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FORENSIC FACIAL RECONSTRUCTION USING 3-D COMPUTER GRAPHICS: EVALUATION AND IMPROVEMENT OF ITS RELIABILITY IN IDENTIFICATION

by

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"It is the common wonder of all men, how among so many millions of faces, there should be none alike"

~Thomas Browne, *Religio Medici*

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Summary

This thesis is concerned with computerised forensic 3-D facial reconstruction as a means of identification and involves the restoration of the face on the skull in an attempt to achieve a close likeness of the individual when alive. The reconstruction process begins with the biological identification of the skeletal remains, (age, sex, ancestry and build). Facial reconstruction is then carried out and essentially works by building the "face" up from the skull using soft tissue thicknesses at specific locations from existing data. However, it is used as a last resort on skeletonised, badly decomposed or mutilated corpses, when no other information is available; even then it is only accepted as corroborative evidence in court. It is performed in the hope that it may stimulate recognition, and consequently narrow the field of identification, allowing other tests to be carried out, such as radiographic and/or dental comparisons, DNA analysis or other means, to establish positive identification.

The advantages of the computerised method over the manual clay reconstruction are speed, rapid editing capability, production of images that can be stored and reconstructions repeated at any time if required.

Furthermore, in many cases, the original skull instead of a cast or model may be used for reconstruction because the 3-D computerised procedure is rapid and non invasive. However, the most significant advantage of this technique with regard to the aims and objectives of the thesis is that a number of alternative reconstructions may be produced sequentially for the same skull by using different facial templates from the database that meet the anthropological/biological criteria of the skull.

The issues addressed by the study and therefore its main aims are:

a) evaluation and b) improvement of the reliability of facial reconstruction using 3-D computer graphics. The methodology involved initially digitizing a skull using a low-power laser scanner and a video camera interfaced to a computer. From a database of previously scanned faces, ten facial templates were selected that matched the anthropological criteria of each of the skulls, i.e. age, sex, ancestry and build. Landmarks with their corresponding soft tissue thicknesses were then located and placed on the skull and the equivalent ones on the face. The 3-D computer graphics then reconstructed the face by morphing (warping) the facial template over the skull by matching the corresponding landmarks on the skull and face with the appropriate

soft tissue thicknesses at those landmark locations. The soft tissue thicknesses used at their specific landmark locations also matched the anthropological criteria of the skulls, since soft tissue depths are dependent on age, sex, ancestry and build.

One of the major problems with any reconstruction which affect its reliability for identification is the uncertainty of the *shape* of some of the individual characteristics of soft tissue structures such as *shape* of lips, ears and nose/nasal tip since there is not direct information on the skull regarding the shape of some of these features. In addition, with the laser scanning system, the faces within the database all have closed eyes, because of the potential laser hazard to the eyes. Thus it is necessary to add "opened" eyes, head and facial hair (where appropriate) to give a realistic appearance to the face. The software provides the facility to export a 2-D view in a TIFF or JPEG format from the 3-D reconstructed image. The file can then be imported into a police identi-kit system such as E-FIT™, which allows the addition of features.

In this study five skulls of known individuals were used for reconstruction in the manner explained. Ten facial templates which fulfilled the anthropological criteria (age, sex, ancestry and build) for each skull were used for the rebuilding process, thus totalling fifty reconstructions.

The study employed a psychological resemblance test (experiment 1) where 20 different assessors, were asked to select in each case study, the best three matches of the ten reconstructions with the ante-mortem photograph of the individual during life. The results from these tests were correlated with a mathematical shape analysis assessment using Procrustes Analysis in which, the skull was compared in turn with each of the ten facial templates of each case study (experiment 2).The ranking of the assessors' reconstruction choice was correlated with the ranking of the Procrustes Analysis by using Spearman's Rank Order Correlation. The results indicate that although not statistically significant, it would seem however, that in some of the case studies, the mathematical approach using Procrustes Analysis does seems to capture *some* perceptual similarity in human observers.

Experiment 3, similar to experiment 1, was a further psychological resemblance test, which involved implementing E-Fit™ features on four of the ten reconstructed images per case study. Assessors were asked to select the closest E-Fit image match with the ante-mortem photograph. Again, results indicated that, although not statistically significant, adding E-Fit feature to the images appears to improve perceptual similarity in human observers, provided, the limitations of adding these characteristics are addressed. Furthermore, there also appears to be good agreement in most of the case studies between the two psychological resemblance tests using the two different sets of assessors in experiment 1 and 3 (reconstruction choice and E-Fit choice, respectively).

Further work involving anthropometric comparisons and using two methods of assessment (landmark line matching between images and proportion indices) was also carried out (experiment 4). It was found that matching landmark lines between images appeared to be only of limited value due to the images not being aligned at exactly the same viewpoint and magnification. It should be appreciated that because the thesis was based on recognition and was not an anthropometric study, precise alignment of viewpoints was not a requirement. Hence using the same data from the study, although images were in the frontal view, they were not aligned to the accuracy acceptable for an anthropometric study as there was no requirement to so. It would appear that, although there was some correspondence between the discrepant distances and the first and second ranked reconstructions, no firm conclusions could be drawn from this technique and therefore does not assist in understanding the way observers made their choices. Further tests would need to be carried out (beyond the scope of the thesis) to reach any firm conclusions.

Undoubtedly, given the complex nature of the recognition process, it would have been desirable to use reconstructions of persons known to the assessors rather than asking them to assess unfamiliar persons, since it is well established that familiar faces are easier to recognize than those that are unfamiliar to observers. It should be appreciated however, that, although the study was designed in this way for practical and ethical reasons, it nevertheless does not truly reflect the real operational forensic scenario.

Furthermore, recognition/matching is a much more complex process and even a reconstructed face which may be generally morphologically similar to the person in life may not capture perceptual similarity in human observers, especially in an unfamiliar scenario. It is not certain that identification will always occur even when the facial reconstruction bears good resemblance to the target individual.

Section I

Introduction Section:

Introduction (Chapter I)

Key Aspects of Cranio-Facial Reconstruction (Chapter II)

Cranio-Facial Identification (Chapter III)

Psychology of Facial Recognition (Chapter IV)

Chapter I

Introduction

The face has been described as the soul of the person. The three-dimensional shape of the human face is the result of the combination of the hard skeletal structure - the skull and the cartilage in the nose, and the soft fatty tissues, muscles and skin. Differences in these tissues, together with variations in colour and texture of the skin, differences in hair and facial features such as eyes, nose and mouth, provides the basic data which is used to categorise the face (Bruce and Young 1998).

With regard to deceased persons, personal recognition and identification by the next-of-kin is possible when the body is intact, recently dead and with little deterioration. However, when the body is decomposed, mutilated, dismembered or skeletonised then visual identification, the most frequent method of identification by next-of-kin, often is not possible.

Such cases are referred to the Coroner in England and Wales and the Procurator Fiscal in Scotland, since one of their responsibilities is to ascertain the identity of the deceased. It is up to the individual Coroner and Procurator Fiscal to decide which methods of identification will be considered acceptable.

Knight (1991) has outlined a number of reasons why identification is essential:

- Ethical and humanitarian need, especially information for surviving relatives.
- The facts of the death need to be ascertained for official, statistical and legal purposes.
- Administrative and ceremonial purposes for burial or cremation.
- To discharge legal claims and obligations regarding for example, property, estate and debts.
- To prove claims for life insurance contracts, survivors' pensions and other financial matters.
- To allow legal proceedings to proceed with a firm knowledge of the identity of the deceased.
- To facilitate enquiries into criminal or suspicious deaths.

With regard to the first consideration it is important to appreciate that families of missing persons suffer the agony of not knowing the fate of their loved ones and thus put their lives on hold, often paralysed with the fear that their loved one is suffering somewhere. They become victims themselves who are frozen in time and cannot move on, fearing that by moving on they are expressing lack of love or hope that their loved one is alive. Parents of soldiers missing in action say that not knowing their fate is far worse than being able to grieve for them. Consequently it is not surprising that families of missing persons say that they experience a sense of relief when the bodies of loved ones are finally identified. They find a sense of closure and even empowerment through the process of funeral rituals (Burns 1999).

Methods for identification include those that are legally accepted such as fingerprints, D.N.A. and dental records. These are considered as primary evidence of identity. Conversely, more circumstantial means of identification such as clothing and jewellery etc. would be more appropriately classed as confirmatory evidence. With any identification, it is good practice to use more than one method to establish identity. Sometimes however, this is not possible or indeed necessary.

Of the many methods available, different ones will carry different weight in the identification process and these will vary depending upon the incident and the state of the victim. A method that is useful for a sudden death in the street may have no value at all a burnt body from a house fire, or on badly decomposed or skeletonised remains.

This thesis is concerned with computerised forensic 3-D facial reconstruction as a means of recognition. This involves restoring the different soft tissues on the skull, taking into account the different criteria mentioned later on in this chapter, in an attempt to achieve as close a likeness to the individual as when alive.

However, facial reconstruction is used as a last resort on skeletonised, badly decomposed or mutilated corpses, when no other information is available. However, the true aim of forensic facial reconstruction is to act as a stimulus to facilitate identification when there are few or no other clues to identity.

Bones often survive the process of decay and provide us with the major evidence for the human form after death. They make up the framework of the body, containing information about man's environment, customs, disease and evolution (Bass 1995). More importantly in forensic cases, they provide information for general (biological) and sometimes personal identification. In this way many parts of the skeleton can provide essential information on the physical makeup of an individual. The skull in particular, is not only a good indicator of general identification, such as sex, age and ancestry, but can also provide the basis for personal identification. ***"In a sense the skull is the matrix of the living head; it is the bony core of the fleshy head***

and face in life" (Krogman & Iscan 1986). This is why the skull may be used to assist with personal identification employing cranio-facial identification in two broad ways: namely by:

a) ***Superimposition,*** where there is a putative identification of the victim and the skull.
b) ***Reconstruction****,* where there is initially no consideration of a putative identity.

Facial reconstruction is the subject of this thesis. This latter method however, is usually used as a last resort to assist in the identification process when there is little or no other evidence available. Facial reconstruction is performed in the hope that it may stimulate recognition, and consequently narrow the field of identification, allowing other legally accepted identification tests, such as radiographic and/or dental comparisons, DNA analysis, or techniques to establish positive identification. Once biological identification has been established on the skeletal remains, i.e. age, sex, ancestry and build, facial reconstruction essentially works by building the "face" up from the skull using soft tissue thicknesses at specific locations. Soft tissue depth data at these specific locations or landmarks exists from the published literature and they are dependent on age, sex, ancestry and build *(see Appendix 1 for published tables of soft tissue thicknesses and Chapter II).* Other soft tissue features like the *shape* of the eyes, nose, lips and ears are more difficult to reconstruct, since there is not always direct information on the skull regarding some of these features. However, some guidelines or canons do exist for positioning of these characteristics that conform to some extent, to the anatomy of the skull.

This thesis will concentrate on the application of forensic facial reconstruction using computerised three-dimensional graphics by evaluating and consequently attempting to improve its reliability in identification. The thesis is divided into two sections.

Section I, which is the introductory section, beginning with this chapter (Chapter I), introduces the reader to the concept of facial identification and the aims of the thesis in a broad context. Chapter II discusses the aims and historical perspective of facial reconstruction; it also discusses the very important aspects of the relationship of the skull to the face, such as soft tissue thicknesses, cranio-facial morphology and correlation together with the limitations. Chapter III discusses the various aspects of cranio-facial identification and in particular the development, current status and limitations of facial reconstruction. The last chapter in this section, Chapter IV, deals with psychology of facial recognition in identification. Finally, at the end of this section, the specific aims, objectives and hypotheses are outlined.

Section II deals with the present study, consisting of the methodology (chapter V), with individual chapters (VI-X) for each of the case studies, and the discussion and conclusions in chapter XI. Finally, the bibliography and appendices are in **Section III.**

Chapter II

Key aspects of cranio-facial reconstruction

Cranio-facial reconstruction has its origins in the 19th Century, initially to recreate and 'bring back to life' the faces of the rich and the famous (see* Historical Perspective *section below). Since then, over the last hundred years, there have been various methods used to produce reconstructions for forensic identification as well as for historical or archaeological purposes. These range from the traditional sculpting methods to those based on up-to-date computer technology. When no other method of identification is available in skeletonised, badly mutilated or decomposing remains, forensic cranio-facial reconstruction may be employed to produce a face which it is hoped will trigger recognition and thus lead to a positive identification.

Aims of facial reconstruction

The ultimate aim of forensic facial reconstruction is to create the appearance of the individual at the time of his/her death. The final image or sculpture is intended to bear an adequate resemblance to the deceased individual so that it may contribute to their identification. Gatliff (1984), states that facial sculpture is used as a last resort when other identifying techniques have been unsuccessful. She goes on to say that if the sculpture is carried out as accurately as possible within the limitations of the technique, "*it is usually worth a try*".

Although some researchers have claimed that facial reconstruction can provide legally admissible positive identification (Harvey 1976 a & b), most recent researchers are in agreement that facial reconstruction cannot on its own be used for such definitive identification (George 1987; Ubelaker et al 1992). Nevertheless the most important objective is to facilitate the production of further evidence that results in a positive identification, such as radiographic or dental comparisons or DNA analysis (Snow et al 1970; Reichs and Craig 1998; Vanezis et al 2000).

Historical perspective

Evidence of what must be considered the first examples of plastic representation of human features can be traced as far back as Pre-pottery Neolithic B Levels (c.7500-5500BC) when in 1952 excavators at Jericho, led by Kathleen Kenyon, director of the

British School of Archaeology in Jerusalem, made an extraordinary find in a level of about 6000 B.C. This comprised ten human skulls on which, after the flesh had been removed, faces had been built up directly over the crania in plaster with shells set into the orbits to simulate the pupils (Eydoux 1971).

Schaaffhausen (1884) reconstructed the head of a woman to simulate soft tissues on the face, but the soft tissue thicknesses had no scientific basis but were merely chosen arbitrarily. Anatomists in the late nineteenth century conducted much of the early research in facial reconstruction. They created visages of famous historical people and then compared them to portraits and death masks in order to corroborate the authenticity of skulls from the tombs in question. The faces of Schiller and Kant (Welcker 1883), Raphael (Welcker 1884) and Dante (Kollman 1898) were produced for these purposes.

The face of Schiller, produced by Welcker, in Germany involved an assessment of soft tissue thicknesses of the face at various points. He did this by inserting a thin blade into the flesh of cadavers at specific locations, which were usually adjacent to the anatomical landmarks of the skull. The blade was then marked and the depth of the knife's penetration was measured. His (1895), in reconstructing Bach's face and comparing it to portraits that were available, used a modification of Welcker's technique to obtain soft tissue depths for his reconstruction. He used a thin sharp needle bearing a small piece of rubber, which was pushed into the flesh at right angles to the bone at various locations until the needle struck bone. The piece of rubber was therefore displaced upwards from the original point. The depth of soft tissue thickness at that particular site was then measured in millimetres as the distance from the point of contact to the point of displaced rubber.

These early scientists categorised the face into four types of build: thin, very thin, well nourished, and very well nourished. Tissue thicknesses were then averaged accordingly: average male (very thin and well nourished); average female (thin and well nourished), and maximum-minimum variations for both sexes. Kollman and Büchly (1898) compared their results with those of His and Welcker and combined the data of soft tissue depths with their own until they had measurements taken from a total of forty-six males and ninety-nine females. Drawing on these measurements, Kollman recommended a specific technical process for reconstructing a face from a skull (Kollman and Büchly 1898). This technique was first applied to reconstruct the skull of an Early Neolithic female between the ages of twenty and thirty years exhumed from Auvernier in Switzerland. Kollman produced the basic 'scheme' of the head but the more difficult task of adding the morphological details of the face such as ears, mouth and nose was completed by Büchly. Merkel (1890) and Kollmann (1910) performed reconstructions on the skulls of ancient people using specific criteria such as the association between the structures of the soft tissue of the nose with that of the nasal aperture of the skull.

Interestingly, some investigators have found that the studies by His (1895) and Kollman and Büchly (1898), although carried out many years ago, still have relevance today in the standards recommended for reconstructions of Caucasian individuals (Caldwell 1986; Krogman and Iscan 1986).

After what appeared to be a gap in the field of facial reconstruction, the Russian Palaeontologist and anthropologist Mikhail Gerasimov (1907-70) developed his own techniques (Gerasimov 1971) by using clay to place musculature on the skull and neck which he considered as essential to the reconstruction of faces. He reconstructed the facial appearance of hominids and modern humans. Today, Gerasimov's technique known as the "Russian method," using clay to place musculature to produce the face on the skull is still used in manual plastic reconstruction in conjunction with utilising soft tissue thickness data at specific landmark locations. This is known as the combination technique (Neave 1980; 1989; Prag and Neave 1997).

Soft tissue thicknesses: past and present limitations of three-dimensional reconstruction

Three-dimensional facial reconstruction relies on the principle of building a "face" onto the skull based on the application of mean tissue thicknesses for given anatomical landmarks. In the past investigators utilised the data taken from measurements of tissue thicknesses of the cadaver head and face. The trend now is to employ the use of data obtained using CT, MRI and ultrasound where the two latter techniques are considered low risk and non-invasive. Lateral craniographs have also been used recently to obtain profile or mid-saggittal soft tissue depths in children and adolescents where there is readily available orthodontic radiographic data.

Unfortunately such soft tissue thickness data described above have certain limitations including:

- Until fairly recently, small numbers of subjects in studies.

- Restricted comparative tissue thickness data for different age groups, sex, ancestry and build.
- Lack of standardisation of landmark sites employed by different studies to obtain soft tissue depth data (especially when using different methodologies).

Some key studies have been conducted to obtain facial soft tissue thicknesses of the main ethnic groups by the needle/cadaver method. Until more recently the most traditionally cited were Rhine and Moore (1982) for Caucasoids; Suzuki (1948) for Mongoloids and Rhine and Campbell (1980) for Negroids. The study by Rhine and Campbell (1980) is a study of soft tissue thicknesses in American blacks.

More recently, Lebedinskaya et al (1993) utilised ultrasound for soft tissue thickness of 1,695 faces of ten different ethnic groups in the former Soviet Union. This method is probably the safest method to the volunteers of measuring soft tissue depths. Furthermore, although this study is probably the most comprehensive study of its type among those particular racial groups, the ultrasound technique also has some limitations when taking soft tissue thicknesses data to aid forensic facial reconstruction.

For example, in one study Helmer (1984) used ultrasound to obtain facial soft tissue thicknesses, however, the soft tissue data can be measured practically only perpendicularly to the bone surface. Additionally, the sample size in this study was rather small consisting of 10 males and 11 females. Aulsebrook et al (1996) also suggested that an experienced ultrasound expert should perform probing soft tissue depths because angulation of the probe is important, and different pressure needs to be applied at each measuring point/landmark. Furthermore, by Aulsebrook et al's (1996) own admission, some landmark locations were obtained on the surface feature of the face which would be approximated on the skull, since some landmarks are not directly correlated in linear fashion from face to skull. Other landmarks were located by palpating the underlying skull and then marking the skin. This makes the procedure difficult to replicate because of the subjectivity involved.

El-Mehallawi and Soliman (2001) conducted an ultrasonic assessment of facial soft tissue thicknesses in adult Egyptians. It provided evidence of notable sexual dimorphism in facial soft tissue thicknesses among Egyptians. However, the study showed the presence of inter-population differences in the facial soft tissue depths as evident from the average measurements in the Egyptian sample when compared with other ethnic groups. These include the African Negroid: the Zulu (Aulsebrook et al 1996), mixed population of South Africa: Caucasoid, Negroid, Khoi and San (Philips and Smuts 1996), Black and White American (Rhine and Campbell 1980), and Mongoloid: Japanese (Suzuki 1948).

In another study Helmer et al (1986) utilised MRI to obtain facial soft tissue thicknesses. The use of magnetic resonance induction (MRI) and computerised tomography (CT) scanning are probably as accurate as that of ultrasound probing for obtaining soft tissue depths, although using MRI may lose internal bone detail (Aulsebrook et al 1995). These are also relatively expensive procedures though, and not readily accessible because of ethical considerations, unless the measurements can be obtained from combining the research with a diagnostic procedure, especially CT scanning which is a radiation hazard to the patient. Phillips and Smuts (1996) use computerised tomography to measure the soft tissue thickness in a mixed race population in South Africa. The authors combined their research with the procedures for diagnosis of facial sinus diseases. They then compared their results to those of Rhine and Campbell (1980) and Rhine and Moore (1982) for the American Blacks and Whites, and with Suzuki (1948) for the Japanese. They found that Negroid males and females have notably thicker soft tissues throughout their faces than their mixed race counterparts. The faces of the mixed race group also have notable differences when compared to the American whites. Similarly the soft tissue thicknesses of the Japanese faces showed little similarity to this mixed race group.

Until very recently, limited existing juvenile soft tissue data presented a problem in reconstructing children’s faces. The few small studies that had been conducted on children using either an ultrasound technique (Hodson et al 1985) or existing orthodontic radiographic material (Dumont 1986) gave some helpful guidelines. The authors conceded that although diagnostic ultrasound is a potentially superior measurement of facial tissue thicknesses, ultrasonic technique requires proficiency in scanning and film interpretation. The authors therefore, went on to conclude that the future of facial reconstruction as a viable method of human identification will be largely determined by the ability to obtain accurate facial tissue thickness data and also, perhaps more importantly, on the ability to assess accurately the effect of bony anatomical variations upon the surface physiognomy of the individual. This latter observation interestingly, is one that Suk (1935) had made fifty years earlier in relation to the limitation of obtaining accurate soft tissue thicknesses on cadavers, where, superficial palpation on the soft tissue does not accurately locate underlying bony landmarks.

More recently large studies have been conducted to obtain and fill the gap in the literature with regards to facial soft tissue data from a large group of children and adolescents (Garlie and Saunders 1999; Smith and Buschang 2001; Williamson et al 2002; Wilkinson 2002).

Garlie and Saunders (1999) conducted the Burlington Canadian growth study by taking fourteen midline facial tissue measurements from 615 tracings of lateral radiographs of subadults aged eight to twenty years old. Their results indicated that males exhibit greater tissue thickness measurements than females but only significantly so after the age of fourteen and therefore, the authors conclude separate standards for older children may need to be used, at a time when skeletal indicators of sex become more reliable; for adolescents and children, they argue, there does not seem to be much reason to separate male and female measurements. This is important due to the difficulty of assessing the sex of a skeleton in early sub-adults

In a fairly comparable study to Garlie and Saunders, Smith and Buschang (2001) conducted the Montreal growth study which represents data from a mixed longitudinal sample of French-Canadian children and adolescents. The authors concluded from their results that they were comparable with Garlie and Saunders findings, that much of the variation in soft tissue thicknesses remains unexplained by changes with age and sex.

Manhein et al (2000) conducted a large study over a two-year period to obtain facial soft tissue thicknesses using ultrasound on a modern sample of children and adults of both sexes and different ages and ethnic groups (Black, White and Hispanic children). In contrast to the findings of Garlie and Saunders (1999) and Smith and Buschang (2001), they found that their new data for children and adults reflected that there were significant differences in tissue thicknesses between sexes and ethnic groups, and there was a significant relationship between these thicknesses and age, although they concede that this variation may not be significant enough to influence identification. The greatest variation they found was in the cheek region both directly above and below the second molars, on the mandibular body below the second molar, and at gonion where their measurements were greater, sometimes overtly so for both children and adults.

However, in the studies by Garlie and Saunders (1999) and Smith and Buschang (2001), only midline soft tissue data were obtained from White Canadian male and female subadults through the ages of eight to twenty years old and six to nineteen years respectively. Therefore the two studies mentioned above can only be partially compared to Manhein et al (2000) findings.

Some investigators in the facial reconstruction area have criticised the previous published standards of soft tissue thicknesses for the cheek region, since they resulted in facial reconstructions with gaunt or very thin faces (Dumont 1986). Manhein et al (2000) report that in their experience of producing facial reconstructions they often ignored or deleted these cheek markers published by Rhine and other contemporaries, as have other facial reconstruction experts. They suggest that future research could assist in this area, and that the variation in tissue depth means at the cheek region reported by different researchers, may reflect the position of the volunteers when measurements were taken.

Gerasimov (1971) however, suggested that the cheek area appeared gaunt because of lack of knowledge regarding the facial anatomy between landmarks themselves; hence reconstructions were produced with rather flat appearance between the landmarks rather than the natural contours of the face.

Williamson et al (2002) conducted a study on 224 African-American children and adolescents, between the ages of seven and fifteen years old, to obtain mid-facial thickness data using lateral craniographs. Only age was found to have a significant effect on mean tissue thickness variation on the sample; however, in many instances, the difference between these means was less than a millimetre. Such a small amount may not impair someone's ability to identify the unknown individual or have any affect on the reconstruction.

However, an important observation that has to be considered is that these current, and albeit, large studies of soft tissue depth data on children, with the exception of Manhein et al (2000), are mid-line soft tissue depths obtained by utilising lateral craniographs. Therefore, any soft tissue depth data lateral to these midline soft tissue measurements cannot be obtained and evaluated with respect to significance, to age, sex and ancestry in children over the whole face, and is therefore of limited value with regard to three-dimensional facial reconstruction.

Wilkinson (2002) obtained tissue depth measurements on white British children and adolescents of both sexes aged between eleven and eighteen years. She took measurements at 21 anatomical points using ultrasonic echo-location. Like Manhein et al (2000) the results indicated that there were significant differences in tissue thickness between sexes, and that there was a significant relationship between tissue thicknesses and age. The results suggest that most of the facial changes associated with puberty occur in the eleven-sixteen age group in males and in females in the eleven-forteen year age group. This study showed similar facial tissue distribution to the Manhein et al (2000) findings for the white children section.

Unfortunately, given the controversy in the soft tissue literature with regards to age, sex and ancestry, it is no wonder that there is no clear correlation between studies. Furthermore, direct comparison between studies is difficult because of the different methods of obtaining measurements in the first place, further compounded by the fact that the actual soft tissue landmark locations are not always standardised (Taylor and Angel 1998; Williamson et al 2002). Finally, regional ancestral differences are sometimes difficult to standardise for direct comparisons (Williamson et al 2002).

Moreover, with the advent of more sophisticated techniques as discussed above, for obtaining “more accurate” soft tissue thicknesses measured *in vivo* - namely, MRI, CT, ultrasound probing and lateral craniographs for the profile, one very significant limitation still remains. Soft tissue thicknesses alone are of limited use, since proper alignment requires a detailed knowledge of cranio-facial correlation. Therefore, for the soft tissue thickness data to have any real impact in facial reconstruction, the experimenter must know if the corresponding points between the skull and face are perpendicular/linear or angled, and, if the latter, by how much (Peck and Peck 1970; George 1993). Therefore, unless these techniques used to obtain soft tissue thicknesses can not only be standardised for landmark location, but can also give accurate correlation between face to skull at the landmark site of obtaining the soft tissue thickness (i.e. the angle between soft tissue on face to skull underneath), then the data can never be totally *accurate* or *repeatable*. Therefore, unless these angles are identified, the measurements cannot be replicated, or accurately applied for the purposes of forensic facial reconstruction techniques, however high-tech the methodology for obtaining the soft tissue thickness data is in the first place.

However, CT, MRI, and ultrasound sonography, by the nature of the way they operate, can only *measure* soft tissue thicknesses directly perpendicular to the measuring device in order to obtain accurate readings. Even then, it is prone to operator judgement as to actual location of landmarks from facial surface site to skeletal location underneath (Aulsebrook et al, 1996).

Therefore, in the absence of exact cranio-facial correlation data for every landmark location, the soft tissue thickness data can only serve as an *approximate* guide. George (1993) produced some good anatomical and artistic guidelines for forensic facial reconstruction with regard to cranio-facial correlation. Especially significant, the relationship between the face and skull at the corresponding anthropological landmarks is indicated. For example, whether a landmark on the face is perpendicular or linear to the corresponding landmark on the skull or if a landmark on the face is higher or lower than on the skull.

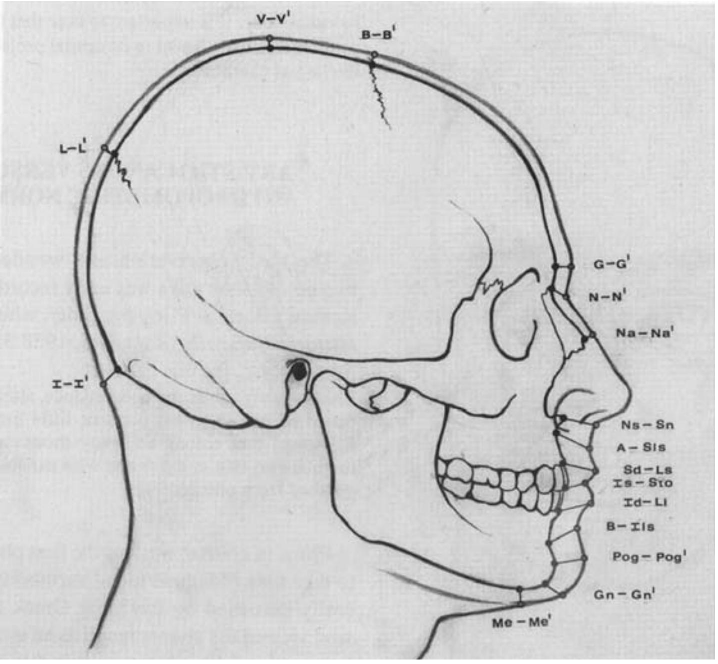

Figure 2.1 *Cranio-facial correlations. Lateral view (George 1993)*

To quote Peck and Peck (1970), "*the points themselves are meaningless. Ultimate appreciation of the profile depends upon the manner in which these points are connected. Harmonious profile flow may be visualised as a series of waves or reversed ' S, s' on the right profile.*"

George (1993) expands on this by saying that the person performing the facial reconstruction must have knowledge of three requisites if the research in this area is to have any validity:

"(1) The distance from N-N'; (2) the direction N' takes from N; and (3) how best to connect points G' to N' to Na', and so on. All three of these requisites are valid areas for future research." (Figure 2.1)

"… The frontal view is even more complex to reconstruct, and some artists lacking the required knowledge of craniofacial landmarks and their relations have been forced to rely on various artistic canons of facial proportion. This is a serious mistake because artistic canons reflect ideals. The forensic artist must always read the skull (or have it translated by a qualified anatomist or physical anthropologist) and not be led astray by artistic generalisations. Otherwise the end result will simply be the reconstruction of "generic" faces, i.e., each new reconstruction will resemble the last. And this should never happen, because to answer Pliny's question, like faces, no two skulls ever look alike." (Figure 2.2)

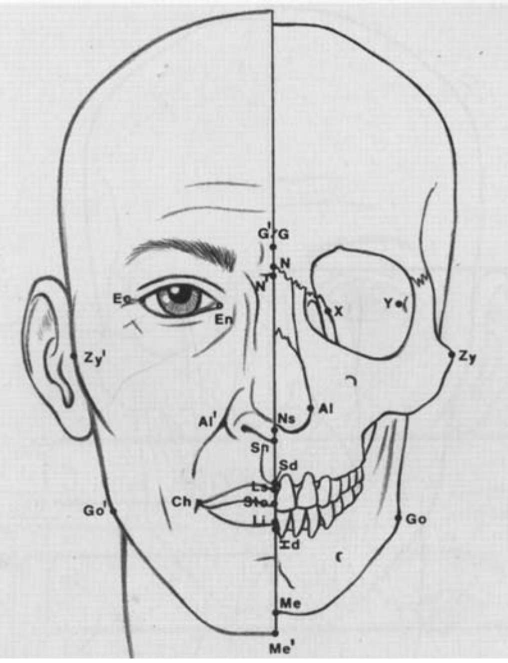

Figure 2.2 *Cranio-facial correlations. Frontal view (George 1993)*

Nelson and Michael (1998) have advocated the use of CT and MRI to allow the simultaneous visualization of the cranium and the soft tissues. Furthermore, they believe that it is not exclusively the accuracy of the soft tissue thickness data, but the sparsity of landmarks themselves, which contribute to a lack of understanding of how soft tissue changes between landmarks. However, CT and MRI are not used routinely in obtaining normal data, and certainly not for longitudinal data analysis studies.

In a pilot study Nelson (1995) collected soft tissue depth data using a vector method (CT) relying solely on bony points to define landmarks. However, the author encountered difficulties in accurately locating landmarks within 5mm scans used in the study and the ambiguous nature of some of the definitions. A further problem was encountered as not all scans were taken exactly parallel to the Frankfort Horizontal Plane[1] and therefore the procedure was deemed impossible to control the measurement angle to the bone.

Nelson and Michael (1998) believe that the new approach to facial reconstruction using a computer graphics technique known as *volume deformation* addresses some of the previous problems encountered. The use of volume deformation techniques allows the facial tissues to be dealt with as a single component, thus freeing the procedure from the constraint and problems associated with the employment of standard soft tissue depth data table. This new advocated method based on volume deformation has therefore one advantage over surface deformation method that the whole of the data representing the facial soft tissues are deformed and not just the surface. In theory facial soft tissues should change in response to the changes in the skull, and therefore the face is not merely a mask depending on a small number of soft tissue depth points. However, this method is still being assessed. Furthermore, contours or volume (3D) measurements of tissue depths are not regarded as cost effective for facial reconstruction applications at present (Tyrrell et al 1997).

Cranio-facial morphology and correlation

As discussed above, soft tissue thickness depth data provide at best a fairly good approximation of the contour of the face, but specific details of some of soft tissue features, such as *shape* of eyes, *shap*e of the *nasal tip*, and *shape* of lips and

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[1] The Frankfort Plane or Frankfort Horizontal Plane is used to define the correct position of the skull; this extends from the upper rim of the external auditory meatus (called porion) to the inferior border of the orbital rim (called orbitale). In 1882 an international congress held in Frankfurt -am- Main, Germany, anatomists and physical anthropologists decided to use a horizontal reference line for the orientation of the skull. About fifty years later, when cephalometrics became established, this reference line was adopted. However, there remains some confusion in the literature in relation to the spelling of the word *Frankf**o**rt* which is used interchangeably with *Frankf**u**rt to* refer to this horizontal plane. Frankfurt is the original German correct spelling and also the modern English name for the German city. However, in 1882, when the cephalomeric horizontal reference was coined, the English spelling for the city was in fact, Frankfort. The historical English spelling first appeared in 1823. (*The Shorter Oxford English Dictionary on Historical Principle,* 1973, reprint 1992, 3rd edition, Volume I, pp801 Oxford: Oxford University Press). Therefore, the present author will use the spelling *Frankfort* to refer to this horizontal plane.Oxford University Press).

ears are not indicated by any bony landmarks. For example the ear and nose have a cartilaginous frame rather than direct bony support. A number of traditional guidelines do exist for reconstructing soft tissue features on the skull such as, eyes (Stewart 1983); nose (Schultz 1918; Macho 1986; 1989; Hoffman et al 1991), ears (Farkas et al 1987); and mouth (Gatliff 1984); some of the above and other soft tissue structures and how they correlate to the skull have also been explored by other investigators (Gerasimov 1971; Gatliff and Snow 1979; Caldwell 1986; Gatliff 1984; Krogman and Iscan 1986; Lebedinskaya et al 1993; George 1993; Fedosyutkin and Nainys 1993; Prag and Neave 1997; Taylor 2001). However, these are by no means definite canons but merely approximations in some instances; some of these guidelines are untested and /or tested but unpublished subjective guidelines (Stephan 2002b Stephan 2002c). Consequently, the reliability of some of these guidelines remains unknown. For example, the canon that eyeballs are centrally positioned in the orbits (Gatliff 1984; Krogman and Iscan 1986); nose projection being equal to three times the length of the nasal spine (Gatliff 1984; Krogman and Iscan 1986), or equal to the junction of tangents where the lower third of the nasal bone bisects the tangent of the anterior nasal spine (Gerasimov 1971; Prag and Neave 1997); height of lips being of equal height to the central incisor enamel (Gatliff 1984). *(For the latest research on these features see below and also sections "**selection of the facial templates and limitations**" and "**reliability, validation, and success**" in Chapter XI).*

Fedosyutkin and Nainys (1993) although, are more optimistic about the degree of authentic reconstruction of features such as mouth, nose, and shape of the eyes, stating that these features are based on their strict correspondence with the bony structure of the skull. They nevertheless, appreciate that the flesh of the face, lower part of the chin, and the eyes and eyelids can only be approximate. And finally, they acknowledge that hair, colour of eyes and skin, ears, and wrinkles can only be conditionally reproduced with less reliability than the more anatomically based characteristics because there is little direct correlation between theses features and the skull. The authors go on to say "*…authenticity of reproduced attributes of appearance depends to a certain degree on the amount of detailed information obtained from the primary examination of the remains by the forensic expert.*"

More recently some researchers have tested these traditional guidelines regarding reconstructing facial soft tissue features to the underlying skull. Stephan

(2003) has tested the traditional guidelines used in facial reconstruction for determining mouth width as being equal to:

- i) inter-pupillary distance (Gatliff and Snow 1979; Caldwell 1981; Krogman and Iscan 1986)
- ii) distance between medial borders of the iris (Broadbent and Matthews 1957; Prag and Neave 1997).
- iii) distance between the most lateral junctions of the canines and first premolars (Krogman and Iscan 1986;Fedosyutkin and Nainys 1993).

He found that all three methods produced widths that were statistically different to the actual mouth widths. However, method ii) was the best method evaluated to represent the mouth width, and on average underrepresented mouth width by approximately 2mm. Stephan suggests that inter canine-width plus 57% of the cumulative distance between the lateral aspect of the canines and the pupil centres can be used to estimate mouth width. Research also suggests that (method ii) the distance between medial borders of the iris approximates the mouth width fairly closely as discussed above. However, the soft tissue prediction guideline proposed by Stephan above is limited, as acknowledged by the author himself, because it relies on accurate medio-lateral positioning of the pupils within the orbits themselves, which cannot be directly determined from the skull and must be therefore estimated with some unknown errors. This limitation also applies to the fairly accurate method ii) that mouth width is equal to the distance between the medial borders of the iris. Since any error in positioning the eyeball in the orbits will result in inaccurate mouth width as well. Stephan and Henneberg (2003) therefore suggest that it would therefore be more appropriate to use known hard tissue landmarks that can be obtained directly from the skull to predict mouth width. He reports the results of using inter-canine width as a percentage of mouth width for its prediction. Inter-canine width was therefore equivalent to 75.8% (accepted as 75% for ease) of mouth width (or mouth width was about 133% of canine width)

In a similar study to the above, Wilkinson et al (2003) studied the relationship between the soft tissues and the skeletal detail of the mouth. They found that the most reliable method of mouth width was the interlimbus (medial borders of iris) distance, and lip thickness was positively related to the height of the teeth. Furthermore, they found no difference in these relationships between males and females. The authors have come up with formulae to calculate lip thickness from the height of the teeth for White Europeans and Asians in the Indian subcontinent. Their results suggested that canons followed by Gatliff and Snow (1979) and Gatliff (1984) that lip thickness is the same as gum line to gum line thickness is inaccurate. Furthermore the same relationship between lips and teeth cannot be assumed for different ethnic origin groups. Wilkinson et al (2003) suggest that broad variation in the lip thickness and tooth height would imply that any relationship must be considered as a generalisation, and that other factors may influence lip thickness such as prognathism age and ethnic origins as first suggested by Gerasimov (1971). Gerasimov maintained that small straight teeth were characteristic of thin lips and orthognathism, and that prominent big teeth were characteristic of thick lips and prognathism.

Furthermore, Wilkinson et al agree with Stephan's study with regards to the inter-pupillary distance as not being an accurate indicator of mouth width, showing that mid pupil to mid pupil distance was shown to be larger than the mouth width by as much as 11.3mm. This was in agreement with Stephan's study, where this discrepancy was found to be on average 11mm. Wilkinson et al suggests that the accuracy of facial reconstructions following this guideline for width of mouth may be compromised. Furthermore the authors acknowledge that the position of the canine teeth will provide the most accurate predictor of the position of the corners of the mouth, but suggest that when the teeth are absent, the corners of the mouth may be positioned relative to the medial borders of the iris. However, as noted by Stephan (2003) and Stephan and Henneberg (2003) above, this canon has the limitation that it relies on the soft tissue guideline of accurate positioning of the eyeball in the orbit itself in the first place with all the unknown errors associated with that.

The canon to determine globe projection by centrally locating the eyeball in the orbit and positioning the cornea so that the most anterior point falls in line with a tangent dropped from the mid-superior and mid-inferior orbital rims has also been cited as being inaccurate and, furthermore, it has been suggested that the anterior globe projection appears to be under-predicted by 4mm. (Stephan 2002b). However, others disagree with this statement citing that this 4mm discrepancy is already compensated for when positioning artificial eyes by most forensic sculptors (Craig 2003).

Wilkinson and Mautner (2003) have come up with a formula to calculate eyeball protrusion: Eyeball protrusion = 18.3 - (0.4 x orbit depth).

Furthermore, it has also been suggested that the guideline used in facial reconstruction that superciliare (the most superior part of the eyebrow) is positioned immediately above the lateral point of the iris (Taylor 2001), is not always very accurate. This is due to the structure of the eyebrows, which are not generally well defined, especially in males Stephan (2002c).

Farkas et al (1987) have demonstrated that the length of the ear is not equal to the length of the nose as reported by some authors (Krogman and Iscan 1986; Gatliff 1984; Fedosyutkin and Nainys 1993) since 90% of people have an ear larger than their nose.

Despite some of the recent and thorough comprehensive reviews discussed above on how to reconstruct some of these facial features from the skull, a considerable amount of individual interpretation is still possible in some of these structures given that accurate correlation between skull and face is not always possible. Therefore, one cannot reconstruct all these features with complete accuracy. For example, Macho (1989) stated that the external nose is a very complex organ and that its soft tissue contour does not strictly follow the underlying bony structure. The author maintained that her study showed that knowledge of soft tissue thicknesses alone is not sufficient for successful facial reconstructions, but a more holistic approach should be used to clarify the relationship between soft tissue cover and the underlying hyaline and bony structures. Wilkinson et al (2003) share this view… "*Any study that increases the knowledge of facial detail that can be extrapolated from the bony skull will increase the degree of accuracy of the facial reconstruction. This is especially valuable in the forensic field, where it will help to improve the success rate of the identification using the facial reconstruction technique.*"

However, exact correlation between skull and soft tissue *may* not be essential to reconstruct from the skull an image that bears enough resemblance to the living person for identification purposes. To conclude by quoting Lebedinskaya et al (1993):

"…Also even if all of the points are not precisely matched, it is still possible for the reconstructed image to resemble the original. It seems that ideal precision may not be so important after all. In all likelihood, the human eye does not perceive deviations of a feature within certain limits and permits some leeway. What are those limits? This problem must be studied next.

Chapter III

Cranio-Facial Identification

This chapter discusses the development and current status of cranio-facial identification and particularly the role of reconstruction together with its limitations.

When one is presented with a skull for the purpose of identification of an individual, the techniques used fall into two groups: cranio-facial superimposition, and cranio-facial reconstruction.

1) Cranio-Facial Superimposition Techniques

- Comparisons with busts, Portraits and death masks (historical)
- Photographic superimposition (forensic scenario)

2) Cranio-Facial Reconstruction techniques

- Two-dimensional facial reconstruction: Traditional and computerised
- Three-dimensional facial reconstruction: Manual/traditional and computerised.

Although cranio-facial superimposition techniques are largely outside the scope of this thesis, which largely concentrates on cranio-facial reconstruction as a means of personal identification, it was, however, felt necessary to deal with some of the aspects of this technique, given its place in the evolution and development in the field of facial identification. Furthermore, some of the technical implications of superimposition have huge relevance in the field of cranio-facial reconstruction.

Cranio-Facial Superimposition Techniques

Whether in a forensic or a historical scenario, cranio-facial superimposition can only be attempted when identity of the skull in question is suspected to be that of the photograph/image to be compared with (putative identity). Sometimes however, superimposition may be used in a process of elimination in a small sample of cases. Superimposition attempts to identify or in some cases, disprove the identity of the suspected person in question by using any of the superimposition techniques mentioned above. The main principles of cranio-facial superimposition are the same as that of cranio-facial reconstruction. That is to say that the correlation of face to skull is of paramount importance. This includes paying special attention to the outline of the two superimposed images, landmark or anthropometric points on the face in relation to the skull, soft tissue thicknesses and the general morphology of face to skull, as discussed in the previous chapter.

Comparisons with busts, portraits and death masks

Although very important in the socio-historical context, comparisons with busts, portraits and death masks must have at times been rather dubious materials to work with since it was very difficult to know how faithful they were with regard to cephalo-facial proportions and relationships to the person in question. Many famous people have been “brought to life” in this manner, for example, Schiller and Kant (Welker 1883, 1888) Raphael (Welcker 1884), and Bach (His 1895). We are indeed, indebted to some of these early workers in the field of facial identification not only for the historical significance but also because the system they devised for measurements can in general be applied to all subsequent work, not only for comparison or superimposition work but also has great relevance in the field of facial reconstruction. Welcker (1883) and His (1895) in particular made countless measurements of soft tissue thicknesses and the relationships between the bony details of the external features. Essentially, all the methods of cranio-facial identification are based on these early studies (Grüner 1993) and their application and usefulness depends on whether the assessor can make a comparison with a suitable portrait, bust or death mask of the person in question. The anatomists His (1895) used a modification of Welcker’s (1883) technique and succeeded in identifying the skull of Johann Sebastian Bach (figure 3.1). He did this by modelling a bust on a plaster cast of the skull taking into account soft tissue thicknesses and then he compared it to a portrait of Bach.

This technique was also later applied to ‘portraits of different races’ (Gross 1899, 1901). Welcker’s method could be used to achieve more reliable results by using any available death masks of figures of historical importance.

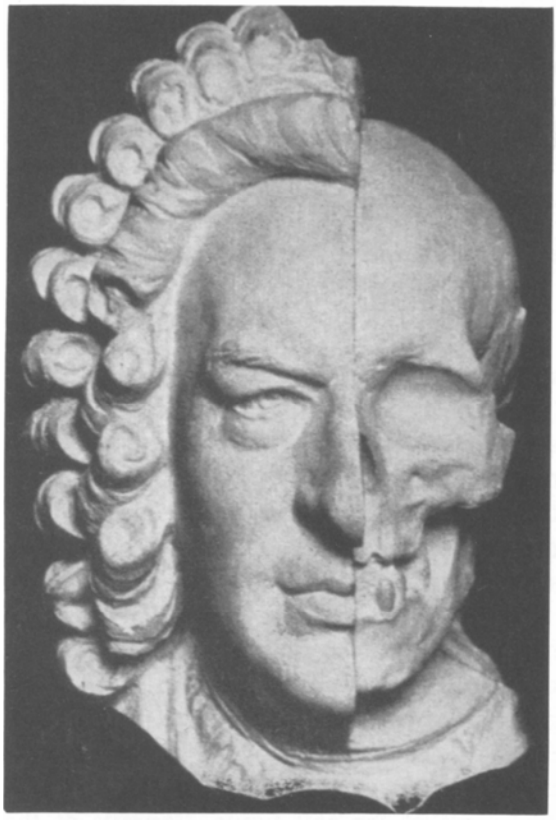

Figure 3.1 *Facial reconstruction of J.S. Bach (His 1895)*

Welcker's method involved producing outline drawings of the skull and the death mask in exact orthogonal perspective by using Lucae's (1873) apparatus, with the two objects held in matching corresponding positions. The drawings should match when allowance is made for soft tissue thicknesses. Using this technique Welcker (1883) managed to prove the identity of the skull of Immanuel Kant (figure 3.2).

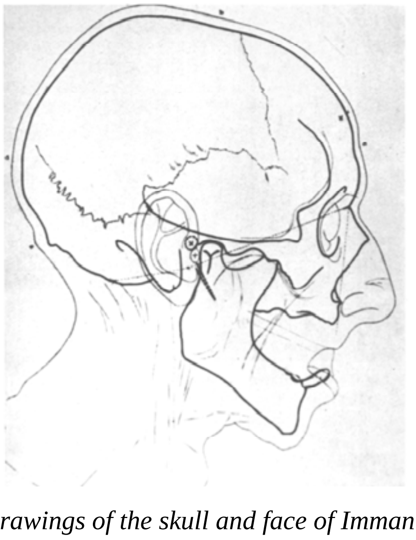

Figure 3.2 *Superimposed drawings of the skull and face of Immanuel Kant (Welcker 1883)*

Similarly the anatomist Tandler (1909) succeeded in identifying the skull of Josef Haydn by using Welcker's method. However, this principle has inherent problems, in that one is assuming that the death masks are anatomically and morphologically an accurate representation of the person in question. For example Welcker (1883) could not prove conclusively the identity of Schiller's skull from Schiller's death mask. The other possibility of course is that the death mask was morphologically faithful to Schiller but the skull was not authentic (Wilder 1912).

Photographic superimposition

With the advent of photography together with the development by French criminalist Bertillon's system of description and characterisation named after him, the so-called 'Bertillonage', more avenues were opened in the facial identification field; since the Bertillon (1895; 1896) system could be used with photographs. The anatomist Stadtmüller (1932) adapted Welcker's (1883) method for photography. In one case he tried to match enlargements of forensic photographs with photographs of the skull taken with a lens of the same focal length at the standard distance as advocated by the Bertillon system. Derry (cited in Pearson and Morant 1934) photographed the head and skull of an executed Egyptian criminal. When allowing for the fact the head and skull were photographed in slightly different positions, one can still see that the two images bear striking similarities to each other when superimposition of skull to face is attempted.

The most celebrated and successful case in a medico-legal context has to be attributed to the 1935 Buck Ruxton murder case (Glaister and Brash, 1937). This was a very important case historically; not only because this was the first genuine forensic facial identification case to be tested, but also demonstrated that the technique was adequately accurate to be accepted in court. Comparisons were made between ante-mortem photographs and two partially macerated skulls believed to be Mrs. Ruxton and her maid Mary Rogerson using the superimposition technique. Outlines of the skulls and photographs were employed and showed that in Mrs Ruxton's case one of the skulls could not possibly belong to her whereas, the other corresponded well with her photograph (Figure 3.3 and figure 3.4). It is generally accepted that superimposition is of greater value in ruling out a match between a skull and a facial photograph than it is for proving conclusively that it a good match in personal identification (Yoshino and Seta 2000).

