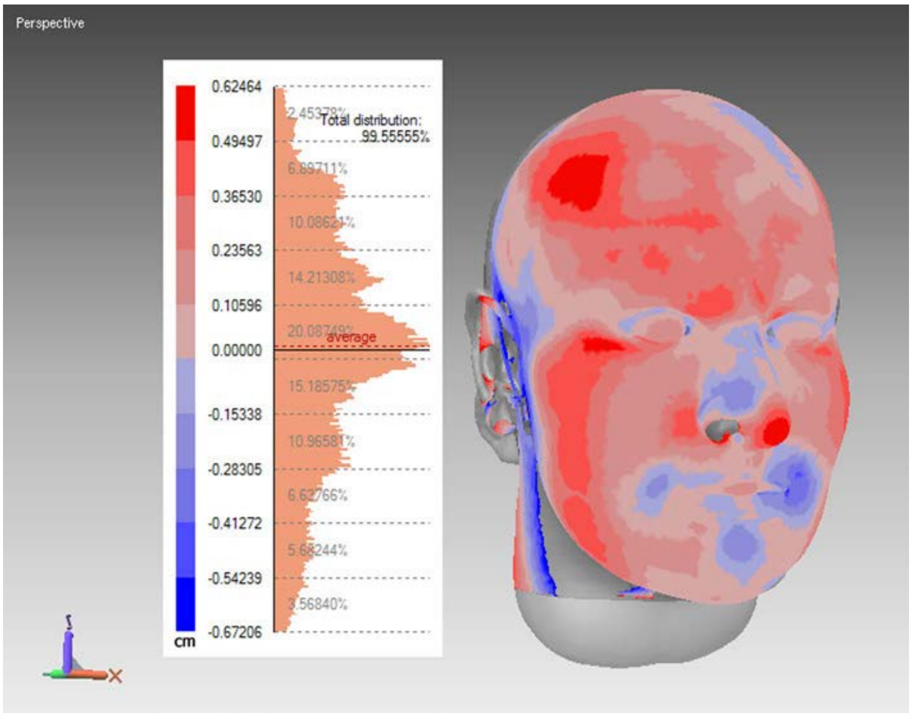

Fig 7: Comparison of the facial reconstruction with the facial scan of the male subject using Rapidform™ 2004 PP2 showing signed values (cm).