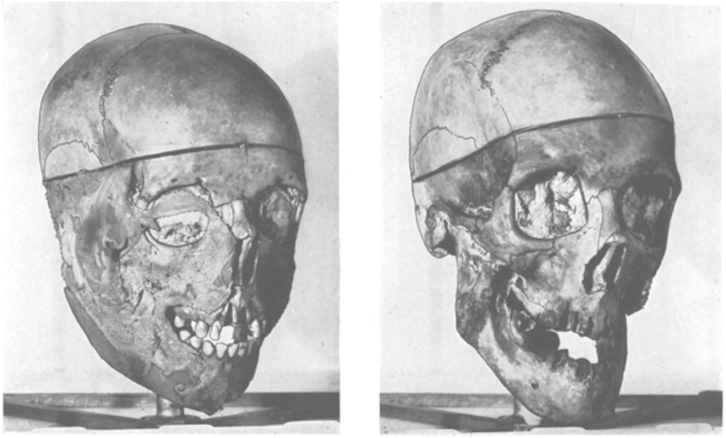

Figure 3.3 *Skull of Mrs Rogerson is seen on the left and that of Mrs Ruxton on the right side (Glaister and Brash 1937)*

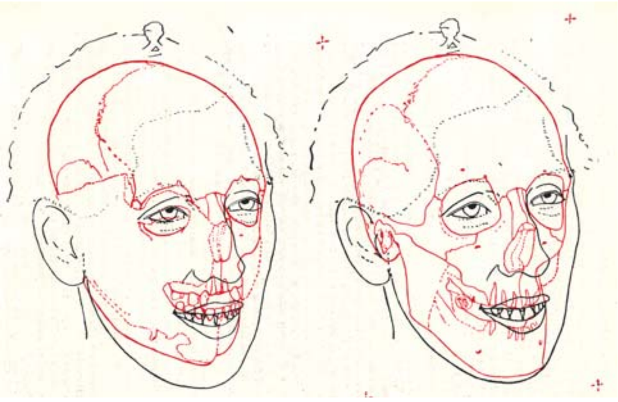

Figure 3.4 *Outline of photograph of Mrs Ruxton after scaling with both skulls, is overlaid over outlines of the skulls. The skull on the left does not show good correspondence whereas the overlaid images on the right side are a good match (Glaister and Brash 1937)*

The superimposition evidence in the Buck Ruxton case was allowed by the court as a means of supportive evidence in the identification of the two skulls but it was not admissible, however, as a means for determining positive identification without other supporting data. Today, the issues of how reliable superimposition techniques are in determining positive identification are still debated by fellow researchers (Austin-Smith and Maples 1994).

Preparation for Cranio-Facial Reconstruction

Preliminary data collection for facial reconstruction

Although the skull is the basis for facial reconstruction, other physical remains may be available at the scene that may be invaluable to the final reconstruction. For this reason scrupulous scene processing is required to recover features from the skeletal remains scene such as teeth and hair, and any accessories such as spectacles, jewellery and hats that may have been worn by the individual. These features and accessories mentioned, particularly finding any hair samples with the human remains is invaluable in establishing any facial hair, colour, length, texture and potentially hairstyle. Furthermore, hair can be examined microscopically to determine racial characteristics or evidence of chemical treatment such as colouring, perming or straightening of the hair. All this potential information can be incorporated in the final image to produce as accurate a facial reconstruction as possible and consequently maximising the chances of establishing recognition and identity.

Given the importance of the presence of hair and hairstyle in any facial reconstruction, it has therefore even been suggested that this scene processing should include examining bird nests, into which hair may have been incorporated (Howard et al 1988). In reality this is a not so practical to achieve nor can one be sure that any hair sample found in bird nests near the scene actually came from the victim.

Furthermore, thorough examination of the scene by assessing the skeletal remains and teeth (*see also section below on skull morphology and craniometric characteristics)* may help to ascertain the general identification of the victim by assessing ancestry, sex, age and build. Similarly, any clothing and jewellery found at the scene although, potentially very important for general and/or personal identification, is classed as secondary evidence of identity and has to be treated with some caution in relation to the gender of the victim or establishing positive identity solely on such evidence.

This kind of information regarding general identification (ancestry, sex, age and stature) of the victim and potentially personal identification is usually provided by police forces, or specialists such as forensic pathologists, odontologists, forensic anthropologists and other forensic experts, usually in the form of a written report. Therefore, it cannot be emphasised enough how invaluable these reports are in improving the accuracy of the facial reconstruction.

Skull morphology and craniometric characteristics

As discussed in chapter II soft tissue thicknesses at specific landmark locations, as well as cranio-facial morphology and correlation are vital considerations for the purpose of facial reconstruction. However, detailed morphological analysis of the skull itself by establishing the osteological variation in terms of size and shape is a crucial starting point. As mentioned elsewhere, both morphological and craniometric examination of the skull can help establish general identification such as ancestry, sex, age and body size of the subject at the time of death. In addition, cephalometric measurements are important in discerning the proportional relationship between the skull and the reconstructed face *(see the present study in section II).* Moreover, the prominence of some anatomical features on the skull, such as the supraorbital ridges and zygomatic arches will determine the general appearance of the eyes and cheeks. The ruggedness of some bony features on the skull, because of muscle attachments such as the mandible and mastoid processes, may give an indication of the gross appearance. Similarly, the dentition and/or dentures should always be closely examined as this indicates how the mandible articulates with the maxilla and hence gives rise to the general appearance of the lower face. It is possible that loss of height or vertical dimension of the face may be due to excessive wear and tear of the occlusal surfaces or abnormal posturing of the mandible and soft tissue support of the lips (Taylor and Angel 1998*).* (See also section below on *Skull assessment and preparation for facial reconstruction* regarding dentition and dentures*)*

Furthermore, assessing any cranial and facial asymmetries, idiosyncrasies, ante-mortem health, pathology, trauma, cultural modifications of head and face and individual habits are helpful in piecing together the evidence before this type of identification is carried out so that it can be incorporated in the final reconstructed face.

Although radiographs are of limited use in this scenario for extracting the cephalometric characteristics mentioned above, they may nevertheless sometimes be useful in that they can show peculiarities that are not visible to the naked eye (Quatrehomme and Işcan 2000).

Skull assessment and preparation for facial reconstruction

The state and preservation of the skull will vary greatly depending on the circumstances surrounding the case. Ideally the skull will be complete with all the more delicate facial bones intact with mandible and teeth all present. The skull is not always clean and dry, and if it is not, then it needs to be appropriately cleaned, dried and rendered sterile before it can be suitably handled, especially in a forensic setting. Similarly, when dealing with fragile and archaeological remains the help that can be obtained from an appropriate member of the archaeological team is invaluable (Prag and Neave 1997). For example, the cleaning and consolidating of the bones can be more appropriately carried out with any conservation work that may be required.

There are of course times when one is presented with an incomplete, badly damaged or fragmented skull. The extent of the bone loss and damage will be a key factor as to whether one proceeds with the facial reconstruction in the first place. For example there has to be enough information present to establish the height and width of the skull so that the true dimensions can be applied to establish the correct proportions of the resulting face. Sometimes this can be accomplished by modelling in wax any missing areas onto the skull by assuming a mirror image of one half of a portion of the skull. Although very few skulls and consequently faces are truly symmetrical, nevertheless, the asymmetry has to be acute before it can affect the overall appearance of the face significantly (Taylor and Angel 1998; Wilkinson 2004).

Research suggests that recognition can still be achieved from composite images made up from mirror image modelling of missing areas (Gerasimov 1975; Wilkinson 2004). Therefore, this would suggest that any small errors created when restoring the missing areas of the skull in this mirror image manner should not have a huge impact in the facial reconstruction procedure and consequently the recognition and identification process. However, when corresponding features from both sides of the skull are missing the mirror image principle cannot be applied. Taylor and Angel (1998) state that the degree of accuracy to which defects can be repaired on the skull varies with the site of the damage, and decreases with the increasing size of the defect. Similarly, Taylor and Gatliff (2001) affirm that: *"Large areas of the cranium can be missing without substantially interfering with the reconstruction process, but most of the facial bones should be present for successful results."*

However, a study conducted at the University of Manchester (Colledge 1996 *cited in Wilkinson 2004*) suggested that when unilateral features are missing, they could nevertheless be estimated with relative accuracy by using the surrounding bones as guides. Colledge (1996) demonstrated this in a blind study by taking five skulls and remodelling a different missing area in each of the five skulls. The remodelled missing areas included the frontal bone, the zygomatic bones, the maxilla, the occipital bone and the mandible. The remodelled samples were then metrically compared with the original specimens. The author found that the modelled features were not significantly different to the original areas except in the case of the mandible. The mandible had been remodelled with substantial errors, particularly with respect to the jawline and chin height. This would result in not only altering the height of the skull and consequently the vertical dimensions of the resulting face, but would also significantly modify the lower general shape of the face. This suggests that the accuracy of any facial reconstruction attempted on skulls with a missing mandible could be severely compromised. This is in agreement with Koelmeyer (1982) referring to cranio-facial superimposition techniques, where he cautions that the complete facial skeleton is required to establish any degree of certainty of identification.

Re-articulation of the mandible to the cranium is fairly straightforward if the teeth are present to establish the vertical dimensions of the mandible and maxilla by assuming normal or centric occlusion, and the mandibular condyles are positioned in the glenoid fossae of the temporal bone. For this reason any loose teeth are secured in the skull before articulation is attempted. Where very few or no teeth are present to articulate the mandible with the maxilla, for example in an edentulous skull where the dentures are not found, or where insufficient number of teeth are present, average measurements are used to establish the vertical dimension between the maxilla and the mandible (Krogman and Işcan 1986). Occlusal wax rims similar to those used in constructing dentures may be used to achieve this (Taylor and Angel 1998). Taylor and Gatliff (2001) advocate a method for such circumstances when dealing with the edentulous skull with no available dentures for finding the correct position and height of the mandible. A pencil or dowel is positioned through the mandibular notch, behind the pterygoid processes of the sphenoid bone and through the opposite mandibular notch. The cranium will then rest on the pencil or dowel at the approximate height above the mandible by assuming the correct alignment of the mandible in relation to the cranium (figure 3.5)

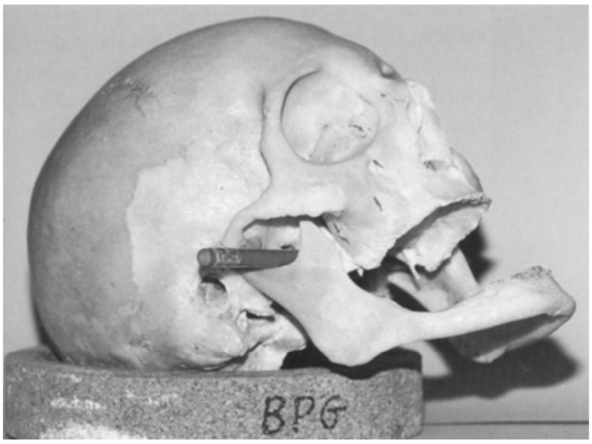

Figure 3.5 *The placement of the mandible in an edentulous skull (Taylor 2001)*

It is crucial to establish whether or not dentures were worn since, as stated above, this can not only radically affect the whole facial appearance of a person but it also emphasises the significance of accurate positioning of the mandible. Therefore, if the skull is edentulous but the dentures are found at the scene, then the positioning of the dentures in the skull to achieve the correct vertical dimension and shape of the lower face is crucial. A layer of clay or wax may be applied to simulate the missing gum tissue or gingiva before the dentures are positioned and mandible articulated in position. Similarly, when articulating and securing the mandible to the cranium the few millimetres “spacing” that exists naturally in life between the condyle on the mandible and the glenoid fossae of the temporal bone on the cranium may be simulated by using wax, clay, cotton, gauze or some other materials *(see also methodology section).* This “spacing” is due to the cartilage that covers the mandibular condyle and also the articular disc in the temporo-mandibular joint. Apart from providing this required “space”, attaching a material such as wax or clay between the mandible and the cranium also avoids bone to bone gluing. Taylor and Gatliff (2001) also advocate gluing a portion of a round toothpick on the surface of the molars to simulate the true state of the face in life, where the jaws are usually relaxed and the teeth are not clenched and therefore the mandible hangs in a slightly slack manner. The mandible may be additionally secured by using dental sticky wax or vinyl acetate along the occlusal surface of the teeth. Taylor and Gatliff (2001) advocate a small amount of glue for this purpose, although the former is preferable because they do not cause any potential damage to the skull.

If, however the person was edentulous in life but did not wear dentures - this can be assessed from the alveolar surfaces or process of the maxilla and mandible -

then this will have a huge impact on how the individual looked in life making the individual very distinct in appearance by giving the impression that the individual had thin lips and a prominent chin and therefore improving the recognition and identification process. Obviously this needs to be clearly illustrated on the reconstruction to maximise the chances of identification. *(See chapter IV Psychology of facial recognition*).

In 1991 a reconstructed image of a murder victim (Sharom et al 1991; Vanezis et al 2000) illustrated such a situation, that although the victim was in fact edentulous she did not wear dentures in life. Within a few days of publication of the reconstructed images the authors were informed of a possible person who might be the victim. Photographs that were subsequently sent were matched to the skull using video-superimposition and the identity was confirmed using mitochondrial DNA from her skull that then subsequently compared to her mother and sisters' DNA. Ideally a report from a dentist or odontologist should always be requested for a dental analysis. The assessment of teeth and articulation, not only provides information to the lower facial appearance, as stated previously, but occasionally may provide clues to the socio-economic status of the person in question. For example, a skull with severely neglected dental hygiene may indicate rather a different demographic background for that individual to one that was presented with perfect or expensively restored teeth (Taylor and Gatliff 2001). Furthermore, the dental assessment of missing teeth is very important with regards to whether the tooth loss is ante-mortem or post-mortem. This is indicated by the state of the alveolar process or tooth sockets, a clean open alveolar process indicates a post-mortem loss, while one that has healed or a partially filled socket with bone indicates an ante-mortem loss. If requested, the dental report will also indicate estimated times of how long the teeth had been extracted or missing during life. If the tooth loss is ante-mortem and the position of the loss in the mouth is sufficiently significant to influence recognition, then this should be reflected in the reconstruction. Similarly, any dental anomalies and unique characteristics can be very distinctive and thus improve the recognition and identification process. Therefore, these unique traits or anomalies should be represented on the reconstruction. For example, a diastema (a gap between teeth), obvious gold crowns, a very marked chip or rotation of a tooth, a very obvious distinct overbite or as mentioned above obvious tooth/teeth loss that had been extracted or missing for many years during the individual's life. This may require a slightly open mouth on the reconstruction to display this to its full advantage. Some advocate that sometimes a smiling facial[2] expression may be used to illustrate these unique characteristics of the teeth (Taylor and Gatliff 2001).

A slightly open mouth image for this purpose was used by the present author (Vanezis et al 2000) in reconstructing the 5,300-year-old Tyrolean mummy known as the Iceman or Ötzi (figure 3.6). He was so named after the Ötztal Alps where he was found in 1991 in the Southern Tyrol region between the border of Austria and Italy (Spindler 1994; MacDermid 1998). The reconstruction required a slightly open mouth to show the upper-midline diastema between the two first incisors

a) **b)** **c)** **d)**

Figure 3.6 *3-D computerised facial reconstruction of the Iceman performed by the present author. A Stereolithograph of the skull (before and after coating) is shown on the left side (**a** and **b**). The reconstructed image **(c)** shows the distinct upper mid-line diastema. The model on the right side **(d),** was produced from the reconstruction and is exhibited at the South Tyrol Museum, Bolzano Museum, Italy.*

Cranio-Facial Reconstruction Techniques

Two-dimensional: Traditional and computer generated

Several techniques are used to produce frontal and profile portrait-style views. The two-dimensional graphic reconstruction method creates a face from the skull with

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[2] The author prefers a slightly open mouth to a smiling face to exhibit these unique characteristics or anomalies in facial reconstructions. This is because occasionally there are some psychological implications when using a smiling face with regard to recognition and identification, as this implies a certain mood. For example the individual in question may have seldom smiled in life and this consequently may influence the recognition and hence identification process. (Bruce and Young (1998) Messages from the face: lip-reading, gaze, and expression In *In the Eye of the Beholder: The Science of Face Perception. Chapter 6 pp.187-219* Oxford: Oxford University Press. (See also *Facial expressions in chapter IV Psychology of facial recognition*)

the aid of soft tissue depth estimates (Krogman 1962: Cherry and Angel 1977; Krogman and Iscan 1986; George 1987; Taylor 2001).

Taylor (2001) referred to the illustration by John Adams (Krogman 1943, 1962 and Krogman and Iscan 1986 as being *"the only reference in the early literature to the usage of any tissue depth data affixed to the skull prior to photography for the drawing process."* (Taylor 2001). All other drawn reconstructions up to that time were produced by following the morphological outlines governed by the given skull. In later years Krogman's methodology was to produce frontal and lateral overlay of radiograph tracings from the given skull and worked with artists to produce sketches of the face, with reported successful identifications (Homa 1983; Krogman and Iscan 1986).

Following the criteria set up by Krogman, Cherry and Angel (1977) used scaled frontal and profile photographs and tracings from the skull taken in the Frankfort Horizontal Plane from which drawing of the resulting face were produced by remaining within the limits established by the anthropological criteria, such as appropriate soft tissue depths "and probable placing of eyes, ears, mouth corners and nasal tip." The victim in the case described above by Cherry and Angel was positively identified.

During the 1970s and 1980s many two-dimensional reconstructions were performed using the anatomical approach on ancient and historical skulls, and some artists produced muscle-by-muscle drawings that were more closely reflecting Gerasimov's (1971) technique for three-dimensional clay reconstructions. Caldwell (1981), a protégé of Angel, extended the guidelines set out by Krogman and the principles of Gatliff's facial feature development for reconstruction (Snow et al 1970; Gatliff and Snow 1979; Gatliff 1984) to develop her own technique. Caldwell's technique for two dimensional reconstruction was to use a life size outline drawing of the skull in two views, most commonly a frontal and either a right or left lateral onto which soft tissue depth data could be added to produce a drawing of the face. However, only a limited number of soft tissue points or indicators could be used in this two-dimensional methodology because the soft tissue depth tables were created for working on three-dimensional reconstructions and many depth indicators were not relevant on a two-dimensional drawing. In 1985 Taylor (2001) herself, a protégé of Betty Pat Gatliff, considered a modified anatomical method for producing 2-Dimensional reconstructions by using Krogman's "Rules of Thumb," soft tissue depth data as conducted by Rhine and Moore (1982) and Gatliff's method of 3-dimensional reconstruction (Snow et al 1970; Gatliff and Snow 1979; Gatliff 1984). Taylor's method was to glue tissue depth indicators onto the skull *before* it was photographed and drawn (as demonstrated by Krogman as early as 1943 (Krogman 1943; 1962; Krogman and Iscan 1986). In this manner it meant that all the tissue depth data could be used because the camera performed the required foreshortening of the depth indicators just as the planes and contours of the face are foreshortened in portrait photography, mirroring the effects of how the human eye perceives the foreshortening of the different views or angles of the face (figure 3.7)

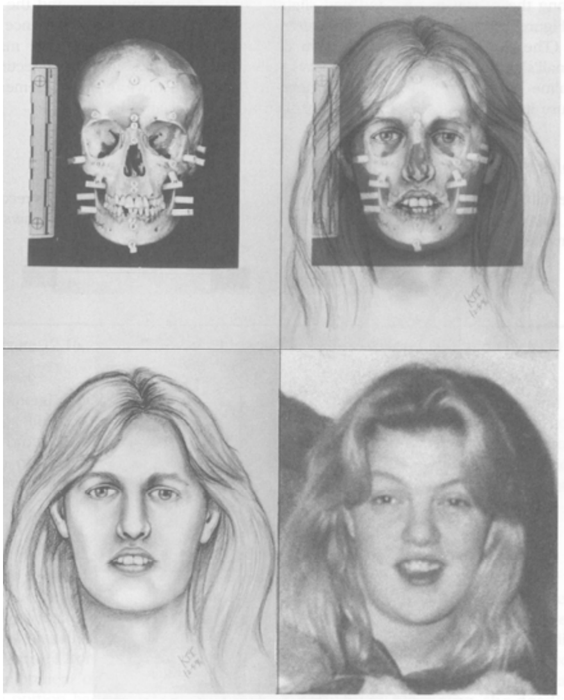

Figure 3.7 *Two dimensional facial reconstruction. The markers are placed on the skull then photographed. The artist then draws the face over the foreshortened face and markers (Taylor 2001).*

In addition Taylor found that by enlarging the skull photographs to life size the rules specified independently by Krogman and Gatliff could be applied directly, similar to the three-dimensional technique. Although Taylor considered this methodology initially experimental she found that as more skulls were identified she worked to refine the technique. Taylor's method was further developed by the publication of George's paper in 1987. George's (1987) methodology is performed by tracing over lateral craniographs and sets out guidelines using mathematical suggestions for the calculation and prediction of lateral facial features. He rightly, cautions that although this method is not for positive identification, the radiographic data can be an important data source for calculating facial profiles. Ubeleker (1989) reports on the modification of the drawing method practiced by Taylor (2001) and described above, claimed a number of successes over the years. This approach, similar to the three-dimensional technique requires the placement of tissue thickness markers on the skull of equivalent length to the soft tissue depth at those specific locations. The cranium, as in the Taylor technique, is then photographed in the Frankfort plane and the anthropologist together with the artist collaborate to add facial features (eyes, nose, ears, lips and so forth), based upon the anatomy of the skull and the anthropological analysis such as age, sex, ancestry and body build. The author reports that the results of this technique can be rapid, economical and reasonably accurate.

With the inevitable arrival of the latest technology of electronic imaging, 2-D computer-assisted approaches to facial reconstruction are becoming more popular. The Face Imaging Reconstructive Morphography technique (FIRM) is described by Perper et al (1988). This method permits the construction of objective composites of facial features based on precise cephalometric measurements. This technique relies on measurements derived from a film taken by the KLS (Kent Laboratory Service) Analytic Morphograph - an integrated radiographic and photographic system. After cephalometric measurements are recorded, a morphometric assessment of facial skeletal class type is made (Sassouni 1971). Identi-Kit™ - a collection of overlay transparencies of various facial components (face contour, eyes, nose, lips, chin, etc.) is then used to create a composite frontal image.

A number of software programmes are now being utilised for two-dimensional facial reconstruction. Many were originally developed for age progression in cases of missing children. Additional uses have included age regression, in instances involving long-sought fugitives where earlier photographs are available, such as war-criminals cases;[3] facial restoration involving cases of burning, decomposition, injury or mutilation involving facial tissues, and finally in facial reconstruction.

F.A.C.E.™ and C.A.R.E.S.™ are two such software systems. These are basically computer-assisted versions of the modified sketching method performed and practiced by Ubelaker (1989) and Taylor (2001) as described above. They work by capturing and digitising radiographs, photographs and images of skulls, and producing electronically altered versions of the image. The F.A.C.E.™ system presented by

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[3] For age regression see chapter IV on Psychology of Facial Recognition, section *Age-Related Differences* from a technique described by Burt and Perrett (1995).

Ubeleker and O'Donnell (1992) consists of scanning and digitising into the computer an image of the skull with appropriate soft tissue thickness markers. Facial features of hand drawings are chosen from an FBI data base according to the anthropometry of the skull and analysis of the anthropological features according to age, sex, ancestry and body build are chosen to match that of the skull. The final image takes several stages and the ultimate reconstructed image can be stored on film. Ubelaker reports that the F.A.C.E system is a computerised version of the composite technique that he has used in collaboration with the FBI since 1977 (Ubelaker 1992).

The C.A.R.E.S.™ (Computer Assisted Recovery Enhancement System) (Sills 1994; Reichs and Craig 1998) is very similar to this, where an image of either a photograph or radiograph of the skull is digitised into the computer and a sketch is produced following the contours of the skull. Photographic parts are then overlaid and blended onto the sketched image by matching angles, measurements, and skeletal landmarks to produce a final composite image by allowing for soft tissue thicknesses.

Another 2-D computer generated facial reconstruction system and very similar to the systems described above, is one developed by Miyasaka et al (1995). Miyasaka et al's (1995) system consists of an image-processing unit for skull morphometry and image editing unit for compositing facial components on the skull image. The image processor generates the framework for constructing a face onto the digitised skull picture. The database has several possible data sets of facial components that are suitable for the skull morphology. Once the most suitable cut-out samples of facial components are pasted over the framework in accordance with the anatomical criteria the facial image is retouched by correcting skin colours and shades with an 'electronic painting device.'

Evenhouse et al (1992) utilised a 2-D computerised system that is similar to the 3-D computerised facial reconstruction system developed by Vanezis et al (1989). Evenhouse et al make use of an "average" face scanned from a frontal photograph to map onto a skull, arguing that the resulting face would take the form of the original owner of the skull. The computer then maps the "average" face onto the skull, using the tissue depth markers to align and warp it. The computer can then add a hairstyle. This technique was used on a known individual and the reconstruction was compared to the ante-mortem photograph. This revealed a good overall match with the general facial form, but problematical areas included the eyes, projection of the nose tip and hairstyle. This reflects the general difficulty with reconstructing some of the facial features from the skull for the purpose of identification, as discussed previously.

However, these two-dimensional computer assisted systems have also been mildly criticised because the final images were *too* lifelike (Craig 1992). Documented studies regarding facial recognition advised against using images that were photographic in nature (Laughery and Fowler 1980). Reportedly, there is a higher identification success rate with facial images that allows the observer to use his or her imagination and recognition skills rather than from images produced from "photographic" segments. Laughery and Fowler (1980) found superior recognition rates and more efficient representation of the target face using artistic sketches than from Identikit composites.

Three-Dimensional: Manual/Traditional and Computer Generated

Manual/Traditional Plastic Facial Reconstruction

Sculptural reconstruction using either clay, plasticine, or wax directly on the skull or more often a replica of the skull has been up to now the most popular and most publicised method of three-dimensional reconstruction (Snow et al 1970; Farrar 1977; Cherry and Angel 1977; Gatliff and Snow 1979; Gatliff 1984; Neave 1980, 1989; Krogman and Iscan 1986; Helmer et al 1993). This method, similar to the two-dimensional method described above, requires the use of tissue depth markers cut to specific lengths to represent the different soft tissue depths, and glued to the skull (Taylor 2001) or inserted into small holes on the skull cast (Wilkinson 2004) at those strategic points or landmarks sites.

Some investigators perform the reconstructions by building the soft tissue thicknesses in bulk without much regard to the rest of the underlying anatomy known as the "American technique" (figure 3.8) (e.g. Gatliff and Snow 1979; Gatliff 1984; Taylor 2001).

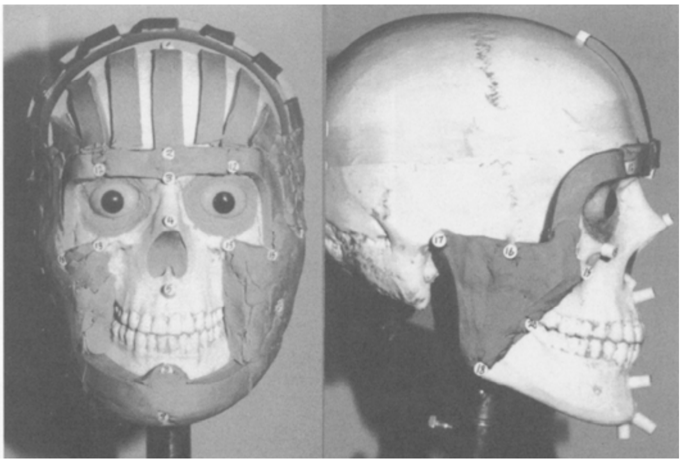

Figure 3.8 *American technique for facial reconstruction (Gatliff 1984)*

Others use a technique where facial muscles are used in an anatomical manner known as the "Russian" or "Gerasimov technique" without soft tissue depth data consideration (Gerasimov 1971) – although nowadays this technique is usually not used in isolation (see below).

Currently, when the "Russian" technique is used, it is more often used as a combination of the two techniques mentioned above to build the face, that is to say both soft tissue thicknesses and facial muscles are taken into account (Neave 1980, 1989; Prag and Neave 1997; Taylor and Angel 1998; Wilkinson 2004); this is known as the "Combination technique" (figure 3.9).

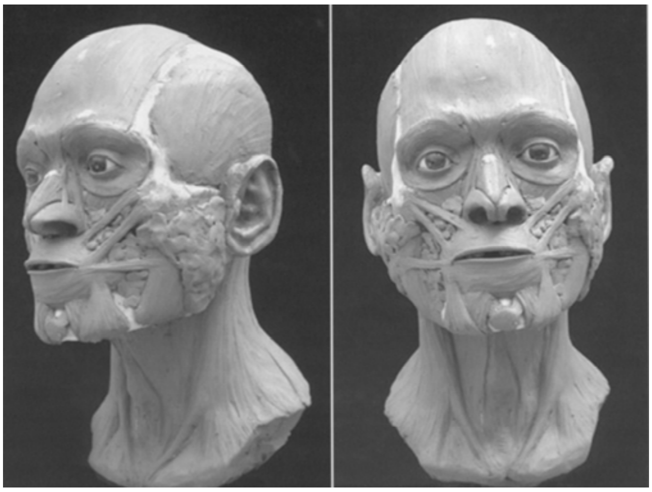

Figure 3.9 *Manchester (combination) technique for reconstruction (Wilkinson 2004)*

Once the cranium and mandible are articulated and secured, the skull is mounted on an adjustable stand in the Frankfort Horizontal Plane. Facial tissue pegs or markers are then added on the skull, either by gluing them on the skull (Taylor 2001), or inserting them on previously drilled holes on the cast at 90 degrees using a

3mm drill bit (Wilkinson 2004). Each peg length represents the mean tissue depth at the anatomical point. The facial tissue depth data is determined by the sex, age, build and ancestry of the individual. Plaster or prosthetic plastic eyeballs of 25mm diameter are secured and centred in the bony orbits according to guidelines (Stephan 2002b, 2002c; Wilkinson and Mautner 2003).

For the combination method the muscles (and glands) of the face are usually modelled onto the skull replica - (see Prag and Neave 1997; Taylor and Angel 1998; Wilkinson 2004 for skull casting) - in clay one by one, then a layer of clay is added over the musculature to represent the skin and subcutaneous fat; strips of clay are then rolled, shaped and added over the muscle/fat structure to create the finished face by maintaining the length of the pegs as guide to the final tissue guides over the face. Prag and Neave (1997) state that:

"There are those that argue that to model the underlying structures in such detail is unnecessary as they will be covered up once the head is completed. Of course this is true. However, this methodical approach is the most logical and foolproof way of ensuring that the face grows from the surface of the skull outwards of its own accord and according to the rules of anatomy, and reduces to a minimum the possibilities of subjectivity by the artist

Furthermore, by using this combination method of reconstructing the face, it frequently becomes apparent that the skull morphology suggests that one or more of the soft tissue pegs are misleading and do not follow the facial contours of the skull, consequently these pegs where they project too much or are too shallow above the surface can be removed or ignored (Wilkinson 2004). This approach of ignoring some of the landmark sites/pegs, although employed for different reasons, is also used with the 3-D computerised method in the present study, where some landmarks with their corresponding soft tissue thicknesses are consistently not used because they are misleading and difficult to locate on the face (see Chapter V for explanation and figures A1.1- A1.5 in appendix 1).

The ears are particularly difficult to reconstruct with any degree of accuracy with regard to size, shape and projection in relation to the underlying skull morphology. The ears are modelled with reference to the mastoid processes and the angle of the mandible, above the external auditory meatus, on a block of clay representing skin thickness. Wilkinson et al (2002) use ear casts for forensic cases attaching small, medium or large ear casts suggested by the dimensions of the skull features, i.e. the size of the mastoid processes, nose length, and head size. However, Prag and Neave (1997) and Taylor (2001) suggest modelling the ears directly with clay onto the reconstruction, and Taylor describes a detailed technique for ear sculpture.

The final stage of smoothing and sculpting the surface of the reconstructed face is very important. Wilkinson (2004) reports that *"…a reconstruction that appears accurate and well formed at the muscle stage can become wooden and mask-like following skin application. A practitioner with poor sculptural skills will have difficulty producing a realistic and believable face, and an artist who does not rigorously follow scientific rules will have difficulty producing an accurate reconstruction."*

As is the practice of the author of this thesis, the practitioners using the Manchester facial reconstruction methodology (e.g. Prag and Neave 1997; Wilkinson 2004) prefer to add facial details that can be directly derived from the underlying skull morphology. For example, although age-related facial details such as, eye bags, neck sagging, jaw-line softness and drooping of the eyelid may help to suggest the age of the individual, nonetheless, they must be cautiously added on, where appropriate, to avoid too much ageing, since these details can only be estimated and false impressions and exaggeration of the appearance may be produced (Wilkinson 2004). Furthermore, the reconstruction with the "wrong" eye and hair colour, skin tone etc. may complicate the recognition process and jeopardise the reconstruction being identified by misleading the public (see section on *Validation, Reliability and Success in chapter XI*). However, Wilkinson (2004) states that in some forensic cases where there the facial reconstruction may not elicit much of a response from the general public and therefore aid identification, further 2-D images of the reconstruction may be produced depicting different hairstyles, skin and eye colour, etc, by using computer software such as Adobe Photoshop™. This is similar to the approach adapted in the present computerised methodology, as briefly discussed below (Vanezis et al 1989; Vanezis et al 2000). Wilkinson acknowledges that although these images may elicit a further response from the general public it must be noted that the images nevertheless, include additional estimated and often uncertain facial detail. However, in archaeological and historical cases, this caution is not a major concern and details such as hairstyles, skin tone, eye and hair colour are estimated by archaeologists/historians or Egyptologists. Hairstyles that fit the criteria of the individual with regard to the period time, status/class, sex and age will be modelled onto the reconstruction or added to the wax head in real hair.

Conversely, Taylor (2001) using the American method estimates the skin tone, eye and hair colour from population statistics, for example Negroid and Mongoloid skulls are reconstructed using brown prosthetic eyes, whilst Caucasoid skulls are reconstructed with hazel eyes. Nevertheless, she acknowledges that although "…*any eye colour can occur in any group, but eye colour choices are best made based on the odds."*

Computer-Generated 3-Dimensional Facial Reconstruction

The concept of three-dimensional computerised reconstruction for forensic identification was first proposed by Vanezis P. and its development and comparison with plastic reconstruction, published subsequently (Vanezis et al 1989). This method has recently been modified and upgraded with new software (Vanezis et al 2000; Vanezis M. and Vanezis P. 2000). *This methodology is described fully in Chapter V*

The reconstructed computer image may then be exported to enable the production of solid model, employing, for example, stereolithography.

Since the software provides facilities to export from a three-dimensional view to a two-dimensional image in a TIFF (tagged image file format) or JPEG format, CD-fit ™ or E-fit™, which are police identi-kit systems, can then be used to "humanise" the face by adding facial features such as hair (only in forensic cases where there is such information available) or using typical hair styles of the period, in historical/archaeological cases. Furthermore, images can also be exported as VRML (virtual reality modelling language) file format via the internet to authorised distant sites such as police stations and may be used for the production of a solid model such as a steriolithograph (Hjalgrim et al 1995). This can be further refined by an artist if appropriate and required for a specific case, such as in historical/archaeological cases by adding more subjective details. The present author and colleagues have produced a number of historical and archaeological reconstructions using the computerised technique and employing the same criteria used for forensic cases for example (Vanezis and Vanezis (2001), (cited by Macleod I and Hill B 2001)**;** Vanezis et al (2004), (figures 3.6, 3.10, 3.11,)

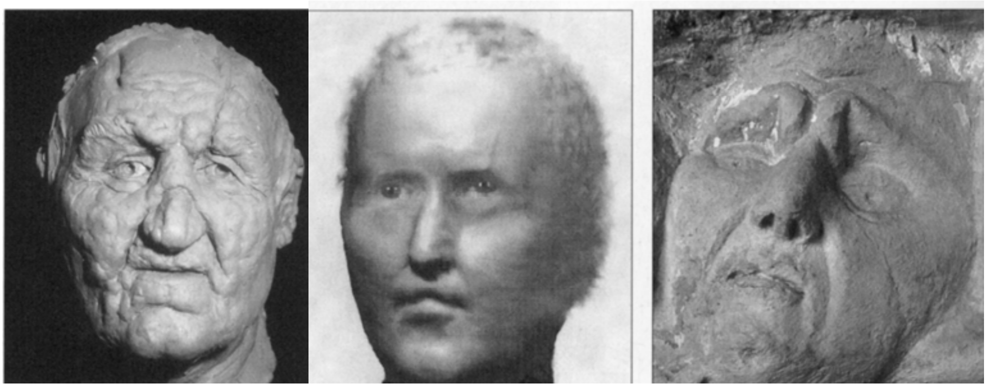

Figure 3.10 *Reconstruction of Robert the Bruce. The image on the left is the manual reconstruction by Richard Neave, the middle reconstruction is by the present author and employs the computerised technique. On the right side is the death mask of the Scottish king (Macleod and Hill 2001)*

Figure 3.11 *Computerised reconstruction of Cangrande de la Scala, 14th Century prince of Verona by the present author (Vanezis et al 2004)*

An artist may also produce a bust of the reconstructed image working directly from the image information provided by the software.

The advantages of such a method over manual reconstruction are speed, versatility and accessibility such as, amenable to rapid editing (Vanezis et al 2000; Tyrrell et al 1997; Stephan and Henneberg 2001). Furthermore, a number of alternative images may be produced at the same time for the same reconstruction (Vanezis et al 1989; Vanezis et al 2000). For example, this is useful when there is dispute over style of hair, and one is consequently requested by the police force in question to produce alternative images with different hairstyles (Wilkinson 2004).

A further advantage is that, in many cases, the original skull may be used rather than a cast or model, since it is a non invasive and rapid technique. **See also section II,** The **present study.**

Other methods of three dimensional computer reconstructions are in the process of development. One such technique is that described by Tyrrell et al (1997), which employs C++ and Open Inventor™ software developed by Silicon Graphics

(Wernecke 1994). This system will allow the user to employ a windows-based medium for scanning, facial reconstruction and display. Features are built into the model to enable the selection of modifications of the reconstruction based on subsets of soft tissue thicknesses data depending on age, sex, ethnic origin and build. Similarly libraries of facial features can be suitably selected for application to the image to be reconstructed. 'Open Inventor' includes facilities for the rendering of colour and texture, for the manipulation of the image in three dimensions and for movement and adjustment of light sources. However, although promising, this technique is still at the developmental stages and is yet to be fully evaluated.

A further technique described by Quatrehomme et al (1997) to produce facial reconstructions based on deformable models, has produced some promising but as yet preliminary work. They scanned two pairs of skulls with a CT scanner and computed three dimensional models of both skulls and their facial tissue. One set of skull/facial data was used as a reference and the second set to validate their method. They applied a global parametric transformation that turned the reference skull into the skull to be reconstructed. However, this technique involves a potentially complex and challenging procedure of determining the relationship between the skull and the facial surface.

Chapter IV

Psychology of facial Recognition

Facial recognition is a basic and significant social skill that we develop from childhood and we become very accomplished as we reach adulthood. However, if all faces are essentially similar (Bruce and Young 1998, chapter I), how do they then communicate our individual and distinct identities? Galton (1883) summed this up by saying:

"The difference in human features must be reckoned great, inasmuch as they enable us to distinguish a single known face among those of thousands of strangers, though they are mostly too minute for measurement. At the same time, they are exceedingly numerous. The general expression of a face is the sum of a multitude of small details, which are viewed in such rapid succession that we seem to perceive them all at a glance. If any one them disagrees with the recollected traits of a known face, the eye is quick at observing it and it dwells upon the difference. One small discordance overweighs a multitude of similarities and suggests a general unlikeness. (Galton 1883, P.3) Today the process of facial recognition has been explored vigilantly giving useful insights into how we achieve this deed.

Facial Features and Configuration

When asked to convey this knowledge regarding our facial recognition memory there is a tendency to express this verbally as if the face is made of a list of individual and separate features, for example, "large brown eyes" or "big ears".

Tools such as Photofit and Identifit, which are used to reconstruct recalled faces seems to be based upon this assumption that a face is made up of a set of features that can be added and subtracted independently of one another in a two-dimensional way. Taking this assumption a face is no more than the sum of its components – eyes, nose, mouth, hair and outline. To quote Penry (1971), the inventor of Photofit *"because each facial part is the sum of its individual details and the whole face is the sum of its sections, the total assessment of it requires a careful visual addition."* Does the brain then add up these different features somehow, very much like a jigsaw puzzle to form a composite image of each face? Or do we encode faces emphasising relationships between features as well as the details of the features themselves? (Bruce 1988).

There is evidence that the face patterns are treated more holistically in facial recognition, that is to say, that not only are the features themselves significant, but the interrelationships or configurations between different features is also important, rather than just a list of these facial characteristics per se. For example, when facial features are kept the same but the distance between them is changed- even subtle changes in the relative position of these features - can have a dramatic effect on the appearance of a face (Hosie et al 1988).

This might be why it has been difficult to produce good likenesses of faces using police 'kits' of face features such as Photofit, E-Fit, or CD-Fit in isolation. It may be then that such kits do not emulate the process of the human brain to describe and retrieve faces. *(See methodology to see how E-Fit is implemented differently there).*

Facial saliency of different features

An influential approach to face recognition has been to attempt to define the salience of facial features (e.g. eyes, mouth). The significance of feature saliency results from the examination that the relative importance of internal (eyes, nose, and mouth) and external (hair, outline) features has been proved to be different for familiar to unfamiliar faces in face recognition (Ellis et al 1979). The authors showed that while internal and external features of faces were equally important cues for recognising previously examined but otherwise unfamiliar faces, recognising familiar faces showed to be more successful using cues from internal rather than external features. These findings have been replicated using Japanese subjects and faces (Endo et al 1984).

Furthermore, Young et al (1985) found that it was more efficient to match internal features in familiar faces than in unfamiliar faces, in an experiment where matches between different views of individual faces had to be achieved.

Some research has pointed out the relative importance of hair, face outline, and eyes in perception and memory of faces, and the relative unimportance of the lower internal features, particularly the nose (Shepherd et al 1981). Similarly, Fraser and Parker (1986) examined feature saliency, where subjects were shown in rapid sequence, each of the components of a line-drawn face. In this way they might see the outline of the face, then the eyes, then the nose then the mouth. The objective was to see if the subjects could detect if all the components of the face were present or not. On some trials one of the components was missing, and the authors were thus able to compare the relative ease of detecting the absence of each of the above components. They found that the subjects were best at observing the absence of the face outline, then the eyes, followed by the mouth, with the nose being the poorest.

An important point that may explain the relative unimportance of the nose in these studies may be due to the difficulty of its perception in a full-face image. A full-face is probably the best view to show the dimensions of the eyes and mouth, but is the worst position for showing the nose, which requires an angled view to perceive the best dimensions. Thus when a witness describes the nose of a suspect in a very precise manner, it may be that the witness had a good look at the profile or three-quarter view of the suspect, in which case, a distinctive nose shape could be more salient than the eyes or mouth (Bruce 1988).

Bruce et al. (1991) suggested, when experimenting with facial surfaces using a laser scanner, that the 'feature salience' literature should be modified, since, they go on to say, the features which are salient for identification appear to differ between the sexes as well as between individuals. Haig (1986) agrees with this theory, suggesting that different features might be salient for different faces.

Viewpoint

The ability to recognise faces is absolutely vital to our everyday social interactions. In order for a face to be recognised the recognition process must be able to discriminate one face from other faces whilst allowing changes in the image of the face from, for example, viewpoint, expression and lighting (Newell et al 1999). Much of the work on face perception though, has mainly focused on frontal views, but as discussed previously, the face is a complex 3-D object that needs to be recognised from all directions. For the most part familiar faces are recognised with little effort, and changes in expression or viewpoint pose no real problem, even from very low quality images. However, people are not so good at recognising or matching, unfamiliar faces (Hancock et al 2000).

There seems to be some advantage of the three-quarter view, often set at 20, 30, or 45 degrees rotation from the frontal view, than the full-face images or profiles which usually produces the poorest results in facial recognition. More specifically the three-quarter view, a 45 degree rotation in depth around the vertical axis from the full face, is often used to portray faces in photographs, portraits and even caricatures and may be regarded as canonical (Krouse, 1981; Logie et al., 1987; Bruce et al., 1987)

Krousse (1981) and Logie et al. (1987) found that found that three-quarter views at presentation led to superior results of recognition memory at test. Fagan (1979) found that infants at 7 months also exhibit superior facial recognition memory for three-quarter view faces, and babies at 5 months could only distinguish faces shown at three-quarter views. A three-quarter view seems to reveal more about the way that face is structured in depth. The face identification task could require information about features which is best exhibited by the geometry of the three-quarter view compared to the full-face or profile view. It would seem that if the three-quarter view maximises the number of encoded features, it is more likely to promote better later memory for faces in the same or different views (Fagan 1979). For example, the shape of the nose in particular, as described in the previous section, is very difficult to see in a full-face image, but is much clearer from an angle such as the three-quarter view.

However, research shows that this three quarter-view preference in face recognition seems to be only an advantage in unfamiliar faces. Familial face recognition seems to be equally easy from full face and three-quarter views. Bruce et al (1987) found that for unfamiliar faces, two three-quarter views differing in expression were matched more quickly than two full-face views. However, this effect was not found when the same faces were familiar to subjects, despite similar requirements and conditions. They propose that the results seem to indicate that the three-quarter view advantage in face recognition memory is a consequence of some explicit matching process, rather than of nature of stored representation for faces. Bruce and Young (1998) further elaborate by suggesting that the three-quarter view may be useful because it allows generalisation to a broader range of views than the full-face image does. However, the authors go on to say when the face is already familiar, our more frequent exposure to full-face images through social interactions may help to counterbalance any natural advantages given by the angled view. Similarly O'Toole et al (1998) confirmed that the recognition rates when there is no change in orientation are highest at the three-quarter view.

Hill et al (1997) found that generalisation from one profile to the other was poor, but generalisation from one three-quarter view to the other produced very good results. It would appear that in contrast to a three-quarter view preference, the profile view appears poor in face identification (Bruce et al., 1987; Hill and Bruce, 1996). Performance at profile may produce bad results because it obscures the configural information such as internal features, which is required in normal face processing.

Hill et al (1997) concluded that with regards to recognizing someone from a picture, a coloured view of a person's face may give the best chance of recognizing that person from a novel viewpoint.

However, the preferred three-quarter view in facial recognition is not without its sceptics. Although Bruce et al. (1987) concluded that the three-quarter view does not function as a "canonical" view in the representation of familiar faces. Liu and Chaudhuri (2002) found in their experiments that it does not function as a canonical view for the recognition of unfamiliar faces either. Subjects were trained and tested on the same views (full-face, three-quarter and profile). Their results showed no difference between the three view conditions. This result is consistent with Newell et al. (1999) finding that the three-quarter view does not produce better performance than the full-face view. Liu and Chaudhuri (2002) analysis showed that a three-quarter view advantage in both different and same-view conditions was not conclusive. They suggest that a better predictor of performance for recognition in different views is the angular difference between learning and test views. Furthermore, they propose that there may be a wide range of views whose effectiveness is comparable to the three-quarter view.

Colour, Light/shade and negation

As suggested in the above section the effects of viewpoint on three-dimensional shapes have a role in face recognition. However, Bruce et al. (1991) found that it is actually very difficult to identify faces when only the three-dimensional shape is presented. In their experiment a number of their university colleagues were asked to have their faces scanned using a laser scanner, resulting in facial surface images being visualised (Linney et al. 1989; Vanezis et al 1989). These images were shown to friends and students of the targets. They found that identification rates were remarkably low, and interestingly, much lower for female faces than for male faces. This indicates that to process the normal recognition procedure superficial features and colouration are important. Classical sculptures lack these features where the hair is sculpted along with the face, and the eyes and the face lack pigmentation. Some classical artists used to paint their busts, most probably in order to improve the resulting resemblance (Bruce and Young 1998). Like classical busts, modern laser scans may have the disadvantage of lightness and lack of colour in the eye pupil area (the present author scans subjects with their eyes closed because of the laser hazards to the eyes and improvises by “opening” the eyes using E-Fit – (*see section on the present study).*

Photographic negatives seem to be more difficult to recognise than inverted faces (Bruce and Langton (1994). It seems that photographic negatives invert the pattern of brightness across an image making it difficult to derive a representation of three-dimensional shape from shading. Therefore, the difficulties experienced with negative images would seem to suggest that visual representation of faces are connected to properties of the original face images, rather than being based on derived measurements. However, other factors are also likely to contribute. For example, the reversal of the brightness in the eyes may contribute to the difficulty in encoding the face, in a similar manner that classical sculptures seem to suffer from their ‘white’ eyes. Furthermore, negation reverses the brightness of significant pigmented areas, so that light skins become dark and dark skins become light, and in doing so potentially ‘disguising’ the face (Bruce and Young 1998). Kemp et al (1990) also examined the combined and independent effects of inversion and negation on face recognition. They found that the combined effects of the two variables exceeded the effect of either alone. In further experiments they found when internal face features are replaced with dots, effects of negation produced results with discriminative accuracy but the effects of inversion did not. They concluded from this that there were different basis for the two effects of inversion and negation. The results of these experiments suggest that inversion and negation affect different aspects of face perceptual processing.

Line drawings of faces are equally easy or difficult to recognise whether it is black on white or white on black, suggesting therefore that it is the shading information that is disrupted when images are negated. Hayes et al (1986) showed that two-tone images could be recognised equally accurately in negative if first filtered by a high-pass spatial filter, which has the effect of leaving only edges in the image. It is lower spatial frequencies that contain information about shading and which, as has been discussed above, is helpful for identification. Therefore, if these are negated, then perception of the underlying shape might be impaired.

What is normally referred to as the colour of an object has three distinct components: the brightness or ‘luminance’, the hue and the saturation. Brightness or ‘luminance’ is basically the amount of light reflected from the surface of the object; the hue is the wavelength of the light reflected from the surface of the object, and the saturation is the purity of the colour, which is why unsaturated colours appear washed out. Luminance and hue are coded separately in a colour image; it is therefore possible to manipulate them independently.

Although negation of the luminance of an image disrupts face processing, Kemp et al (1996) demonstrated that changing image hue does not. In their experiments they produced face images in which the luminance, the hue, or both were negated. Recognition of familiar faces was impaired by the change in luminance, but not by hue. However, it was a different story for unfamiliar faces, where it was hue dependent, suggesting that initial picture memory is affected by hue changes, but that this variability is not important in the process following familiarisation with faces. This is probably because unfamiliar face recognition is strongly influenced by the exact details of the image. This sensitivity of memory to colour of images also explains why we may be extremely sensitive to the authenticity with which colours of faces are replicated in copies of photographs or paintings.

Hill and Bruce (1996) reported a series of experiments that investigated the effects of variations in lighting and viewpoint on the recognition and matching of facial surfaces. They found that in matching tasks, changing lighting decreased performance, as did changing view, but that changing both did not further reduce performance. There were also differences between top and bottom lighting. Recognising familiar surfaces and matching across changes in viewpoint were more accurate when lighting was from above than when it was from below the heads, and matching between different directions of top light was more accurate than between different direction of bottom lighting. This would suggest that representations preserve image properties, as similar contours could be derived from heads lit from different directions.

The effects of lighting from below would appear to resemble the effects of photographic negation on an image. Johnston et al (1992) showed that such lighting also disrupts identification. They also showed in their experiments that bottom lighting alleviated the effects of inversion or negation on the identification process. Therefore, an inverted or negated familiar face is easier to recognise if it has been bottom-lit. This would imply that inversion not only disrupts the normal process of configuration but has some effect on perception of shape as well.

Anthropological differences in faces: Age, Sex, and Ethnicity

Human beings are remarkably good at categorising faces into different types of social groups and establishing personal recognition purely from their appearances. The human face results from the combination of the underlying skeletal structure (facial bones), the soft tissues (fatty tissues and muscle) cartilage in the nose, and skin. Difference in these structures, plus colour variation and texture of skin, eyes and hair provide the fundamental information from which we categorise faces. For example, we are very good at deciding the sex, ancestry and approximate age from first impressions. Fundamentally, since all human faces are basically identical in structure and design, it is essential therefore, to establish subtle differences in appearance in order to be able to classify group membership and personal identification.

Age-related differences

Age-related changes therefore, fall crudely into two categories (Bruce and Young 1998):

- changes in shape, which may happen through growth (cardioidal strain) or weight gain or loss

- and changes in the characteristics of the facial surface texture and colour of skin and hair.

Burt and Perrett (1995) investigated visual cues to age using facial composites, which blended colour and shaper information from multiple faces. By using computer graphic techniques they collected a number of male faces ranging from 20-60 years within seven specific age groups. They found that subjects were quite accurate at judging the age of these original images. Composite images were then produced from multiple images of different faces, by averaging face shape and then blending red, green and blue intensity (RGB colour) across comparable pixels. This is achieved by using computer morphing or warping techniques, where careful alignment of a large set of key points or landmarks on each individual face is located, faces can then be averaged together without blurring due to misalignment of features from different faces.

The perceived age of the composite images depended on the age category of the component faces. However, blended or composite faces were in fact rated younger than their component faces, and this tendency became more obvious with increased component age. This is thought to be because the composite technique softens the effect of wrinkles and skin texture changes from each of the individual contributing face. Individuals that are used to make the blends may possess wrinkles and skin features that are probably not in the same position. The averaging process will only maintain features with consistent topographic relationship and consequently wrinkles skin texture changes will be averaged out giving a slightly blurred appearance and contributing to more youthful composite. Averaging was first reported by Galton (1878) who blended faces in by using photographic multiple exposure. Galton matched the eye position of each component face to minimise blur in the photographic composite.

Burt and Perrett were then able to study how each composite face varied from the adjacent composites and were consequently able to explain how the faces from each age group deviated from the others, with regards to their shape and in terms of colour and texture information. Using this method it was possible to exaggerate the differences between one group and the next to produce a ‘caricature’ of age-related changes.

Automated shape caricaturing exaggerates the differences between the feature positions of a target face and those of the population average. The same algorithm was used to colour caricature information associated with age. The colour and texture differences between the average 50 – 54 year old and the population average manufactured by combining the seven composite age group blends have been exaggerated to give a face where the age-related differences between the older age-group and the mean have been enhanced. Using these computer techniques, Burt and Perrett were able to use any individual face and transform its shape or colour information, or both, towards the characteristics of an older or younger age group.

Given that this technique has been used convincingly to age the appearance of an individual, a situation where this age enhancing procedure would be very useful is in a forensic setting. Issued images of children or adults who have been missing for several years need to be updated by including these age related changes if successful identification is to take place by the general public. Therefore it is essential that projectively aged face images are realistic and maintain as much information as possible about identity (Burt and Perrett 1995). Davies et al (1978) found that recognition of photographs was greater than that to the recognition of accurate artistic renditions (shaded line drawings) of the same faces. Therefore such fully automated computer procedures, such as the ones described by Burt and Perrett for projective ageing, may therefore be superior to procedures involving artistic impressions. Furthermore, the cardioidal strain transformation may be more useful when applied to photographs of young children to displace their features in a way that simulates growth through ageing, but when ageing photographs of adults, then the procedure described by Burt and Perrett may be more appropriate.

Sex differences

Human subjects are remarkably accurate at deciding the sex of faces. Even when images are presented with hairstyle concealed, men being clean-shaven and cosmetic cues avoided, people are still about 95 per cent accurate at deciding whether faces are male or female (Bruce and Young 1998). One broad characteristic or measurement that differs quite a lot between men and women is the head size, since generally men are taller and broader than women. However, the head size and consequently the size of the face is not necessarily a useful cue to sex identification per se.

A depiction of the overall differences in three-dimensional shape that are found between male and female faces can be acquired by using laser- scanning techniques. Subjects were actually considerably less accurate when asked to judge the sex of these three-dimensional representations of the faces obtained by laser-scanning, compared with a condition where photographs were taken with hair concealed and eyes closed (to replicate the manner that the laser scans were obtained) (Bruce at al 1993). This would suggest that cues from texture information (such as eyebrows, visible hair and stubble, and skin texture) are important in the sex judgement decisions. This is consistent with the study reported by Bruce et al (1991) who found that it was the female faces whose recognition is particularly impaired in the laser scans. Furthermore, Bruce at al (1993) reported that performance with the laser-scanned heads remained quite high with three-quarter view faces (around 85%), where the 3-D shape of the face is easier to see. This suggests that the 3-D shape of the face contributes further information for classification of its sex (*see section on viewpoint*). However, it still fell considerably below that found with photographs (94% in three-quarter view pictures).

Although the surface images were judged quite accurately in the three-quarter view, where their 3D shape could be seen, the accuracy of judging these images was greatly reduced when they were represented in full-face (75 per cent correct), while accuracy with photographs remained at 95 per cent correct in full-face images. The local texture cues of eyebrows, visible hair, stubble, and skin texture are equally visible in both full-face and three-quarter view in photographs, while cues such as nose and chin protuberance are less visible in full-face image scans and must be derived entirely by an analysis of shape-from- shading.

When photographs (with hair concealed) were inverted, the sex judgement performance was disrupted, which would further suggest that the superficial cues contributing to the decision are not processed in a purely ‘local’ way. Performance was also disrupted if the faces shown in photographic negatives, which is consistent with the processing of 3-D information, since negation probably operates by disrupting the computation of shape information from shading. *See section on colour light/shade and negation*. The above observations made by Bruce et al (1993) with regards to inversion disrupting performance on sex judgements using photographs are consistent with the results reported by Bruce and Langton (1994) when using laser head scans. Whereas, performance with negation on laser heads was not so obvious, although, it had a slowing response to sex judgements, the results were non-significant.

Bruce et al (1993) obtained different facial surfaces from a database of male and female faces that were used to produce the ‘average’ male and ‘average’ female surfaces in order to compare the differences between the sexes (see Coombes et al 1992 for a fuller description on average male and female face). The differences were shown by using the colours of the spectrum, with red showing extreme positive differences all the way through to violet indicating extreme negative differences.

Ethnic differences

In some ways human memory for faces is remarkable, and yet limited in others. One well known restrictive factor is the difficulty experienced in recognising faces of other ethnic origins (Shepherd 1981; Shapiro and Penrod 1986). (Recognition here simply means the decision whether or not we know a face). The ‘*other-race’* phenomenon is accepted in the psychology literature of facial recognition and shows that faces from other ethnic groups ‘all look alike’ and the assumption therefore is that faces from other-ethnic groups are more similar to each other than one's own-ethnic group. However, most experiments on this topic have shown that each different ethnic group experiences a similar difficulty with faces from other ethnic groups. This was clearly demonstrated by Brigham (1986) and Bothwell et al. (1989) who combined the data in a 'meta-analysis' technique from fourteen different studies of '*cross-race'* face recognition in which there was a substantial number of Black and White participants, each of whom had the task of identifying both Black and White faces. They found that the difficulty in recognising faces from '*other-race'* compared with '*own-race'* was very similar for both Black and White participants. Therefore it cannot be the simple case that one ethnic group is intrinsically more difficult to recognise than another.

The notion that *'other-race'* faces are in fact more similar to each other than are '*own-race'* faces suggest that human beings find it difficult to encode the information in individual *'other-race'* faces that makes them unique. O'Toole et al (1996) suggests that to accurately recognise a face, we must encode something special about a face that distinguishes it from all other faces. Furthermore, the *'other-race'* effect in face recognition is generally thought to be the consequence of the immensely different amounts of experience we have with *'own-race'* as opposed to '*other-race'* faces. This theory suggests that people of one particular ethnic group have learnt to pay attention to rather subtle characteristics which distinguish different individuals within their own ethnic group but, in contrast, have not learnt as well the features which are more significant to other ethnic groups. Lately, perceptual learning has been proposed as a significant device fundamental to the effects of differential experience on processing *'own-race'* versus '*other-race'* faces (O'Toole et al 1995). By this means, *'other-race'* faces may be assumed to be different statistical categories of faces, each varying about its own prototype (O'Toole et al 1991).

Distinctiveness

Although human faces with all the anatomical features are basically the same there some subtle differences between them. Some faces however, deviate from the average or prototype face and are regarded therefore as more distinctive in appearance, while other faces are regarded as more average or typical. Research in this area of facial recognition has shown that 'distinctive' faces or ones with more deviant appearance are recognised not only more accurately but also more quickly than faces with more typical characteristics (Bartlett et al 1984; Valentine and Bruce 1986; Bruce et al 1994).

Valentine and Bruce (1986) found in their experiments that the results clearly demonstrated that both distinctiveness and familiarity affect the time taken to accept a face as being familiar. The more distinctive or the more familiar a face is, the faster it can be recognised as being familiar. Furthermore, they found that the partial correlation shows that the two factors appear to be independent. This hypothesis predicts that perceived familiarity would be correlated with distinctiveness, because every time a distinctive face is seen the familiarity of that face would be increased more than when a typical face is seen. Therefore, following this line of thought, distinctive familiar faces should generally be perceived as more familiar than typical faces. However, the rank orders of familiarity and distinctiveness were not found to be significantly correlated in Valentine and Bruce's experiments (1986), although there was a small positive relationship. Consequently, the authors concluded that the effects of distinctiveness could not be explained in terms of familiarity alone.

Furthermore, Valentine and Bruce (1986) summarise the effects of distinctiveness, which is based upon distinctiveness of encoding, and which may account for the effects found in the recognition of both familiar and unfamiliar faces:

"Distinctive faces are assumed to be more distinctively encoded because they are distant from a population mean or prototype, so there will be few faces that are similarly encoded. The distance from the prototype would be unaffected by familiarity. A face that is very unusual will remain unusual compared with the population of faces even if it is a very familiar face."

Similarly Valentine (1991) describes the effects of distinctiveness with a 'face space' framework. This hypothesis suggests that a face can be described by its value along numerous dimensions of facial variation. Dimensions could be simple features such as mouth width or more universal characteristics such as age or face height. Therefore, faces which are classed as more typical will tend to have values on the dimensions which are true of many faces (e.g. average length nose), whereas those which are rated as more distinctive will tend to have values that are more extreme (e.g. a very long nose or very thin lips). Typical faces will tend to cluster more closely together within the space framework, while more distinctive faces are scattered around the periphery (Valentine 1991).

When it comes to identifying a face the task requires a comparison of the target face dimensions with those of stored faces (such as a database) to see if a stored face can be found that shares the same set of physical dimensions. When they are many stored faces with similar physical characteristics, as in the case of more typical faces; the faces are located in areas where the density of points is high in the space framework, and it would therefore be more difficult to distinguish true from false matches. One would therefore expect the process to take longer and be more prone to errors. However, distinctive faces are located in regions where the density of points is low in the multidimensional space framework. Therefore, when a distinctive familiar face is encountered in a recognition task, the location encoded in this multidimensional space framework will be much closer to the representation of the "target" face stored in memory than to the location of another more typical face. By definition few faces will resemble a distinctive face; Valentine (1991) states that… *"The norm-based coding model can still support the prediction that distinctive faces can be more accurately recognised than typical faces because distinctive faces are less densely clustered (i.e. further apart from each other) than typical faces".* Therefore distinctive familiar faces can be identified with more precision and speed than more typical familiar faces. Furthermore, following this line of thought, the framework predicts that distinctive faces can be rejected more accurately or more quickly than typical faces.

The Research Questions, Aims and Objectives

As was demonstrated in chapters II and III, forensic facial reconstruction for the purpose of identification has certain limitations. Furthermore, the psychology of facial recognition, as described above in this chapter discusses the mitigating circumstances why recognition or matching is so complicated, especially in a forensic scenario, where, most of the testing, for ethical and practical reasons is performed in unfamiliar situations.

The present study examines the psychological approach to recognition in unfamiliar faces and compares this to a mathematical (shape) analysis.

Therefore, the issues that need to be addressed including the main aims of this thesis are: ***The evaluation and improvement of the reliability of facial reconstruction using 3-D computer graphics.***

Using the present 3-dimensional computerised technique a number of alternative reconstructions may be produced at the same instance for the same skull by using different facial templates from the database that meet anthropological criteria to warp over the skull. Following from this, the question that needs to be addressed, and therefore the first objective is:

1. **Can the accuracy of computer generated facial reconstructions be improved by choosing the most "appropriate" facial template derived from the database and thus improve identification?**

Furthermore, the software (Vanezis et al 2000) provides facilities to export from a three-dimensional view to a two-dimensional image in a TIFF (tagged image file format) and subsequently E-FIT™, which is a police identi-kit system, can then be used to complete the facial reconstruction by adding facial features such as hair and "opened" eyes (see methodology, chapter V).
Therefore, the next objective or question that needs to be addressed and evaluated is:

2. **Can specific E-Fit™ facial features be implemented on the final reconstructed image to improve facial recognition and identification with as little artistic licence as possible?**

The Research Hypothesis

To reject the null hypothesis and thus, find an effect on the identification process, the research hypothesis is formulated.

Thus, ***the research hypothesis (alternative hypothesis Ha)*** is as follows:
Having met the anthropological criteria for a given skull (age, sex, ancestry and build) and by selecting the most "appropriate" facial template that conform to those criteria from the database, and secondly, implementing specific E-FIT™ facial features to that final reconstruction, the identification process can be improved.

The Null Hypothesis

Therefore, the ***null hypothesis (Ho)*** for this thesis is as follows:

Having met the anthropological criteria for a given skull, whichever of the facial templates that conform to these criteria chosen from the database to be reconstructed over the skull, the final reconstructed faces do not show sufficiently discriminatory differences between them. Thus, there is no effect on the identification process, regardless of the appearance of the reconstructed image or, secondly, of the image which upon which facial features have been added, using the E-FIT system.

Section II

The Study:

Methodology (Chapter V)

The five case studies (Chapters VI-X)

Discussion and Conclusions (Chapter XI)

Chapter V

Methodology

Overview

In this chapter, I outline the methodology used to reconstruct faces from skulls and their assessment. The approach is to take a given skull and combine this with a facial surface scanned from a volunteer, using computer graphics techniques. This process of “warping” surfaces on to skulls produces a new graphical object, which can be displayed in a variety of ways on a computer screen.

In subsequent chapters, I report studies on the effectiveness of this approach. In particular, these studies aim to establish whether the approach is useful in generating likenesses which are sufficiently good to allow recognition in practice by people who knew the individual whose skull has been used. To study this I will examine the effects of warping different facial surfaces on to the skull, and hence evaluate the effectiveness of this technique across a range of different combinations.

For the present study, five skulls were used. In the studies reported in the following chapters, I have used facial surfaces which correspond to what is known about these skulls in terms of their sex, ancestry, stature and approximate age. So, for example, where a skull was known to be that of a young male Caucasian, only surfaces derived from people from the same groups were used. For each of the skulls used here, there were forensic pathology and anthropological reports available, for example, from the police forces which had requested a reconstruction. The procedure adopted here relies on the accuracy of these reports, since various aspects of the reconstruction rely on characteristics derived from the population from which the skull is drawn. For example, soft tissue thickness data is derived from studies across individuals within the same group, and this is used in a variety of different reconstruction techniques.

For the research presented here, 500 volunteers had their faces scanned (table 5.1). The procedure for doing this is described below. The data from these scans was combined with an existing database of approximately 4500 faces, many of which had also been scanned by the author, for projects prior to the current doctoral project, thus providing a database of approximately 5000 faces (Table 5.2). The table shows the combined databases which indicate the sex, age group and ethnic distribution along anthropological parameters.

Since most of the individuals that were scanned were mainly of average build, the category of stature was not further sub divided into thin, medium or fat but kept to a single category of average build. Significantly, for the purpose of the dissertation, the facial templates required for facial reconstructions were all of average stature, as dictated by information provided in the forensic anthropological reports of the five skulls in the study.

Additionally, individuals with very obese faces were thought not be useful for scanning because the characteristics in these facial templates, due to excess fat deposition, would not morph accurately over the allocated skull land mark locations to produce an acceptable reconstruction.

Table 5.1 ***Database of the 500 new scanned faces***

Males (291)

Age Range	**18-30**	**31-40**	**41-50**	**51-60**	**61-70**
Caucasian (259)	141	100	14	3	**1**
Negroid (10)	6	3	1	0	**0**
Mongoloid (22)	12	7	3	0	**0**

Females (209)

Age Range	**18-30**	**31-40**	**41-50**	**51-60**	**61-70**
Caucasian (188)	95	73	15	4	**1**
Negroid (5)	2	2	1	0	**0**
Mongoloid (16)	**7**	**6**	**1**	**1**	**1**

Table 5.2 ***The combined facial template database (4973)***

Males (3158)

Age Range	**18-30**	**31-40**	**41-50**	**51-60**	**61-70**
Caucasian (2915)	1224	1211	371	93	**16**
Negroid (73)	52	12	5	2	**2**
Mongoloid (170)	74	66	21	7	**2**

Females (1815)

Age Range	**18-30**	**31-40**	**41-50**	**51-60**	**61-70**
Caucasian (1781)	943	725	97	13	**3**
Negroid (16)	7	6	3	0	**0**
Mongoloid (18)	**8**	**6**	**2**	**1**	**1**

As mentioned above the new 500 faces (table 5.1) were scanned to give a database of sufficient diversity to allow combinations of skulls and surfaces which are described in subsequent chapters. Faces in the database are classified by sex, by ancestry (Mongoloid, Negroid and Caucasoid) and by age (in 10-year bins).

As dictated by the study, most of the new 500 faces scanned in both the male and female categories were Caucasian, and mainly from the two age groups of 18-30 and 31-40.

For example, in the male Caucasian section, 141 faces were scanned from the 18-30 age category to add to the existing database of 1083 faces, totalling 1224 faces in that particular category (table 5.2). This increased the total number within the database in that category by 13%. Similarly, 100 new faces were scanned from the 31-40 age group, to total 1211 faces, an increase of 9%.

Likewise, in the Caucasian female facial section, 95 faces were scanned in the 18-30 age group, totalling 943 facial templates in that category, an increase of 11.2%

and in the 31-40 age group 73 faces were scanned to total 725 facial templates, an increase of 11.2%.

In the following sections, I provide a more detailed description of the techniques used which include:

- **Scanning Procedure**
- **Acquisition of facial database**
- **Skull preparation**
- **Facial reconstruction procedure**
- **Psychological and mathematical assessments**
- **Anthropometric assessment**

Scanning Procedure

The techniques used here rely on accurate capture of 3D surface data from both faces and skulls. A laser scanning system was used for both these operations. This was the Facia Optical Surface Scanner™ developed by the Medical Physics Department of University College London (Moss et al, 1989; Linney et al 1993). The technique for computerized facial reconstruction was originally described by Vanezis et al (1989) and its subsequent development by Vanezis et al (2000). The following scanning account of the procedure is based largely from the latter paper with additional material.[4]

The system which is based on the triangulation principle was originally developed for recording the body surface, as shown in the plan of figure 5.1 (See also Arridge et al 1985 and Moss et al 1987 for earlier versions of this technique). With the room in darkness, a thin beam of light is emitted from the laser and strikes a small cylindrical prism filter in front, which fans it out to produce a vertical line on the skull or face which is 0.7mm wide (Fig. 5.2 a, b). Viewed obliquely, the laser line appears distorted, reflecting the shape of the surface anatomy. The distorted line is recorded by a CCD (charge coupled devise) camera connected to a computer via a customized interface board. The illuminated profile is reflected off two sets of mirrors (to the left and right of the object), producing two profile lines. This arrangement of the mirrors

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[4] It should be appreciated that the methodology for the paper (Vanezis et al 2000) was written by the present author who is the second contributor to the paper; the first author is attributed with the intellectual concept.

allows the laser line to be viewed by the camera in two opposing directions (Fig 5.3). The opposing views are required to avoid the loss of any data due to the occlusion of parts of the facial surface by the prominence of the nose. Video signals from the camera preprocessed by the interface board. The distance between the two profile lines as seen by the camera is proportional to the distance of the profile from the centre of rotation. By measuring the distances between corresponding points on the two profile lines, a set of discrete points are produced on the actual profile. As the object continues to rotate, further profiles are illuminated and the discrete points on them are captured. The way this happens is that for each television frame, a set of numbers is generated representing the midpoint of the pulses on the video scan lines produced by the projected laser line. A calibration program converts these numbers into spatial coordinates of points lying along the laser line illuminating the surface. The laser used is low power (1mW) and the intensity does not exceed 5W/cm^2. When a live subject's face is scanned, despite the fact that there is no hazard to the person, it is recommended that the beam is not observed directly any closer than 30cm from the laser source.

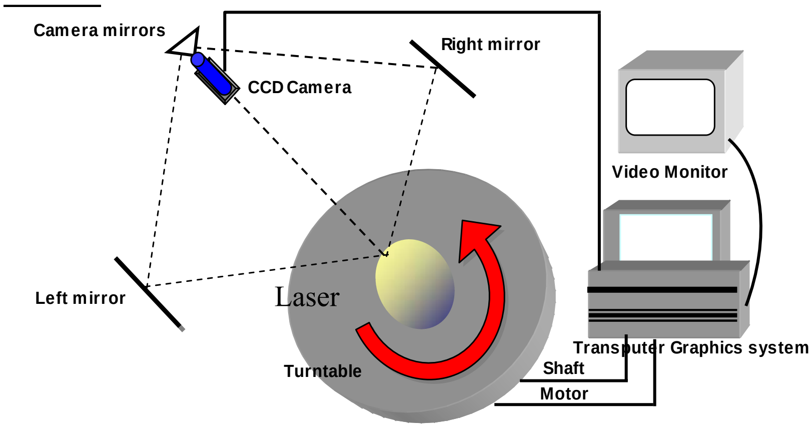

Figure 5.1 The optical laser scanner system

To scan the skull or facial surface, the skull is secured on a platform or the subject sat in a chair which is rotated through 360° under computer control at a distance of one metre from the laser source. The height of the platform and chair can be adjusted as explained above (Fig. 5.4)

An optical shaft encoder is attached to the platform and as the skull or subject turns, a series of profiles are collected at programmed intervals. Up to 200 profiles are read into the computer at one scan, although up to 256 may be recorded if required, memory permitting, and the angles at which these are recorded may be programmed, allowing finer sampling over anatomical areas where greatest detail is required (e.g. mid face). The resolution may therefore be adjusted to correspond to surface detail and curvature (Linney et al. 1993). The time taken for a complete rotation varies between 30- 55 seconds, although both speed and extent of rotation can be adjusted to suit the subject, by the end of which 30-60,000 three-dimensional coordinates of points have been acquired on the anatomical surface in a single scan. A patchwork of triangles (facets) is constructed from these to represent the facial surface. The accuracy and repeatability of these measurements have been investigated thoroughly (Moss et al 1989). The points on facial profiles are recorded with a resolution or precision of 0.5mm.

The raw data from the scanner is stored in the form of an LSM (Laser Scan Multiple). An LSM file contains each of the measurements from each profile captured by the camera. As mentioned before these measurements are converted into Cartesian co-ordinates by the software.

(a) **(b)**

Figure 5.2 (a, b) *Views of skull with vertical line emitted from laser scanner*

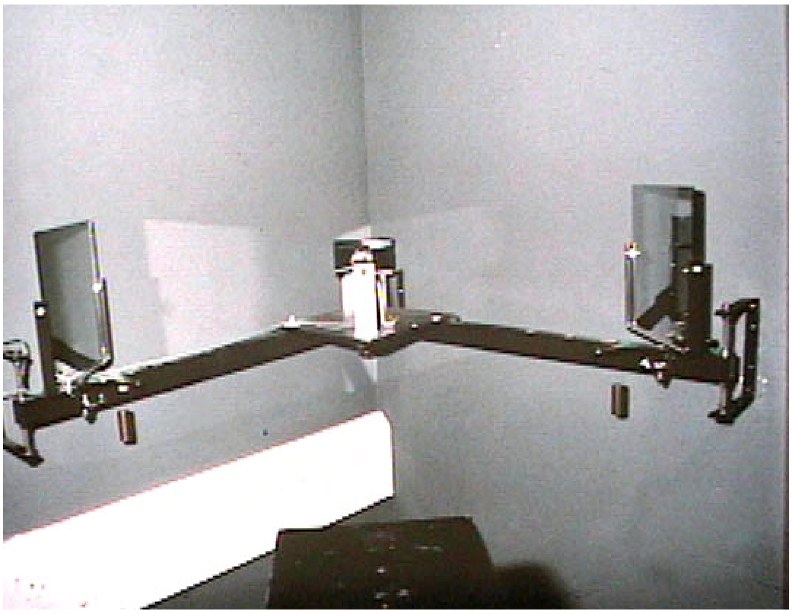

Figure 5.3 *View showing the arrangement of the two opposing mirrors*

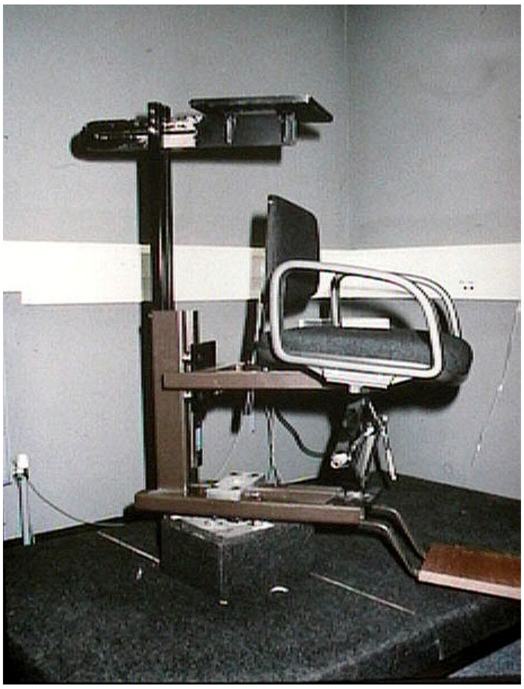

Figure 5.4 *View of the rotating chair under computer control*

Acquisition of facial database

The new set of 500 faces for scanning were volunteers recruited mainly from the University of Glasgow campus. The volunteers were mainly staff and students, and were recruited by either advertising throughout the University campus, or by word of mouth (table 5.1). There was a range of facial types though the subjects were predominantly Caucasian of both sexes, between the age range of 18-30 and 31-40 as dictated by the study. The only exception to this requirement was skull 5/case study 5, which had mixed ethnic origin, both Mongoloid and Caucasian Ancestry, see chapter X for details. Furthermore, only clean-shaven male subjects were used.

The complete procedure of scanning each volunteer's face from arrival in the laboratory took on average between 30-40 minutes. Subjects were initially asked to fill in a form giving details of their anthropological group e.g. age, ethnic background, sex and build. Once the volunteer entered the scanning room the procedure of scanning their face was briefly explained to them. As the scanner performs poorly with visible hair, with very bushy dark eyebrows, or male subjects with a very fine facial hair were dusted with face powder to avoid a facial scan with missing data around those areas. Similarly, subjects with a lot of dark head hair were requested to wear a swimming cap, making sure their forehead and ears were showing freely and naturally outside the cap. Subjects were also requested to remove items such as spectacles, hair accessories, hats and jewellery e.g. earrings, nose and eyebrow rings before the scanning process began.

The subjects were then asked to sit in the computer controlled rotating chair; and the neck rest was adjusted until the volunteers were sitting with their head and neck comfortable supported on the rest in the Frankfort Horizontal Plane. As explained earlier in Chapter III, faces that are scanned and stored within the database all have closed eyes as a precaution to avoid shining a laser beam directly onto the retina. However, following a Laser Survey Report (see appendix 3) it was established that it is in fact, safe for the subjects to peer into the beam for up to 100 seconds, although in practice the eyes are scanned for a much shorter time than this. Nevertheless, it was decided to scan them with their eyes closed, to avoid any accidents and for the absolute safety of the subjects involved. Therefore, all the subjects were told to close their eyes and to keep very still for the duration of the scan when the chair rotated 360° and the laser beam was turned on. This was explained to the volunteer would take no more than 60 seconds.

When the laser beam was turned on and projected on the subject's face with their eyes closed, the height of the chair was adjusted for each volunteer; this was achieved by checking that the facial profile line produced by the laser beam on the video monitor was complete and visible and no area of the head at the top or bottom would be cut off, indicating that the face was at the appropriate height for the scanning area. The subject was then rotated to the starting position so that the laser line was projected on the subject behind left the ear. This was because when the chair rotates 360° and digitises an object, a fine black line is detected where the scan joins up i.e. where the scan begins and ends producing a "gap". Therefore, it is essential that this "gap" is obtained outside the region of the face, where data is not so important with regard to facial reconstruction. Once this procedure was completed satisfactorily, subjects were thanked and dismissed.

Skull Preparation

In each of the five cases the mandible required re-articulation with the cranium; a plastic fixer such as WHITE-TAC™ was ideal for this purpose.

Articulating and securing the mandible to the cranium with WHITE-TAC™ also simulates the few millimetres "spacing" that exists naturally in life between the condyle on the mandible and the glenoid fossae of the temporal bone on the cranium. This "spacing" is due to the cartilage that covers the mandibular condyle and also the articular disc in the temporo-mandibular joint. Apart from providing this required "space", attaching a material such WHITE-TAC™ between the mandible and the cranium for the purpose of re-articulation also avoids bone to bone gluing.

Before digitising the five skulls and attempting facial reconstructions in the study, it was necessary to make a general assessment of each of the skull for age, ancestry and sex, for the reasons explained above. In addition, the build of the person and stature was ascertained from examination of the post-cranial skeleton and other associated findings such as clothing and footwear. This was also obtained from the forensic anthropological and pathological reports. In addition to this material, I also carried out my own examination of the skulls, looking for asymmetries or any other local features that would have been sufficiently discriminatory to assist in the reconstruction. This has been covered in detail in the section on *Skull morphology and craniometric characteristics* and also in the section on *Skull assessment and preparation for facial reconstruction* in Chapter III.

One of the advantages that the computerised system has over manual sculpting methods is that there is no need to produce a cast of the skull, and thus reduces the need of a rather lengthy stage. This is because the method of digitising skulls is non-invasive and non destructive since, the only requirement was that each skull was rotated on a platform and a laser beam projected on to it (see section below). Once this was completed each of the skulls was stored safely away.

It was necessary, however, in order that no data was lost that all defects or natural orifices such orbits, nasal aperture and the space between and behind the mandible and the maxilla were blocked with cotton wool so that the projected laser beam did not pass through the specimen. Placement of each of the skulls on to the platform for rotation was achieved by fixing the base of the skull on to a cylinder. Adhesive tape was used for this as this did not interfere with the laser beam projection and could be easily removed. The skull was fixed and secured on a cylinder in the Frankfort Horizontal Plane and placed on the platform which was attached to the chair ready for rotation (fig 5.4); when the laser beam was then projected on the skull, the height of the platform was adjusted to the appropriate height until the skull's entire profile line produced on the video monitor was completely visible. When all this was satisfactory, the skull was rotated by manually rotating the chair to the starting position, this was so the laser beam projected onto the skull behind the left mastoid process, and hence avoiding the facial bones, so when the automated chair rotated 360° and digitised the skull, the "gap" was produced outside the region of the facial bones, as described in the above section.

Facial Reconstruction Procedure

In this final section, I describe how the data from skulls and facial surfaces are combined to generate a graphical representation of a head. The software used for these reconstructions is implemented on a Silicon Graphics Indigo^2 workstation, running the IRIX 5.3 operating system.

The user interface to the Facial Reconstruction (FR) software is constructed using the TCL/Tk scripting language. The scripts make use of the C3D® system, developed by the Turing Institute of Glasgow University. This is a major C++ subroutine library built using OpenGL, which provides industry standard methods for viewing and manipulating objects in three dimensions. The FR software provides facilities to view the digitised skulls and facial templates, position corresponding landmarks on them and to perform a reconstruction using a predefined set of tissue thicknesses, according to sex, ancestry, age and stature (thin, medium or fat) of the skull under examination. Key features in the facial reconstruction software include:

- being able to rotate objects to be rotated in real time
- being able to zoom-in and zoom-out on objects in real time
- being able to view objects from three different vantage points at the same time (by default: left profile, anterior-posterior and right profile) to assist in the placement of landmarks
- repositioning landmarks easily using a mouse to drag them from one position to another
- identifying landmarks simply by moving the mouse pointer over them
- being able to see a skull landmark in three dimensions, including the direction in which it points
- being able to alter the direction of a skull landmark using the mouse
- alpha-blending (mixed view) to allow the operator to see where the skull and skull landmarks are in relation to the reconstructed face
- being able to store (template) faces with their facial landmarks so that previously marked-up faces can be reused for further reconstructions.

Landmark placement and selection of soft tissue thicknesses on skull

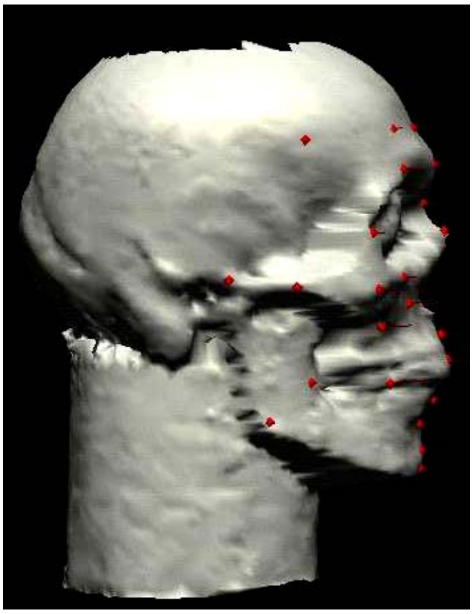

Figure 5.5 *View of digitized image of skull with landmark placement*

Once the digitised three-dimensional skull image has been acquired and displayed, landmarks are then located on the skull (Figure 5.5). Each skull landmark is uniquely numbered and has a name, which describes its anatomical location. Associated with each landmark is a set of tissue thicknesses derived from measurements taken from real subjects (the current data is from Rhine and Moore 1982; Helmer 1984). (See figures A1.1, A1.3 and A1.4 in appendix 1). These thicknesses are classified according to their anthropological type (e.g. Caucasian male) and are further subdivided for thin, medium and obese tissue thicknesses (see the five case studies in chapters VI-X for specific details of the individual cases studied here). A fourth, user-defined tissue thickness can be used to replace any of these values as required. The soft tissue thicknesses are represented as lines projecting from these landmarks and the length of these lines correspond to the depth of the soft tissue at that particular anatomical location. Furthermore, the direction of these lines projecting from the skull landmarks can be altered to match the required direction and location of soft tissue thicknesses, very much like the pegs used in manual facial reconstruction.

The types of landmarks used are those for which facial thickness data is available. There are forty skull landmarks and the same number of corresponding facial landmarks available for use and more may be added if required. However, for the purpose of this thesis (and other related forensic work) only 36 landmarks were used. This is because essentially, some landmarks are cranial landmarks and therefore are difficult and misleading to locate their corresponding landmarks on the face, i.e. right and left supra and sub M2 (see figures A1.1–A1.5 in appendix 1). As discussed in chapter III, and although not for the same reasons as stated here, however, problems regarding some soft tissue pegs are sometimes experienced with manual facial reconstruction as well, when it frequently becomes apparent that the skull morphology suggests that one or more of the soft tissue pegs are misleading and do not follow the facial contours of the skull, consequently these pegs where they project too much or are too shallow above the surface can be removed or ignored (Wilkinson 2004). Manhein et al (2000) report that in their experience of producing facial reconstructions they often ignored or deleted these cheek markers published by Rhine and other contemporaries.

It is crucial that the landmarks are placed in their correct anatomical location on not only the skull but the face as well (see section below on *Facial template selection and landmark placement*), consequently, if an error has occurred, the software allows for the landmarks to be relocated to a preferred anatomical position. Some landmarks for example are best located by rotating the skull and face laterally; (see appendix 1 for classification and location of both the skull and facial landmarks and their corresponding soft tissue thicknesses).

Facial template selection and landmark placement

The next stage is the selection of the facial templates from the database of faces, which have been scanned into the system (table 5.2). Facial templates are chosen which correspond to the skull on anthropological criteria (age, sex and ethnicity) and have features that are standard, average and typical; templates with anomalous or exaggerated features are excluded (see section, *selection of the facial templates and limitations,* in Chapter XI). Additionally, facial templates are chosen which are visually consistent with the morphological features on the skull.

The last stage of selection was to choose the final ten facial templates from the remaining faces by judging which ones were the most appropriate in terms of their image quality. As explained above, the scanner performs poorly with visible hair, very bushy dark eyebrows, or in male subjects with a very fine facial hair. Although subjects were dusted with face powder to improve data acquisition in areas with facial hair, sometimes small disparities still occurred in some of the images.

In terms of repeatability, if the above procedure is followed, it is reasonable to expect that a substantial proportion of the templates chosen in each of the case studies would also be selected by another researcher, even though there is bound to be some variation in choice due to subjectivity in the final selection process. Details of the selection process are found in the subsequent chapters relating to each case study.

Landmarks are then placed on the face, which correspond in location and equivalent facial name to those of the skull (figure 5.6). (See figures A1.1 and A1.5 in Appendix 1). The number given to each facial landmark is the same, as the number given to the skull landmark that will point to it for the purpose of the reconstruction. This one-to-one mapping is used to calculate the mathematical transformation, which will produce the reconstructed face. Since landmark placement and correspondence between facial landmarks and skull landmarks is crucial to producing a realistic reconstruction that will faithfully match the skull anatomy, detailed knowledge of craniofacial correlation is essential.

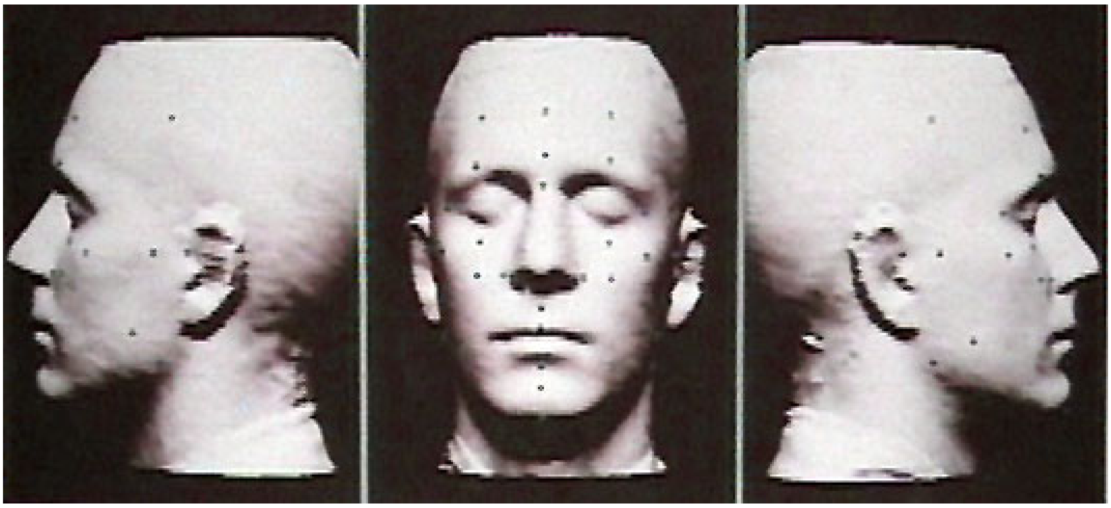

Figure 5.6 *Views of male facial template with landmarks in position.*

This issue of craniofacial correlation has been thoroughly discussed in section *soft tissue thicknesses: past and present limitations of three dimensional reconstruction* and also section on *cranio-facial morphology and correlation* in chapter II. Thus, when the operator is satisfied that all the landmarks have been correctly placed then facial thickness data is selected to give either a fat, medium or thin appearance to the face. For the purpose of this study only medium soft tissue depths were used, as suggested by their case histories (see chapters VI-X). The distance between and relative position of these corresponding landmarks on the skull and the face after the reconstruction has been performed, will be the tissue thickness chosen.

Producing the reconstructed face

The computer is now ready to *fit* the face over the skull. The process involves moving every point on the original template face to a new position. This is achieved using a three dimensional transformation termed a warp. First a Procrustes transform (Goodall 1991) is determined to provide a best fit mapping between the before and after positions of the facial landmarks (the result of the reconstruction places each facial landmark at the position pointed to by its corresponding skull landmark). A set of radial-base functions is then derived (Hardy 1971) and combined with the Procrustes transform to produce the final warp. The warp is then applied to every point on the original face, producing the reconstructed face (Figure 5.7).

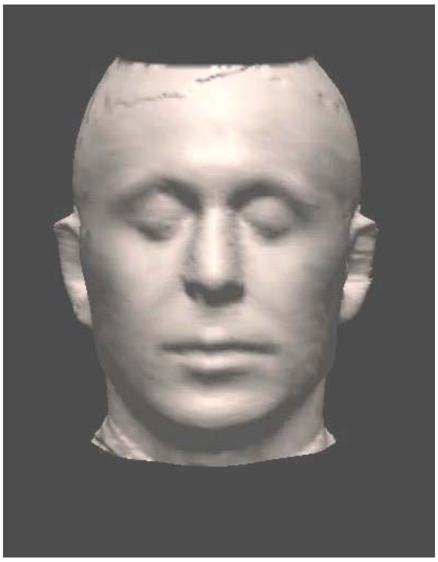

Figure 5.7 *View of reconstructed male face*

The warp produces the reconstructed face in a point wise-fashion. The advantage of this, as opposed for example, to deformation of a triangular mesh as described by Waters and Terzopoulos (1983) is that it is independent of the representation of the face. The corresponding disadvantage is that detailed information about how the deformation should proceed based on particular facial properties cannot be used. It should be noted that mesh-based procedures will not work for the reconstruction of faces from skulls, as there is no skull surface from which to work. The above warping process is automated and takes a minute or two to produce the reconstructed face via a point wise-fashion once all the stages described previously have been completed and checked.

Superimposition of the skull and the reconstructed face (alpha blending) allows the operator to check soft tissue to skull alignment and to see if there are any obvious errors (Figure 5.8)

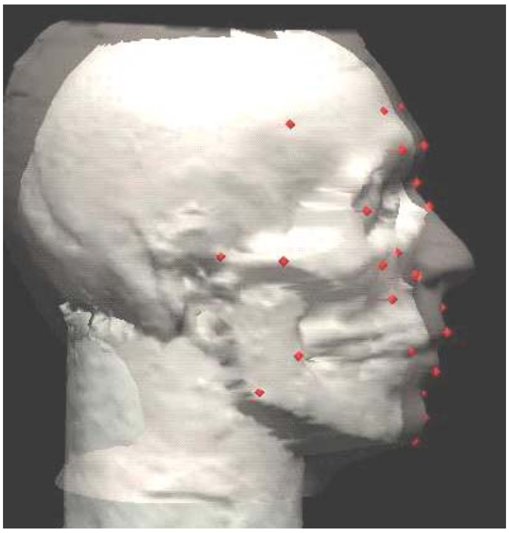

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Figure 5.8 *Alpha blending of skull and reconstructed face to check soft tissue alignment.*

Exporting the reconstructed face including treatment with E-Fit™ software

This process involves:

- Exporting the 3-D reconstructed face from the silicon graphics work station to a 2-D TIFF image on a PC work station
- Choosing the features from the F-Fit™ programme database
- Implementing the E-Fit™ features onto the 2-D facial reconstruction TIFF image
- Editing the E-Fit™ features to correspond to the reconstructed image's morphology and dimensions (see below)
- Finally blending the E-Fit™ features into the 2-D image by using the software programme Adobe Photoshop™.

As discussed in chapter II, one of the major problems with any reconstruction from a skull is the uncertainty of the exact *shape* of some of the individual characteristics of soft tissue structures such as shape of ears, lips and tip of nose. In addition, with the laser scanning system, the faces within the database all have closed eyes, as described earlier. Therefore, in the present study it was necessary to add *opened* eyes and head hair to give a realistic appearance to the face. The software provides the facility to export a two-dimensional view from the three-dimensional reconstructed image in a TIFF and JPEG format. The file can then be imported into a police identi-kit system such as E-FIT™, which allows the addition of facial features (Fig 5.9 a, b, 5.10 and 5.11).

The system, where applicable to any reconstruction, also provides a database for features such as facial hair for example moustache or beard, and accessories such as hats and scarves and spectacles.

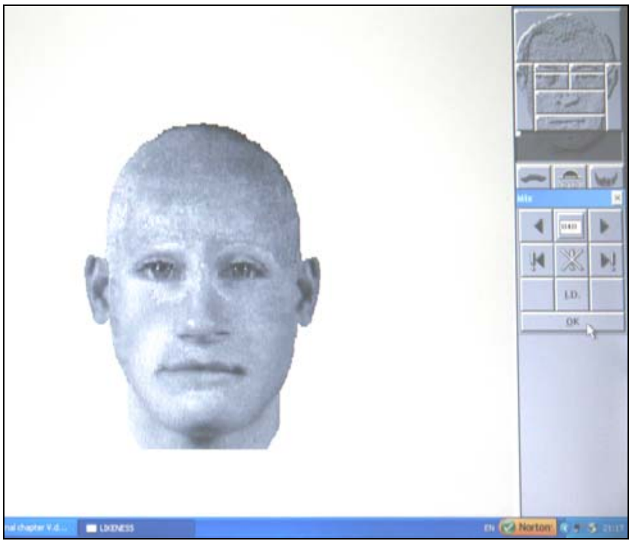


Figure 5.9 (a) *Illustration of generic E-Ft™ template*

Figure 5.9 *(b) Detail of E-Fit™ facial feature tool kit*

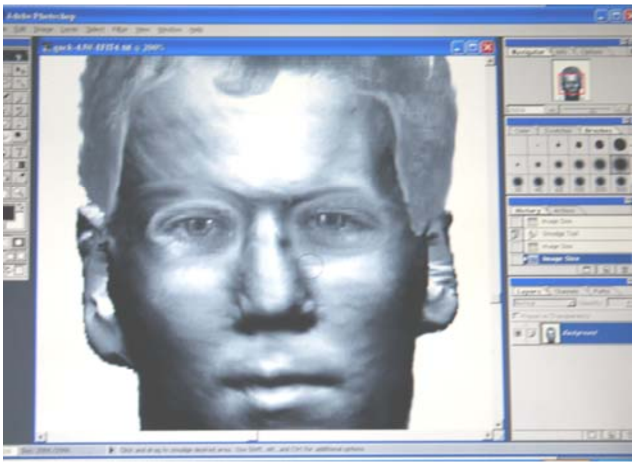


Figure 5.10 *Image in Adobe Photoshop™. This programme is used to blend and smooth edges of imported facial features with the original reconstructed image*

Figure 5.11 *Views of a male reconstruction and with E-FIT™ features*

As discussed in chapter IV, the technology of feature composites has advanced from Identikit through Photo-fit to computer-based systems such as E-Fit™ (Shepherd and Ellis 1992) and CD-Fit™. These computerised systems are more sophisticated and more user friendly than their predecessors and allow the size of facial features to be altered. For example, when "opened" eyes were added in the present study, they were selected from an E-Fit™ database of sets of eyes, and where necessary, subsequently, edited with regards to size of each eye separately so that they matched and corresponded to the dimensions and morphology of the closed eyes of the reconstructed face. This was achieved by matching each of the E-Fit™ eyes individually to the landmark location of the inner and outer canthi of each of the closed eyes on the reconstructed image (see figure 5.11). The closed reconstructed eyes were originally reconstructed according to the anatomy and the landmark locations on the orbits of the skull and the equivalent landmark sites on the eyes from the corresponding facial template.

The 2-D TIFF reconstructed images with the added E-Fit™ features were produced in greyscale rather than colour, because as stated elsewhere, reconstructions with the "wrong" colour of facial features such as eye and hair colour, skin tone etc. may complicate the recognition process and jeopardise the reconstruction being identified by misleading the public (see section *reliability validation and success* in Chapter XI for fuller explanation). Therefore, by producing images in greyscale one can generalise more than one can in colour. This is especially significant with regards to eye colour which, are very difficult to predict, even when hair samples have been found at the death scene to indicate if the individual was dark or fair and thus, potentially, give an indication about eye colour. Similarly, "colour" of hair in this context is indicated via the range of greyscale, indicating whether it is light, medium light or dark. *(For more specific information see individual case studies in subsequent chapters).*

The software programme Adobe Photoshop™ (figure 5.10) was used to *complete* the final image by blending in the added E-Fit™ features to the 2-D reconstructed image. This programme enables the user to blend the different tones and shades of the imported feature with the surrounding facial surface by using different "brushes". It allows brightness/contrast, and hue/saturation control of the image. Adobe Photoshop™ provides several tools for retouching images if appropriate: the rubber stamp tool, the smudge tool, the blur and sharpen tools, and the dodge, burn, and sponge tools.

The Assessment Tests

Preparation for experiment 1

Using the present 3-Dimensional computerised facial reconstruction software, a number of facial reconstructions may be obtained per skull by using different facial templates which correspond to what is anthropologically known about these skulls in terms of their sex, ancestry, stature and approximate age.

Ten facial surfaces were selected from the database to warp over each skull and produce ten facial reconstructions in each of the five case studies. This produced a total of fifty reconstructions for the complete study.

Within the criteria mentioned above, the facial templates were further selected to have standard and typical features; this was largely because of the way the software has been designed to function, if one were to use faces with features that were distinct and morphologically unusual the results would be unreliable (see the Discussion Chapter for fuller explanation on the limitations of the software).

The stages involved to produce each of the reconstructions are outlined in the sections ***Scanning procedure*** and ***Facial reconstruction procedure.*** Excluding the timing and procedure for the sections ***Skull preparation*** *and* ***Facial database acquisition,*** which have been described previously, each reconstruction took on average two hours to complete, totalling on average about twenty hours per case, and one hundred hours for the complete study.

The procedure and timing for ***Skull preparation*** which has been described earlier will also be covered in more specific detail in each of the subsequent chapters (Chapters VI –X).

To reject the null hypothesis, which basically states that *"…whichever of the facial templates that conform to these criteria chosen from the database to be reconstructed over the skull, the final reconstructed faces do not show sufficiently discriminatory differences between them…"* and therefore, to find an effect on the identification process, a resemblance ranking technique was used in experiment 1.

The resemblance techniques are direct comparison of facial reconstruction(s) to a photograph of the target individual to determine the similarity between them.

These studies aim to establish whether the approach, in principle, is useful in producing similarities which are sufficiently adequate to allow identification.

In experiment 1, the ten facial reconstructions were compared for similarities by ranking the best three with the corresponding ante-mortem photograph in each case study. Similarly, resemblance rating techniques (Stephan 2002a; Stephan and Arthur

2006) measure the rate of similarity between (a) reconstruction/s and the target photograph.

In contrast to these resemblance techniques, the face pool method used elsewhere in other studies as an assessment test, compares a facial reconstruction/s to a face pool (a number of photographs from different individuals, of which the target individual may or may not be present), to determine the ability for the target individual to be recognised from a facial reconstruction (Stephan and Henneberg 2001) (see Discussion chapter).

Each of the ten reconstructions produced per case were printed out separately in greyscale on A4 paper for assessment. It was decided that only frontal views of the ten reconstructions in each case study would be shown to the assessors for evaluation throughout the complete study. This was mainly because in some of the case studies only frontal ante-mortem photographs were available, and since image viewpoint affects facial recognition (see section *viewpoint* in Chapter IV Psychology of Facial Recognition), to make the whole study more congruent and balanced, it was decided to use only the frontal ante-mortem facial photographs to control as many of the variables as possible.

Rather than the usual Frankfort Horizontal position, the exact position and angle of the frontal view of the ten reconstructions printed out was determined by the position of the available frontal ante-mortem photograph in each of the case study. The reason for this was so that the corresponding frontal views between the ante-mortem photograph of the target individual and the ten respective reconstructions in each case study matched as closely as possible with regards to direction and position.

Experiment 1:

The psychological assessment test on the facial reconstruction: using a resemblance technique

Twenty different assessors, mainly staff, students and visitors from the University of Glasgow were recruited for the resemblance assessment test in each of the five case studies, requiring a total of one hundred assessors for evaluation in experiment 1 in the complete study.

In each case, the respective twenty assessors evaluating the ten reconstructions with the ante-mortem photograph came to the Facial Identification Centre one by one, at various times during the duration of experiment 1.