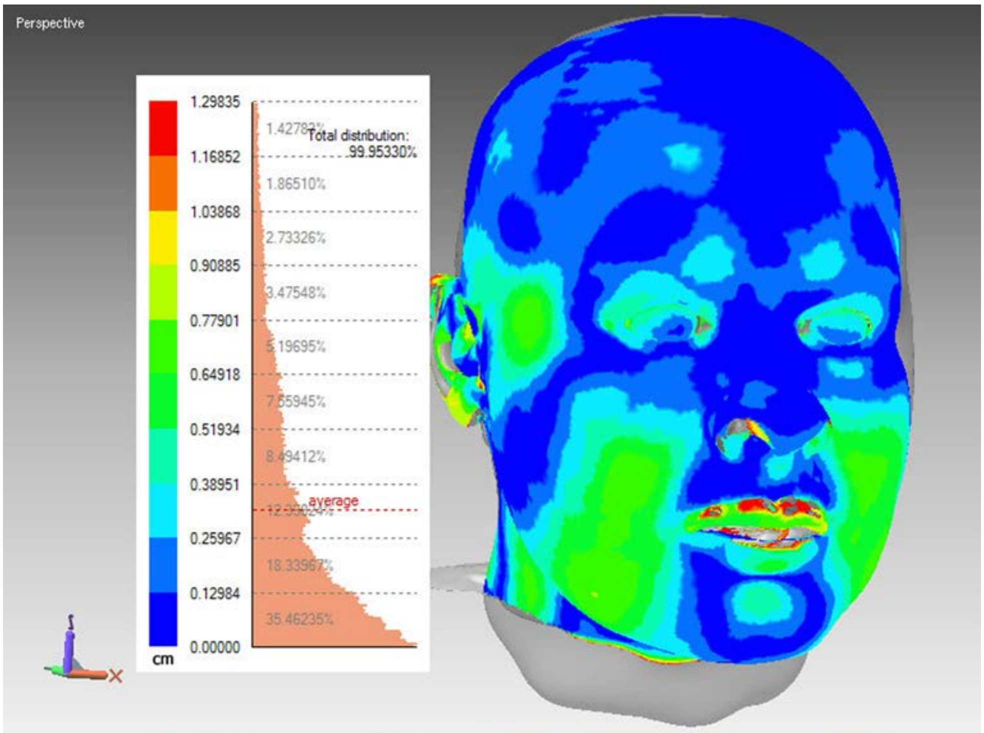

Fig 8: Comparison of the facial reconstruction with the facial scan of the female subject using Rapidform™ 2004 PP2 showing absolute values (cm).

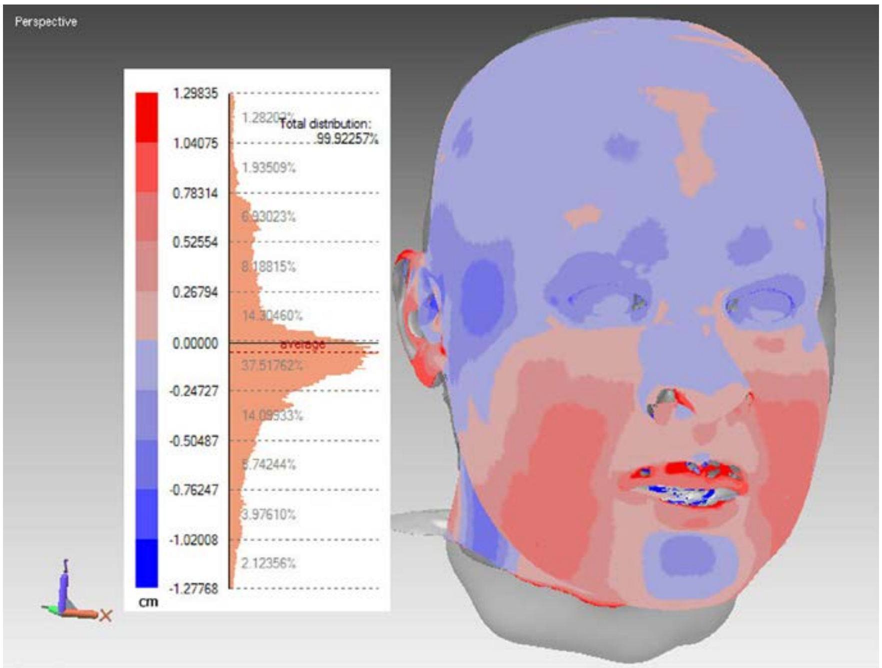

Fig 9: Comparison of the facial reconstruction with the facial scan of the female subject using Rapidform™ 2004 PP2 showing signed values (cm).

Face Pool	Total volunteers		Male volunteers		Female volunteers	
White Male	n (52)	%	n (26)	%	n (26)	%
A	2	3.8	1	3.8	1	3.8
B	4	7.7	0	0	4	15.4
C	1	1.9	1	3.8	0	0
D	36	69.2	20	76.9	16	61.5
E	9	17.3	4	15.4	5	19.2
Hit rate	36	69.2	20	76.9	16	61.5
Chi squared	<0.001	0.006	<0.001	0.006	<0.001	0.239
Mann-Whitney	0.629	0.234				
White Female	n (52)	%	n (26)	%	n (26)	%
A	1	1.9	0	0	1	3.8
B	37	71.2	20	76.9	17	65.4
C	11	21.2	4	15.4	7	26.9
D	1	1.9	0	0	1	3.8
E	2	3.8	2	7.7	0	0
Hit rate	37	71.2	20	76.9	17	65.4
Chi squared	<0.001	0.002	<0.001	0.006	<0.001	0.116
Mann-Whitney	0.363	0.818				
Both cases	n (104)	%	n (52)	%	n (52)	%
Hit rate	73	70.2	40	76.9	33	63.5
Chi squared	<0.001	<0.001	<0.001	<0.001	<0.001	0.052
Mann-Whitney	0.498	0.135				

Table 1: Face pool identification results for two facial reconstruction cases.