Recruiting the assessors for this experiment was a similar process to those subjects that were recruited to be scanned for the facial database, i.e. advertisements were placed throughout the University Campus, and also by word of mouth. Once the assessor made contact and a mutual appointment was arranged, the individual assessor arrived in the Facial Identification Centre, where the procedure was explained to them, where upon, they carried out the experiment of comparing and assessing the reconstructions with the ante-mortem photograph and subsequently filling in the form (Figure A2.1in Appendix 2) with their best three choices from a choice of the ten reconstructions.

Using the resemblance technique, visual comparisons and evaluations were made between the ten reconstructions and the ante-mortem photograph, the twenty assessors in each case study evaluated, in their opinion, the most "faithful" facial reconstructions and indirectly, the most "faithful" corresponding facial templates.

Consequently, experiment 1 aimed to establish whether this approach is useful in generating similarities which are sufficiently good to allow recognition, in practice, by people who knew the target individual in life.

The ten printed greyscale reconstructions were displayed flat on a large table grouped together with the ante-mortem photograph in the middle. The assessors had the choice if they so wished, to pick up the ante-mortem photograph and compare it to each of the reconstructions in turn, by placing it side by side. Some assessors were quicker than others, and the whole process from the time the individual arrived in the Facial Identification Centre to the time the forms were completed, took anything between 20-40 minutes on average for each subject. In each case, the timing of experiment 1 to be completed as a whole by all assessors took several weeks.

In experiment 1, the corresponding twenty assessors in each case study were asked to choose from the selection of the ten reconstructions in order of preference (1st, 2nd and 3rd choice) which reconstructions resembled more accurately the target ante-mortem photograph belonging to the respective skull. At this stage it was stressed to the assessors that this was a resemblance technique, where, the ante-mortem photograph corresponding to the skull under examination was used to compare with a number of reconstructions with regard to similarity between them. Consequently, there was no *right* or *wrong* reconstruction corresponding or belonging to the ante-mortem photograph, other than each assessor's own judgement in relation to resemblance between the ante-mortem photograph and each of the ten reconstructions.

However, the assessors were advised not to exclude reconstructions that although, they thought were very similar or faithful to the ante-mortem photograph with regard to the general shape of the reconstructed face, for example, the shape of the jaw, cheekbones and forehead, and general facial features, but would perhaps have otherwise excluded because some parts of the facial characteristics, such as *exact shape* of lips, and/or *shape* of the tip of the nose (pronasale) were not so similar or accurately resembled the corresponding features on the ante-mortem photograph. It is well documented in the literature that the reconstruction of the *shape* of such facial feature characteristics still remains largely subjective (see Chapter II). Essentially, although there is information and canons to reconstruct features such as, the mouth and nose from the skull with regard to size and position, there is no direct information on the skull to reconstruct the *exact shape* of the lips and *shape* of the pronasale part of the nose (see Discussion Chapter for fuller explanation).

Furthermore, this part of the assessment was also complicated by the fact that the eyes were scanned with the eyelids closed and consequently, trying to assess these features between the reconstructions and the ante-mortem photograph in each case study was not an option

Provision was made in the reconstruction forms for the subjects to comment, if they wished, on the reasons for their choices (figure A2.1, Appendix 2).

The assessors informed me through their comments on the forms (Figure A2.1 in Appendix 2) and verbally, that, although they had relatively little difficulty in choosing three out of the ten reconstructions, they found it very difficult to rank their first three choices. It was decided therefore at this stage that it would be preferable to give all three choices the same weighting and not rank them.

Experiment 1 should have produced a total of sixty reconstruction choices from each of twenty assessors (20 x 3 choices) per case study; however, one assessor in the first case only chose two reconstructions instead of the required three, producing a total of fifty nine reconstructions instead of sixty. The fifty nine reconstruction choices in case 1 and sixty in the other four cases were given the same weighting for the purpose of the whole study bearing in mind as stated above, that a reconstruction selected by an assessor as a first choice was not distinguished from one chosen as second or third choice from another assessor.

Experiment 2

The mathematical assessment test on the facial images: using Procrustes (Shape) Analysis

Experiment 2 attempts to assess the mathematical significance of the facial reconstructions. It does this by evaluating how close the *match* is between the skull and each of the ten corresponding facial templates used in each case study to produce the facial reconstructions in the manner already described.

To evaluate this part of the experiment with mathematical significance, Procrustes Analysis (Shape Analysis) was performed on each of the original ten facial templates by comparing them separately to their corresponding skull. Procrustes Analysis (Shape Analysis) compares one shape to another shape configuration and indicates how close the match is between them by a single number; the smaller the number, the closer is the match. In this context, these measures are a way of ranking the levels of agreement between the skull and each of the ten facial surfaces separately, in each of the five case studies.

The measurements calculated are based on full ordinary Procrustes Analysis (full OPA) matches**.** They are “ordinary” because in each case only two configurations are compared (face vs. skull); (“Generalised” methods apply when there are more than two configurations to be compared simultaneously). They are “full” because all three similarity transformations have been used (rotation, translation, and scaling) to align the configurations as closely as possible. After this alignment has been performed, the distance measure used is the **full Procrustes distance** between two configurations. (See Dryden and Mardia 1998). This is the square root of the sum of the squared differences between individual (x, y, and z) co-ordinates, after they have been aligned. Therefore, since there are 36 3-D points on each image (faces and skull), this sum consists of 108 (36x3)-squared distances.

Each template was separately compared and matched to the skull. This was done by matching all the x, y, and z co-ordinates for each of the 36 landmarks per facial template to the corresponding 36 landmarks on the skull. This means that each of the ten face co-ordinates was separately matched to the skull's co-ordinates every time. This produced the Full Procrustes Distance between the face and the skull configuration for each of the ten facial templates. Since there were ten facial templates in each case study to be compared separately to the one skull, producing ten Full Procrustes Distances i.e. ten numbers, with closest to furthest match in proportions. This is a distance measure after the configurations have been scaled, rotated and translated to minimize this distance. The closer the Full Procrustes distance (the smaller the number) between face and skull configuration, the closer is the match.

Performing Statistical Analysis between experiment 1 and 2

The results from experiment 1 performed by the assessors using the resemblance technique, were then ranked according to the number of times each reconstruction was chosen as one of the best three from ten in each case study, and then correlated with the Procrustes Analysis results from experiment 2 in that case study.

The analysis was carried out using the SPSS (11.5) statistical package. Spearman's Rank Order Correlation (Spearman's rho) was used to statistically analyse the results by correlating the results of the assessors' choice in ranking order of best reconstruction to that of the full Procrustes distances in ranking order of the best shape analysis match between skull and facial surface (the smallest Procrustes distances being the closest match).

If proved successful, Procrustes Analysis may then be used in the first instance to refine the choice of facial template(s) and exclude extreme shapes as a means of improving the reliability in identification in the present study.

Preparation for experiment 3

The purpose of experiment 3 was to assess whether by adding E-Fit™ features to the facial reconstructions in the context of the present study, it had any effect on the identification process. E-fit features were added to some of the facial reconstructions in each case study for evaluation by assessors.

As previously discussed all the subjects' faces that are scanned into the database system are scanned with their eyes closed because of the possible laser beam hazards to the eyes; consequently all the corresponding reconstructions are also shown with the eyes closed. This precaution was taken for the absolute safety of the subjects, notwithstanding a Laser Survey Report (see appendix 3) which established that it is in fact safe for subjects to peer into the beam for up to 100 seconds (in practice the eyes are scanned for a much shorter time than this). When case work therefore, is undertaken using the present system, whether it is performing facial reconstructions at the request of different police forces or for historical/archaeological reconstructions for different museums, "opened eyes" and hair are imported onto the facial reconstructions for a more realistic effect if appropriate to the case, as discussed elsewhere. Experiment 3 aims to simulate those scenarios by implementing E-Fit™ facial features onto 2-D reconstructed images in the form of a TIFF file that had been exported from a 3-D reconstructed format from the Silicon graphics workstation.

It was decided that from the resulting ten reconstructions obtained for each skull, E-Fit features would be implemented on only four of the reconstructed images in each case study, with identical features used on all four images per case to control the variables. The four images in each instance were selected by choosing the most extreme results obtained from both the psychological resemblance assessment in experiment 1 and the mathematical evaluation using Procrustes analysis in experiment 2. For example, some reconstructions were selected to apply E-Fit features because they produced the best and worst results in the psychological and/or the mathematical experiments, whereas other reconstructions, may have produced results that were either very good in the psychological assessment but the same reconstruction may have produced very poor results with Procrustes analysis or visa versa. Only four of the ten possible reconstructions were chosen in each case study to perform the E-Fit images (see E-Fit images in the subsequent chapters); this was because the most significant stage was selecting the facial templates to warp or morph over the skull to perform the reconstruction. The E-Fit stage, although important, was a further evaluation only once the first and most significant stage was established and assessed. Consequently, the E-Fit features were implemented on the four reconstructions which produced the most extreme results from the psychological assessment and mathematical evaluation (for further comparisons see subsequent chapters for individual case studies).

In forensic scenarios, E-Fit features - with the exception of perhaps “open” eyes - are only ever added with any certainty and confidence when samples of hair, accessories etc. are found at the death scene, otherwise the latter E-Fit™ features are not included.

The E-Fit hair features implemented on the set of four reconstructed 2-D images were selected so that they matched as closely as possible to the corresponding ante-mortem photograph in each case study. Furthermore, the replicated hairstyle and type was identical in all the four corresponding reconstructed images in order to minimize any variables between the resulting four E-fit images, thus allowing the observer to concentrate on the facial form and facial features. This was upheld in each of the five case studies with their corresponding sets of four E-Fit images and matching ante-mortem photograph.

However, the “opened” eyes E-Fit features were implemented as discussed above, not by replicating them from the corresponding ante-mortem photograph, but, by respecting the morphology and dimensions of the closed eyes on the reconstructed images.

Case studies 3 and 4 had some exceptions with the manner and reasons the E-Fit features were implemented to their respective four reconstructed images; this is covered in their subsequent respective chapters.

Each E-Fit image took on average between 3-6 hours to complete and a total of approximately twenty hours for the four images in each of the case study.

Experiment 3

The psychological assessment test on the E-Fit™ images: using a resemblance technique

Similarly to experiment 1, twenty new assessors, mainly staff, students and visitors from the University of Glasgow were recruited for the E-Fit resemblance technique assessment in each of the five case studies, requiring a total of one hundred assessors for evaluation in experiment 3. This brought the total number of assessors in the study as a whole, to 200.

In each case, the respective twenty assessors evaluating the four E-Fit images with the ante-mortem photograph came to the Facial Identification Centre separately during experiment 3.

Recruiting the assessors for this experiment was a similar process to those assessors recruited in experiment 1 and the subjects that were scanned for the facial database, i.e. advertisements were placed throughout the University Campus and by word of mouth. Once the assessor made contact and a mutual appointment was arranged, the individual assessor arrived in the Facial Identification Centre, where the procedure was explained to them, where upon, they carried out the experiment of comparing and assessing the four E-Fit reconstructed images with the ante-mortem photograph and subsequently filling in the form (Figure A2.2 in Appendix 2).

As in experiment 1, the four E-Fit images were printed in greyscale A4 paper and displayed flat on a large table grouped together with the ante-mortem photograph in the middle, The assessors had the choice if they so wished, to pick up the ante-mortem photograph and compare it to each of the four E-Fit images in turn, by placing it side by side. Some assessors were quicker than others; the whole process, from the time the individual arrived in the Facial Identification Centre, having the procedure explained to them and allowing for any questions, to the time the forms were completed, lasted on average between 20-30 minutes. Overall, however, experiment 3 took several weeks to be completed.

As in experiment 1, it was stressed to the assessors that this was a resemblance technique, where the ante-mortem photograph corresponding to the skull under examination, was used to compare to a number of images with regards to similarity between them. Consequently, there was no *right* or *wrong* image corresponding or belonging to the ante-mortem photograph, other than each assessor's own judgement regarding resemblance between the ante-mortem photograph and each of the four E-Fit™ images.

Since in each case study the four E-Fit™ images were pre-selected according to the results in experiments 1 and 2 and consequently they were to some extent weighted, the assessors on this occasion were simply asked to choose *one* E-Fit™ image that most closely resembled the target individual's ante-mortem photograph.

Thus, twenty E-Fit choices were produced from the twenty assessors in experiment 3 in each case study.

Furthermore, because the four E-Fit™ images in each case study were produced from the original reconstructions in experiment 1, the four E-Fit™ images shown to the assessors were full frontal views (as in experiment 1), thus corresponding to the position and direction of each of the ante-mortem photograph in each of the five cases.

As with the reconstructions, provision was also made for comments on their reasons for the E-Fit™ choice made (figure A2.2, appendix 2).

Using the resemblance technique, visual comparisons and evaluations were made between the four E-Fit™ images and the ante-mortem photograph; the twenty assessors in each case study chose the E-Fit image which they thought most closely resembled the ante-mortem photograph. Experiment 3, therefore aimed to establish whether the addition of E-Fit™ features to the reconstructions was of further assistance to the identification process.

The statistical package SPSS (11.5), was used to analyze the results in experiment 3.

Although the author had access to the ante-mortem photographs in each case study, they were not employed in the *preparation stage* in experiment 1, i.e. in the selection of the ten facial templates and subsequently the production of the reconstructions in the manner described above; the respective photographs were only used in the evaluation stage in experiment 1 with the assessors. However, the target photographs in each case study were crucial in experiment 3, both in the preparation and the evaluation stage as it was illustrated above. The ante-mortem photographs were not required in experiment 2 because that required the mathematical shape analysis between the skull and the ten corresponding facial templates. (See also sections "*The ante-mortem photographs", "The E-Fit™ criteria in the present study*" and **"***Reliability, validation and success"* in Chapter XI for fuller discussion).

Experiment 4

Further work was carried out involving anthropometric comparison of each of the five cases in the study, in which the reconstructed images were assessed against the respective photographs of the subject.

Two methods were used for assessment:

1. *Matching of images by alignment using lines between landmarks on compared images*
2. *Assessment of proportions of inter-landmark distances using proportion indices.*

The best three ranked and last ranked reconstructions in each case study, as assessed by the observers in experiment 1, were examined. The last ranked reconstruction was assessed to see how it compared with the best three reconstructions.

The Procrustes Analysis order from the observers' best three and last ranked reconstructions was also assessed in the same manner.

Matching using alignment of inter-landmark lines

For the alignment technique, Adobe® ImageReady CS® was used and images scaled using the arbitrary units of the programme so that they were at a similar distance and approximately magnified to the same extent in relation to each other. Both horizontal and vertical lines (nine in total) were drawn between the following selected landmarks of compared images:

Horizontal lines		***Vertical lines***	
Image A	Image B	Image A	Image B
Right Ectocanthion	Left Ectocanthion	Nasion	Nasion
Right Alare	Left Alare	Right Ectocanthion	Right Ectocanthion
Stomion	Stomion	Left Ectocanthion	Left Ectocanthion
Gnathion	Gnathion	Right Zygion	Right Zygion
		Left Zygion	Left Zygion

Images used were arranged as shown in figure 5.12.

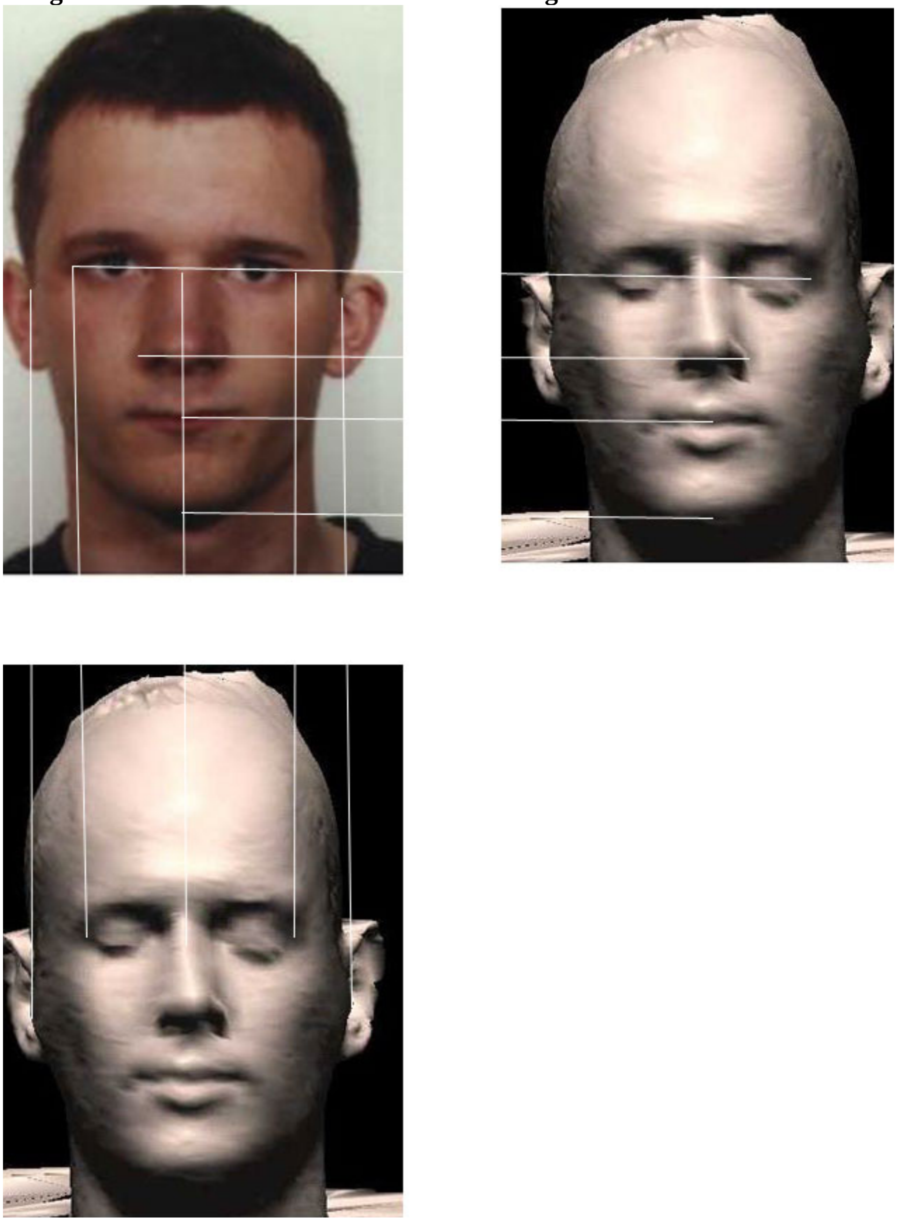


Image A **Image B**

Image B

Figure 5.12 Arrangement of images with inter landmark lines shown

When the lines were drawn, the Adobe® ImageReady CS® programme displayed any discrepancy between the horizontal or vertical plane of the images and the line in question drawn between the landmarks as a straight line between them which can be measured (figure 5.13).

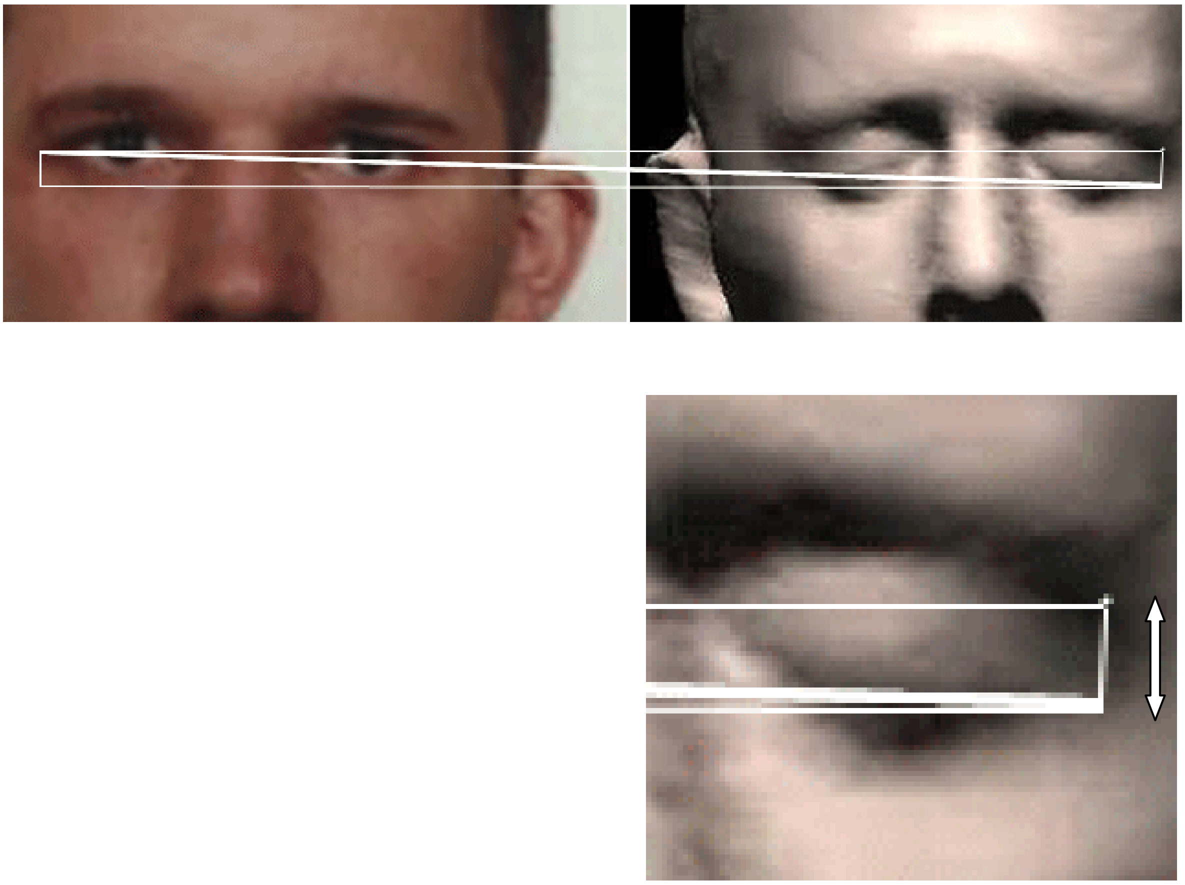


Figure 5.13 Discrepant distance between horizontal plane and plane of inter landmark line

The discrepancies, expressed as distances derived from the nine inter-landmark lines, were then added and the mean of the total obtained. The mean was then assessed against the observers' ranking order of each reconstruction.

Comparison between subject photographs and reconstructions using Proportional measurements (Proportion Indices)

Proportional assessment between selected landmark lines was carried out to compare the proportions of each reconstruction with the proportions of the subject ante-mortem photograph.

The following inter-landmark lines were used:

Ectocanthion line
Nasion-stomion line
Zygion line
Alare line

The same images used for alignment were also used for Proportional Indices (PI) assessment. So as to avoid unnecessary repetition of similar images, only one example is shown here, illustrating position of landmark lines used (figure 5.14).

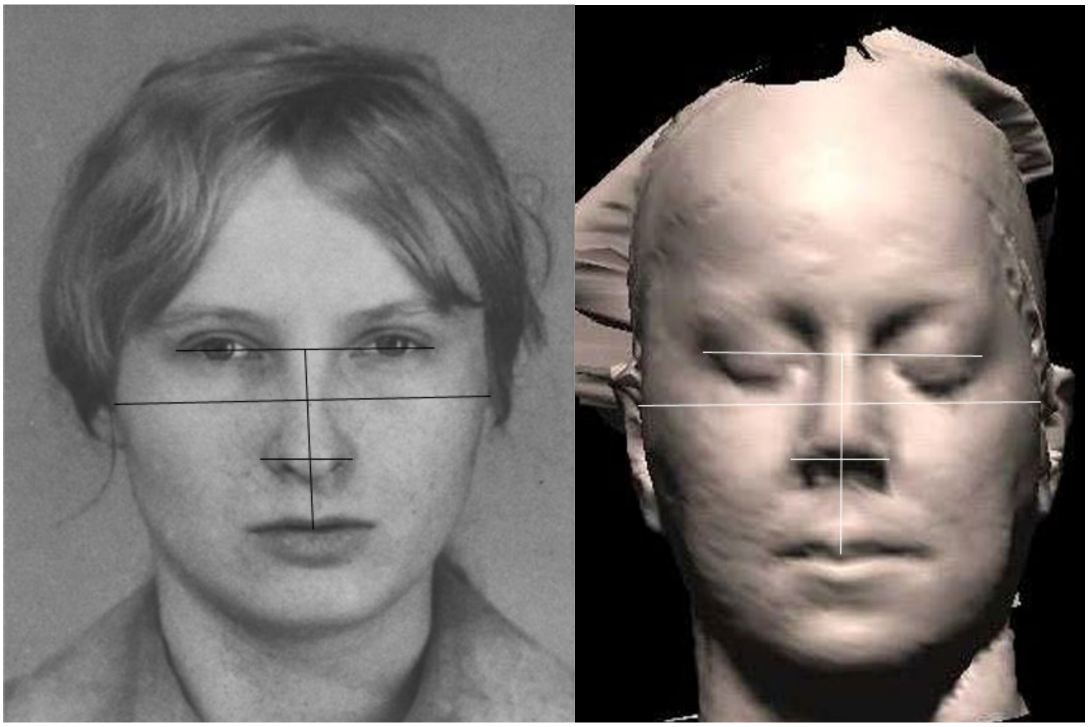


Figure 5.14. Inter landmark lines used for proportion indices assessment

The proportion indices were derived for each inter-landmark line combination using:

$$\mathbf{PI} = \frac{\textbf{Numerator (lower value)}}{\textbf{Denominator (higher value)}} \mathbf{\times 100}$$

The inter-landmark combinations used were:

Numerator/Denominator
Nasion-Stomion/Ectocanthion line
Nasion-Stomion/Zygion line

Ectocanthion line/Zygion line

Alare line/ Ectocanthion line

Alare line/Nasion-Stomion

Alare line/Zygion line

The corresponding differences in the proportion indices between the subject photo and each reconstruction were calculated. Each PI difference was then added, and from the total, the mean difference was derived and plotted against each reconstruction in each case study.

Chapter VI

Case study 1

Introduction

In the previous chapter, I described the technique in which a facial surface, scanned from a volunteer, can be “warped” around a given skull to produce the facial reconstruction as a new graphical object. In this chapter, and the four following, I describe the application of this procedure to five skulls. The intention is to establish whether the technique can support recognition of the skull’s facial reconstruction by observers.

For each of the skulls (one per chapter) I describe three different experiments, comparing the relative identifiability of the skull when combined with ten different facial surfaces. In the first experiment, twenty assessors were shown the graphical reconstructions alongside a photograph of the person whose skull was under examination, and asked to choose which reconstruction most resembled the person. In experiment two, a mathematical procedure was used for the comparison, based on Procrustes Analysis. The perceptual and physical analyses were then compared. In experiment 3 the graphical reconstructions were combined with surface features (e.g., hair and eyes) using E-fit for a sub-set of the reconstructions. Once again, the E-fit reconstructions were shown to assessors, who were asked which most resembled the target person.

Skull 1

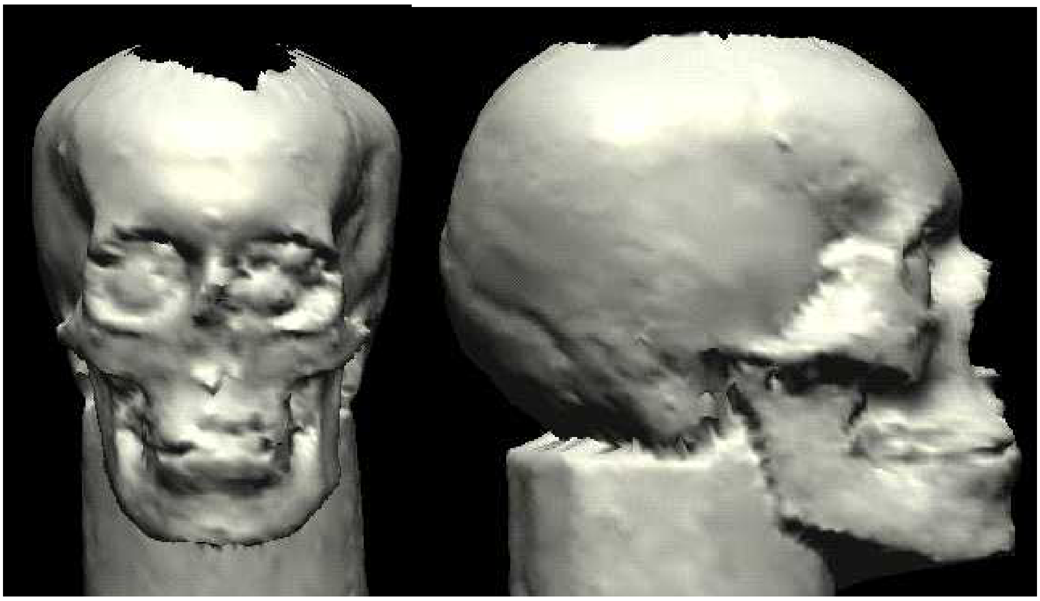
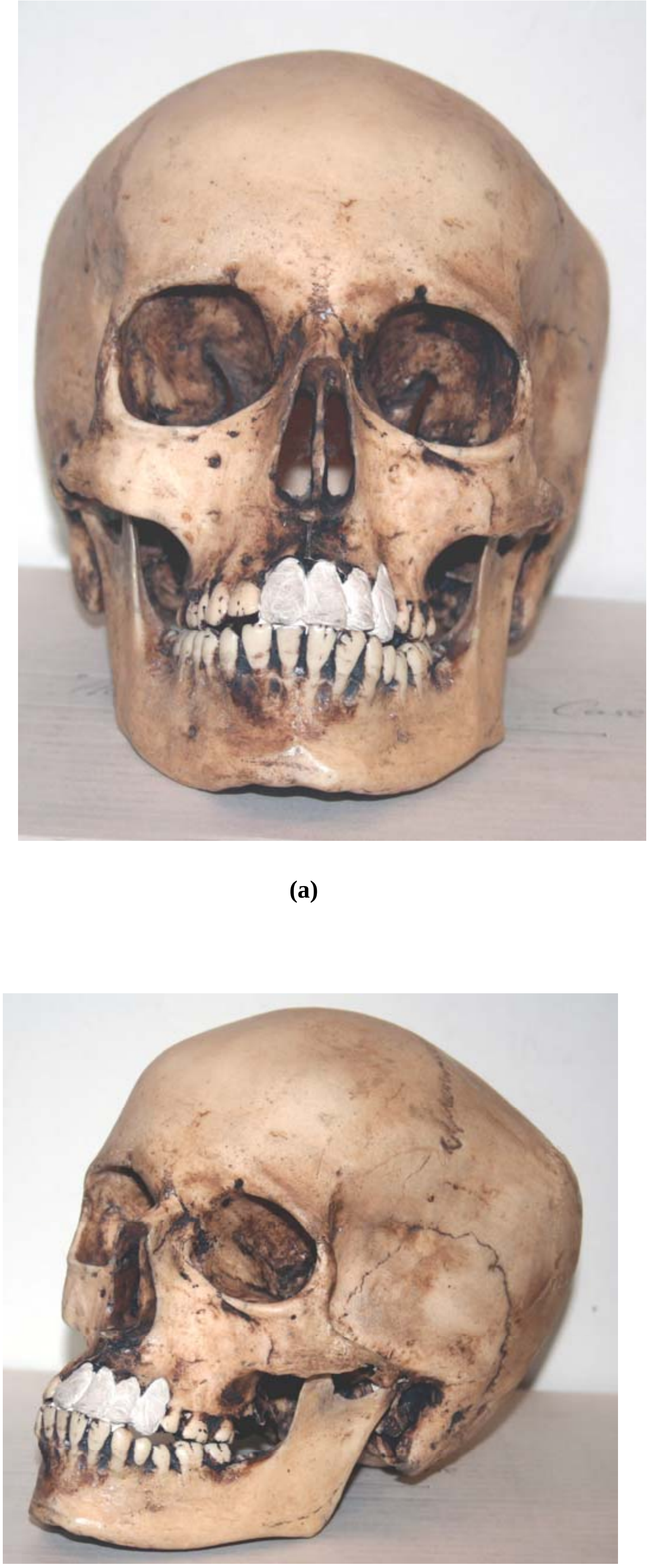


Figure 6.1 *Anterior and right lateral scan of the skull*

Skull 1(figures 6.1 and 6.2 a, b) was of a Caucasian female aged between 30 – 40 years old, of medium build. The skull was assessed as metromorph, slightly dysmorph and hypoplastic. Furthermore, four teeth had been lost: Upper right and left first (central) incisors, upper left second (lateral) and upper left canine. The lost teeth were post-mortem. Skull 1 was the only case in the study that was not the original skull but a cast produced by Ronn Taylor from the University of Melbourne, Australia. This was donated to the Department of Forensic Medicine and Science, University of Glasgow for research purposes. Prior to this, the original skull was a forensic case and the identity of the skull had been established. Consequently, the ante-mortem photograph of the individual became available to the author once the first part (preparation) of experiment 1 - the selection of the ten facial templates and performing the reconstructions - was completed. Consequently, the ante-mortem photograph was used in the evaluation part of experiment 1 with the assessors; additionally, it was used in both stages of experiment 3, (there was no requirement for the ante-mortem photograph in experiment 2, as this was the mathematical assessment between the skull and the ten facial templates).



(a)

(b)

Figure 6.2 (a), (b) *photographs of skull 1 (a) anterior and (b) left oblique*

The general preparation and scanning of skull 1, as discussed under the sections *Skull Preparation before the scanning procedure* and *Scanning Procedure: digitising skulls and facial templates for the database* in Chapter V, took approximately two-three hours. It involved the usual assessment of skull morphology and craniometric characteristics for the preparation of facial reconstruction (see also sections *Skull morphology and craniometric characteristics* and *Skull assessment and preparation for facial reconstruction* in chapter III). Furthermore, it involved re-articulation of the mandible to the cranium to complete the skull for scanning and reconstruction purposes, as described in Chapter V.

It was also necessary to replicate some of the missing teeth for this skull (figure 6.2 a, b). This is necessary to maintain the vertical dimensions of the skull, since the dentition should always be closely examined as this indicates how the mandible articulates with the maxilla and hence gives rise to the general appearance of the lower face. However, maintaining the height of the skull was not an issue in this case because there were enough teeth present to retain the articulation height between the mandible and the maxilla. However, the loss of data which happens when the projected laser beam passes through open orifices, such as missing teeth, was more of a concern, and hence replicating the teeth whilst maintaining the correct maxilla and mandible height was necessary; this was achieved as before, by using WHITE-TAC™. WHITE-TAC™, unlike wax, is a good material for this purpose because it is easily removed from the skull without causing any damage or staining. This is more significant with the present computerized technique because very often the original skulls and not replicas are used for computerized facial reconstruction

As reported in the Methodology chapter V, ten facial templates were selected to reconstruct over each skull according to the anthropological criteria that was known about each skull. Therefore in Case study 1 the facial templates selected had to correspond with the anthropological criteria of skull 1: they were all Caucasian females between 31-40 years of age and of average build. In that category there were 725 faces in the combined database (table 5.2) of which 73 were from the new database of 500 faces (table 5.1).

The most typical and standard templates were selected from the appropriate anthropological category, and also taking into account the morphology of the skull. For example, it was evident from skull 1 that the person in question had rather gracile facial features, even for a female. At this stage the selection was narrowed down to 68 facial templates.

The next stage was to choose the final ten facial templates from the 68 faces by judging which ones were the most appropriate in terms of their image quality (see chapter V).

Excluding the timing and procedures for *Skull preparation* and digitising the templates in *Acquisition of the facial database,* each of the ten reconstructions in Case 1 took on average two hours to complete; this has been covered in the section *Facial Reconstruction Procedure* discussed in chapter V.

The exact position and angle of the frontal view of the ten reconstructions printed out (figures 6.4 - 6.13) was determined by the position of the available frontal ante-mortem photograph (figure 6.3), rather than the usual Frankfort Horizontal position, as explained in chapter V.

The first experiment attempts to determine the psychological assessment of the facial reconstructions by using human observers to evaluate the similarity of the ten reconstructions when compared with the individual's ante-mortem photograph belonging to skull 1.

Experiment 1

The psychological assessment test on the facial reconstructions using a resemblance technique

The twenty assessors in experiment 1 were asked to choose from the selection of the ten reconstructions (figures 6.4 - 6.13), their three best reconstruction choices, which, in their opinion, resembled more accurately to the ante-mortem photograph (figure 6.3) of the target individual belonging to skull 1.

As explained in Chapter V, this should have produced a total of sixty reconstruction choices from the twenty subjects (20 x 3 choices); however, one assessor in this case only chose two reconstructions instead of the required three, producing a total of fifty nine reconstructions instead of sixty.

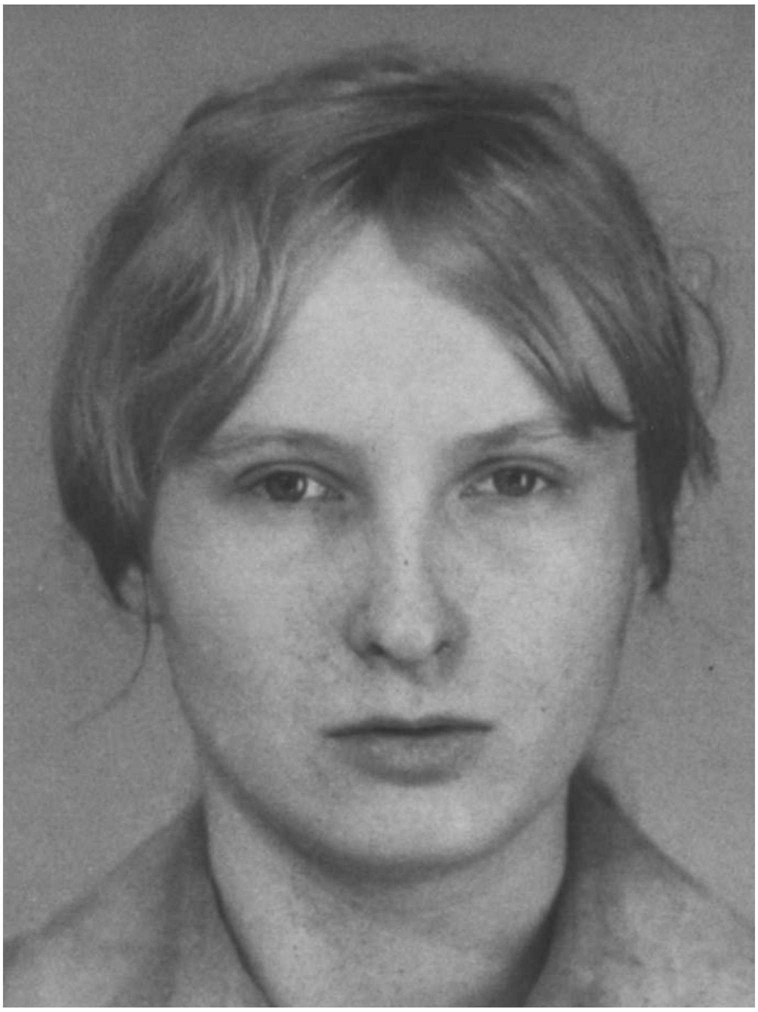


Figure 6.3 *Ante-mortem photograph of the target individual (Case study 1)*

Figure 6.4 *Reconstruction 1*

Figure 6.5 *Reconstruction 2*

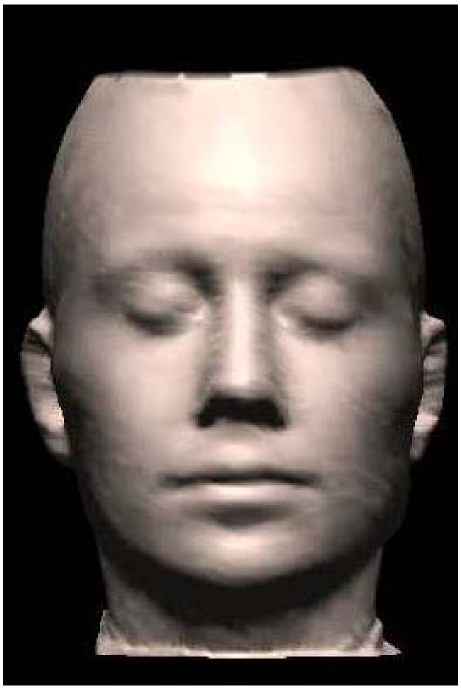


Figure 6.6 *Reconstruction 3*

Figure 6.7 *Reconstruction 4*

Figure 6.8 *Reconstruction 5*

Figure 6.9 *Reconstruction 6*

Figure 6.10 *Reconstruction 7*

Figure 6.11 *Reconstruction 8*

Figure 6.12 *Reconstruction 9*

Figure 6.13 *Reconstruction 10*

Results

(*Experiment 1*)

The twenty assessors' best three reconstruction choices (1st, 2nd and 3rd) from a choice of ten reconstructions, figures 6.4. – 6.13., **(R1, R2, R3……R10),** are shown in Table 6.1.

Table 6.1 ***Assessors' three reconstruction choices and ranking***

Reconstructions (R)	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**Total**
1st choice	1	3	7	0	7	0	1	0	0	1	**20**
2nd choice	3	4	2	2	2	5	0	1	1	0	**20**
3rd choice	5	2	1	1	3	1	1	3	1	1	**19**
Total number of times (1st, 2nd and 3rd) each reconstruction(R) was chosen by assessors	**9**	**9**	**10**	**3**	**12**	**6**	**2**	**4**	**2**	**2**	**59**
Rank of Total Reconstruction (R) Choice	**3.5**	**3.5**	**2.0**	**7.0**	**1.0**	**5.0**	**9.0**	**6.0**	**9.0**	**9.0**	___

These results show that some of the reconstructions are consistently preferred over others. Whatever the accuracy of the skull/surface combination, it seems clear that some combinations are better than others.

In the second experiment, I will apply a physical analysis to assess the mathematical significance of the facial reconstructions. It does this by evaluating how close the *match* is between skull 1 and each of the ten corresponding facial templates used to produce the facial reconstructions. To do this, I will use the Procrustes Analysis technique in the manner already described in Chapter V.

Experiment 2

The mathematical assessment test on the facial images: using Procrustes (Shape) Analysis

Each of the ten facial templates in case study 1 were separately compared and matched to skull 1. This was achieved by matching all the x, y, and z co-ordinates for each of the 36 landmarks per template (A1.2 in appendix 1) to the corresponding 36 landmarks on skull 1 (A1.1 in appendix 1). This means that each of the ten face co-ordinates was separately matched to skull 1's co-ordinates every time. This produced the Full Procrustes Distance between the face and the skull configuration for each of the ten facial templates. There were ten facial templates to be compared separately to skull 1, producing ten Full Procrustes Distances i.e. ten numbers, ranging from the closest to furthest. The closer the Full Procrustes distance (the smaller the number) between face and skull configuration, the closer is the match (tables 6.2 and figure 6.14).

Results

(Experiment 2)

Table 6.2 ***Procrustes Distances and Ranking produced between skull 1 and each of the ten facial templates***

Facial Templates	Procrustes Distances with skull 1	Rank of Procrustes Distances
1	0.1557	9.0
2	0.1444	6.0
3	0.1319	3.0
4	0.1552	8.0
5	0.1565	10.0
6	0.1390	4.0
7	0.1433	5.0
8	0.1446	7.0
9	0.1293	2.0
10	0.1133	1.0

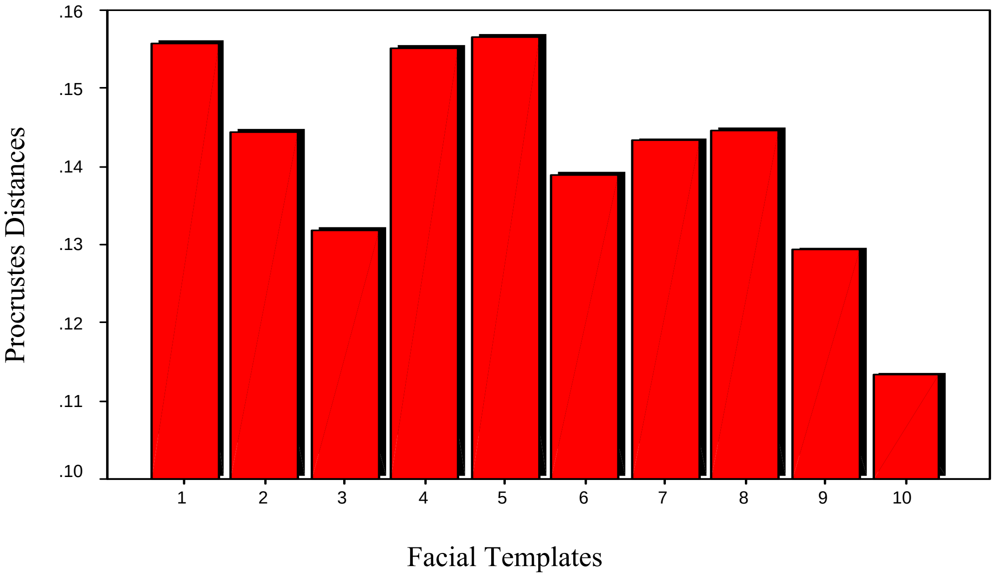


Figure 6.14 ***Procrustes Distances between skull 1 and each of the ten facial templates (closest match is smallest distance i.e. facial template no.10)***

Statistical Analysis between experiments 1 and 2

Statistical analysis was performed using the statistical pack SPSS™ 11.5.1 for Windows. This was to establish the association between experiment 1 and experiment 2. Since the correlation between the ranks of the assessors' reconstruction choice and the ranks of the Procrustes Distances (Analysis) was being assessed, Spearman's Rank Order Correlation was most appropriate for this.

Figure 6.15 is a scatter plot showing the correlation between the ranks of the Procrustes Distances (Analysis) and of the rank of the assessors' reconstruction choice. It shows a negative correlation because the Correlation Coefficient was computed as **-0.542** and as shown from figure 6.15 the relationship displays an inverse relationship, in which, as the ranks of the Procrustes Distances increase, the ranks of the assessors' reconstruction choice decreases, and visa versa.

Furthermore, at the 0.05 significance level, the tabulated value from the Critical values of Spearman's Rank-Order Correlation Coefficient table (Siegel 1956; Edwards and Talbot 1994) is **0.564** when the N = 10. Since the calculated/computed Spearman's correlation coefficient is *less* than the table value, the correlation is a weak one, and *not* significant. Therefore, from the results of this particular case, one can conclude that there is not enough evidence to reject the null hypothesis at the 0.05 significance level.

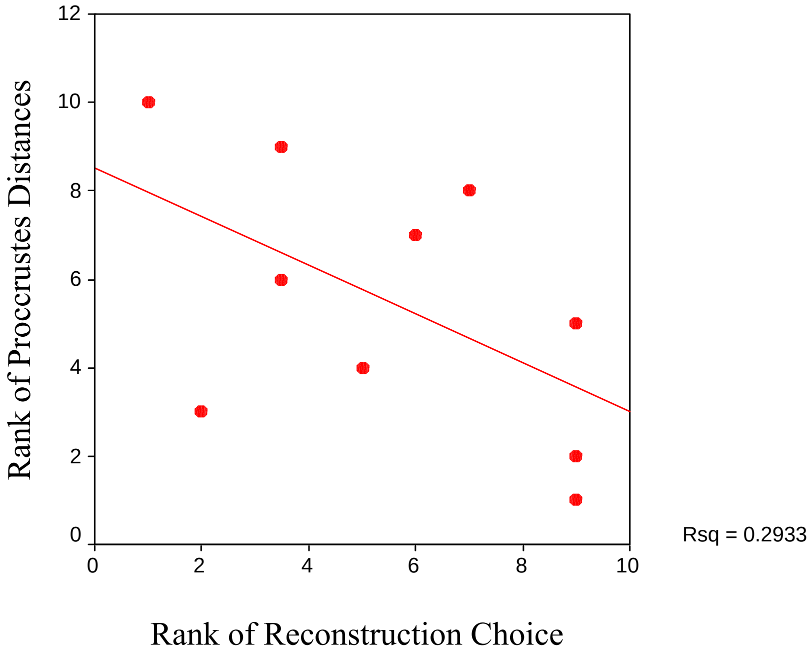


Figure 6.15 ***Scatter plot showing correlation between Procrustes Analysis and Assessors' Reconstruction Choice***

Discussion
(Comparisons between experiment 1 and experiment 2)

In experiment 1, the assessors' choice as the closest match between the ante-mortem photograph and reconstruction, was reconstruction 5, selected by 12 subjects and ranked 1st (table 6.1). The least preferred reconstructions selected by only 2 subjects each were reconstructions 7, 9 and 10, ranking equal 9th (lowest rank). However, reconstruction 3 scored a close second ranking with the assessors' choice being chosen by 10 subjects; and reconstructions 1 and 2 scored equal third position, being chosen by 9 assessors.

However, reconstruction 5, which was chosen in experiment 1 by the assessors as the closest reconstruction choice to match to the ante-mortem photograph, was assigned 10th and last in the Procrustes Analysis evaluation in experiment 2, having produced the largest distance (0.1565) between the skull and the corresponding facial template 5 (table 6.3).

The least preferred reconstruction with the assessors' choice as a good match with the ante-mortem photograph, selected by only 2 volunteers was reconstruction 10, ranking equal 9th with reconstructions 7 and 9 (lowest rank). Conversely, with the Procrustes Analysis assessment in experiment 2 (table 6.2 and figure 6.14) reconstruction 10 produced the best match between skull 1 and its corresponding facial template 10, having produced the shortest Procrustes Distance of 0.1133. The shortest Procrustes distance indicates the closest match between skull and the facial template that produced the same (numbered) reconstruction 10. Consequently the 1st ranking was assigned to reconstruction 10 in experiment 2 (table 6.3).

Reconstruction 3, which as discussed above scored a close second ranking with the assessors' choice in experiment 1, also scored quite high with the Procrustes Analysis in experiment 2, and ranked third (table 6.3).

As discussed above in the statistical analysis between experiments 1 and 2, the results in case study/skull 1 produced a negative correlation between the ranks of the assessors' reconstruction choice and the ranks of the Procrustes Distances (Analysis). Since the correlation is weak and not significant, we can conclude that Procrustes

Analysis in this case study, using skull 1, does not seem to capture perceptual similarity in human observers, and is therefore a poor candidate for use in this setting.

The purpose of the third experiment was to ascertain whether by adding E-Fit™ features to the facial reconstructions in the context of the present study, there was an effect on the identification process. E-fit features were added to the four selected facial reconstructions for evaluation by the assessors.

Experiment 3

The psychological assessment test on the E-Fit™ images using a resemblance technique

As discussed in Chapter V, E-Fit™ features were implemented on four reconstructions which produced the most extreme results from both the psychological assessment in experiment 1 and/or the mathematical evaluation in experiment 2 in each of the case studies for further comparisons.

From the results in the present case study (table 6.3), reconstructions 3, 5, 9 and 10 were chosen to implement the E-Fit™ features.

Reconstruction ***3*** was chosen from the ten reconstructions to implement E-Fit features because it was the only reconstruction which ranked relatively high in both experiment 1 and 2, i.e. it ranked 2nd in the assessors' choice in experiment 1 and ranked 3rd with the Procrustes analysis.

Reconstruction ***5*** was chosen because it ranked 1st with the assessors' choice in experiment 1, yet the same reconstruction produced from facial template 5 ranked last with the Procrustes analysis in experiment 2.

Reconstructions ***9*** and ***10*** were chosen because they both ranked equal last (with reconstruction 7) in experiment 1, yet both reconstructions scored the highest ranking with the Procrustes analysis in experiment 2: reconstruction 9 scored 2nd rank and reconstruction 10 scored 1st rank.

Consequently, in numerical order:

- Reconstruction 3 with E-Fit™ features was assigned as E-Fit 1 (figure 6.16)

- Reconstruction 5 with E-Fit™ features was assigned as E-Fit 2 (figure 6.17)
- Reconstruction 9 with E-Fit™ features was assigned as E-Fit 3 (figure 6.18)
- Reconstruction 10 with E-Fit™ features was assigned as E-Fit 4 (figure 6.19)

These four E-Fits were subsequently shown to the twenty new assessors in experiment 3 together with the ante-mortem photograph (figures 6.20) for evaluation in the manner described in Chapter V.

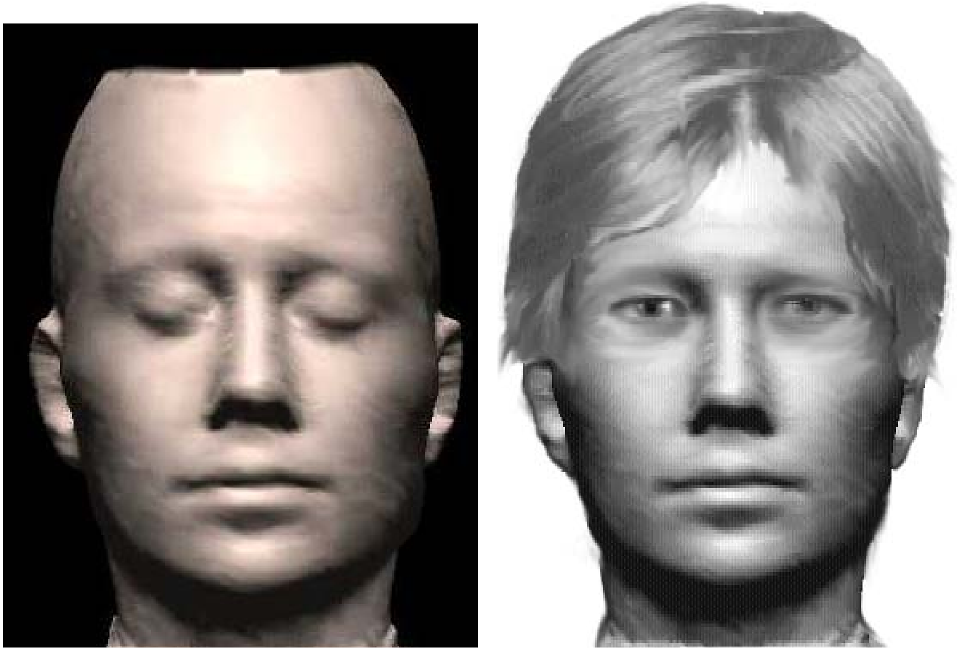


Figure 6.16 ***Reconstruction 3 with its E-Fit features –E-Fit 1***

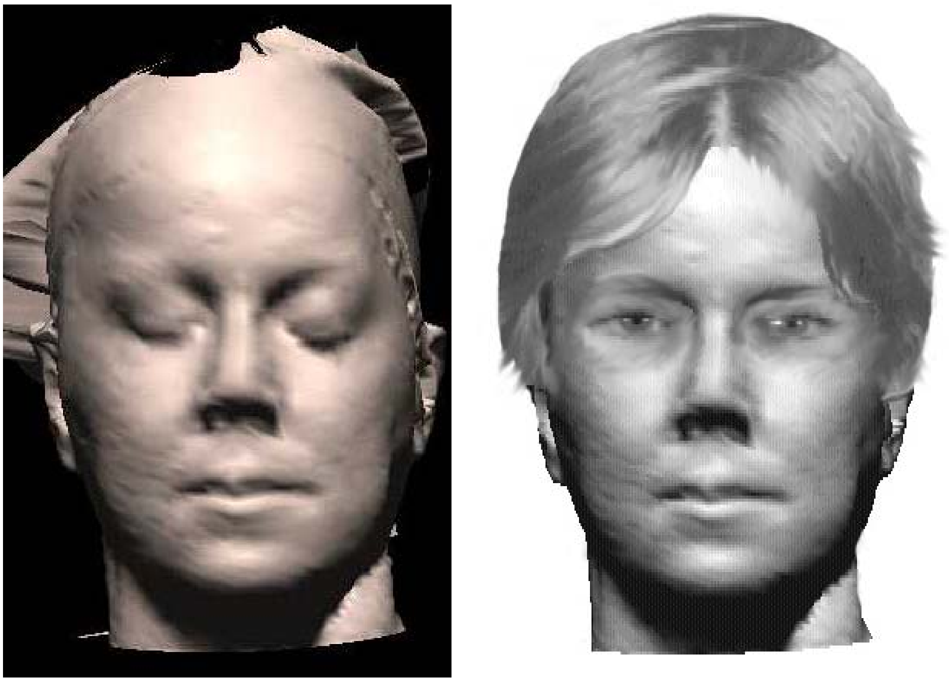


Figure 6.17 ***Reconstruction 5 with its E-Fit features –E-Fit 2***

Figure 6.18 ***Reconstruction 9 with its E-Fit features –E-Fit 3***

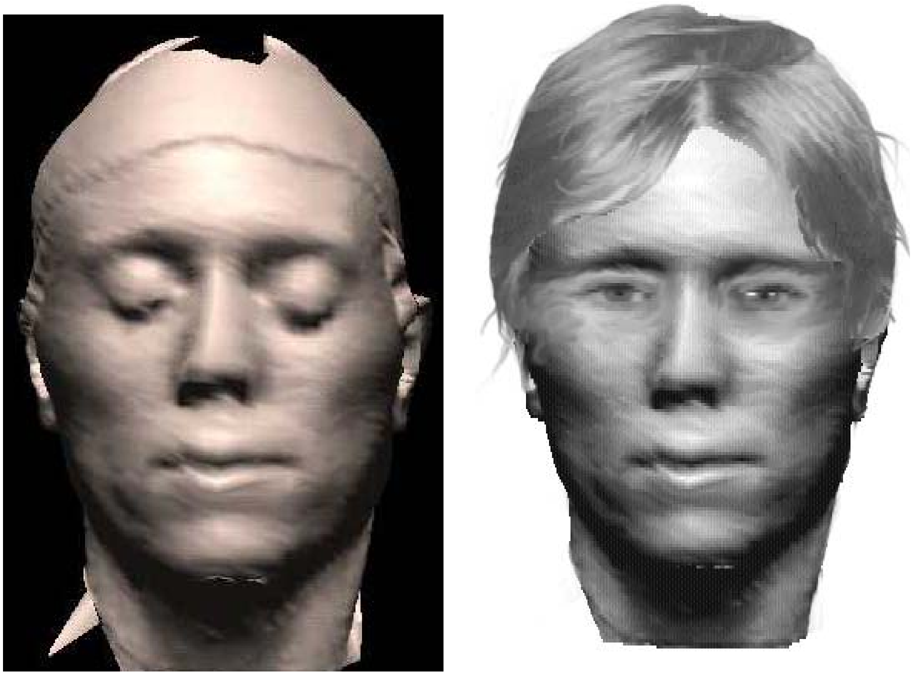


Figure 6.19 ***Reconstruction 10 with its E-Fit features –E-Fit 4***

E-Fit 1 ***E-Fit 2***

E-Fit 3 ***Ante-mortem photograph*** ***E-Fit 4***

Figure 6.20 ***The four E-Fit images with ante-mortem photograph***

Results

(Experiment 3)

Table 6.3 ***Assessors' Reconstruction Choice, Procrustes Distances and Assessors'E-Fit Choice (Comparisons between experiments 1, 2 and 3)***

	Experiment 1		*Experiment 2*		*Experiment 3*		
Recon-structions R	**Total/No of Assessors R Choice**	**Rank of R Choice**	**Procrustes Distances With skull 1**	**Rank of Procrustes Distances**	**EFit**	**Assessors' EFit-Choice**	**Rank of E-Fit Choice**
1	9	3.5	0.1557	9.0	.	.	
2	9	3.5	0.1444	6.0	.	.	.
3	10	2.0	0.1319	3.0	1	5	2.5
4	3	7.0	0.1552	8.0	.	.	.
5	12	1.0	0.1565	10.0	2	8	1.0
6	6	5.0	0.1390	4.0	.	.	.
7	2	9.0	0.1433	5.0	.	.	.
8	4	6.0	0.1446	7.0	.	.	.
9	2	9.0	0.1293	2.0	3	5	2.5
10	2	9.0	0.1133	1.0	4	2	4.0

Discussion

In experiment 3 above, only descriptive statistics are provided, since the relatively small data set lends itself to clinical observation only.

The most preferred E-Fit which was selected by 8 from the 20 assessors as most closely resembling the ante-mortem photograph was E-Fit 2 and consequently ranked 1st (table 6.3).

The least preferred was E-Fit 4 which was selected by only 2 of the 20 assessors and ranked 4th. E-Fit 1 and E-Fit 3 were in equal second place, ranked 2.5 and selected by 5 assessors each.

As stated previously, case study 1 /skull 1 produced a negative correlation between the assessors' evaluation using the resemblance technique in experiment 1 and the mathematical assessment using Procrustes Analysis in experiment 2. However, there appears to be good agreement with the two sets of assessors between the two psychological resemblance tests in experiment 1 (images without E-Fit™ features) and experiment 3 (same corresponding images with E-Fit™ features).

For example E-Fit 2, which ranked 1st in experiment 3, was produced from reconstruction 5 after E-Fit features were implemented. This was the same reconstruction (5) chosen by the previous assessors in experiment 1 as the closest match to the ante-mortem photograph (table 6.3), and consequently also ranked 1st.

Similarly, the least preferred E-Fit with the assessor's choice to most closely resemble the ante-mortem photograph was E-Fit 4, which was produced from reconstruction 10 after E-Fit features were implemented. This again was in agreement with experiment 1, where reconstruction 10 scored equal last ranking with reconstructions 7 and 9 (table 6.3)

The results from experiment 3, the assessors' E-Fit evaluation (as in experiment 1), therefore, also seem to suggest a negative correlation with the results from the Procrustes Analysis in experiment 2.

For example, E-Fit 2, which was produced from reconstruction 5 (ranked 1st in experiments 1 and 3) did very poorly with the Procrustes Analysis, and was therefore, ranked 10th and last (table 6.3).

E-Fit 4 was produced from reconstruction 10 which both of which ranked last in experiments 1 and 3. However, in experiment 2, the facial template which produced reconstruction 10 ranked 1st with the Procrustes Analysis (table 6.3).

From this case study using skull 1, the results indicate that although there is a negative correlation between experiments 1 and 2 and between experiments 3 and 2. There is however, good agreement between the two psychological resemblance tests using the two different sets of assessors in experiments 1 and 3.

Therefore, we can conclude from the results of this case study, that Procrustes Analysis does not capture perceptual similarity in human observers, and is therefore not a very good tool for evaluation in this setting.

Experiment 4

Results (for all five cases)

The discrepancies were obtained from the nine inter-landmark lines, as explained in Chapter V, and expressed as distances. These were then added and the mean of the total obtained. The mean was then assessed against the observers' ranking order of each reconstruction (figure 6.21).

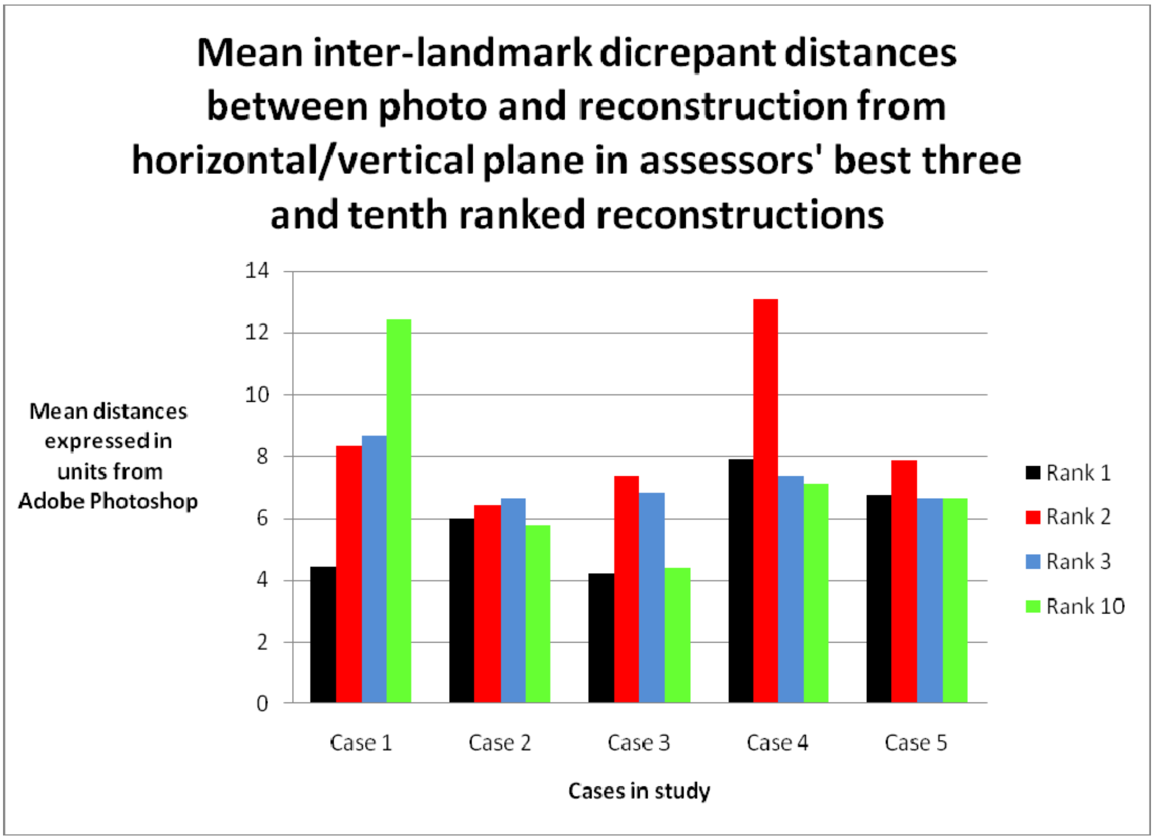


Figure 6.21

It is seen from visual inspection of figure 6.21 that the first and second ranked reconstructions correspond with the distance measurements (lesser distance corresponds to first ranked reconstruction and greater distance to the second ranked reconstruction), in all five case studies. However, there is no relationship between the observers' ranking order and alignment assessment of the remaining reconstructions.

The Procrustes Analysis order from the observers' best three and last ranked reconstructions was also assessed and visual inspection did not reveal any correlation between mean discrepant distances and Procrustes Analysis order of these reconstructions (figure 6.22).

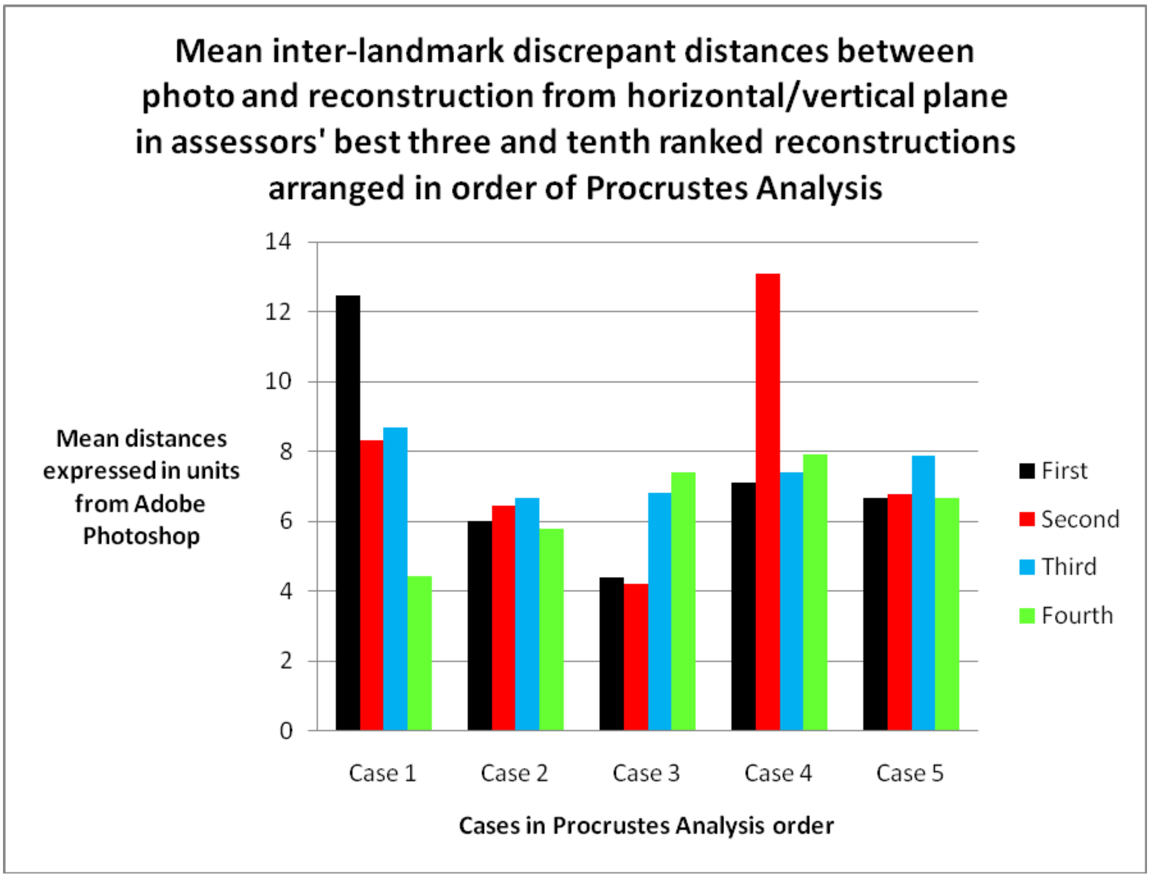
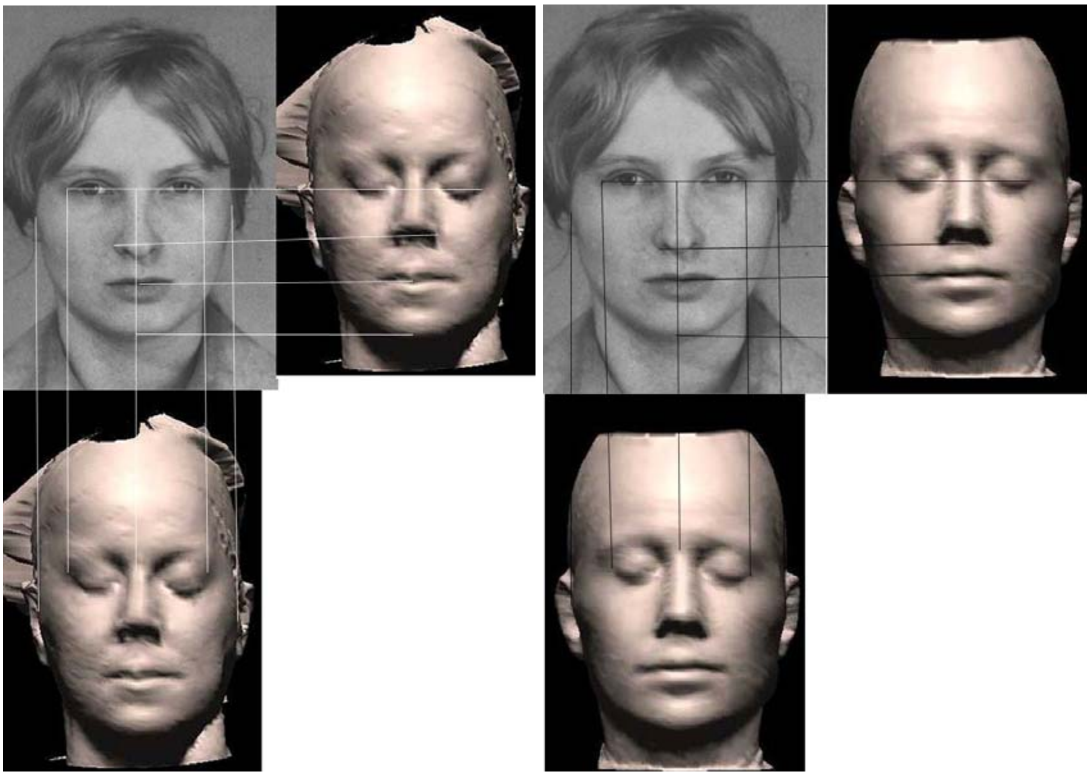
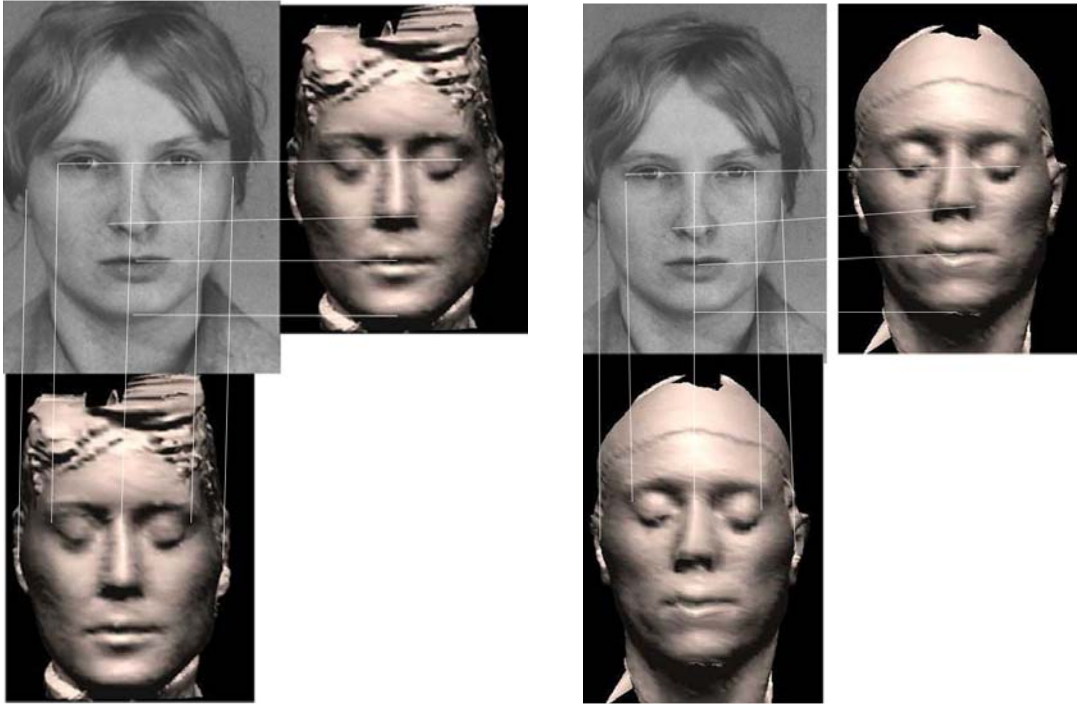


Figure 6.22



Reconstruction 5 (Observers' Rank 1)

Reconstruction 3 (Observers' Rank 2)



Reconstruction 1 (Rank 3)

Reconstruction10 (Rank joint 9th)

Figure 6.23 : Case 1. Inter landmark lines between subject and reconstructions

On visual inspection there was no correlation between the rank of the reconstructions of the observers in each case study and the mean proportion indices differences between the subject photo and each reconstruction (figure 6.24).

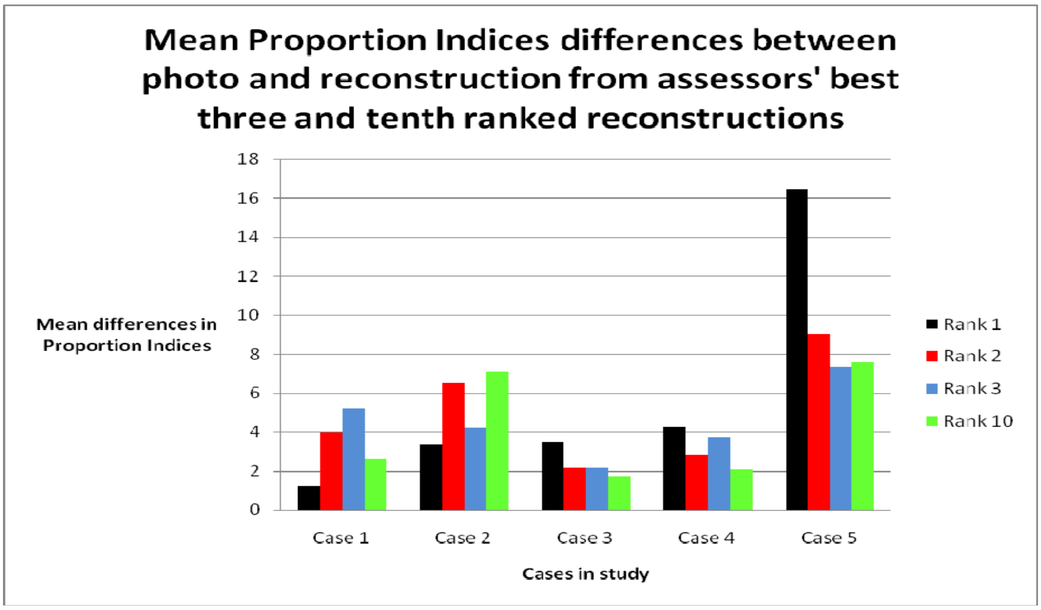


Figure 6.24

When these same four reconstructions (as chosen by the observers in experiment 1) were placed in the order of the Procrustes Analysis ranking, there appeared to be a visual correspondence between the first and second PA order with their PI differences (6.25).

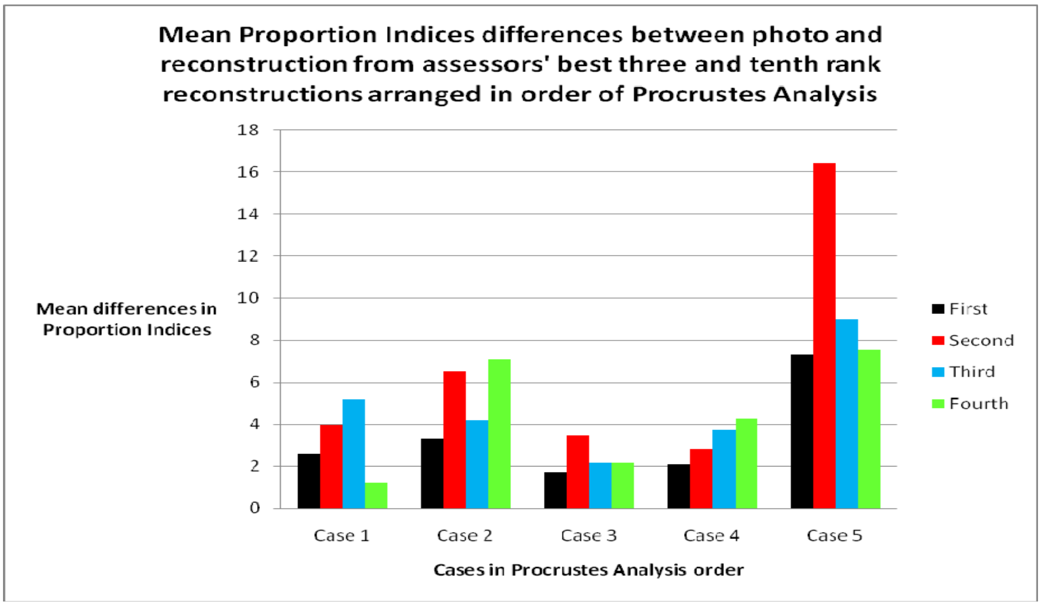


Figure 6.25

Chapter VII

Case study 2

Skull 2

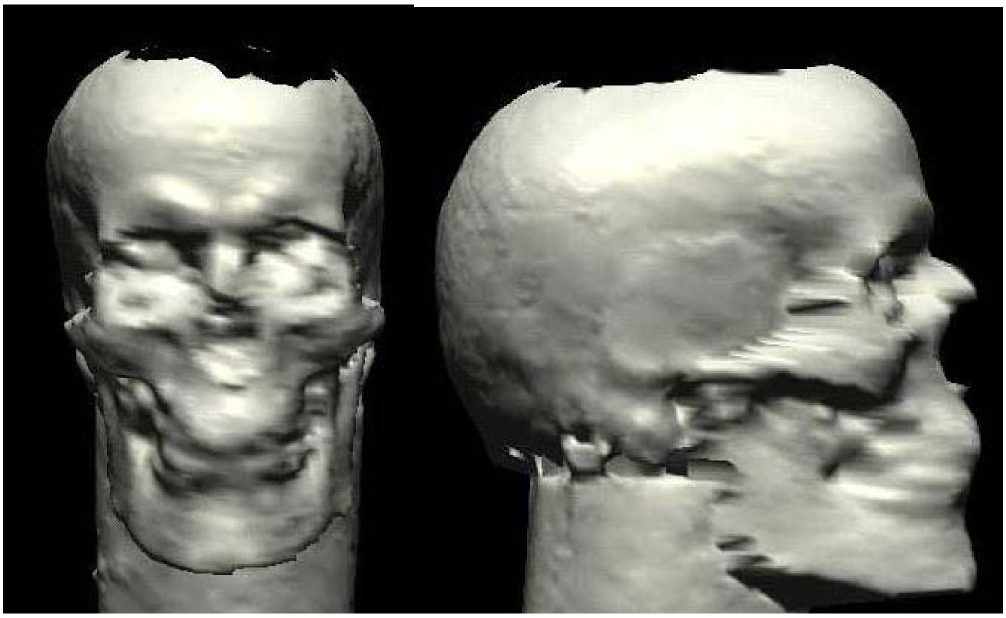


Figure 7.1 *Anterior and right lateral scan of the skull*

Skull 2 was of a homicide case from a young Caucasian male (figures 7.1, 7.2 a, b). The skull exhibited a bullet hole in the cranium. Anthropologically, the skull was large displaying rugged, well built and muscular characteristics with pronounced supra orbital ridges, glabella, well developed mastoid processes and a prominent external occipital protuberance. The mandible was large, robust and the mental region was squared.

This was a forensic case and permission was obtained from the appropriate police force for skull 2 to be used in this thesis. A photograph of the identified individual was only available to the author to be used in experiment 3 and in the evaluation stage with the assessors of experiment 1, but not in the preparation of experiment 1 where, the facial templates were selected from the database to match only the anthropological criteria of what was already known about the skull from the forensic and anthropological reports, and subsequently perform the reconstructions as described in Chapter V. (See also ***preparations for experiments 1 and 3*** in chapter V and Chapter XI for the rationale of the experiments).

(a)

(b)

Figure 7.2 (a), (b) *photographs of skull 2 (a) anterior and (b) left oblique*

The general preparation and scanning of skull 2, as discussed under the sections *Skull Preparation before the scanning procedure* and *Scanning Procedure: digitising skulls and facial templates for the database* in Chapter V, took approximately three-four hours. It involved the usual assessment of skull morphology and craniometric characteristics for the preparation of facial reconstruction (see also sections *Skull morphology and craniometric characteristics* and *Skull assessment and preparation for facial reconstruction* in chapter III). It also involved re-articulation of the mandible to the cranium to complete the skull for scanning and reconstruction purposes, as described before.

The skull also required replicating most of the missing teeth (figure 7.2 a, b). As explained before, this was necessary to maintain the vertical dimensions of the skull, by examining the dentition closely as this indicates how the mandible articulates with the maxilla and hence gives rise to the general appearance of the lower face.

However, the loss of data which happens when the projected laser beam passes through open orifices, such as missing teeth, was also an important consideration, and hence replicating the teeth whilst maintaining the correct maxilla and mandible height is necessary; this was achieved in this case study by using BLUE-TAC™ (same material and serves same purpose as WHITE-TAC™)

As reported in the Methodology chapter V, ten facial templates were selected to reconstruct over each skull according to the anthropological criteria that is known about each skull. Therefore, in Case study 2 the facial templates selected had to correspond with the anthropological criteria of skull 2: they were all Caucasian males between the ages of 18-30 years of age, of average build.

In that particular category there were 1224 faces in the combined database (table 5.2), of which, 141 of those facial templates were from the new database of 500 faces (table 5.1).

The first stage was to select the most typical and standard facial templates from the appropriate anthropological category mentioned above, excluding any templates with anomalous or exaggerated features, this also took into account faces that *visually* matched with the morphology of skull 2. For example, it was evident from skull 2 that the person in question had rather robust facial features. At this stage the selection was narrowed down to 103 facial templates.

The final stage was to choose the ten facial templates from the 103 faces by judging which ones were the most appropriate in terms of their image quality.

Excluding the timing and procedures for *Skull preparation* and digitising the templates in *Acquisition of the facial database,* each of the ten reconstructions in Case 2 took on average two hours to complete; this has been covered in the section *Facial Reconstruction Procedure* discussed in chapter V.

As in the previous case study, the exact position and angle of the frontal view of the ten reconstructions printed out (figures 7.4 - 7.13) was determined by the position of the available frontal ante-mortem photograph (figure 7.3), rather than the usual Frankfort Horizontal position, as explained in chapter V.

As in the previous chapter, the first experiment attempts to determine the psychological assessment of the facial reconstructions by using human observers to evaluate the similarity of the ten reconstructions when compared with the individual's ante-mortem photograph belonging to skull 2.

Experiment 1
The psychological assessment test on the facial reconstructions using a resemblance technique

The twenty assessors in experiment 1 were asked to choose from the selection of the ten reconstructions (figures 7.4 - 7.13), their three best reconstruction choices, which, in their opinion, resembled more accurately to the ante-mortem photograph (figure 7.3) of the target individual belonging to skull 2.

As explained in Chapter V, this produced a total of sixty reconstruction choices from the twenty subjects (20 x 3 choices).

Figure 7.3 *Ante-mortem photograph of the target individual (Case study 2)*

Figure 7.4 *Reconstruction 1*

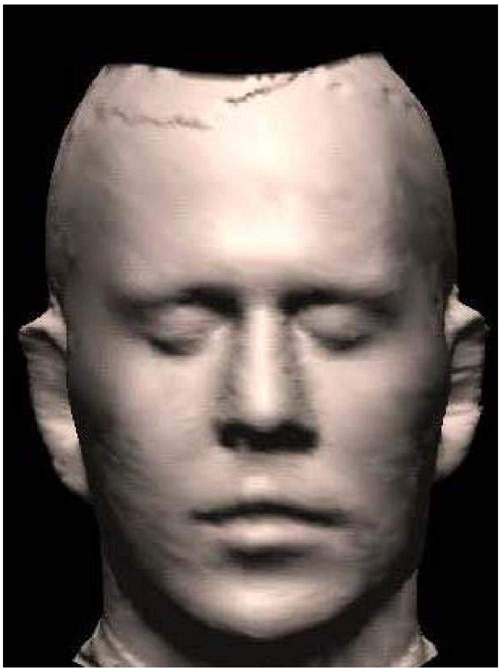


Figure 7.5 *Reconstruction 2*

Figure 7.6 *Reconstruction 3*

Figure 7.7 *Reconstruction 4*

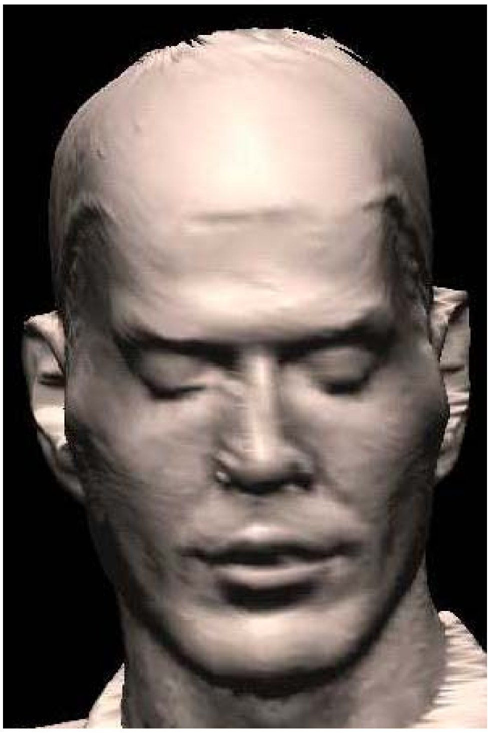


Figure 7.8 *Reconstruction 5*

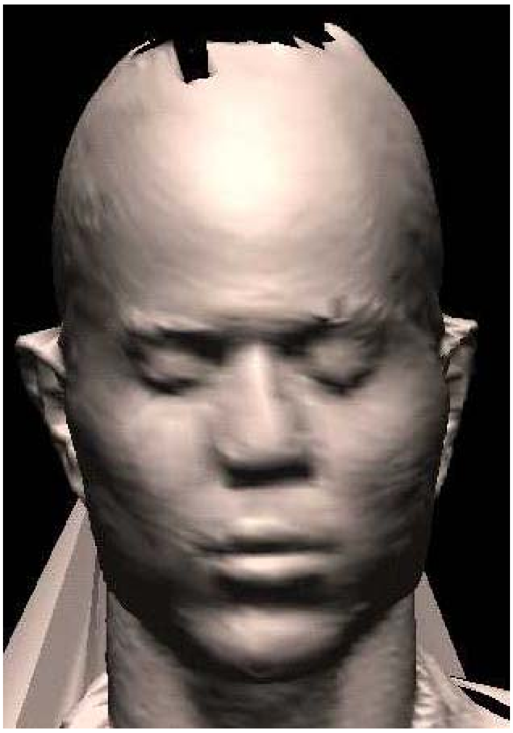


Figure 7.9 *Reconstruction 6*

Figure 7.10 *Reconstruction 7*

Figure 7.11 *Reconstruction 8*

Figure 7.12 *Reconstruction 9*

Figure 7.13 *Reconstruction 10*

Results

(*Experiment 1*)

The twenty assessors' best three reconstruction choices (1st, 2nd and 3rd) from a choice of ten reconstructions, figures 7.4. – 713., **(R1, R2, R3……R10),** are shown in Table 7.1.

Table 7.1 ***Assessors' three reconstruction choices and ranking***

Reconstructions (R)	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**Total**
1st choice	0	0	0	0	5	0	2	6	2	5	**20**
2nd choice	1	2	0	1	4	1	2	2	4	3	**20**
3rd choice	2	2	0	6	1	0	0	2	6	1	**20**
Total number of times (1st, 2nd and 3rd) each reconstruction was chosen by assessors	**3**	**4**	**0**	**7**	**10**	**1**	**4**	**10**	**12**	**9**	**60**
Rank of Total Reconstruction(R)) Choice	**8.0**	**6.5**	**10.0**	**5.0**	**2.5**	**9.0**	**6.5**	**2.5**	**1.0**	**4.0**	__

Similar to the previous chapter, these results show that some of the reconstructions are consistently preferred over others. Whatever the accuracy of the skull/surface combination, it seems clear that some combinations are better than others.

In the second experiment, like the previous chapter, VI, a physical analysis was used to assess the mathematical significance of the facial reconstructions. To do this, I will use the Procrustes Analysis technique in the manner already described in Chapter V.

Experiment 2

The mathematical assessment test on the facial images: using Procrustes (Shape) Analysis

Like before, each of the ten facial templates in case study 2, were separately compared and matched to skull 2.

As explained in more detail in chapter V, there were ten facial templates to be compared separately to skull 2, producing ten Full Procrustes Distances i.e. ten numbers, ranging from the closest to furthest. The closer the Full Procrustes distance (the smaller the number) between face and skull configuration, the closer is the match (table 7.2 and figure 7.14).

Results

(Experiment 2)

Table 7.2 ***Procrustes Distances and Ranking produced between skull 2 and each of the ten facial templates***

Facial Templates	Procrustes Distances with skull 2	Ranking of Procrustes Distances
1	0.1519	3.0
2	0.1667	7.0
3	0.1675	8.0
4	0.1735	10.0
5	0.1438	2.0
6	0.1565	5.0
7	0.1725	9.0
8	0.1592	6.0
9	0.1383	1.0
10	0.1553	4.0

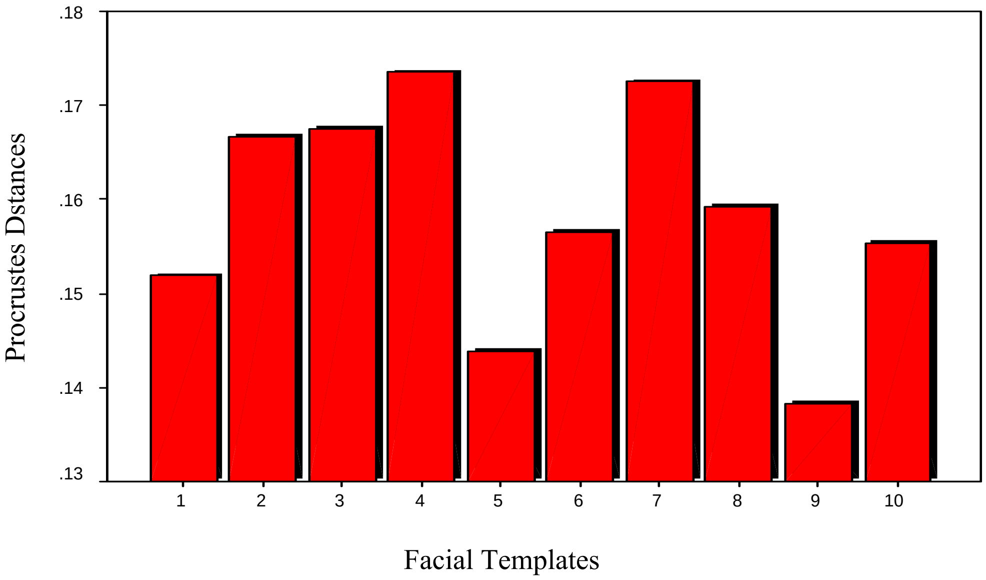


Figure 7.14 ***Procrustes Distances between skull 2 and each of the ten facial templates (closest match is smallest distance i.e. facial template no.9)***

Statistical Analysis between experiments 1 and 2

Statistical analysis was performed using the statistical pack SPSS™ 11.5.1 for Windows. This was to establish the association between experiment 1 and experiment

2. Since the correlation between the ranks of the assessors' reconstruction choice and the ranks of the Procrustes Distances (Analysis) was being assessed, Spearman's Rank Order Correlation was most appropriate for this.

Figure 7.15 is a scatter plot showing the correlation between the ranks of the Procrustes Distances (Analysis) and the ranks of the assessors' reconstruction choice. The Correlation Coefficient was computed as **0.457** and as shown from figure 7.15 the relationship displays a positive correlation because as the ranks of the Procrustes Distances increases, so do the ranks of the volunteers' reconstruction choice.

However, at the 0.05 significance level, the tabulated value from the Critical values of Spearman's Rank-Order Correlation Coefficient table is **0.564** when the N = 10. Since the calculated/computed Spearman's correlation coefficient is *less* than the table value the correlation is a weak one, and *not* significant. Therefore, from the results of this case, one can conclude that there is not enough evidence to reject the null hypothesis at the 0.05 significance level.

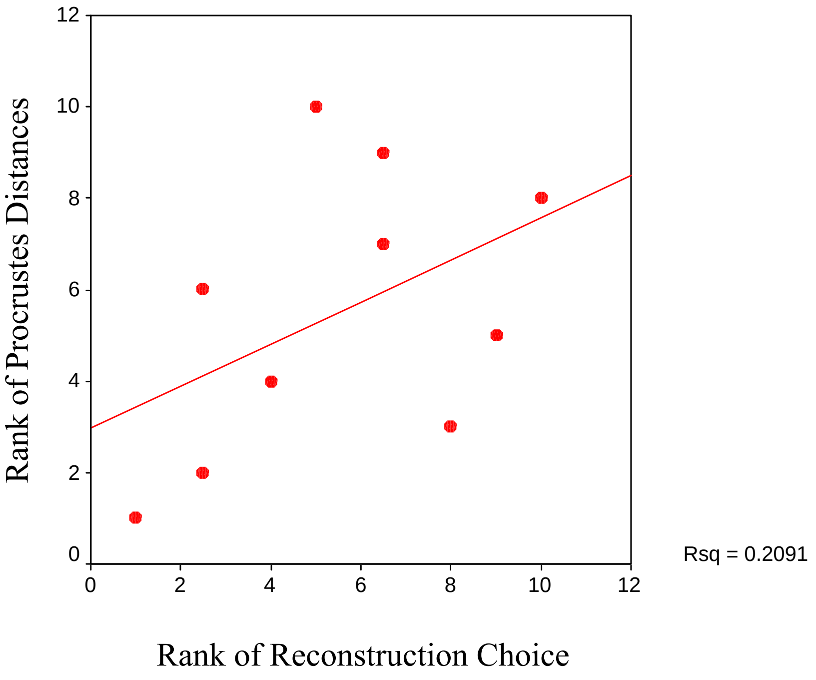


Figure 7.15 ***Scatter plot showing correlation between Procrustes Analysis and Assessors' Reconstruction Choice***

Discussion
(Comparisons between experiment 1 and experiment 2)

In experiment 1, and illustrated in table 7.1, the assessors' choice for closest reconstruction match to the ante-mortem photograph (fig 7.3) was reconstruction 9 selected by a total of 12 assessor's choices and ranked 1st.

The worst reconstructions match and not selected by any of the assessors was reconstruction 3, and therefore ranked 10th.

Reconstruction 5 and 8 scored a close equal second choice (2.5th) having produced a total of ten assessors' choices each.

There was good agreement with reconstruction 9 between the assessors' choice in experiment 1 (above), and the Procrustes Analysis in experiment 2, where reconstruction 9 ranked 1st in both experiments (table 7.3), having also produced the smallest Procrustes Distance (table 7.3) between the skull and its corresponding facial template 9 (0.1383),.

Similarly, there was good agreement with reconstruction 10, between the assessor's choices in experiment 1, and with the Procrustes Analysis in experiment 2, where reconstruction 10 ranked 4th in both experiments.

As reported above, reconstruction 3, which ranked 10th and last, with the assessors' choice in experiment 1, was in fairly good agreement with the Procrustes Analysis, where reconstruction 3 ranked 8th, having produced a distance of 0.1675 between the skull and facial template 3.

The largest Procrustes Distance was produced between the skull and facial template 4 (0.1735), therefore reconstruction 4 was ranked 10th.

Although as discussed above in the statistical analysis between experiments 1 and 2, the correlation was not *statistically* significant, however, there seems to be some good general agreement between the ranks of the assessors' reconstructions choice in experiment 1 and the ranks of the Procrustes Analysis in experiment 2 using skull 2.

Therefore, although not statistically significant, nevertheless, using Procrustes Analysis in this case study with skull 2 still seems to capture some perceptual similarity in human observers.

As discussed before, the purpose of the third experiment was to ascertain whether by adding E-Fit™ features to the facial reconstructions in the context of the present study, there was an effect on the identification process. E-fit features were added to the four selected facial reconstructions for evaluation by the assessors.

Experiment 3

The psychological assessment test on the E-Fit™ images using a resemblance technique

As discussed in Chapter V, E-Fit™ features were implemented on four reconstructions which produced the most extreme results from both the psychological assessment in experiment 1 and/or the mathematical evaluation in experiment 2 in each of the case studies for further comparisons.

From the results in the present case study, using skull 2, reconstructions 3, 5, 7 and 9 were chosen to implement the E-Fit™ features (table 7.3).

Reconstruction ***3*** was selected from the ten reconstructions to implement E-Fit features because it ranked 10th and last with the assessors' choices in experiment 1, and it also performed quite poorly, having ranked 8th, with the Procrustes Analysis in experiment 2.

Reconstruction ***5*** was selected because it ranked high in both experiments, having ranked equal second (2.5th) with reconstruction 8 with the assessors' choices in experiment 1, and ranked 2nd with the Procrustes Analysis in experiment 2.

Reconstruction ***7*** was chosen because it ranked low at 9th place out of the ten reconstructions with the Procrustes Analysis in experiment 2, and scored quite low in experiment 1, with the assessors' choice, having scored 6.5th rank.

Reconstruction ***9*** was selected because it scored 1st ranking in both experiments.

Consequently, in numerical order:

- Reconstruction 3 with E-Fit™ features was assigned as E-Fit 1 (figure 7.16)
- Reconstruction 5 with E-Fit™ features was assigned as E-Fit 2 (figure 7.17)
- Reconstruction 7 with E-Fit™ features was assigned as E-Fit 3 (figure 7.18)
- Reconstruction 9 with E-Fit™ features was assigned as E-Fit 4 (figure 7.19)

These four E-Fits were subsequently shown to the twenty new assessors in experiment 3 together with the ante-mortem photograph (figures 7.20) for evaluation in the manner described in Chapter V.

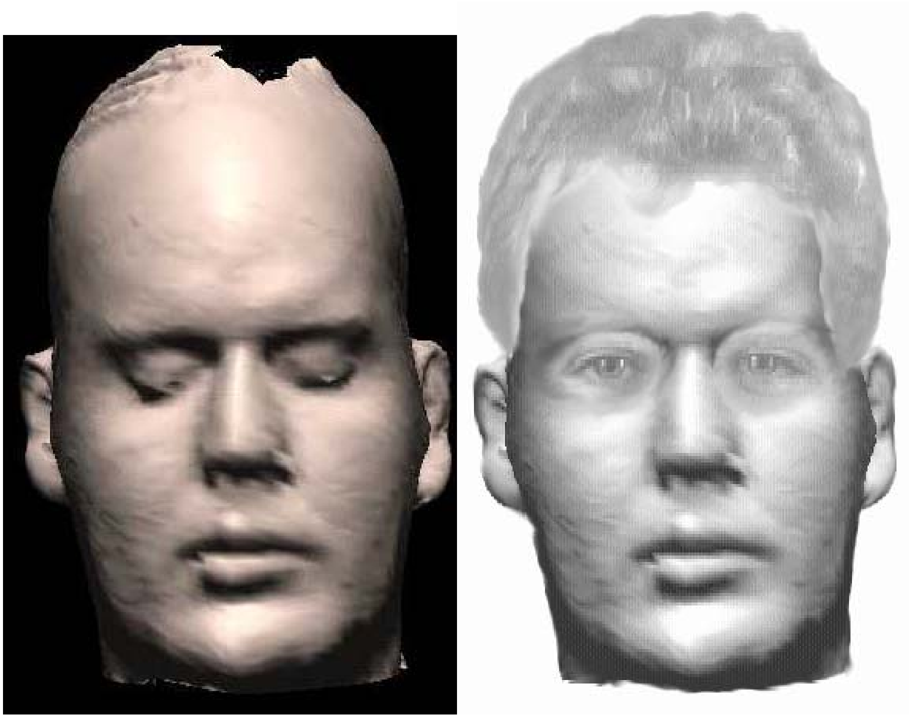


Figure 7.16 ***Reconstruction 3 with its E-Fit features –E-Fit 1***

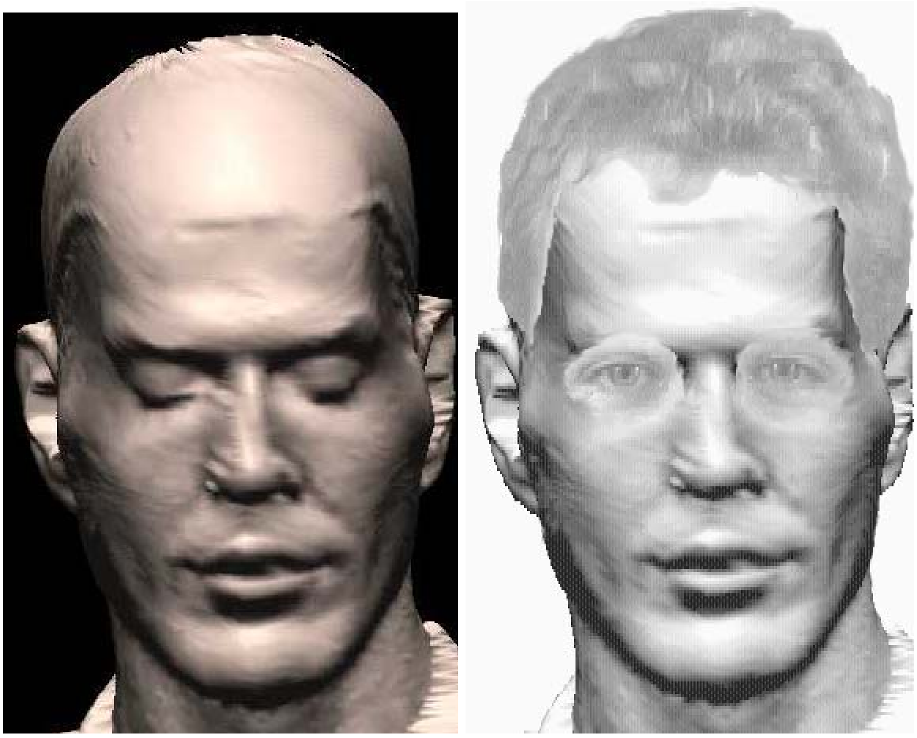


Figure 7.17 ***Reconstruction 5 with its E-Fit features –E-Fit 2***

Figure 7.18 ***Reconstruction 7 with its E-Fit features –E-Fit 3***

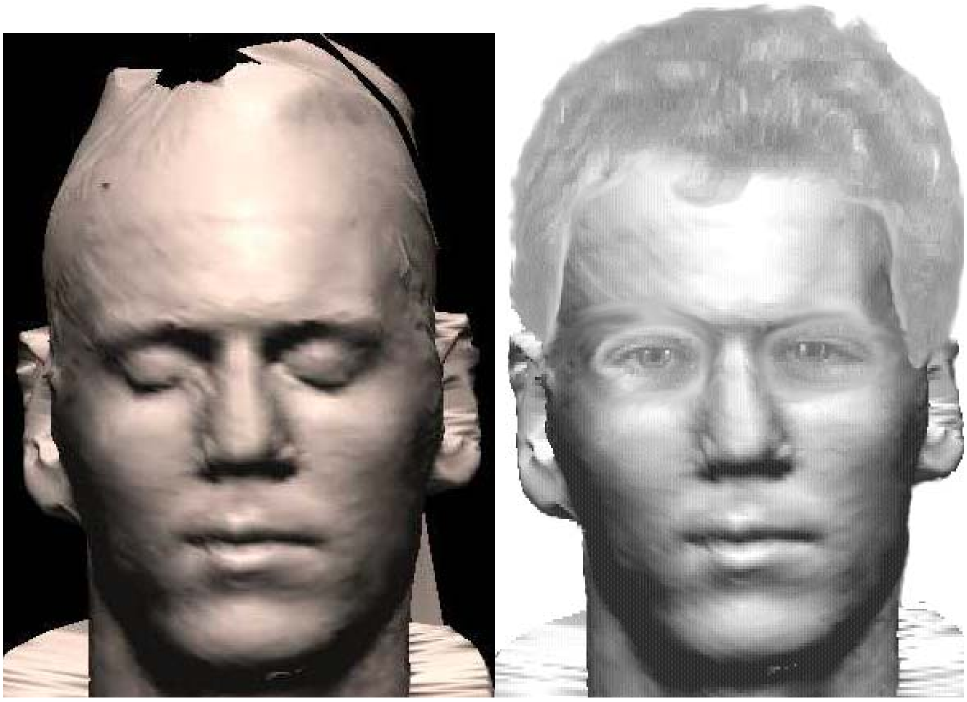


Figure 7.19 *Reconstruction 9 with its E-Fit features –E-Fit 4*

E-Fit 1

E-Fit 2

E-Fit 3

E-Fit 4

Figure 7.20 ***The four E-Fit images with the ante-mortem photograph***

Results

(Experiment 3)

Table 7.3 ***Assessors' Reconstruction Choice, Procrustes Distances and Assessors'E-Fit Choice (Comparisons between experiments 1, 2 and 3)***

	Experiment 1		***Experiment 2***		***Experiment 3***		
Recon-structions R	**Total/No of Assessors R Choice**	**Rank of R Choice**	**Procrustes Distances**	**Rank of Procrustes Distances**	**EFit**	**Assessors' EFit-Choice**	**Rank of E-Fit Choice**
1	3	8.0	0.1519	3.0	.	.	.
2	4	6.5	0.1667	7.0	.	.	.
3	0	10.0	0.1675	8.0	1	3	4.0
4	7	5.0	0.1735	10.0	.	.	.
5	10	2.5	0.1438	2.0	2	5	2.0
6	1	9.0	0.1565	5.0	.	.	.
7	4	6.5	0.1725	9.0	3	4	3.0
8	10	2.5	0.1592	6.0	.	.	.
9	12	1.0	0.1383	1.0	4	8	1.0
10	9	4.0	0.1553	4.0	.	.	.

Discussion

Like before, only descriptive statistics are provided for experiment 3, since the relatively small data set lends itself to clinical observation only.

The most preferred E-Fit which was selected by 8 from the 20 assessors as most closely resembling the ante-mortem photograph was E-Fit 4 and consequently ranked 1st (table 7.3).

The least preferred was E-Fit 1 which was selected by only 3 of the 20 assessors and ranked 4th.

E-Fit 2 ranked 2nd and was selected by 5 assessors; and E-Fit 3 was selected by 4 assessors and ranked 3rd .

As discussed above, E-Fit 4 which ranked 1st with the assessors' E-Fit choice in experiment 3, was produced using reconstruction 9 (table 7.3). Correspondingly, reconstruction 9 also ranked 1st in the two previous experiments with the assessors' reconstruction choice and with the Procrustes Analysis.

Similarly, E-Fit 1 which ranked 4th and last, in experiment 3 was produced using reconstruction 3. Reconstruction 3 also ranked low with experiments 1, the assessors' reconstruction choice, and with experiment 2, the Procrustes Analysis: in experiment 1, reconstruction 3 ranked 10th and last, and with the Procrustes Analysis this same reconstruction ranked 8th (table 7.3).

This same agreement between the three experiments is also observed with E-Fit 2, which ranked 2nd in experiment 3, the assessors' E-Fit choice. E-Fit 2 was produced by using reconstruction 5, which also ranked equal second (together with reconstruction 8) in experiment 1, with the assessors' reconstruction choice, and also ranked second in experiment 2, with the Procrustes Analysis.

Likewise, E-Fit 3 which ranked 3rd out of the four ranks was produced from reconstruction 7. This same reconstruction (7) in the previous two experiments also ranked fairly low as well; in experiment 1, reconstruction 7 ranked 6.5 with the assessors' reconstruction choice, and in experiment 2, reconstruction 7 ranked 9th using Procrustes Analysis.

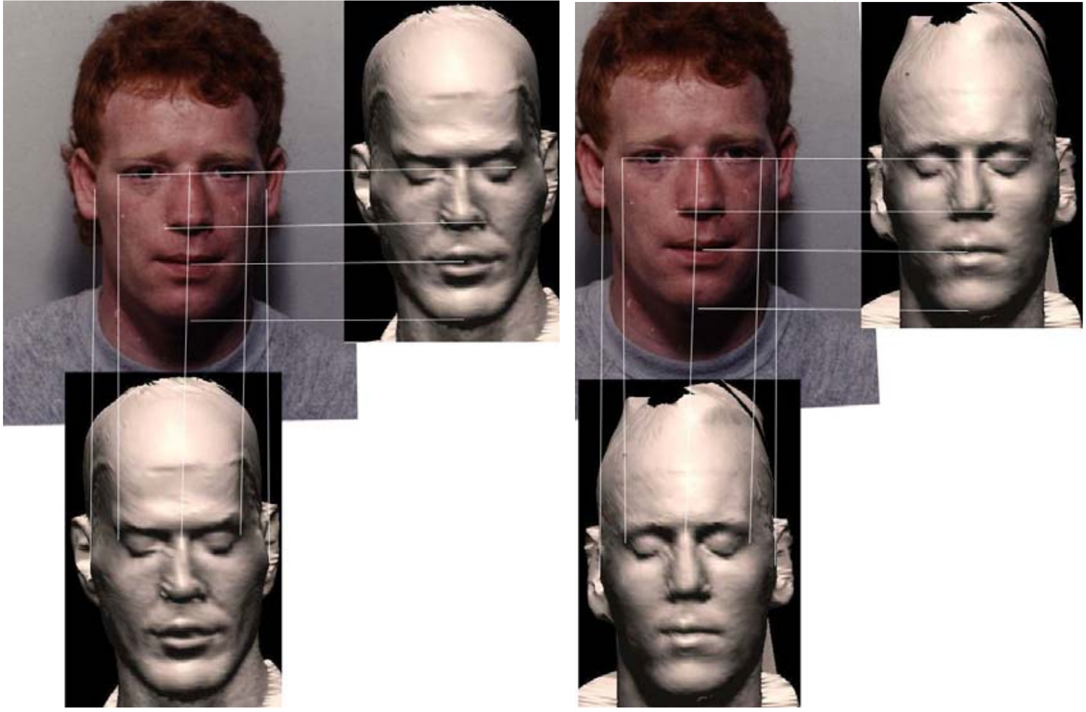
As discussed above, the results from the assessors' E-Fit choice in experiment 3 seem to be in good agreement with the results in experiment 1, the assessors' reconstruction choice.

Furthermore, as discussed in the statistical analysis section above, although the correlation between experiment 2 and 1 was shown not to be statistically significant, there nevertheless, seems to be some good general agreement between experiment 2, the Procrustes Analysis, with the two different sets of assessors' choices, experiments 1, and experiment 3

Therefore, we can conclude from this case study using skull 2, that using Procrustes Analysis, although not statistically significant, still seems to capture some perceptual similarity in human observers.

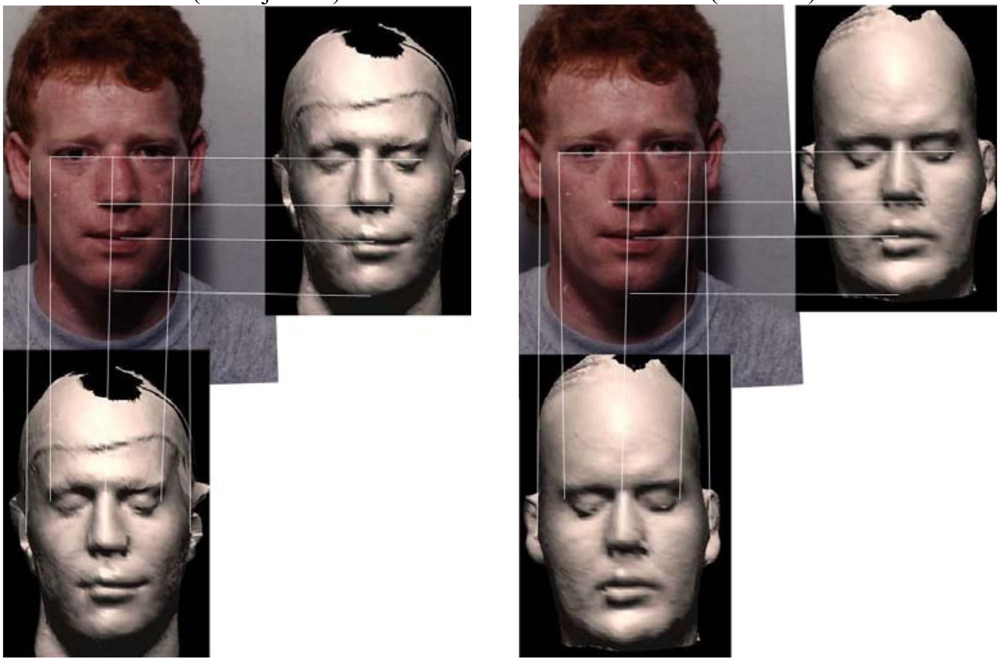
Experiment 4

Results (see Chapter VI)



Reconstruction 9 (Rank 1)

Reconstruction 5 (Rank joint 2)



Reconstruction 8 (Rank joint 2)

Reconstruction 3 (Rank 10)

Figure 7.21: Case 2. Inter landmark lines between subject and reconstruction

Chapter VIII

Case study 3

Skull 3

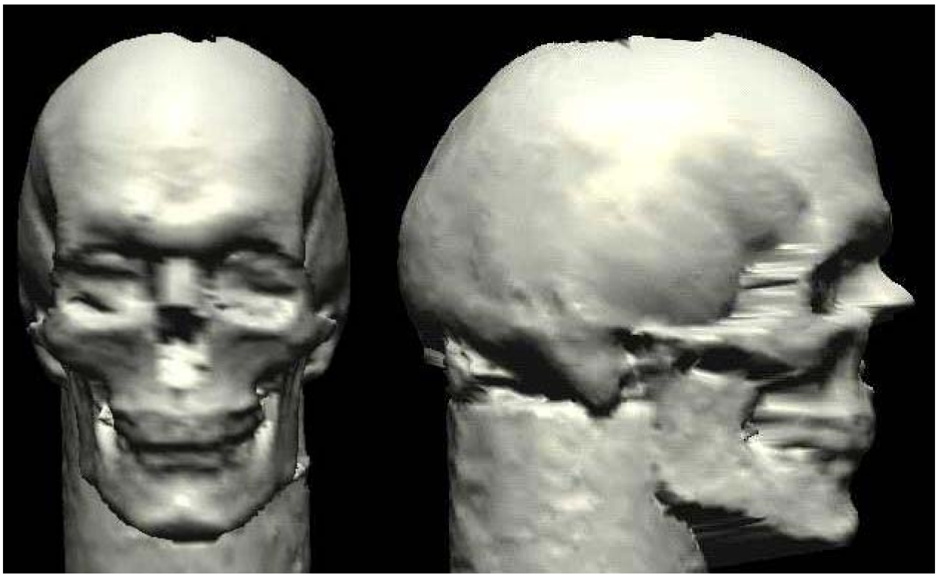


Figure 8.1 *Anterior and right lateral scan of the skull*

Skull 3 was of a young gracile Caucasian male (figure 8.1 and figures 8.2 a, b). Examination of the scene and remains indicated that death was probably caused by hanging. Some items of clothing, shoes and a belt were also found attached to the remains. The anthropological/osteological report placed him between 20-25 years and between 5’ 5’’ and 5’ 8’’ in height (approx 171cm). He had no restorative dental work although all 4 first premolars had been extracted ante mortem to prevent crowding of the remaining teeth. Removal of these teeth in the mandible resulted in a gap on both sides but due to their lateral position it was unlikely that they could have been seen on a photograph of the deceased when alive.

Furthermore, seven teeth had been lost post-mortem. There was little or no wear on the occlusal surfaces of the molars although all anterior teeth showed considerable wear on the biting surface with the dentine being exposed on the central incisors in particular. When the jaws were articulated, it was apparent that the normal bite was not edge to edge resulting in an “overbite” and he may have grounded his anterior teeth to obtain such wear. The skull showed prominent supra-orbital ridging, prominent glabella, well defined nuchal markings, rounded orbital margins, a prominent external occipital protuberance and moderately developed mastoid processes.

The mandible although relatively small, was robust and the mental region was square. All these characteristics suggested the individual was male. The patent nature of the sutures suggested an age of mid 20’s or below. The spheno-occipital synchondrosis was fused externally suggesting an age at death in excess of 18 years.

(a)

(b)

Figure 8.2 (a), (b) *photographs of skull 3 (a) anterior and (b) left oblique*

Case study 3 was a forensic case in which a police force requested a facial reconstruction on skull 3 (figures 8.1 and 8.2 a, b) to facilitate identification. The facial reconstruction was performed by the present author (figure 8.16- reconstruction 1 with E-Fit 1; and figure 8.21a,b) before the present dissertation commenced. The facial reconstruction appeared on Crimewatch UK for wider media coverage and was subsequently recognised by relatives; the identity was then confirmed using DNA.

Once the identification was confirmed and the case closed, permission was granted by the particular police force involved for skull 3 to be included in the present dissertation.

The original reconstruction with the original E-Fit features, as it appeared on Crimewatch UK (figures 8.16; 8.21b) was obviously performed without the aid of ante-mortem photographs to facilitate with the E-Fit features stage, as this was initially a forensic case and the identity of skull 3 at the time of performing the original reconstruction with E-Fit features was unknown.

Once the identity of the skull was confirmed, ante-mortem photographs then became available for the purpose of the dissertation.

However, it was decided not to use the now available ante-mortem photographs (figures 8.3; 8.22b) to aid with the preparation of the E-Fit stage in experiment 3, as was the situation in the two previous case studies, but to use the same pre-identification E-Fit features as they appeared on the original (forensic) reconstructed image on Crimewatch UK (figure 8.16; 8.21b) on the remaining three reconstructed images in experiment 3 for continuity. Consequently, identical E-Fit features were used in all the four images in the experiment to control as many variables as possible, as was the condition in all the case studies.

As stated above, E-Fit features were implemented on the original reconstruction (as it appeared on Crimewatch UK) in a total forensic manner (figure 8.16; 8.21b), where there were no ante-mortem photographs available for reference. The E-Fit hair feature was implemented with some confidence because hair samples were found at the scene, indicating hair colour, length and structure (see also chapter V, pp.75-78).

Unsurprisingly, when the four E-FIT images (figures 8.16-8.20) were compared with the ante-mortem photograph one can observe some differences in the hairstyle.

The “opened eyes” E-Fit feature was implemented in this case study, as with all the other four case studies, not with the aid of the ante-mortem photograph but by respecting the dimensions of the orbits of skull 3 and the morphology of the reconstructed eyes in experiment 1.

The colour of the “opened eyes” E-Fit feature implemented was kept as neutral as possible by using greyscale as explained in chapter V, pp 77.

Furthermore, as was the rationale in all the case studies, the ante-mortem photographs were not used for the preparation in experiments 1, i.e. selecting the facial templates and performing the reconstructions.

This case study acted to a certain extent, as a control, since reconstruction 1 was reconstructed together with their E-FIT features- E-Fit 1 (figure 8.16), following a true forensic scenario, where no ante-mortem photographs were available for reference until it was recognised with the aid of the reconstruction and then positively identified.

The general preparation and scanning of skull 3, as discussed under the sections *Skull Preparation before the scanning procedure* and *Scanning Procedure: digitising skulls and facial templates for the database* in Chapter V, took approximately two-three hours. It involved the usual assessment of skull morphology and craniometric characteristics for the preparation of facial reconstruction (see also sections *Skull morphology and craniometric characteristics* and *Skull assessment and preparation for facial reconstruction* in chapter III). Furthermore, it involved re-articulation of the mandible to the cranium to complete the skull for scanning and reconstruction purposes, as described in Chapter V.

The skull also required replicating some of the missing teeth (figure 8.2 a, b). As explained before in the other case studies, this was necessary to maintain the vertical dimensions of the skull, since the dentition should always be closely examined as this indicates how the mandible articulates with the maxilla and hence gives rise to the general appearance of the lower face. However, similar to case study 1, (chapter VI) maintaining the height of the skull was not an issue in this case study because there were just enough teeth present to retain the articulation height between the mandible and the maxilla. As mentioned before in the previous chapters, the loss of data which happens when the projected laser beam passes through open orifices, such as missing teeth, was also a concern, and hence replicating the teeth whilst maintaining the correct maxilla and mandible height was necessary; this was achieved as before, by using WHITE-TAC™.

As reported in the Methodology chapter V, ten facial templates were selected to reconstruct over each skull according to the anthropological criteria that is known about each skull. Therefore in Case study 3 the facial templates selected had to correspond with the anthropological criteria of skull 3: they were male Caucasian and in the age category of 18-30 years of age.

In that particular category there were 1224 faces in the combined database (table 5.2), of which, 141 of those facial templates were from the new database of 500 faces (table 5.1).

The first stage, as explained elsewhere, was to select the most typical and standard facial templates from the appropriate anthropological category as reported above, whilst, excluding all the templates with exaggerated and anomalous features. This also included faces that were *visually* consistent with the morphology of skull 3. For example, it was evident from skull 3 that the person in question had rather gracile facial features, with a mandible that, although relatively small, was robust and the mental region was square. At this stage the selection was narrowed down to 87 facial templates.

The final stage was to select the ten facial templates from the 87 faces by judging which ones were the most appropriate in terms of their image quality.

Excluding the timing and procedures for *Skull preparation* and digitising the templates in *Acquisition of the facial database,* each of the ten reconstructions in Case study 3 took on average two hours to complete; this has been covered in the section *Facial Reconstruction Procedure* discussed in chapter V.

Again, the exact position and angle of the frontal view of the ten reconstructions printed out (figures 8.4 - 8.13) was determined by the position of the available frontal ante-mortem photograph (figure 8.3), as explained in chapter V.

As explained before, the first experiment attempts to determine the psychological assessment of the facial reconstructions by using human observers to evaluate the similarity of the ten reconstructions when compared with the individual's ante-mortem photograph belonging to skull 3.

Experiment 1

The psychological assessment test on the facial reconstructions using a resemblance technique

The twenty assessors in experiment 1 were asked to choose from the selection of the ten reconstructions (figures 8.4 - 8.13), their three best reconstruction choices, which, in their opinion, resembled more accurately to the ante-mortem photograph (figure 8.3) of the target individual belonging to skull 3.

As explained in Chapter V, this produced a total of sixty reconstruction choices from the twenty subjects (20 x 3 choices).

Figure 8.3 *Ante-mortem photograph of the target individual (Case study 3)*

Figure 8.4 *Reconstruction 1*

Figure 8.5 *Reconstruction 2*

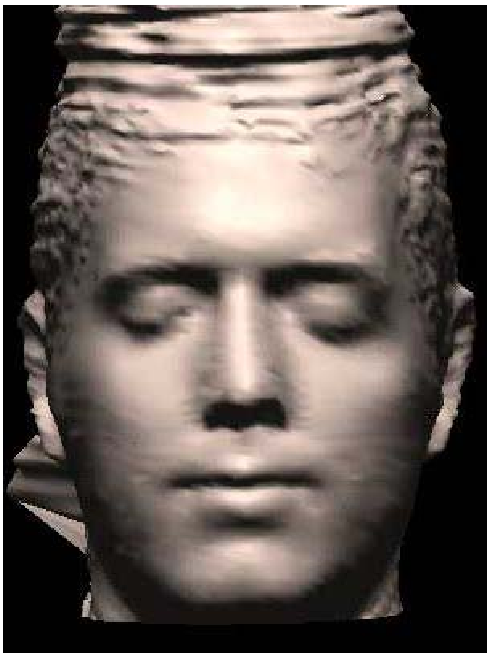


Figure 8.6 *Reconstruction 3*

Figure 8.7 *Reconstruction 4*

Figure 8.8 *Reconstruction 5*

Figure 8.9 *Reconstruction 6*

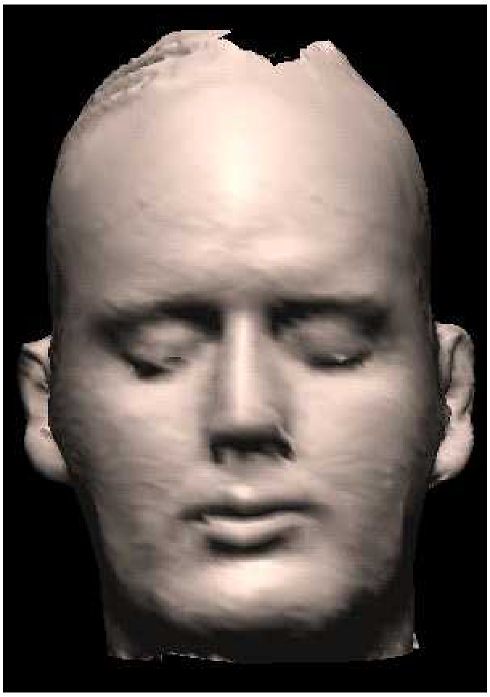


Figure 8.10 *Reconstruction 7*

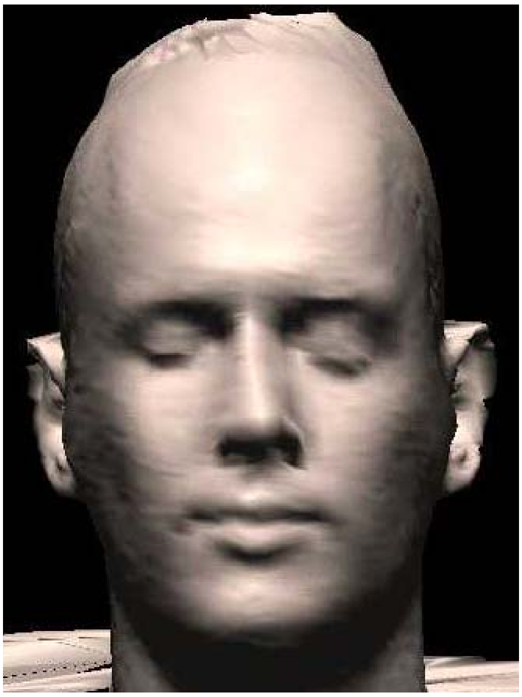


Figure 8.11 *Reconstruction 8*

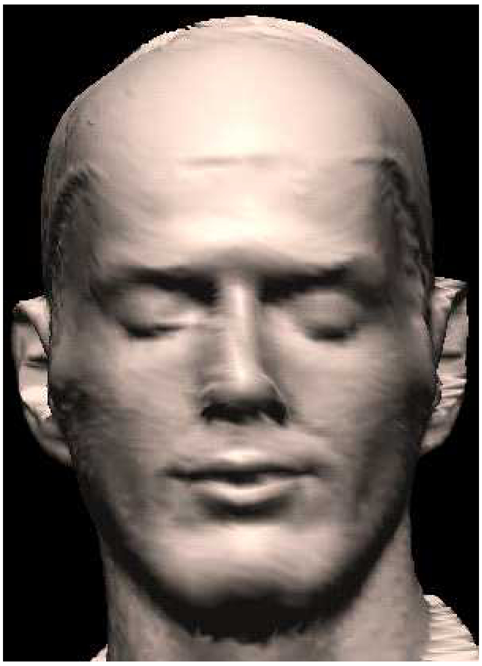


Figure 8.12 *Reconstruction 9*

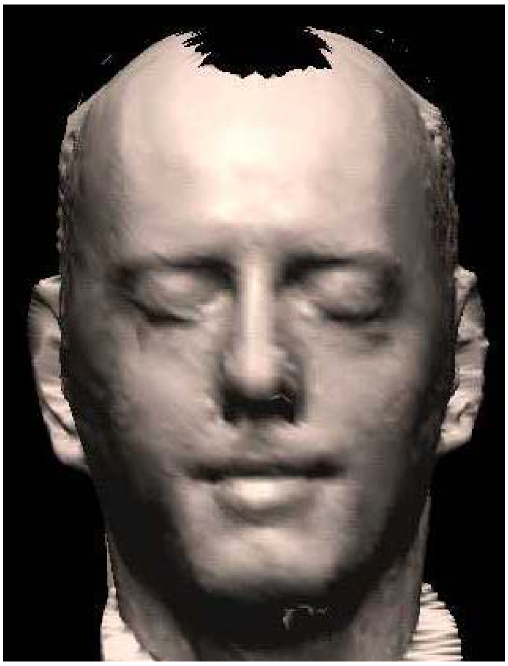


Figure 8.13 *Reconstruction 10*

Results

(*Experiment 1*)

The twenty assessors' best three reconstruction choices (1st, 2nd and 3rd) from a choice of ten reconstructions, figures 8.4.-8.13, **(R1, R2, R3……R10),** are shown in Table 8.1.

Table 8.1 ***Assessors' three reconstruction choice and ranking***

Reconstructions (R)	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**Total**
1st choice	0	6	2	1	0	2	0	6	1	2	**20**
2nd choice	0	2	0	4	1	1	1	7	2	2	**20**
3rd choice	0	3	4	3	0	6	0	1	1	2	**20**
Total number of times (1st, 2nd and 3rd) each reconstruction(R) was chosen by assessors	**0**	**11**	**6**	**8**	**1**	**9**	**1**	**14**	**4**	**6**	**60**
Rank of Total Reconstruction (R) Choice	**10.0**	**2.0**	**5.5**	**4.0**	**8.5**	**3.0**	**8.5**	**1.0**	**7.0**	**5.5**	___

Like before, these results show that some of the reconstructions are consistently preferred over others. Whatever the accuracy of the skull/surface combination, it would appear that some combinations are better than others.

In the second experiment, as before, the mathematical significance of the facial reconstructions is being assessed by using Procrustes Analysis in the manner already described in Chapter V.

Experiment 2

The mathematical assessment test on the facial images: using Procrustes (Shape) Analysis

Like before, each of the ten facial templates in case study 3 were separately compared and matched to skull 3, producing ten Full Procrustes Distances, in the manner explained in the methodology chapter.

The closer the Full Procrustes distance (the smaller the number) between face and skull configuration, the closer is the match (tables 8.2 and figure 8.14).

Results

(Experiment 2)

Table 8.2 ***Procrustes Distances and Ranking produced between skull 3 and each of the ten facial templates***

Facial Templates	Procrustes Distances with skull 3	Ranking of Procrustes Distances
1	0.1469	2.0
2	0.1699	10.0
3	0.1553	6.0
4	0.1470	3.0
5	0.1502	5.0
6	0.1596	9.0
7	0.1581	8.0
8	0.1564	7.0
9	0.1495	4.0
10	0.1386	1.0

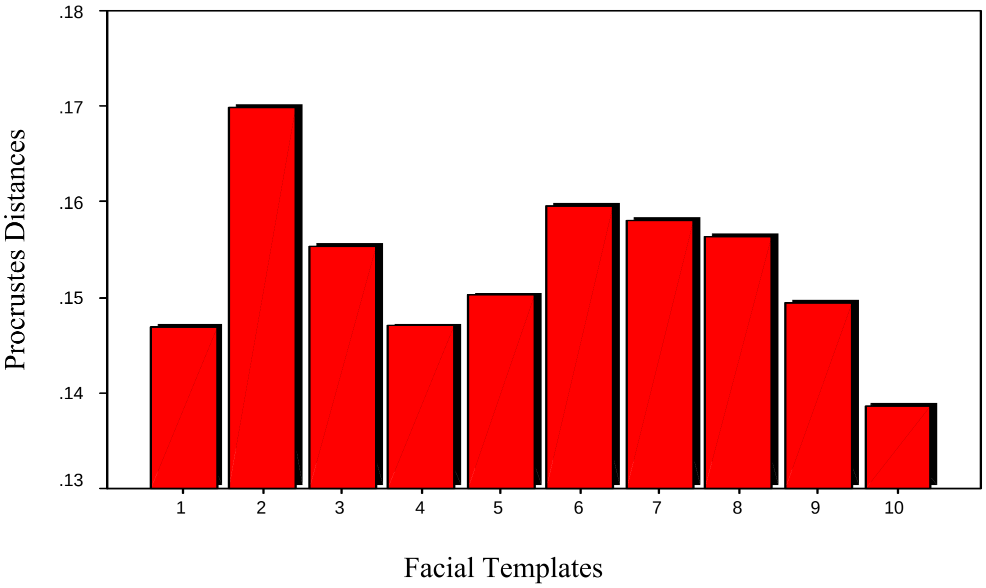


Figure 8.14 ***Procrustes Distances between skull 3 and each of the ten facial templates (closest match is smallest distance i.e. facial template no.10)***

Statistical Analysis between experiments 1 and 2

Statistical analysis was performed using the statistical pack SPSS™ 11.5.1 for Windows. This was to establish the association between experiment 1 and experiment

2. Since the correlation between the ranks of the assessors' reconstruction choice and the ranks of the Procrustes Distances (Analysis) was being assessed, Spearman's Rank Order Correlation was most appropriate for this.

Figure 8.15 is a scatter plot showing the correlation between the ranks of the Procrustes Distances (Analysis) and of the volunteers' reconstruction choice. It shows a negative correlation because the Correlation Coefficient was computed as **-0.482** and as shown from figure 8.15 the relationship displays an inverse relationship, in which, as the ranks of the Procrustes Distances increase, the ranks of the assessors' reconstruction choice decreases, and visa versa.

Furthermore, at the 0.05 significance level, the tabulated value from the Critical values of Spearman's Rank-Order Correlation Coefficient table is **0.564** when the N = 10. Since the calculated/computed Spearman's correlation coefficient is *less* than the table value the correlation is a weak one, and *not* significant. Therefore, from these results, one can conclude that there is not enough evidence to reject the null hypothesis at the 0.05 significance level.

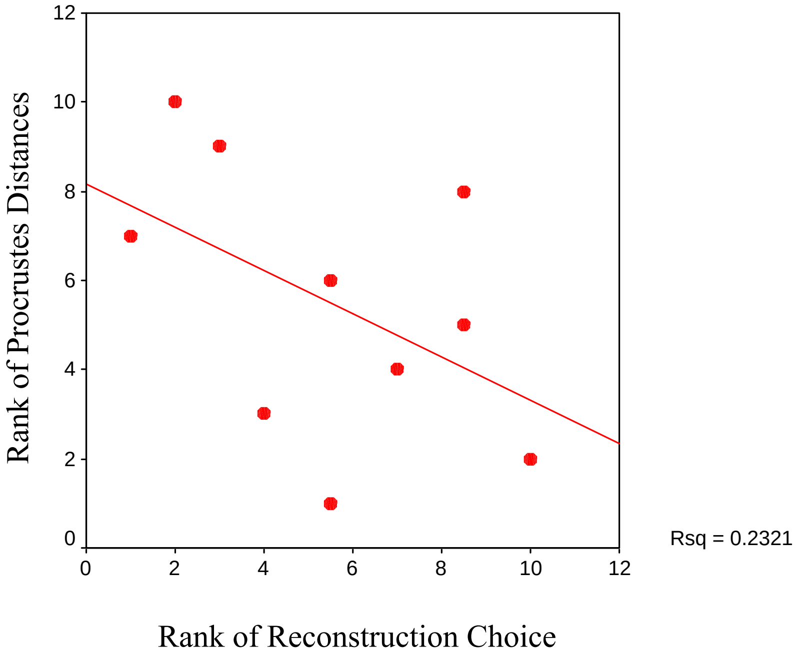


Figure 8.15 ***Scatter plot showing correlation between Procrustes Analysis and Assessors' Reconstruction Choice***

Discussion
(Comparisons between experiment 1 and experiment 2)

In experiment 1, as shown in table 8.1 the assessors' choice for closest reconstruction match to the ante-mortem photograph (figure 8.3) was reconstruction 8 selected by 14 assessors and ranked 1st.

Reconstruction 2, selected by 11 assessors' was a close second choice and therefore ranked second.

Third ranking was assigned to reconstruction 6 and selected by 9 assessors' as a good match to the ante-mortem photograph.

However, the least preferred reconstruction as a good match to the ante-mortem photograph, and not selected by any of the assessors was reconstruction 1, and therefore ranked 10th.

Similarly, reconstructions 5 and 7 only marginally ranked better than reconstruction 1 having being selected by one assessor each, and consequently ranked joint 8.5th place each.

In experiment 2, the closest reconstruction match according to the Procrustes Analysis shown in tables 8.2 and 8.3 and illustrated in figure 8.14, was reconstruction 10 having produced the smallest Procrustes Distance between the skull and its corresponding facial template10 (0.1386), and therefore reconstruction 10 was ranked 1st.

The largest Procrustes Distance was produced between the skull and facial template 2 (0.1699), therefore reconstruction 2 was ranked 10th. Conversely, in experiment 1, reconstruction 2 ranked 2nd with the assessors' reconstruction choice.

Similarly, reconstruction 1, which in experiment 1 above scored 10th and bottom rank with the assessors' reconstruction choice, scored very high and came second in the ranking in experiment 2 with the Procrustes Analysis.

Finally, although reconstruction 8 was the favourite with the assessors' reconstruction choice in experiment 1 and scored top rank, however, in experiment 2 it scored 7th with the Procrustes Analysis (table 8.3).

As discussed above in the statistical analysis between experiments 1 and 2, the results in case study/skull 3 produced a negative correlation between the ranks of the assessors' reconstruction choice and the ranks of the Procrustes Distances (Analysis). Since the correlation was weak and not significant, it would suggest that Procrustes analysis in this case study, using skull 3, did not seem to capture perceptual similarity in human observers, and was therefore a poor candidate for use in this setting.

However, this was not only a test situation, where assessors (in experiments 1 and 3) were evaluating the reconstructions compared to an unfamiliar individual (figure 8.3) - as in the two previous case studies- but initially, this was also a forensic case involving the present author, who performed the facial reconstruction in a true forensic scenario involving a familiar situation. Consequently the persons identifying the individual in question were relatives and friends who knew the individual well.

As stated previously, this case study was publicised on Crimewatch UK for wider media coverage, and was subsequently identified with the aid of reconstruction 1 (figure 8.4) plus E-Fit 1 (figures 8.16; 8.21b).

As demonstrated earlier, reconstruction 1 performed very poorly with the assessors' reconstruction choice, ranking 10th and last in experiment 1; however in experiment 2, this same reconstruction (1) produced from the corresponding facial template (1) performed much better, ranking 2nd with the Procrustes Analysis (table 8.3).

This would suggest that although Procrustes Analysis in this case study did not seem to capture perceptual similarity in observers where they were *unfamiliar* with the subject; however, although not statistically proven, Procrustes Analysis does seem to capture some perceptual similarity where the observer is *familiar* with the subject, since it was this same reconstruction 1 that aided with the identification of the individual in question (figure 8.3), and subsequently confirmed using DNA.

As discussed before, the purpose of the third experiment was to ascertain whether by adding E-Fit™ features to the facial reconstructions in the context of the present study, there was any improvement on the identification process. Consequently, E-fit features were added to the subset of four facial reconstructions for evaluation by the assessors.

Experiment 3

The psychological assessment test on the E-Fit™ images using a resemblance technique

As discussed in Chapter V, E-Fit™ features were implemented on four reconstructions which produced the most extreme results from both the psychological assessment in experiment 1 and/or the mathematical evaluation in experiment 2 in each of the case studies for further comparisons.

From the results in the present case study, using skull 3, reconstructions 1, 2, 8 and 10 were chosen to implement the E-Fit™ features (table 8.3).

Reconstruction ***1*** was selected because although it performed very badly with the assessors' choice and consequently ranked 10th and last, conversely, it performed much better with the Procrustes Analysis by producing the second smallest Procrustes distance between skull 3 and facial template 1, and consequently reconstruction 1 ranked second (table 8.3).

Also Reconstruction ***1*** was selected because it was the reconstruction (used with the E-Fit features, figure 8.16) to appear on Crimewatch UK, so it was used to a certain extent as a control between a familiar scenario (the relatives and friends that would potentially *recognise* the reconstruction) and an unfamiliar scenario (the assessors evaluating the images in experiments 1 and 3 by *matching* the reconstructions to the ante-mortem photograph).

Reconstruction ***2*** was selected because although it performed very well with the assessors' choice in experiment 1 and consequently ranking 2nd, on the other hand, it performed very poorly with the Procrustes Analysis in experiment 2 since it produced the largest Procrustes distance between the skull and facial template 2, and consequently reconstruction 2 ranked 10th and last.

Reconstruction ***8*** was selected because it ranked 1st with the assessors' reconstruction choice in experiment 1, conversely it ranked a poor 7th place with the Procrustes Analysis in experiment 2.

Reconstruction ***10*** was selected because it ranked 1st in experiment 2 with the Procrustes Analysis; however it only ranked 5.5th place with the assessors' reconstruction choice.

Consequently, in numerical order:

- Reconstruction 1 with E-Fit™ features was assigned as E-Fit 1 (figure 8.16)
- Reconstruction 2 with E-Fit™ features was assigned as E-Fit 2 (figure 8.17)
- Reconstruction 8 with E-Fit™ features was assigned as E-Fit 3 (figure 8.18)
- Reconstruction 10 with E-Fit™ features was assigned as E-Fit 4 (figure 8.19)

These four reconstruction E-Fit images were subsequently shown to the twenty new assessors in experiment 3 together with the ante-mortem photograph (figures 8.20) for evaluation in the manner described in Chapter V.

Figure 8.16 ***Reconstruction 1 with its E-Fit features –E-Fit 1***

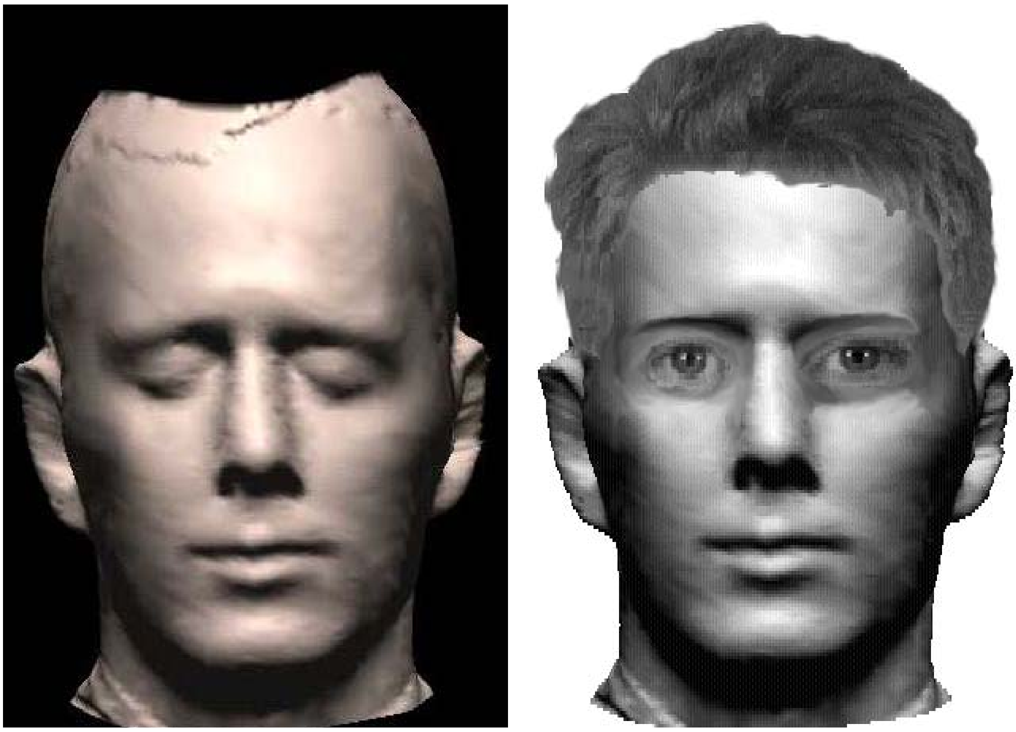


Figure 8.17 *Reconstruction 2 with its E-Fit features –E-Fit 2*

Figure 8.18 *Reconstruction 8 with its E-Fit features –E-Fit 3*

Figure 8.19 ***Reconstruction 10 with its E-Fit features –E-Fit***

E-Fit 1 *E-Fit 2*

E-Fit 3 *E-Fit 4*

Figure 8.20 ***The four E-Fit images with the ante-mortem photograph***

Results
(Experiment 3)

Table 8.3 ***Assessors' Reconstruction Choice, Procrustes Distances and Assessors'E-Fit Choice (Comparisons between experiments 1, 2 and 3)***

Experiment 1			*Experiment 2*		*Experiment 3*		
Recon-structions R	**Total/No Of Assessors R Choice**	**Rank Of R Choice**	**Procrustes Distances**	**Rank of Procrustes Distances**	**E-Fit**	**Assessors' EFit-Choice**	**Rank Of E-Fit Choice**
1	0	10.0	.1469	2.0	1	2	3.0
2	11	2.0	.1699	10.0	2	13	1.0
3	6	5.5	.1553	6.0	.	.	.
4	8	4.0	.1470	3.0	.	.	.
5	1	8.5	.1502	5.0	.	.	.
6	9	3.0	.1596	9.0	.	.	.
7	1	8.5	.1581	8.0	.	.	.
8	14	1.0	.1564	7.0	3	4	2.0
9	4	7.0	.1495	4.0	.	.	.
10	6	5.5	.1386	1.0	4	1	4.0

Discussion

In experiment 3 above, as explained before, only descriptive statistics are provided, since the relatively small data set lends itself to clinical observation only.

The most preferred E-Fit which was selected by 13 from the 20 assessors as most closely resembling the ante-mortem photograph was E-FIT 2, and consequently ranked 1st (table 8.3).

The least preferred E-Fit as a good match to the ante-mortem photograph and selected by one assessor was E-Fit 4 and ranked 4th.

E-Fit 3 was selected by four assessors and ranked 2nd and E-Fit 1 selected by 2 assessors ranked 3rd.

As stated previously, case study 3 /skull 3 produced a negative correlation between the assessors' evaluation using the resemblance technique in experiment 1 and the mathematical assessment using Procrustes Analysis in experiment 2. However, there appears to be fairly good agreement with the two sets of assessors between the two psychological resemblance tests in experiment 1 (images without E-Fit™ features) and experiment 3 (same corresponding images with E-Fit™ features).

For example, E-Fit 2 which ranked 1st with the assessors' E-Fit choice in experiment 3, was produced using reconstruction 2 (table 8.3), and this was fairly comparable with the assessors' choice in experiment 1, where reconstruction 2 was selected by 11 assessors and ranked 2nd.

However, reconstruction 2 ranked 10th and last in experiment 2 - the Procrustes Analysis assessment having produced the largest distance of 0.1699 between the skull and its corresponding facial template 2.

In experiment 3, E-Fit 4 which ranked 4th and last was produced from reconstruction 10, and again this was in fairly good agreement with the assessors' reconstruction choice in experiment 1, where reconstruction 10 scored 5.5th place (table 8.3).

However, reconstruction 10 was ranked 1st in the Procrustes Analysis evaluation in experiment 2.

From this case study using skull 3, the results indicate that although there is a negative correlation between experiments 1 and 2 and between experiments 3 and 2. There is however, fairly good agreement between the two psychological resemblance tests using the two different sets of assessors in experiments 1 and 3.

As demonstrated earlier, reconstruction 1 performed very poorly with the assessors' reconstruction choice, ranking 10th and last in experiment 1, and similarly in experiment 3, E-Fit 1 which was produced from reconstruction 1 also rated fairly low at rank 3 out of a possible four ranks.

However, in experiment 2 this same reconstruction (1) produced from the corresponding facial template (1) performed much better, ranking 2nd with the Procrustes Analysis (table 8.3).

This would suggest that Procrustes Analysis in this case study did not seem to capture perceptual similarity where the observers were *unfamiliar* with the subject (experiments 1 and 3). However, it would suggest that, although not statistically proven, Procrustes Analysis does seem to capture *some* perceptual similarity in a situation where the observer is *familiar* with the subject, since it was this same reconstruction 1 that aided with the identification of the individual in question (figure 8.3), and subsequently confirmed using DNA. (See Validation, Reliability and Success in Chapter XI and Psychology of Facial Recognition in Chapter IV) Images are shown below as they appeared on Crime Watch UK (fig.8.21 a, b), and subsequent ante-mortem photographs after positive identification for comparisons (fig.8.22 a, b).

(a) **(b)**

Figure 8.21 ***Reconstruction 1 with E-FIT (1) features as it appeared on Crime watch U.K. (before identification)***

(a) **(b)**

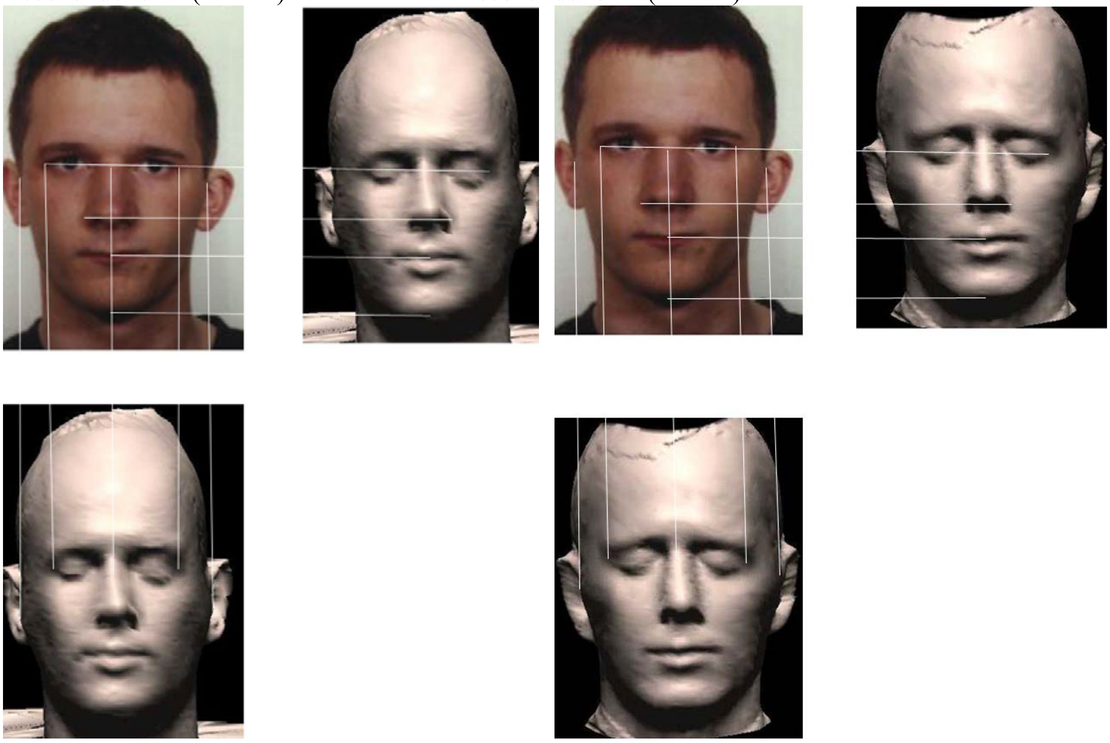
Figure 8.22 ***Ante-mortem photographs of victim after positive identification***

***N.B. For continuity with all the other case studies, only images 8.21 (b) and 8.22 (b) were used for the purpose of the dissertation*.**

Experiment 4

Results (see Chapter VI)

Reconstruction 8 (Rank 1) Reconstruction 2 (Rank 2)



Reconstruction 6 (Rank 3) Reconstruction 1 (Rank 10)

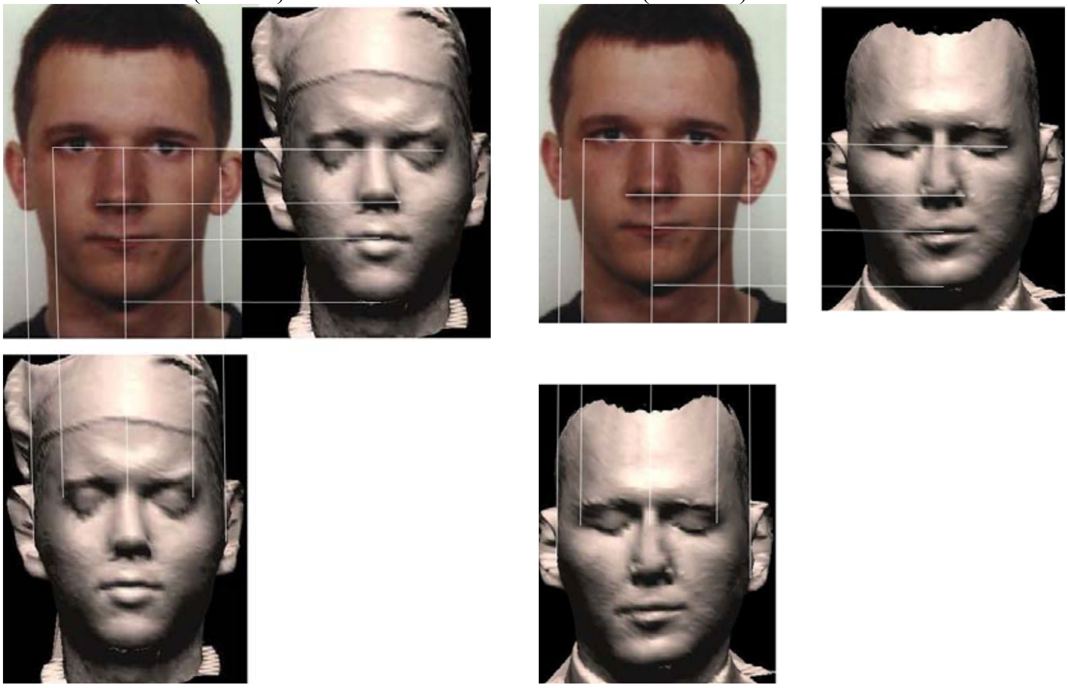


Figure 8.23 *Case 3. Inter landmark lines between subject and reconstructions*

Chapter IX

Case study 4

Skull 4

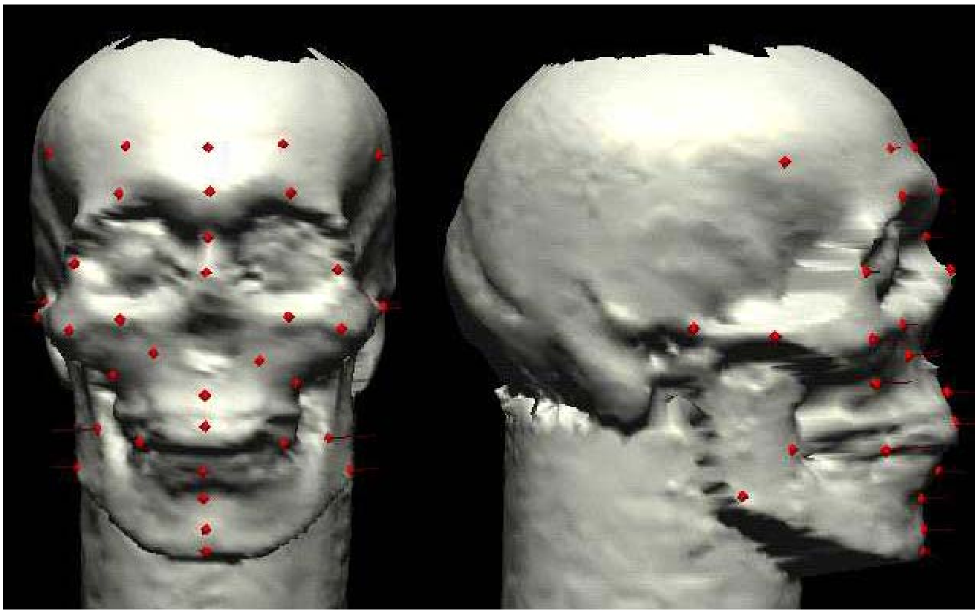
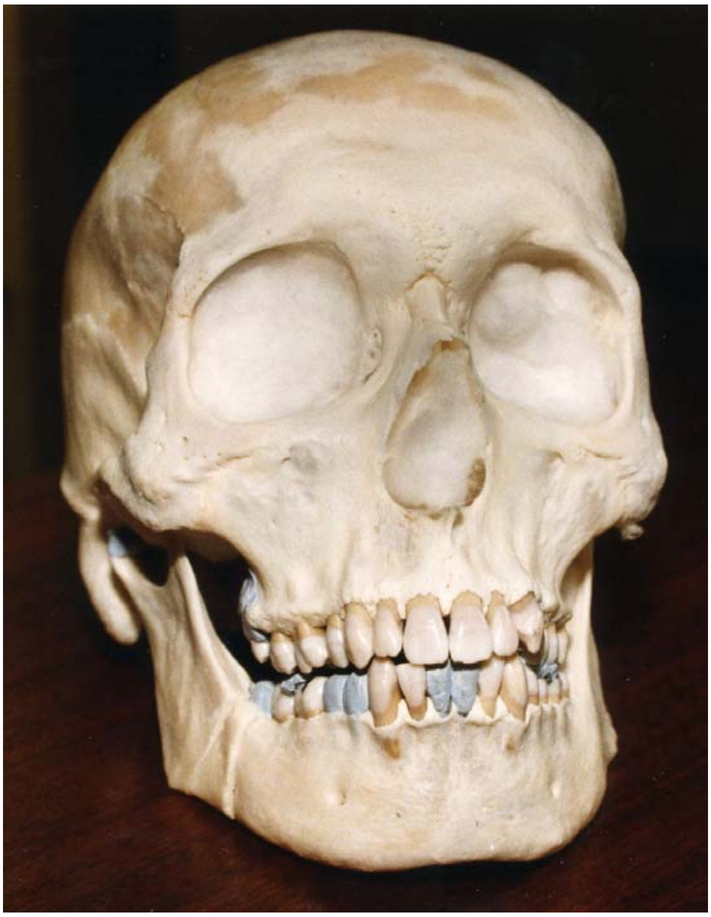


Figure 9.1 *Anterior and right lateral scan of the skull*

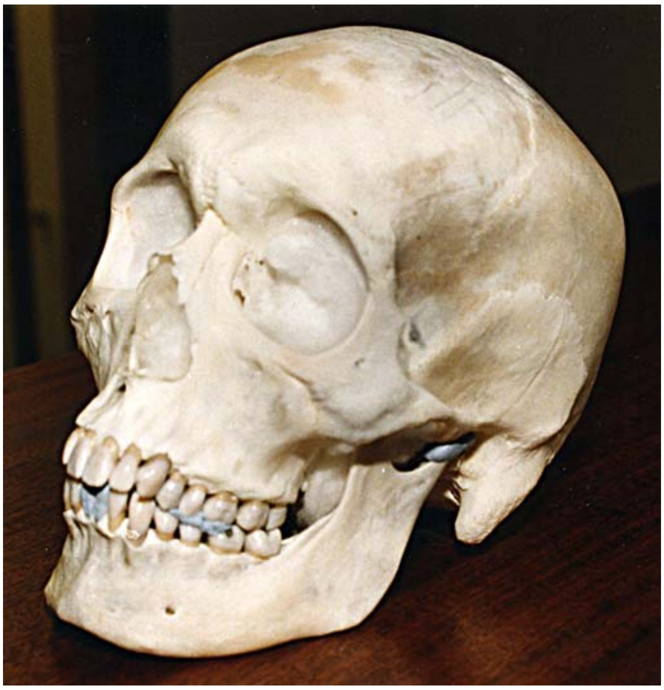
The skull was of a young male Caucasian (figure 9.1 and figures 9.2 a,b). The well nourished adult body was in an advanced state of decomposition and almost completely skeletonised. There was residual, partly detached tissue on the scalp, bearing evenly trimmed light to mid-brown hair, average length 5cm. The deceased had also some very distinctive tattoos on his arms.

Furthermore some items of clothing and a watch of the deceased were recovered, and a substantial amount of money was discovered in his pocket. The upper jaw contained a full set of teeth, some with dental restoration. The lower jaw had some teeth missing that appeared to be post-mortem; the right 2nd, 4th, 5th and left 2nd and 4th were missing however, the 3rd molars were present.

Osteological analysis aged the body between twenty four and thirty two years of age and the femur gave an estimated height of 173.51cm ±3.27 cm and the fibula 174.156 ± 3.29 cm (5’7” and 5’8”). No osteological abnormalities were observed. The cause of death due to an overdose of Temazepam.



(a)



(b)

Figure 9.2 (a), (b) *photographs of skull 4 (a) anterior and (b) left oblique*

Case study 4, like case study 3, was initially a forensic case in which the present author was involved before the start of the dissertation.

The forensic investigation of case study 4 was hampered by insufficient evidence as to the identity of the deceased. However, it was felt that since the money found on the deceased consisted of Bank of England notes then the likelihood was that the deceased was either from England or from abroad and changed money at a Bureau de Change. Furthermore, given the media coverage the case received, it was felt that the tattoos should have been instantly recognisable. However, there was no guarantee that the tattoos were made in Britain, and they could have easily been created from abroad. Given all these queries, it was felt that this case needed wider national media coverage rather than just a local Scottish one. Since the man remained unidentified for some time, it was felt appropriate by the Dumbarton police to request a facial reconstruction in an attempt to discover his identity. The facial reconstruction appeared on Crimewatch UK for wider media coverage and was subsequently recognised by relatives; the identity was then confirmed using dental records.

Once the identification was confirmed and the case closed, permission was granted by the particular police force involved for skull 4 to be included in the present dissertation.

The CD-FIT™ image (figure 9.21a, b) was produced by the present author prior to the start of the dissertation. As reported above, the CD-FIT™ image was publicised on Crimewatch UK for the purpose of identification, and was subsequently successfully identified.

CD-FIT™ was used in this forensic case because this was an earlier but similar electronic identikit system to E-FIT. However, the same facial template that was used to produce the reconstruction in the forensic CD-FIT™ image was also used to produce reconstruction 1 (figure 9.4) and subsequently E-FIT 1 in case study 4 (figure 9. 16).

The hair feature was implemented with some confidence on the CD-FIT™ image because, as mentioned above, samples of hair were found at the scene indicating colour, structure and length. The CD-FIT™ "opened eyes" feature was implemented by respecting the dimensions of the orbits of skull 4 and the morphology of the reconstructed eyes in the original reconstructed image.

The colour of the CD-FIT "opened eyes" feature implemented was kept as neutral as possible by using greyscale as explained in chapter V.

As mentioned above, the identity of the skull was confirmed and consequently ante-mortem photographs were available for the purpose of the dissertation.

However, similar to the previous case study 3, it was decided not to use the now available ante-mortem photographs (figures 9.3; 9.22) to aid with the preparation of the E-Fit stage in experiment 3- as was the practice in case studies 1 and 2 and 5- but to try and simulate the pre-identification features as they appeared on the original (forensic) CD-FIT™ image on Crimewatch UK (9.21a) on all the four reconstructed images for continuity. Consequently, identical E-Fit features were used in all the four images (figures 9.16 - 9.20) in experiment 3 to control as many variables as possible, as was the condition in all the case studies. Similar to the previous case study, 3, this case study, acted to a certain extent, as a control with regards to E-Fit features.

However, it became apparent after positive identification that the victim wore spectacles, a fact that was not apparent at the time of death from the scene of investigation, and consequently this was reflected in the CD-FIT™ image (figure 9.21a, b). This was rectified for experiment 3 and identical spectacles were implemented for all four E-FIT images (figures 9.16 - 9.20) in the case study to match the victim's ante-mortem photograph (figures 9.3; 9.22). Although, as discussed in Chapter XI, replicating correct features such as hairstyle and type (as was the situation in cases 1, 2 and 5), or, as in this particular case study, adding the appropriate spectacles as a feature on the reconstruction, undoubtedly, improves perceptual similarity, nevertheless, when one controls this variable in all the corresponding reconstructions per skull, such as in this study then this is valid under these circumstances (Helmer et al 1993).

Furthermore, as was the rationale in all the case studies, the ante-mortem photographs were not used for the preparation in experiments 1, i.e. when selecting the facial templates to perform the reconstructions. (The ante-mortem photographs were not required in experiment 2).

The general preparation and scanning of skull 4, as discussed under the sections *Skull Preparation before the scanning procedure* and *Scanning Procedure: digitizing skulls and facial templates for the database* in Chapter V, took approximately two-three hours. It involved the usual assessment of skull morphology and craniometric characteristics for the preparation of facial reconstruction (see also sections *Skull morphology and craniometric characteristics* and *Skull assessment and preparation for facial reconstruction* in chapter III). Furthermore, it involved re-articulation of the mandible to the cranium to complete the skull for scanning and reconstruction purposes, as described in Chapter V.

The skull also required replicating some of the missing teeth (figure 9.2 a, b). As explained before in the other case studies, this was necessary to maintain the vertical dimensions of the skull, since the dentition should always be closely examined as this indicates how the mandible articulates with the maxilla and hence gives rise to the general appearance of the lower face. However, similar to case studies 1 and 3 maintaining the height of the skull was not an issue in this case study because there were just enough teeth present to retain the articulation height between the mandible and the maxilla. However, as mentioned before in the previous chapters, the loss of data which happens when the projected laser beam passes through open orifices, such as missing teeth, was also a concern, and hence replicating the teeth whilst maintaining the correct maxilla and mandible height was necessary; in this case study this was achieved by using BLUE-TAC™. (BLUE-TAC™ is the same material and serves same purpose as WHITE-TAC™).

As reported in the Methodology chapter V, ten facial templates were selected to reconstruct over each skull according to the anthropological criteria that is known about each skull. Therefore in Case study 4 the facial templates selected had to correspond with the anthropological criteria of skull 4: Caucasian males of average build in the age category of 18-30 years of age.

In that particular category there were 1224 faces in the combined database (table 5.2), of which, 141 of those facial templates were from the new database of 500 faces (table 5.1).

The first stage was to select the most typical and standard facial templates and exclude the ones with the most exaggerated and anomalous features from the appropriate anthropological category as described above. This included faces that were visually consistent with the morphology of skull 4. For example, it was evident from skull 4 that the person in question had fairly robust facial features, with a strong square mandible. At this stage the selection was narrowed down to 121 facial templates.

The final stage was to choose the ten facial templates from the 121 faces by judging which ones were the most appropriate in terms of their image quality.

Excluding the timing and procedures for *Skull preparation* and digitising the templates in *Acquisition of the facial database,* each of the ten reconstructions in Case study 4 took on average two hours to complete; this has been covered in the section *Facial Reconstruction Procedure* discussed in chapter V.

Again, the exact position and angle of the frontal view of the ten reconstructions printed out (figures 9.4 - 9.13) was determined by the position of the available frontal ante-mortem photograph (figure 9.3), as explained in chapter V.

As stated in the previous case studies chapters, the first experiment attempts to determine the psychological assessment of the facial reconstructions by using human observers to evaluate the similarity of the ten reconstructions when compared with the individual's ante-mortem photograph belonging to skull 4.

Experiment 1

The psychological assessment test on the facial reconstructions using a resemblance technique

The twenty assessors in experiment 1 were asked to choose from the selection of the ten reconstructions (figures 9.4 - 9.13), their three best reconstruction choices, which, in their opinion, resembled more accurately to the ante-mortem photograph (figure 9.3) of the target individual belonging to skull 4.

As explained in the methodology Chapter V, this produced a total of sixty reconstruction choices from the twenty subjects (20 x 3 choices).

Figure 9.3 *Ante-mortem photograph of the target individual (Case study 4)*

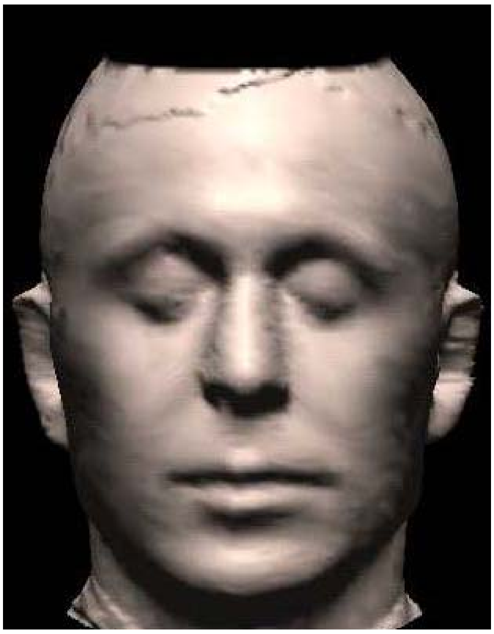


Figure 9.4 *Reconstruction 1*

Figure 9.5 *Reconstruction 2*

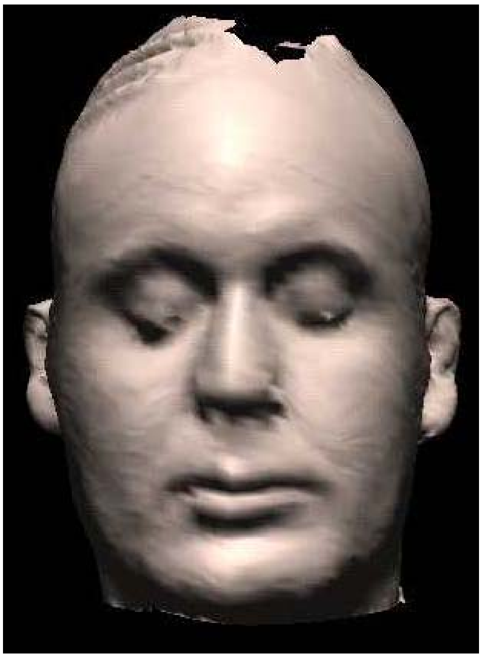


Figure 9.6 *Reconstruction 3*

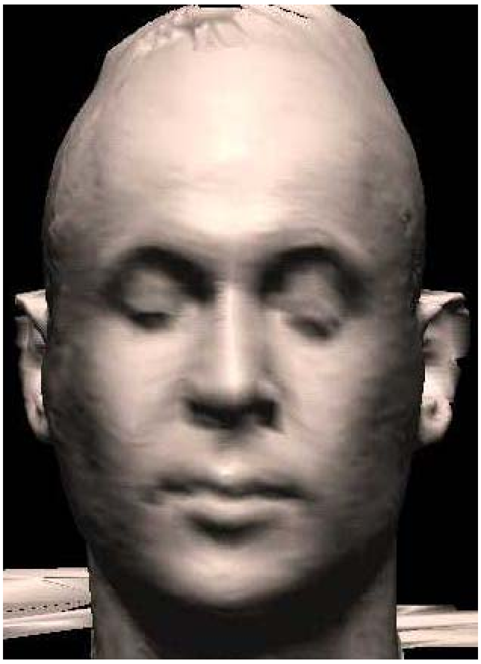


Figure 9.7 *Reconstruction 4*

Figure 9.8 *Reconstruction 5*

Figure 9.9 *Reconstruction 6*

Figure 9.10 *Reconstruction 7*

Figure 9.11 *Reconstruction 8*

Figure 9.12 *Reconstruction 9*

Figure 9.13 *Reconstruction 10*

Results

(*Experiment 1*)

The twenty assessors' best three reconstruction choices (1st, 2nd and 3rd) from a choice of ten reconstructions, figures 9.4.-9.13, **(R1, R2, R3……R10),** are shown in Table 9.1.

Table 9.1 ***Assessors' three reconstruction choices and ranking***

Reconstructions (R)	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**Total**
1st choice	1	3	2	3	1	4	0	3	0	3	**20**
2nd choice	3	2	6	1	5	2	0	0	0	1	**20**
3rd choice	4	3	2	1	2	4	2	1	1	0	**20**
Total number of times (1st, 2nd and 3rd) each reconstruction(R) was chosen by assessors	**8**	**8**	**10**	**5**	**8**	**10**	**2**	**4**	**1**	**4**	**60**
Rank of Total Reconstruction (R) choice	**4.0**	**4.0**	**1.5**	**6.0**	**4.0**	**1.5**	**9.0**	**7.5**	**10.0**	**7.5**	___

Similar to before, these results show that some of the skull/surface combinations are consistently preferred over others. Whatever the accuracy of these reconstructions it seems clear that some reconstructions are better than others.

In the second experiment, I will use Procrustes Analysis to assess the mathematical significance of the facial reconstructions. It does this by evaluating how close the *match* is between skull 4 and each of the ten corresponding facial templates used to produce the facial reconstructions in the manner already described in Chapter V.

Experiment 2

The mathematical assessment test on the facial images: using Procrustes (Shape) Analysis

Each of the ten templates in case study 4 were separately compared and matched to skull 4. This was achieved by matching all the x, y, and z co-ordinates for each of the 36 landmarks per facial template (A1.2 in appendix 1) to the corresponding 36 landmarks on skull 1 (A1.1 in appendix 1). This means that each of the ten face co-ordinates was separately matched to skull 4's co-ordinates every time. This produced the Full Procrustes Distance between the face and the skull configuration for each of the ten facial templates. There were ten facial templates to be compared separately to skull 4, producing ten Full Procrustes Distances i.e. ten numbers, ranging from the closest to furthest. The closer the Full Procrustes distance (the smaller the number) between face and skull configuration, the closer is the match (tables 9.2 and figure 9.14).

Table 9.2 ***Procrustes Distances and Ranking produced between skull 4 and each of the ten facial templates***

Facial Templates	Procrustes Distances with skull 4	Ranking of Procrustes Distances
1	0.1532	7.0
2	0.1453	5.0
3	0.1616	9.0
4	0.1718	10.0
5	0.1567	8.0
6	0.1340	2.0
7	0.1391	3.0
8	0.1426	4.0
9	0.1326	1.0
10	0.1465	6.0

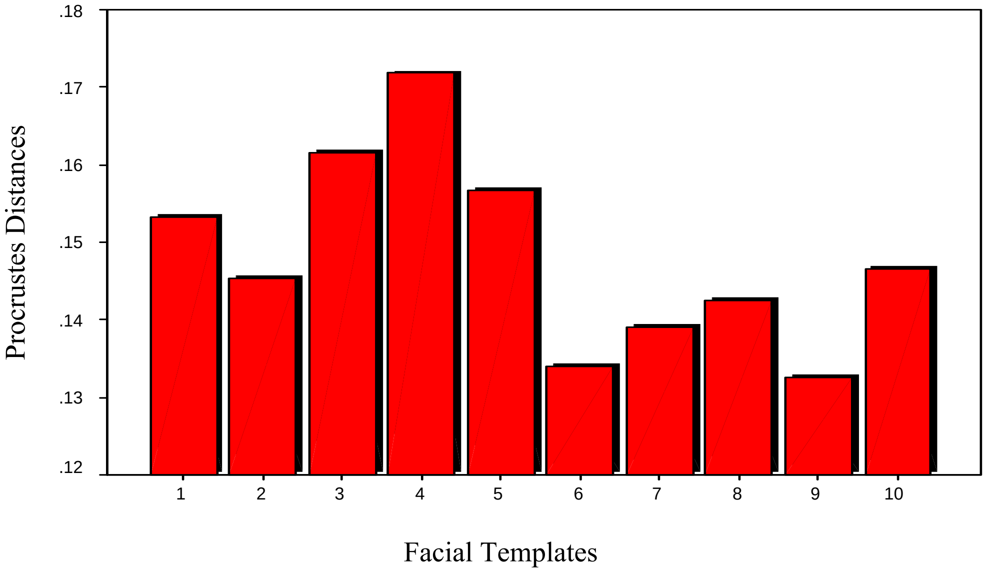


Figure 9.14 ***Procrustes Distances between skull 4 and each of the ten facial templates (closest match is smallest distance i.e. facial template no.9)***

Statistical Analysis between experiments 1 and 2

Statistical analysis was performed using the statistical pack SPSS™ 11.5.1 for Windows. This was to establish the association between experiment 1 and experiment

2. Since the correlation between the ranks of the assessors' reconstruction choice and the ranks of the Procrustes Distances (Analysis) was being assessed, Spearman's Rank Order Correlation was most appropriate for this.

Figure 9.15 is a scatter plot showing the correlation between the ranks of the Procrustes Distances (Analysis) and of the volunteers' reconstruction choice. It shows a negative correlation because the Correlation Coefficient was computed as **-0.420** and as shown from figure 13 the relationship displays an inverse relationship, in which, as the ranks of the Procrustes Distances increase, the ranks of the volunteers' reconstruction choice decreases, and visa versa.

Furthermore, at the 0.05 significance level, the tabulated value from the Critical values of Spearman's Rank-Order Correlation Coefficient table is **0.564** when the N= 10. Since the calculated/computed Spearman's correlation coefficient is *less* than the table value the correlation is a weak one, and *not* significant. Therefore, from these results, one can conclude that there is not enough evidence to reject the null hypothesis at the 0.05 significance level.

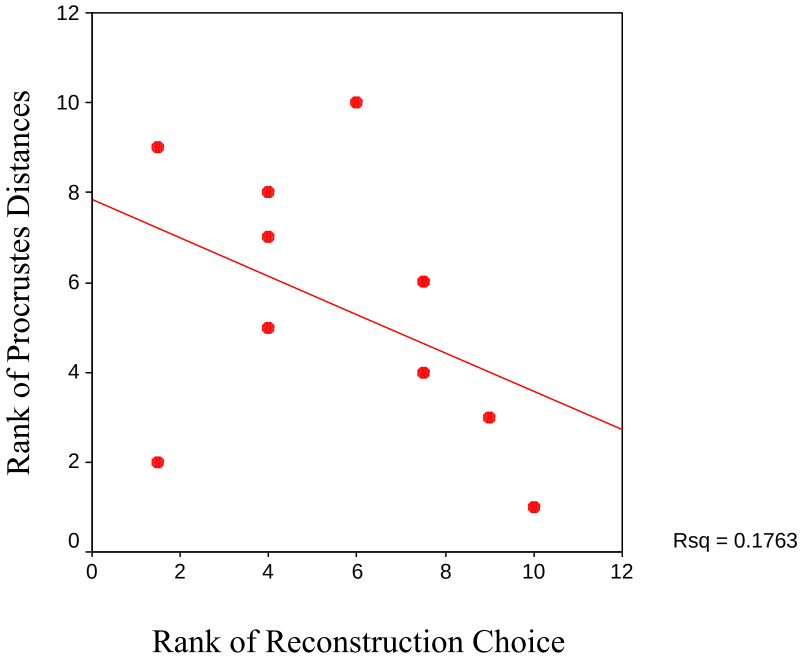


Figure 9.15 ***Scatter plot showing correlation between Procrustes Analysis and Assessors' Reconstruction Choice***

Discussion
(Comparisons between experiment 1 and experiment 2)

In experiment 1, as shown in table 9.1 the assessors' choice for closest reconstruction match to the ante-mortem photograph (figure 9.3) was reconstruction 3 and 6 selected by 10 assessors each and ranked equal 1.5. Next ranking was Reconstruction 1, 2 and 5, where they were all selected by 10 assessors each, and consequently they ranked equally at 4th place.

As mentioned above reconstruction 6, which ranked equal 1.5 places with reconstruction 3 in experiment 1, also ranked very high, scoring 2nd position in experiment 2, using Procrustes Analysis (table 9.3).

The least preferred reconstruction as a good match to the ante-mortem photograph and selected 1 assessor was reconstruction 9, and therefore ranked 10th.

However, in experiment 2, reconstruction 9 was the closest match to the skull according to the Procrustes Analysis shown in tables 9.2 and 9.3 and illustrated in figure 9.14, having produced the smallest Procrustes Distance (0.1326) between the skull and its corresponding facial template 9.

The largest Procrustes Distance was produced between the skull and facial template 4 (0.1718), therefore reconstruction 4 was ranked 10th.

As discussed above in the statistical analysis between experiments 1 and 2, the results in case study/skull 4 produced a negative correlation between the ranks of the assessors' reconstruction choice and the ranks of the Procrustes Distances (Analysis). Since the correlation was weak and not significant, it would suggest that Procrustes analysis in this case study, using skull 4, did not seem to capture perceptual similarity in human observers, and was therefore a poor candidate for use in this setting.

As discussed before, the purpose of the third experiment was to ascertain whether by adding E-Fit™ features to the facial reconstructions in the context of the present study, there was an effect on the identification process. E-fit features were therefore added to the four selected facial reconstructions for evaluation by the assessors.

Experiment 3

The psychological assessment test on the E-Fit™ images using a resemblance technique

As discussed in Chapter V, E-Fit™ features were implemented on four reconstructions which produced the most extreme results from both the psychological assessment in experiment 1 and/or the mathematical evaluation in experiment 2 in each of the case studies for further comparisons.

From the results in the present case study, using skull 4, reconstructions 1, 3, 6 and 9 were chosen to implement the E-Fit™ features (table 9.3).

Reconstruction ***1*** was selected because it was the reconstructed image obtained by using the same facial template that was also used to obtain the forensic CD-FIT™ image (figure 9.21 a, b) which appeared on Crimewatch UK. Consequently, it was used to a certain extent as a control between a familiar scenario (the relatives and friends that would potentially *recognise* the CD-FIT™) and an unfamiliar scenario, where the assessors were evaluating the images in experiments 1 and 3 by *matching* the reconstructions and E-FIT images respectively, to the ante-mortem photograph, where reconstruction 1 and correspondingly E-FIT 1 were present).

Reconstruction ***3*** was selected because it ranked equal 1st with reconstruction 6 in experiment 1, the assessors reconstruction choice; however, inversely it ranked 9th in experiment 2, the Procrustes Analysis evaluation.

Reconstruction ***6*** was selected because, as stated above, it scored equal top ranking with reconstruction 3 in experiment 1, and it also scored high with the Procrustes Analysis in experiment 2, ranking 2nd.

Reconstruction ***9*** was selected because although it scored top ranking in experiment 2 with the Procrustes Analysis, inversely, it scored bottom ranking in experiment 1 with the assessors' reconstruction choice.

Consequently, in numerical order:

- Reconstruction 1 with E-Fit™ features was assigned as E-Fit 1 (figure 9.16)
- Reconstruction 3 with E-Fit™ features was assigned as E-Fit 2 (figure 9.17)
- Reconstruction 6 with E-Fit™ features was assigned as E-Fit 3 (figure 9.18)
- Reconstruction 9 with E-Fit™ features was assigned as E-Fit 4 (figure 9.19)

These four E-Fits were subsequently shown to the twenty new assessors in experiment 3 together with the ante-mortem photograph (figures 9.20) for evaluation in the manner described in the methodology Chapter V.

Figure 9.16 ***Reconstruction 1 with its E-Fit features –E-Fit 1***

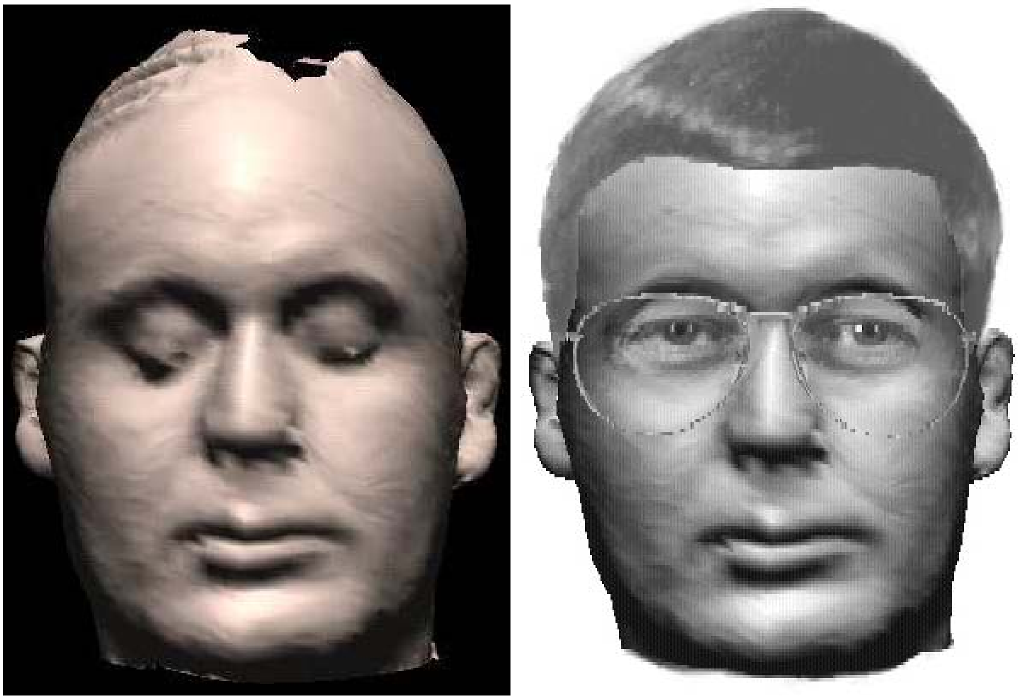


Figure 9.17 ***Reconstruction 3 with its E-Fit features –E-Fit 2***

Figure 9.18 ***Reconstruction 6 with its E-Fit features –E-Fit 3***

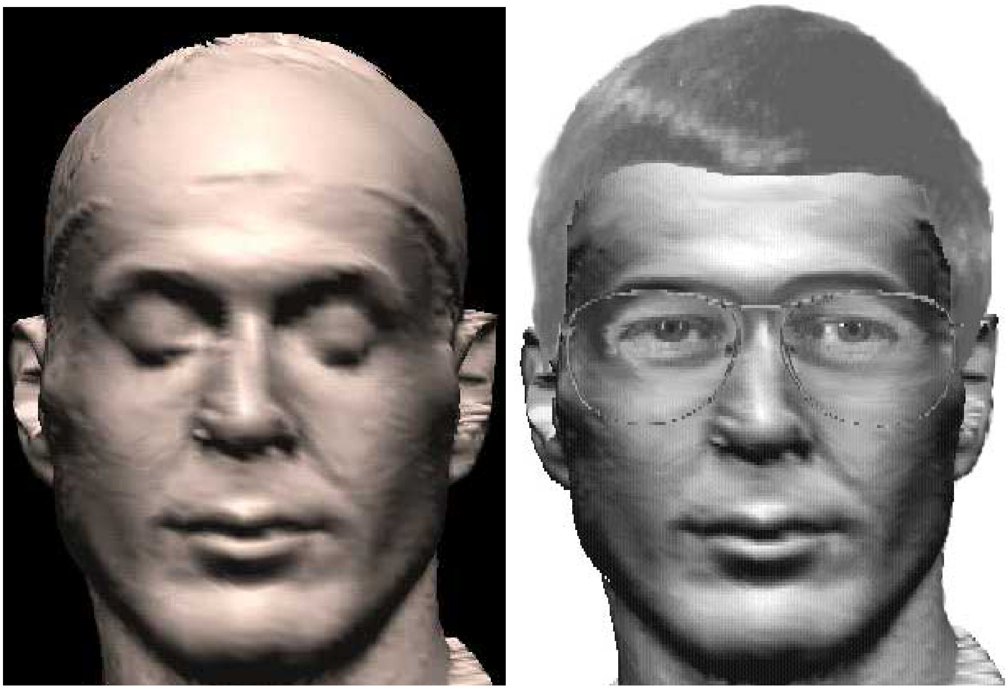


Figure 9.19 ***Reconstruction 9 with its E-Fit features –E-Fit 4***

E-Fit 1

E-Fit 2

E-Fit 3

E-Fit 4

Figure 9.20 ***The four E-Fit images with the ante-mortem photograph***

Results

(Experiment 3)

Table 9.3 ***Assessors' Reconstruction Choice, Procrustes Distances and Assessors'E-Fit Choice (Comparisons between experiments 1, 2 and 3)***

Experiment 1			*Experiment 2*		*Experiment 3*		
Recon-structions R	**Total/No Of Assessors R Choice**	**Rank Of R Choice**	**Procrustes Distances**	**Rank of Procrustes Distances**	**E-Fit**	**Assessors' EFit-Choice**	**Rank Of E-Fit Choice**
1	8	4.0	0.1532	7.0	1	11	1.0
2	8	4.0	0.1453	5.0	.	.	.
3	10	1.5	0.1616	9.0	2	4	2.5
4	5	6.0	0.1718	10.0	.	.	.
5	8	4.0	0.1567	8.0	.	.	.
6	10	1.5	0.1340	2.0	3	1	4.0
7	2	9.0	0.1391	3.0	.	.	.
8	4	7.5	0.1426	4.0	.	.	.
9	1	10.0	0.1326	1.0	4	4	2.5
10	4	7.5	0.1465	6.0	.	.	.

Discussion

In experiment 3, as explained in previous chapters, only descriptive statistics are provided, since the relatively small data set lends itself to clinical observation only.

In this experiment, the assessors' E-Fit assessment (table 9.3) the most preferred E-Fit, selected by 11 assessors as most closely resembling the ante-mortem photograph, was E-Fit 1, ranked 1st. The least preferred E-Fit, ranked 4th and last and only selected by 1 assessor was E-Fit 3. E-Fit 2 and E-Fit 4 were selected by 4 assessors each and ranked equal 2.5.

E-Fit 1 was produced from reconstruction 1; reconstruction 1 ranked 4th together with reconstructions 2 and 5 by the previous assessors, in experiment 1. Reconstruction 1, ranked 7th in the Procrustes Analysis evaluation.

As mentioned above, E-Fit 3 which scored 4th and last ranking in experiment 3 was produced from reconstruction 6; however, reconstruction 6 produced very good results in experiment 1 where the assessors' choice ranked it equal 1.5th together with reconstruction 3. Similarly reconstruction 6 scored high in experiment 2 and it was assigned 2nd ranking with the Procrustes Analysis testing.

As stated above in the section *Statistical Analysis between experiments 1 and 2,* case study 4 /skull 4 produced a negative correlation between the assessors' evaluation using the resemblance technique in experiment 1 and the mathematical assessment using Procrustes Analysis in experiment 2. This would suggest Procrustes Analysis in this case study did not seem to capture perceptual similarity in human observers.

Furthermore, there was not an obvious agreement between the two sets of assessors in experiments 1 and 3, using the resemblance technique (table 9.3).

Interestingly though, E-FIT 1 - which was produced from reconstruction 1 by using the same facial template as the one used to produce the forensic CD-FIT™ reconstructed image previously, unanimously scored the highest rank in experiment 3, with the assessors' E-Fit choice; however in experiment 1 the same image without the E-Fit features (reconstruction 1) only scored reasonably well with the assessors' reconstruction choice (equal 4th rank together with reconstructions 2 and 5).

Although, not statistically proven, this would suggest that applying E-FIT features on the image may improve the perceptual similarity in human observers.

Images are shown below as they appeared on Crime Watch UK (fig.9.21 a, b), and subsequent ante-mortem photographs after positive identification for comparisons (fig.9.22).

(a) **(b)**

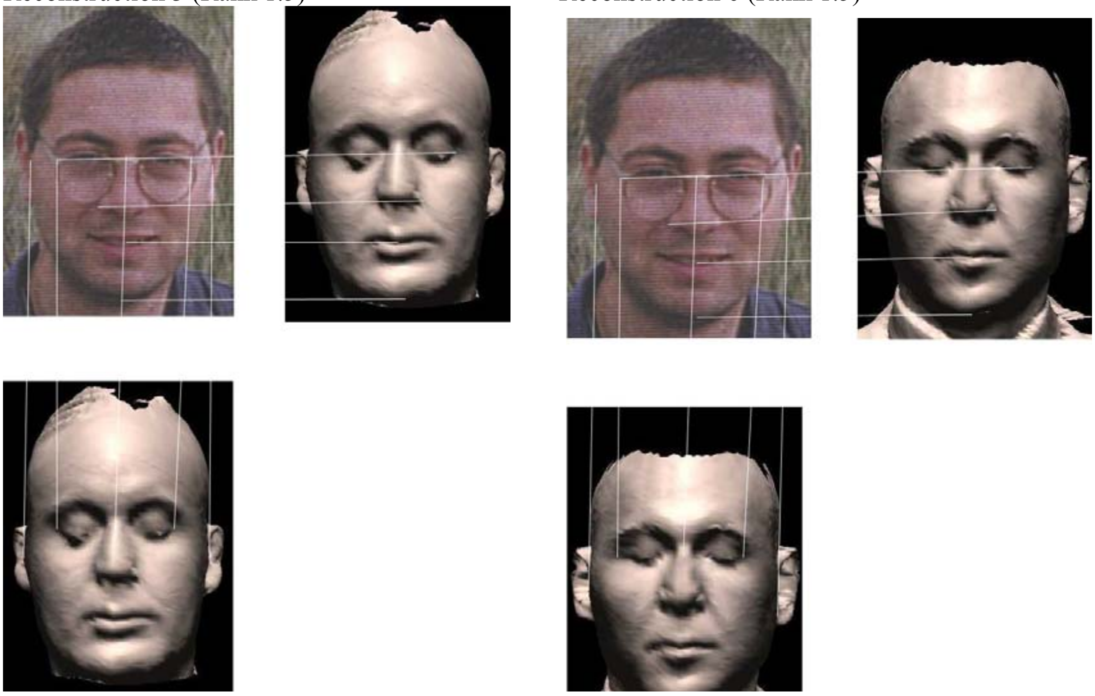
Figure 9.21 *Reconstruction with CD-FIT™ features as it appeared on Crime Watch U.K. (before identification)*

Figure 9.22 *Ante-mortem photograph of victim after positive identification*

N.B. For continuity with all the other case studies, only images 9.21 (a) and 9.22 were used for the purpose of the dissertation.

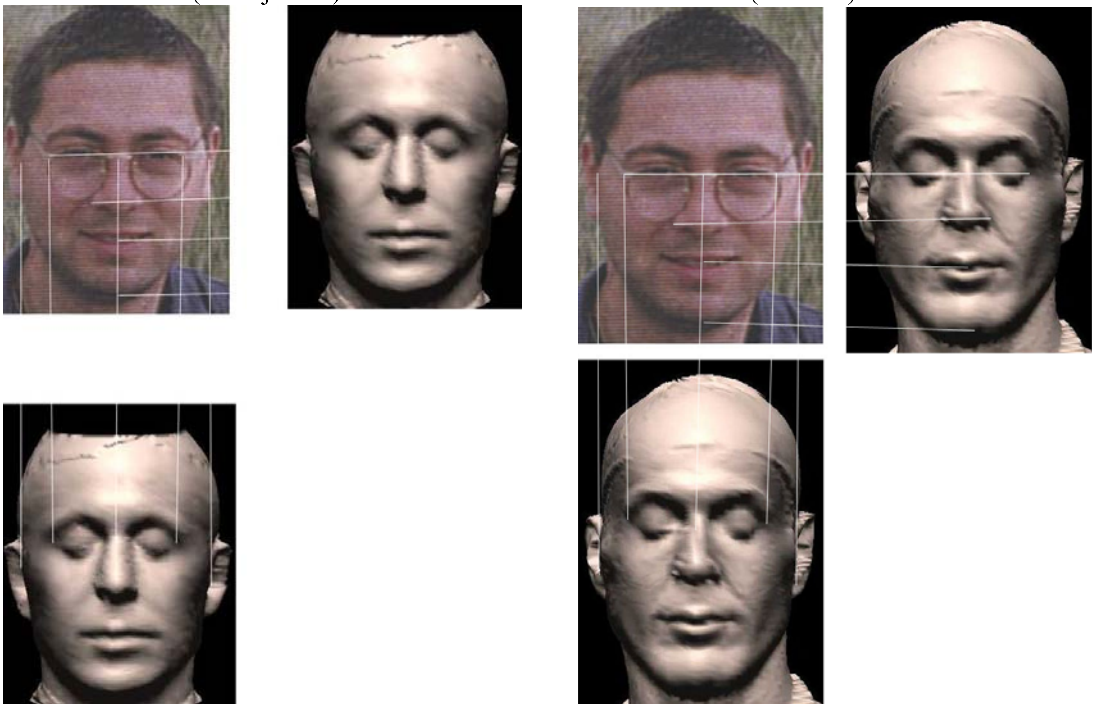
Experiment 4

Results. (See Chapter VI)



Reconstruction 3 (Rank 1.5)

Reconstruction 6 (Rank 1.5)



Reconstruction 1 (Rank joint 4)

Reconstruction 9 (Rank 10)

Figure 9.23: Case 4. Inter landmark lines between subject and reconstructions

Chapter X

Case study 5

Skull 5

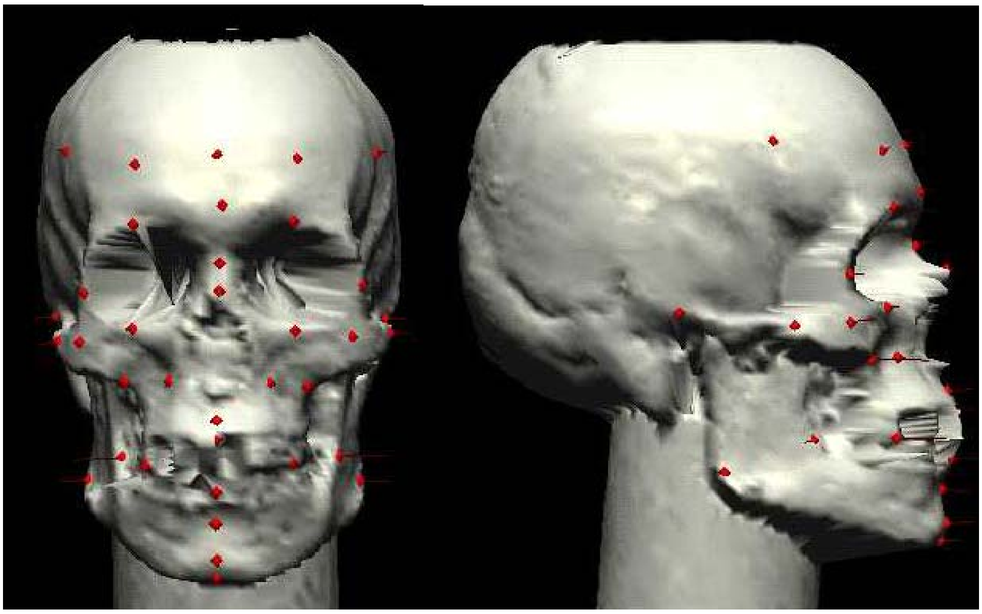


Figure 10.1 *Anterior and right lateral scan of the skull*

Skeletal remains found in a wood and their examination suggested that they were those of a male person aged between twenty and thirty years of age. The skull had some teeth missing that appeared to have been lost after death (figures 10.1, 10.2 a, b). Original reports suggested that the deceased was Caucasian but further examination revealed that he was of mixed ethnic origin, having both Caucasian and Mongoloid ancestry. The deceased person was later positively identified through ante-mortem dental records.This case was previously reconstructed using the original scanning equipment and software (Sharom et al 1996). However, these authors were not aware of the deceased's correct ethnic background until after the reconstruction, and he was reconstructed using only Caucasian characteristics.

The present author did not have access to the original skull, only the scanned image of the skull in the database as mentioned above. However the present author has used the appropriate racial characteristics and data to reconstruct the face from the skull. Additionally, the present author has used the same scanning equipment as the authors above, but this time using the new software. See section *Facial Reconstruction Procedure* in Chapter V.

(a)

(b)

Figure 10. 2 (a, b) Video superimposition of skull with photograph of deceased (Sharom et 1996)

As reported in the Methodology chapter V, ten facial templates were selected to reconstruct over each skull according to the anthropological criteria that is known about each skull. Therefore in Case study 5 the facial templates selected had to correspond with the anthropological criteria of skull 5: they were all between the 18-30 years of age category, male, of mixed Caucasian and Mongoloid ancestry and of average build. Because there was no category of mixed ethnicity in the database, most of the facial templates were selected mainly from the Mongoloid category of South American origin. Although indigenous South Americans (Amerindians) are broadly categorised as Mongoloid, most have features that are both Mongoloid and Caucasian, whilst others have features that are either predominately Mongoloid or Caucasian. From the 74 faces in the male mongoloid age group of 18-30 years of age (table 5.2) there were only twelve facial templates that corresponded with the above anthropological criteria. These twelve faces came from the new 500 facial database (table5.1), and were scanned specifically for the purpose of case study 5 by the author. Of these, only seven (reconstructions 1-7; figures 10.4- 10.10) were considered suitable when the templates with anomalous and exaggerated features were excluded, taking into consideration the morphology of the skull and image quality of the faces. Consequently, the other three faces (reconstructions 8-10; figures 10.11-10.13) were selected from the Caucasian category that corresponded with most of the above criteria. This was deemed acceptable because as stated above, the ethnicity of the skull was mixed, including Caucasian ancestry; furthermore, the anthropological criteria was ultimately satisfied in experiment 3, by adding the appropriate ethnic E-Fit features.

Again, once the above preparation stage of experiment 1 was completed the ante-mortem photograph was available to be used for the rest of the case study as explained elsewhere.

Excluding the timing and procedures for *Skull preparation* and digitising the templates in *Acquisition of the facial database,* each of the ten reconstructions in Case 2 took on average two hours to complete; this has been covered in the section *Facial Reconstruction Procedure* discussed in chapter V.

As in the previous case study, the exact position and angle of the frontal view of the ten reconstructions printed out (figures 10.4 - 10.13) was determined by the position of the available frontal ante-mortem photograph (figure 10.3), rather than the usual Frankfort Horizontal position, as explained in chapter V.

As before, the first experiment attempts to determine the psychological assessment of the facial reconstructions by using human observers to evaluate the similarity of the ten reconstructions when compared with the individual's ante-mortem photograph belonging to skull 5.

Experiment 1

The psychological assessment test on the facial reconstructions using a resemblance technique

The twenty assessors in experiment 1 were asked to choose from the selection of the ten reconstructions (figures 10.4 - 10.13), their three best reconstruction choices, which, in their opinion, resembled more accurately to the ante-mortem photograph (figure 10.3) of the target individual belonging to skull 5.

As explained in Chapter V, this produced a total of sixty reconstruction choices from the twenty subjects (20 x 3 choices).

Figure 10.3 *Ante-mortem photograph of the target individual (Case study 5)*

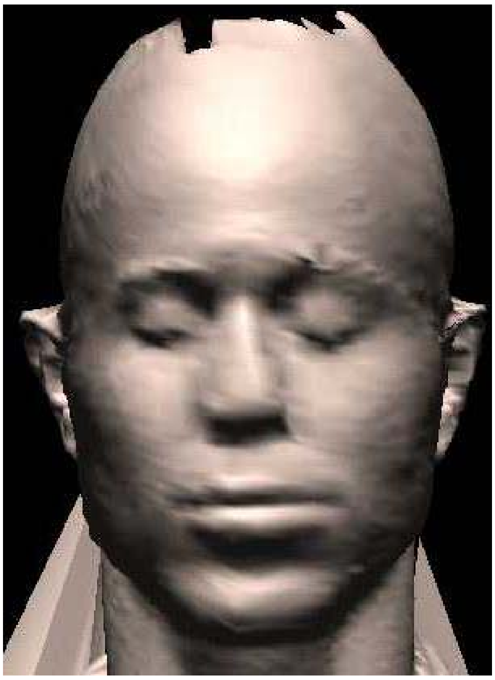


Figure 10.4 *Reconstruction 1*

Figure 10.5 *Reconstruction 2*

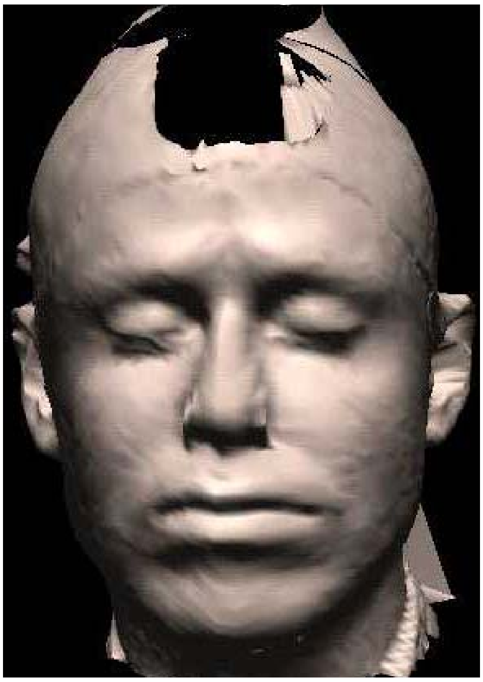


Figure 10.6 *Reconstruction 3*

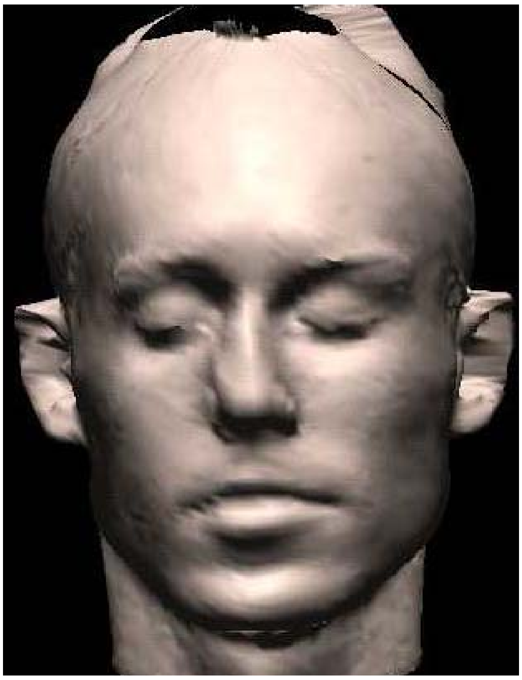


Figure 10.7 *Reconstruction 4*

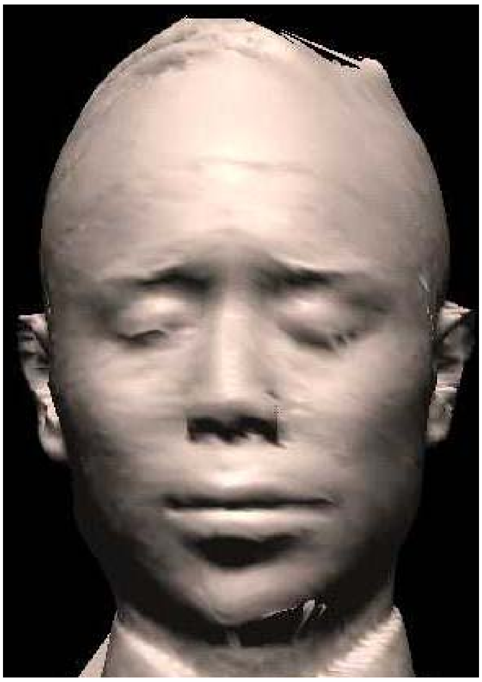


Figure 10.8 *Reconstruction 5*

Figure 10.9 *Reconstruction 6*

Figure 10.10 *Reconstruction 7*

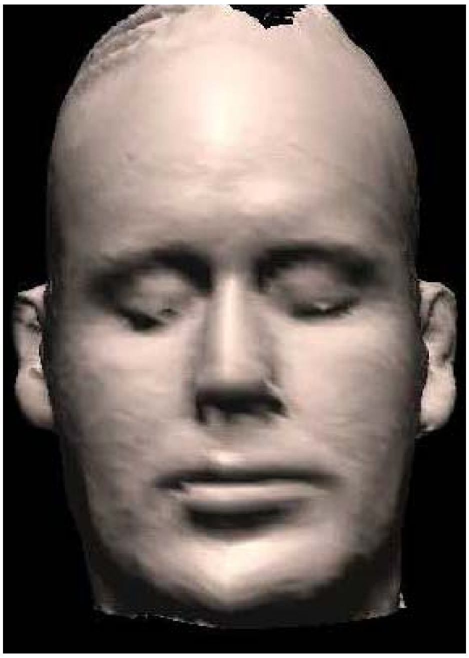


Figure 10.11 *Reconstruction 8*

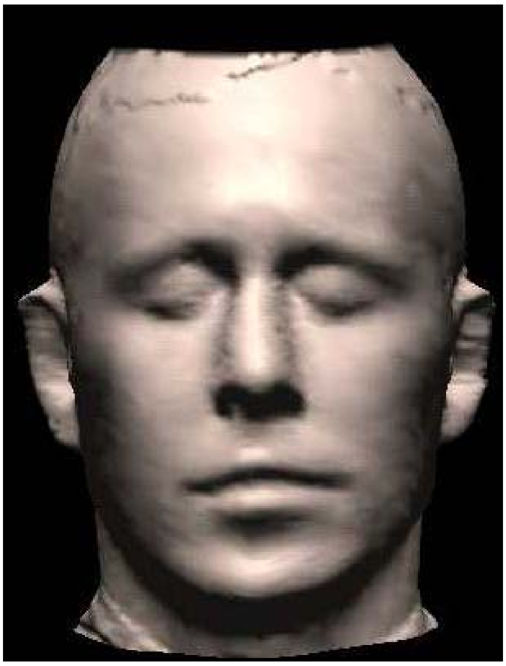


Figure 10.12 *Reconstruction 9*

Figure 10.13 *Reconstruction 10*

Results

(*Experiment 1*)

The twenty assessors' best three reconstruction choices (1st, 2nd and 3rd) from a choice of ten reconstructions, figures 10.4.-10.13, **(R1, R2, R3……R10),** are shown in Table 10.1.

Table 10.1 ***Assessors' three reconstruction choices and ranking***

Reconstructions (R)	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**Total**
1st choice	3	0	0	5	4	2	1	0	2	3	**20**
2nd choice	5	0	2	3	3	2	3	0	1	1	**20**
3rd choice	5	1	1	1	0	3	6	0	1	2	**20**
Total number of times (1st, 2nd and 3rd) each reconstruction was chosen by assessors	**13**	**1**	**3**	**9**	**7**	**7**	**10**	**0**	**4**	**6**	**60**
Rank of Total Reconstruction (R) Choice	**1.0**	**9.0**	**8.0**	**3.0**	**4.5**	**4.5**	**2.0**	**10.0**	**7.0**	**6.0**	___

Similarly to before, these results show that some of the reconstructions are consistently preferred over others. Whatever the accuracy of the skull/surface combination, it seems clear that some combinations are better than others.

In the second experiment I will assess the mathematical significance of the facial reconstructions by using Procrustes Analysis. It does this by evaluating how close the *match* is between skull 5 and each of the ten corresponding facial templates used to produce the facial reconstructions in the manner already described in Chapter V.

Experiment 2

The mathematical assessment test on the facial images: using Procrustes (Shape) Analysis

Each of the ten facial templates in case study 5 were separately compared and matched to skull 5. This means that each of the ten face co-ordinates was separately matched to skull 5’s co-ordinates every time. There were ten facial templates to be compared separately to skull 5, producing ten Full Procrustes Distances i.e. ten numbers, ranging from the closest to furthest. The closer the Full Procrustes distance (the smaller the number) between face and skull configuration, the closer is the match (tables 10.2 and figure 10.14).

Table 10.2 ***Procrustes Distances and Ranking produced between skull 5 and each of the ten facial templates***

Facial Templates	**Procrustes Distances with skull 5**	**Ranking of Procrustes Distances**
1	0.1377	5.0
2	0.1306	4.0
3	0.1612	10.0
4	0.1270	3.0
5	0.1212	1.0
6	0.1249	2.0
7	0.1435	6.0
8	0.1544	9.0
9	0.1496	7.0
10	0.1542	8.0

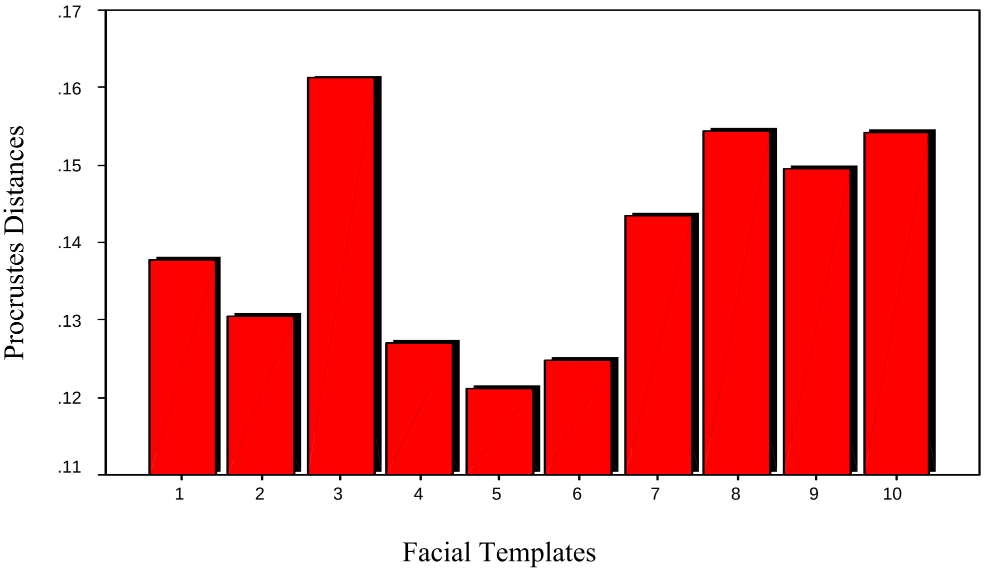


Figure 10.14 ***Procrustes Distances between skull 5 and each of the ten facial templates (closest match is smallest distance i.e. facial template no.5)***

Statistical Analysis between experiments 1 and 2

Statistical analysis was performed using the statistical pack SPSS™ 11.5.1 for Windows. This was to establish the association between experiment 1 and experiment 2. Since the correlation between the ranks of the assessors' reconstruction choice and the ranks of the Procrustes Distances (Analysis) was being assessed, Spearman's Rank Order Correlation was most appropriate for this.

Figure 10.15 is a scatter plot showing the correlation between the ranks of the Procrustes Distances (Analysis) and of the volunteers' reconstruction choice. The Correlation Coefficient was computed as **0.486** and as shown from figure 10.15 the relationship displays a positive correlation because as the ranks of the Procrustes Distances increases, so do the ranks of the volunteers reconstruction choice.

However, at the 0.05 significance level, the tabulated value from the Critical values of Spearman's Rank-Order Correlation Coefficient table is **0.564** when the N = 10. Since the calculated/computed Spearman's correlation coefficient is *less* than the table value the correlation is a weak one, and *not* significant. Therefore, from the results of this case, one can conclude that there is not enough evidence to reject the null hypothesis at the 0.05 significance level.

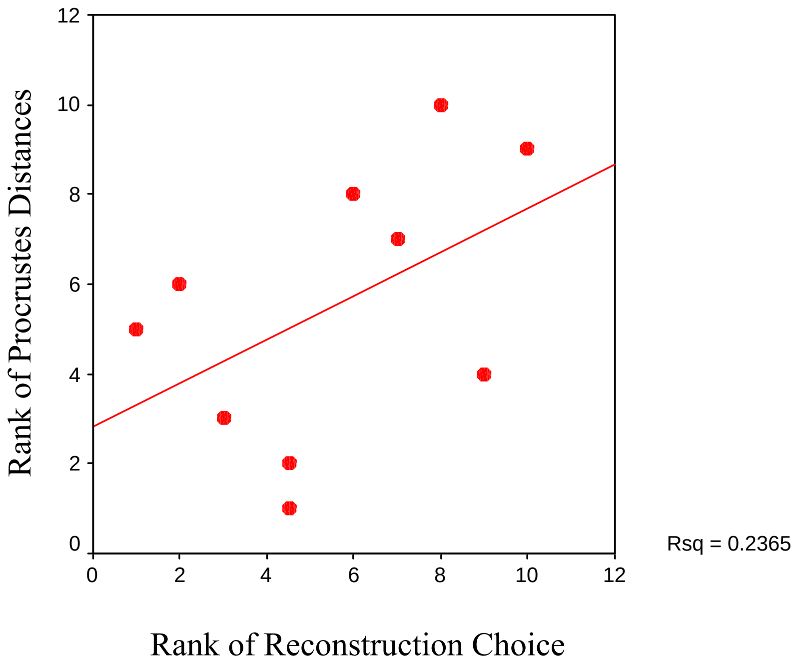


Figure 10.15 ***Scatter plot showing correlation between Procrustes Analysis and Assessors' Reconstruction Choice***

Discussion
(Comparisons between experiment 1 and experiment 2)

In experiment 1, as shown in table 10.1 the assessors' choice for closest reconstruction match to the ante-mortem photograph (figure 10.3) was reconstruction 1 selected by 13 assessors and ranked 1st.

Reconstruction 7, selected by 10 assessors' was the second choice and therefore ranked second.

Third ranking was assigned to reconstruction 4 and selected by 9 assessors' as a good match to the ante-mortem photograph.

However, the least preferred reconstruction as a good match to the ante-mortem photograph (figure 10.3) and not selected by any of the assessors was reconstruction 8, and therefore ranked 10th. Reconstruction 8, also ranked very low (9th) in experiment 2, the Procrustes Analysis evaluation, shown in tables 8.2 and 8.3 and illustrated in figure 8.14.

The closest reconstruction match according to the Procrustes Analysis in experiment 2 was reconstruction 5, having produced the smallest Procrustes Distance (0.1212) between the skull and its corresponding facial template 5; reconstruction 5 therefore, ranked top with the Procrustes Analysis. In experiment 1, reconstruction 5 scored fourth equal places with reconstruction 6 having being selected by 7 assessors each, and therefore ranked 4.5th.

The largest Procrustes Distance (0.1612) was produced between the skull and facial template 3, therefore reconstruction 3 was ranked 10th. This same reconstruction (3) also scored low in experiment 1, with the assessors reconstruction choice, where it was selected by 3 assessors and ranked 8th.

Although as discussed above in the statistical analysis between experiments 1 and 2, the correlation was not *statistically* significant, however, there seems to be some general agreement between the ranks of the assessors' reconstructions choice in experiment 1 and the ranks of the Procrustes Analysis in experiment 2.

Therefore, although not statistically significant, nevertheless, using Procrustes Analysis in this case study with skull 5 still seems to capture some perceptual similarity in human observers.

As discussed before, the purpose of the third experiment was to ascertain whether by adding E-Fit™ features to the facial reconstructions in the context of the present study, there was any improvement on the identification process. Therefore, E-fit features were added to the four selected facial reconstructions for evaluation by the assessors.

Experiment 3

The psychological assessment test on the E-Fit™ images using a resemblance technique

As discussed in Chapter V, E-Fit™ features were implemented on four reconstructions which produced the most extreme results from both the psychological assessment in experiment 1 and/or the mathematical evaluation in experiment 2 in each of the case studies for further comparisons.

From the results in the present case study, using skull 5, reconstructions 1, 3, 5 and 8 were chosen to implement the E-Fit™ features (table 10.3).

Reconstruction ***1*** was selected from the ten reconstructions to implement E-Fit features because it was the top ranking with the assessors' reconstruction choice in experiment 1; this same reconstruction (1) in experiment 2 ranked 5th with the Procrustes Analysis.

Reconstruction ***3*** was selected because it ranked 10th and bottom ranking with the Procrustes Analysis in experiment 2, and it also ranked low (8th) in experiment 1 with the assessors' reconstruction choice.

Reconstruction ***5*** was selected because it ranked top with the Procrustes Analysis in experiment 2, and also this same reconstruction scored reasonably high (4.5th) in experiment 1.

Reconstruction ***8*** was selected because it scored bottom ranking in experiment 1, with the assessors' reconstruction choice; similarly reconstruction 8 scored very low (9th) with the Procrustes Analysis in experiment 2.

Consequently, in numerical order:

- Reconstruction 1 with E-Fit™ features was assigned as E-Fit 1 (figure 10.16)
- Reconstruction 3 with E-Fit™ features was assigned as E-Fit 2 (figure 10.17)
- Reconstruction 5 with E-Fit™ features was assigned as E-Fit 3 (figure 10.18)
- Reconstruction 8 with E-Fit™ features was assigned as E-Fit 4 (figure 10.19)

These four E-Fits were subsequently shown to the twenty new assessors in experiment 3 together with the ante-mortem photograph (figures 10.20) for evaluation in the manner described in Chapter V.

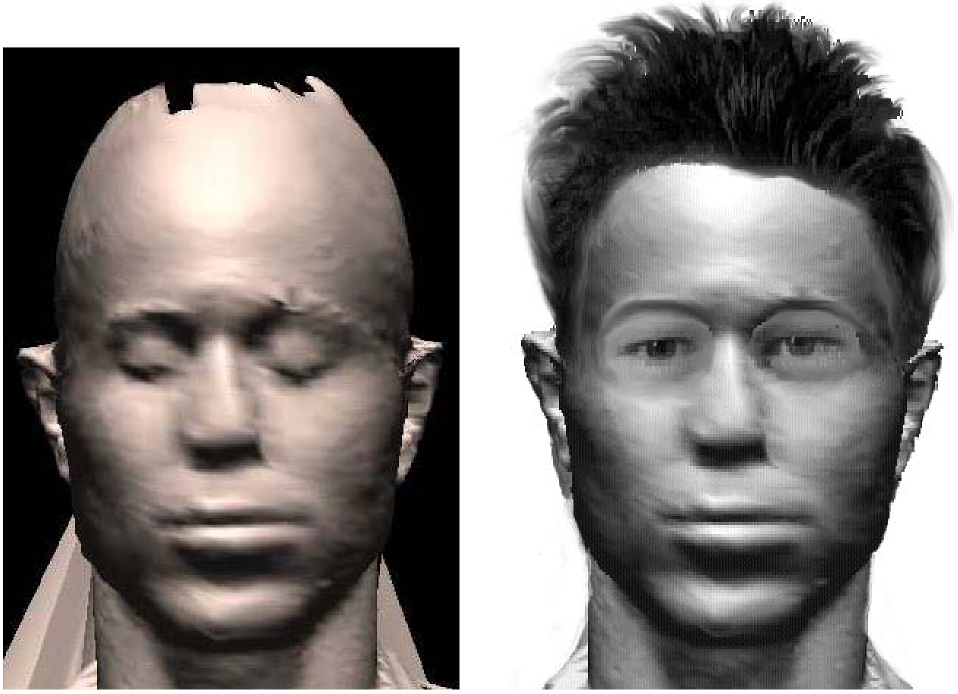


Figure 10.16 ***Reconstruction 1 with its E-Fit features –E-Fit 1***

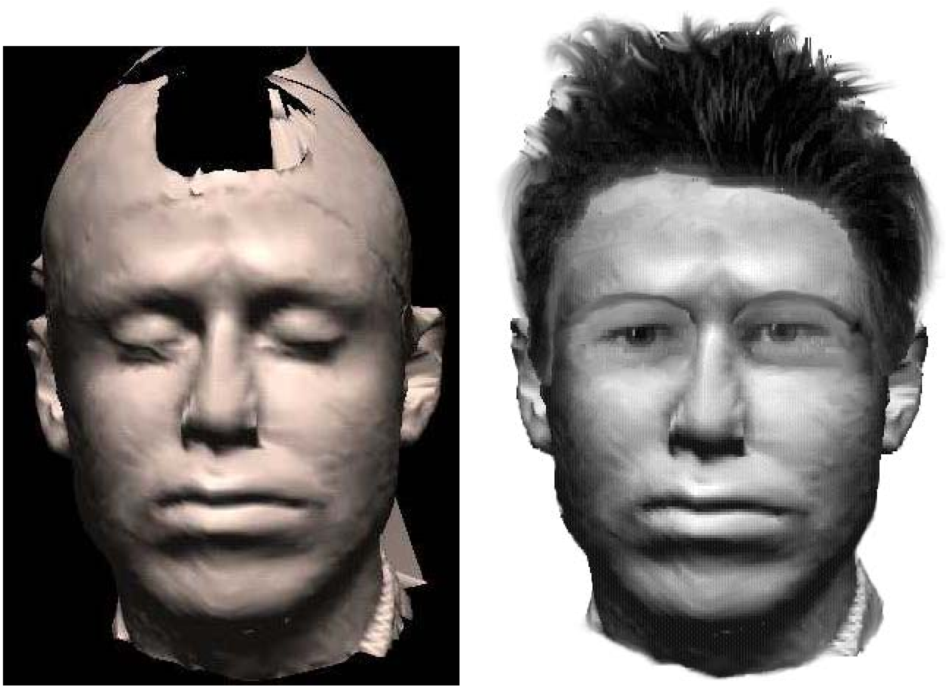


Figure 10.17 ***Reconstruction 3 with its E-Fit features –E-Fit 2***

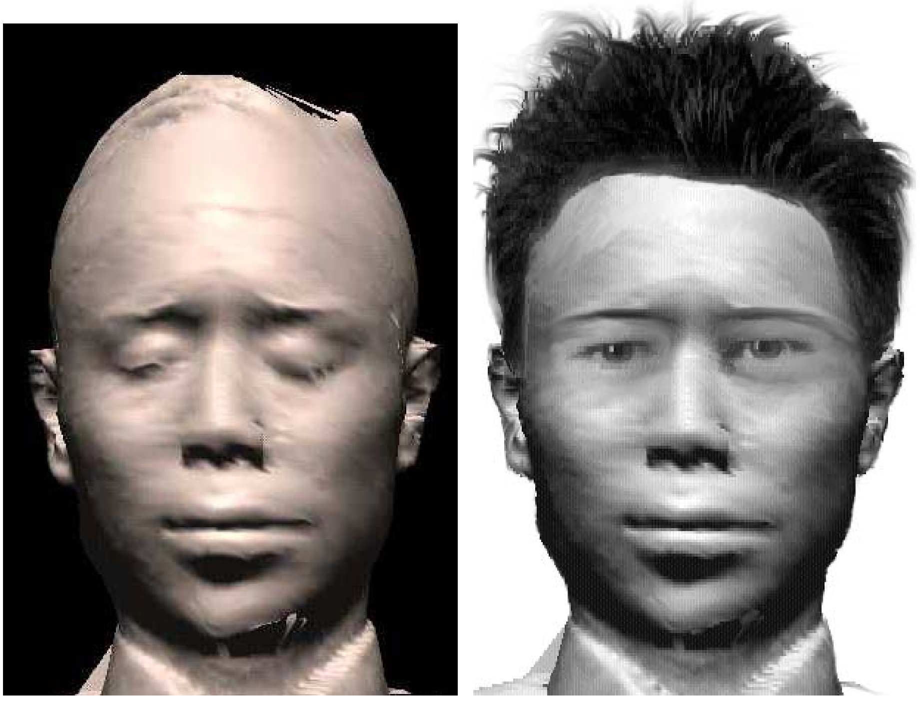


Figure 10.18 ***Reconstruction 5 with its E-Fit features –E-Fit 3***

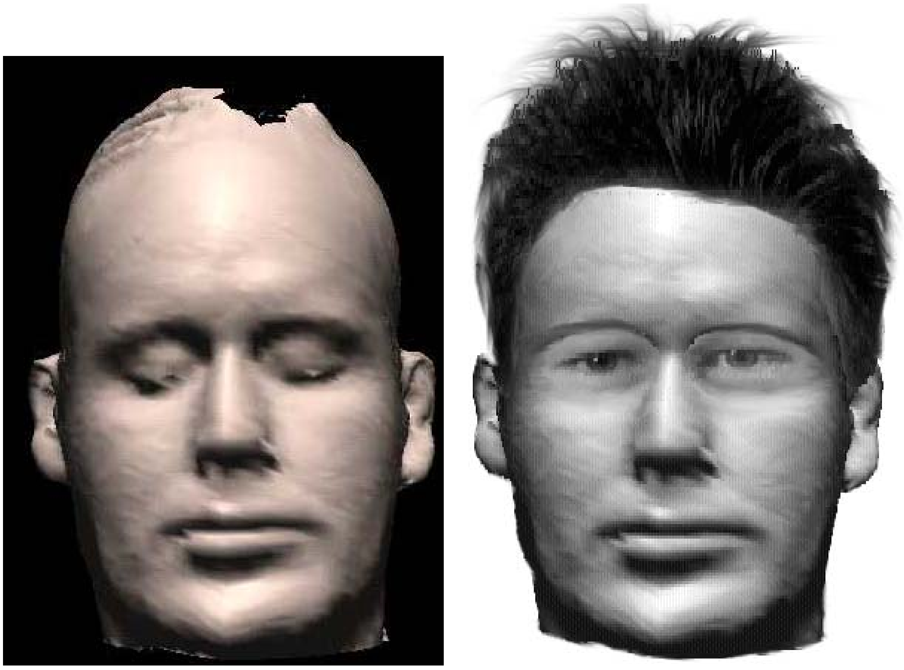


Figure 10.19 ***Reconstruction 8 with its E-Fit features –E-Fit 4***

E-Fit 1

E-Fit 2

E-Fit 3

E-Fit 4

Figure 10.20 ***The four E-Fit images with the ante-mortem photograph***

Results
(Experiment 3)

Table 10.3 ***Assessors' Reconstruction Choice, Procrustes Distances and Assessors'E-Fit Choice (Comparisons between experiments 1, 2 and 3)***

	Experiment 1		*Experiment 2*		*Experiment 3*		
Recon-structions R	**Total/No of Assessors R Choice**	**Rank of R Choice**	**Procrustes Distances**	**Rank of Procrustes Distances**	**EFit**	**Assessors' EFit-Choice**	**Rank of E-Fit Choice**
1	13	1.0	0.1377	5.0	1	3	2.0
2	1	9.0	0.1306	4.0	.	.	.
3	3	8.0	0.1612	10.0	2	0	3.5
4	9	3.0	0.1270	3.0	.	.	.
5	7	4.5	0.1212	1.0	3	17	1.0
6	7	4.5	0.1249	2.0	.	.	.
7	10	2.0	0.1435	6.0	.	.	.
8	0	10.0	0.1544	9.0	4	0	3.5
9	4	7.0	0.1496	7.0	.	.	.
10	6	6.0	0.1542	8.0	.	.	.

Discussion

In experiment 3 above, as mentioned before, only descriptive statistics are provided, since the relatively small data set lends itself to clinical observation only.

In this experiment the assessors' E-Fit evaluation, as shown in table 10.3, the most preferred E-Fit to closely match the ante-mortem photograph (figures 10.3; 10.20), selected by 17 assessors, was E-Fit 3 and consequently ranked 1st.

E-Fit's 2 and 4 were not selected by any of the assessors and therefore scored bottom position, at equal 3.5 ranks.

E-Fit 1 was second choice having being selected by 3 assessors and therefore ranked 2nd.

E-Fit 1, which was produced from reconstruction 1 ranked second in the E-Fit assessment in experiment 3; in experiment 1 the corresponding reconstruction 1 scored top ranking. However, in experiment 2, the Procrustes Analysis, reconstruction 1 ranked 5th.

The clear and unanimous assessors' E-Fit choice was E-Fit 3, having being chosen by 17 out of the twenty assessors. E-Fit 3 was created from reconstruction 5. This concurred strongly with the Procrustes Analysis, where reconstruction 5 ranked 1st (table 10.3). However, this was not so straightforward in experiment 1, the assessors' reconstruction choice, where this reconstruction scored equal 4.5th rank with reconstruction 6.

This strong agreement occurred with E-Fits 2 and 4 - which ranked equal bottom ranking in experiment 3 - were produced from reconstructions 3 and 8 respectively, also ranked bottom (10th and 9th respectively) in experiment 2 with the Procrustes Analysis (table 10.3). Similarly, these two reconstructions ranked very low in experiment 1 with the assessors' reconstruction choice (reconstruction 3 ranked 8th and reconstruction 8 ranked 10th).

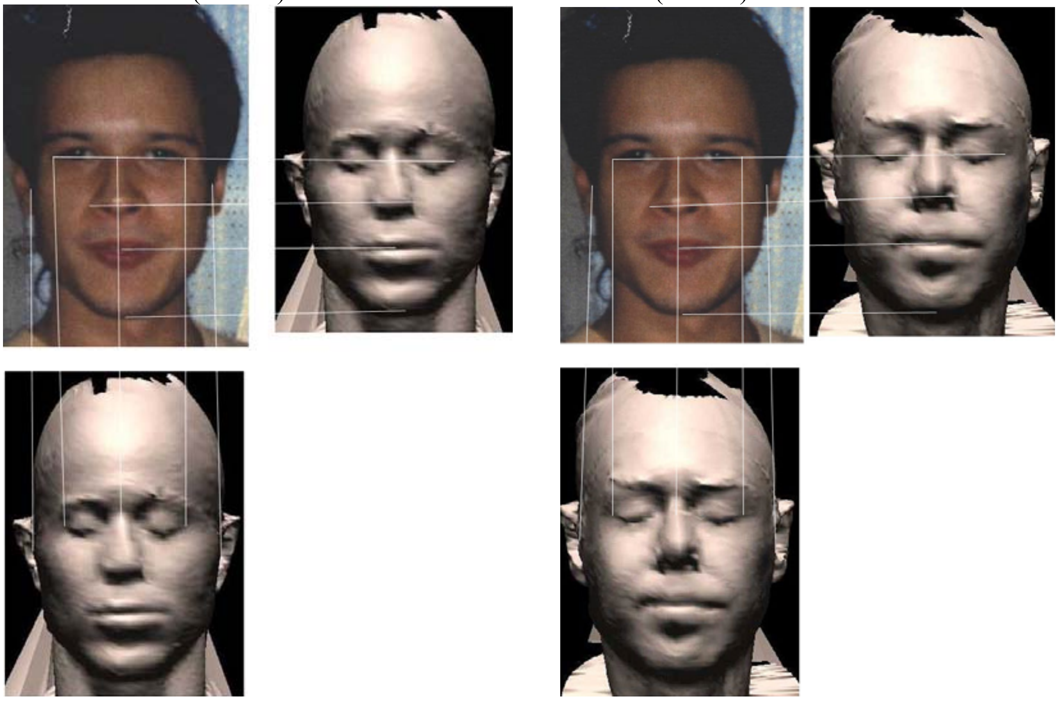
As discussed in the statistical analysis section above, although the correlation between experiment 2 and 1 was shown not to be statistically significant, there nevertheless, seems to be some agreement between experiment 2, the Procrustes Analysis, with the two sets of assessors' choices, experiments 1, and especially experiment 3. Furthermore, there was also some agreement between the two sets of assessors in experiment 1 and 3.

Therefore, we can conclude from this case study using skull 5, that using Procrustes Analysis, although not statistically significant, it still seems to capture some perceptual similarity in human observers, especially in experiment 3 – the assessors' reconstructions choice with the added E-Fits. Furthermore, it would suggest that applying E-FIT features on the image improves the perceptual similarity in human observers.

Experiments 4.

Results:. (See Chapter VI)

Reconstruction 1 (Rank 1) Reconstruction 7 (Rank 2)



Reconstruction 4 (Rank 3) Reconstruction 8 (Rank 10)

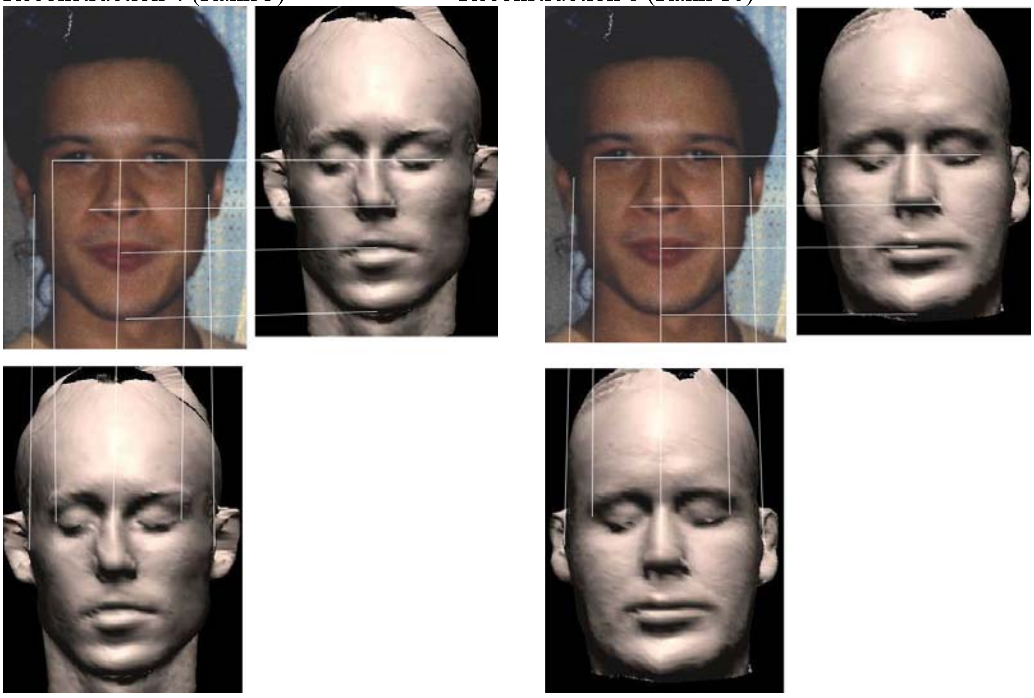


Figure 10.21: Case 5. Inter landmark lines between subject and reconstructions

Chapter XI

Discussion and Conclusions

The present study: overview of the case studies

The results from the five case studies generally show good agreement between the two psychological resemblance tests (experiment 1 and 3). The association between psychological measures and physical measures (captured in Procrustes analysis, experiment 2) were, however, weak. There is some suggestion of a positive association between psychological and physical measures, but this does not come close to reaching statistical significance. Interestingly, the stronger association appeared when psychological measures were taken using the surfaces with E-Fit added (experiment 3) rather than the raw surfaces (experiment 1). Although this addition leaves measures of the physical surface unchanged, it appears to improve the association between human perception and the Procrustes analysis. This was highlighted particularly in case study 5 (chapter X), where, the Procrustes Analysis very strongly concurred with the assessors' unanimous E-Fit choice in experiment 3.

In Case study 5 the target individual was of mixed ethnic origin, having both Caucasian and Asian ancestry. This would suggest that the application of the appropriate ethnic E-Fit features in such situations may improve perceptual similarity in human observers; features such as eyes and hair are significant cues regarding perceptual similarity in a scenario of a specific ethnic origin. Furthermore the *'other-race'* effect (See *Ethnic Differences* in Chapter IV) may be a significant factor in this case study and the application of the appropriate E-fit features may enhance the perceptual similarity in the assessors.

For Case study 4, E-Fit 1 (figure 9.16; 9.22 a, b) produced from reconstruction 1, was the image made to appear on Crimewatch UK for broad media coverage. As a result, this image was recognised by the person's relatives, and subsequently positively identified with dental records. However, findings in the laboratory from this case study were rather mixed. Reconstruction 1 ranked 4th (together with reconstructions 2 and 5) in the assessors' reconstruction choice in experiment 1, and 7th in the Procrustes Analysis evaluation in experiment 2. However, once the E-Fit features were applied, E-Fit 1 was selected by 11 out of the 20 assessors and ranked 1st in experiment 3. The results from this case study would seem to suggest that even if the facial template chosen to warp and reconstruct over the skull may not be the closest *match* to the skull according to the Procrustes Analysis, when E-FIT features are applied *appropriately* to the reconstruction, it appears to enhance the perceptual similarity in human observers (see section below *Reliability, validation, and success).*

Some of the diverse results obtained in the present study, particularly the correlation between experiment 1, the assessors' reconstruction choice (*without* E-Fit features) and experiment 2, the Procrustes Analysis (mathematical testing), may be put into perspective by the research conducted in the psychology of facial recognition, even when conducted in the very favourable conditions of testing facial recognition in a familiar situation. Bruce et al. (1991) found that it is actually very difficult to identify faces when only the three-dimensional laser shape is presented. In their experiment a number of their university colleagues were asked to have their faces scanned using a laser scanner, resulting in facial surface images being visualized (Linney et al. 1989; Vanezis et al 1989). These images were shown to friends and students of the targets. They found that identification rates were remarkably low, and interestingly, much lower for female faces than for male faces. This was rather surprising despite the fact that this was conducted in a familiar situation, and furthermore, this was a direct comparison where the laser facial scan represented a face of exactly the same proportions, shape and size as one of the individuals (i.e. the target individual was present in both the laser scan and the array of photographs - face pool), unlike three-dimensional laser reconstruction image(s) which, can only have levels of similarities to the target individual's photograph. This indicates that to process the normal recognition procedure superficial features and colouration are important. This seems to be reflected in the most of the case studies, where, perceptual similarity improved when E-Fit features were added to the reconstructions. It would appear that the addition of E-Fit features, when implemented *appropriately* and as cephalometrically accurate as possible, as discussed in chapter V, may "humanise" the facial image, thus forcing the human eye to look at the image in a more holistic way, rather than concentrating on just specific isolated areas on the face.

Another issue raised when looking at the results in case study 3 in particular (Chapter VIII), is that although Procrustes Analysis did not seem to capture perceptual similarity where the observers were *unfamiliar* with the subject (experiments 1 and 3); however, and although not statistically proven, it would suggest that Procrustes Analysis did appear to capture perceptual similarity in a situation where the observer was *familiar* with the subject in question (figure 8.3). For example, reconstruction 1, in this case study (3) performed very poorly with the assessors' reconstruction choice, ranking 10th and last in experiment 1, and similarly in experiment 3, E-Fit 1, which was produced from reconstruction 1, also rated fairly low at rank 3 out of a possible four ranks. However, in experiment 2 this same reconstruction (1) produced from the corresponding facial template (1) performed much better, ranking 2nd with the Procrustes Analysis (table 8.3). Significantly, since this same reconstruction 1 with its E-Fit features – E-Fit 1 (figures 8.16; 8.22 a, b) was the image that was used to facilitate in the identification of the individual by a relative after appearing on Crimewatch UK, this would suggest that Procrustes Analysis may capture perceptual similarity in a familiar situation. *Familiar vs. unfamiliar scenario is discussed below.*

Selection of the facial templates and limitations

As discussed previously, facial templates were selected from the database that corresponded anthropologically to the skull under examination, for example age, sex, ancestry and build. This of course is an essential prerequisite whether using a computerized or manual reconstruction technique in order to establish the correct anthropological criteria to match with the skull under examination.

From that particular anthropological category, ten facial templates that had *typical* and *standard* facial features and characteristics were chosen to perform the ten reconstructions in each case study. This reflects other 3-dimensional computerized techniques, where the software *averages* a final facial template from a number of facial templates in that particular anthropological category to be used as a base for reconstruction (Vanezis et al 1989; Evenhouse et al 1992). This is effectively what principal component analysis (PCA) achieves with regard to the facial templates (Claes et al 2006). This has the affect of producing a facial template which is as statistically as *average* as possible within that particular anthropological category to act as a *mask* and perform the warp over the skull. Any unusual and distinct characteristics should then be exhibited on the reconstruction as dictated by the skull and *not* from the original facial template.

As discussed in the section *Distinctiveness* in Chapter IV, Psychology of Facial recognition, faces which are classed as more typical will tend to have values based on the dimensions which are true of many faces (e.g. average length nose), whereas those which are rated as more distinctive will tend to have values that are more extreme (e.g. a very long nose or very thin lips). Therefore, typical faces will tend to cluster more closely together within the space framework, while more distinctive faces are scattered around the periphery (Valentine 1991).

With regard to the present study, facial templates that had very *distinct* and *unusual* characteristics were not chosen; this is largely because of the way some of the computer software has been designed to work, including the present study. Essentially, each of the facial templates acts as a mask that is stretched over the skull via the specific landmark locations on both the skull and the corresponding ones on the facial template with their appropriate soft tissue thicknesses at those sites to produce the new reconstructed face. However, some characteristics from the original facial template that cannot be predicted from the skull, may still be exhibited on the corresponding reconstruction, albeit, distorted because of the warping process. Although the ten reconstructions per case study bear similar general resemblance to each other – since they were reconstructed using the same skull –some features however, from each of the resulting reconstruction bear *some* resemblance to some of the characteristics from their corresponding facial template.

Consequently, since some *feature similarity* is still exhibited on the reconstruction warped from its corresponding facial template, only average and standard facial templates are sub selected from the given anthropological group in each case study. Otherwise, very distinct characteristics on the original facial template may to some extent be exhibited on the reconstruction; for example, features such as very distinct and unusual shape of lips and shape of nasal tip (pronasale) produced on the final facial reconstruction would to some degree reflect the facial template selected, rather than as distinct and unusual characteristics indicated directly by the skull and since there is no direct provision on the skull to allow reconstruction of some of these features with exact precision, the resulting reconstruction would be unreliable.

With regard to the present study, the software cannot reconstruct some of these features to directly indicate the exact *shape* of these facial characteristics by using anatomical sites or landmarks alone. For example, the reconstruction of the nose, requires landmarks that are located around the nasal aperture and nasal bones on the skull with its appropriate soft tissue thicknesses (figure A1.1 in Appendix 1) and its corresponding landmarks on the nose from the facial template (figure A1.2); this will indicate the width (landmarks 23 and 43) and length (landmarks 3, 4 and 5) of the nose, but will not indicate the *shape* of the nose and *shape* of the nasal tip (pronasale).

This problem is due, in part, to the fact that landmark sites selected on the skull and corresponding points on the facial template are restricted to where there is soft tissue data available from previous studies. Further complications arise with the way the present software essentially operates; landmarks are chosen on the skull that corresponds with the soft tissue sites on the facial template. For example, the pronasale is a soft tissue cartilaginous feature rather than direct bony support, there is no corresponding landmark location on the skull to perform the warp and reconstruct the nose around that area. Consequently, the shape of the pronasale produced on the final reconstruction exhibits to a certain extent the shape mainly warped from the corresponding facial template, although the reconstructed nose itself is produced from distorting the one on the facial template by the warp according to the landmark locations on both the skull and the corresponding ones on the facial template.

Although, canons do exist to predict and approximate the nasal projection as discussed in chapter II, those guidelines however, do not make provisions for the exact *shape* of the nose and especially the *shape* of the pronasale. In fact, even with the latest published papers on the topic, there still seems to be some controversy in the literature regarding the best canons to use to predict the nose projection and pronasale position (Stephan et al 2003; Rynn and Wilkinson 2006).

As mentioned before, Macho (1989) pointed out that the external nose is a very complex organ and that its soft tissue contour does not strictly follow the underlying bony structure. The author maintained that her study showed that knowledge of soft tissue thicknesses alone is not sufficient for successful facial reconstructions, but a more holistic approach should be used to clarify the relationship between soft tissue cover and the underlying hyaline and bony structures. Similarly, Stephan et al (2003) maintain that:

"*While this study systematically examines one aspect of soft-tissue nose prediction from the skull, there is much nose anatomy that, as yet, cannot be predicted with reliable estimates of error, e.g. prediction of the shape of the profile of the nose, nostrils, nose apex or bulb, columella, and alars.*"

Similar problems also arise with the *shape* of the lips in the present study, where landmarks 6 and 7 indicate the height and landmarks 24 and 44 the width of the mouth (figures A1.1; A1.2 in Appendix 1), but the software has no provision for determining the actual *shape* of the individual lips i.e. the vermillion borders of the lips. As before, while some rules exist in the literature for reconstructing the height, width and projection of the mouth as discussed in Chapter II, however, the exact *shape* of the lips are more difficult to determine and reconstruct from the skull.

Therefore, the lips reconstructed in the ten final images per case study, although adhere to the landmark location on the dentition to produce the height, width and projection of the mouth in each reconstruction, the *shape* of the lips in each of the reconstructed images nevertheless, may bear *some* resemblance to the original shape of the lips on their original corresponding facial templates.

Similarly, Stephan and Henneberg (2006) stated that although, the general position of features such as mouth location over teeth and ratio of face height to width can be predicted from the skull, the *shape* of the vermillion borders of the lips or the *shape* of the nose cannot be predicted well when performing clay facial reconstruction techniques.

Significantly, it would seem that this is, to some extent, a universal problem with facial reconstruction when rebuilding these features, whether one is using a computerized method like the present study or by manual facial reconstruction. Furthermore, despite these problems and limitations, the automatic procedure studied here is perhaps no less adequate under those circumstances, and in some ways are no less acceptable than those produced by a manual method where, for example, ten reconstructions produced by ten different practitioners for the same skull will exhibit their individual variations, particularly in those areas. In fact, this scenario possibly simulates the different personal approach one exhibits with manual facial reconstruction under these circumstances, given that some individual interpretation is still possible with these structures (Macho 1989). Individuals develop their own personal styles of reconstruction, and furthermore, the largest areas of variation appear to be the mouth, eye regions (Helmer et al 1993) and nose (Stephan and Henneberg 2006)

In fact some practitioners in the field of facial reconstructions have illustrated that in the context of the entire face, it has become apparent that facial reconstruction is based on only a small number of known relationships, which are probably inadequate for building a complete face that is representative of the individual to whom the skull belonged (Gatliff 1984; Stephan 2003b Stephan et al 2003; Stephan and Henneberg 2006).

In future developments of the software used here, provisions should be considered to include a *virtual* anatomical landmark to confirm the location of the tip of the nose (Claes et al 2006) and nasal projection obtained on the reconstruction, rather than relying on existing landmark sites on the nasal area on the skull and the corresponding facial template sites alone. This can be accomplished by allowing the operator to locate this *virtual* landmark, perhaps being guided by existing canons. However, similar to manual facial reconstruction techniques, this may give a better indication of the nasal projection on the final reconstruction but will not give a better suggestion regarding the *shape* of the nose and particularly the nasal tip (pronasale).

Furthermore, with regard to the present study, as discussed in the section *Producing the reconstructed face* in chapter V, once the facial template is warped over the skull to produce the facial reconstruction, the *alpha blending* mode which is inherent to the present software, shows the superimposition of the skull and the reconstructed face and allows the operator to check soft tissue to skull alignment and to see if there are any obvious minor errors (figure 5.8). This is the same principle one adopts when attempting skull to photo superimposition in putative identification or skull to reconstruction to aid with identification, as discussed in chapter III (Cranio-Facial Identification).

Any facial features that have to be distorted substantially from the original facial template in order to warp onto the skull are indicated on the alpha blending by too much *stretching* or *squashing* between the corresponding landmarks of skull and the reconstructed face. As a result, facial characteristics on the reconstruction appear uneven and distorted. Consequently, these facial templates/reconstructions are excluded because they demonstrate that they are not as cephalometrically suitable to the skull as the others.

In reality, as long as the corresponding landmark sites on the skull and facial template are located as accurately as possible, then the above scenario of too much *stretching* or *squashing* between the skull and reconstructed face is a rare occurrence, since the software is able to adapt to most situations. Furthermore, most extreme scenarios are avoided since only *typical* facial templates are used and all the *unsuitable* facial templates with regard to very unusual and very distinct features, as discussed above, are naturally excluded in the first place. The selections of the *typical* facial templates are chosen visually by observing the faces in a number of different views, frontal, lateral profile and the two opposite three quarter oblique views.

Therefore, once the specific anthropological category (age, sex, ancestry and build) that is available for each skull is established, then further sub selection of the facial templates from that particular category is relatively standard and repeatable by other practitioners by selecting facial templates that have typical and standard facial features and characteristics. Furthermore, the alpha-blending can indicate the rather unusual situation where a facial template is unsuitable as indicated on the final reconstruction by performing, effectively, a superimposition of the skull to the facial reconstruction.

Procrustes Analysis vs. Resemblance Testing

As established from the whole study, the correlations between the ranks of the assessors' reconstruction choice, in experiment 1, and the ranks of the Procrustes Distances (Analysis), in experiment 2, were not statistically significant. However, it is important to emphasize that the full Procrustes Distances between each of the ten facial templates and the skull examined in each of the five case studies are difficult to fully interpret because the disparity between the Procrustes Distances in each case study is fairly small.

For example in case study 1, the difference between the closest match produced between the skull and facial template 10 (Reconstruction 10,) and the worst match produced between the skull and facial template 5 (Reconstruction 5) produced Procrustes Distances of 0.1133 and 0.1565 respectively. This small difference in the Procrustes Analysis between the closest and worst match between skull and facial templates is also reflected in the other four cases.

A possible reason for the fairly small disparity in the ten Procrustes Distances in each of the case studies, may be that since the facial templates are all pre-selected for their *typical* characteristics, in the same way that a facial template is *averaged* when using other computer software programs (Vanezis et al 1989; Evenhouse et al 1992; Claes et al 2006), this would appear to reflect the small disparity in the ten Procrustes Distances in each of the case studies. With regard to the present study, whilst, the facial templates were pre-selected to reflect the normal working procedure one would undertake when performing a facial reconstruction in a forensic scenario, it may have also been useful to have selected ten very *diverse* facial templates within the anthropological criteria dictated by the skull to see if Procrustes Analysis captured perceptual similarity in the assessors to a statistically significant degree.

Furthermore, it is difficult to *precisely* interpret the significance of the Procrustes Distances, for example, these measures are merely a way of ranking the levels of agreement between the ten facial templates and the skull in each case study. The

Procrustes Analysis (shape analysis) compares the two configurations, face vs. skull at the 36 3-D landmark sites. However, the facial templates and skull examined in each case study do not have landmarks everywhere on the face and skull to be fully compared at every site on every morphological feature. For example, there is no landmark on the tip of the nose or pronasale and vermillion borders of the lips.

Additionally, as discussed in Chapter V, the assessors were advised when evaluating the facial images to pay particular attention to the general shape of the face, chin, cheeks and general overall impression of their combination with the facial features; soft tissue characteristics such as *shape* of nasal tip/pronasale and the *shape* of the lips alone, were of lesser importance because the underlying skull provided insufficient information to enable these structures to be accurately reconstructed (Appendix 1, Figures A1.1; A1.2). Although a substantial number of assessors' choices were made based on the general shape of structures such as chin, cheekbones, brow ridges, and the relationship or configuration between soft tissue features, as described by the assessors comments, some reconstruction choices, however, were based on the shape of the soft tissue features alone, such as the shape of the nasal tips and or the shape of the lips. In one isolated case, the assessor's choice was based on the position and size of ears, rather than the overall holistic effect of general shape of face and configuration between these soft tissue features. (See also section below - *Experienced versus inexperienced observers).*

Therefore, based on some of these assessors' comments made for the reconstruction choices, one of the reasons for the weak correlation between experiment 1 and 2 may have had a psychological basis. For example, was the human eye detecting a feature or configuration on the reconstructed image that did *not* match with the subject's ante-mortem photograph and therefore excluding that image as a good likeness, even though it may have been otherwise a good match cephalometrically, as indicated by the Procrustes Analysis? For example, and significantly, for the reasons discussed previously, they may have been excluding a reconstruction as a potential good match to the target photograph because the shape of the nose, shape of lips or even shape of the ears did not have enough similarities between them, as was indicated on the assessor's reconstruction forms (Appendix 2, Figure A2.1). With regard to resemblance tests, research seems to indicate that assessors tend to look for errors rather than similarities in the reconstruction when comparing it to the target individual, (Wilkinson 2004).

The rationale of the study between experiments 1 and 2 was to assess the *accuracy* of the selected facial templates by using Procrustes Analysis (experiment 2) with perceptual similarity in assessors (experiment 1). The aim of Procrustes Analysis if, it had proven to be statistically significant, was to have a mathematical means (shape analysis) of refining the selection of facial template(s) and excluding extreme shapes to be used for facial reconstruction for each particular skull.

Although there were some promising associations between all the experiments, as discussed above, there was no statistical correlation between the Procrustes Analysis of the facial templates and the perceptual similarity in assessors. However, as discussed elsewhere, *the psychology of facial recognition* is rather complex, for example, despite apparent similarity of a facial reconstruction to the target individual, tests indicated that *recognition* frequencies of that facial reconstruction were low (Stephan and Henneberg 2006).

It may be the case that the use of assessors to capture perceptual similarity of the facial reconstructions with the target individual may not be the best way to assess the statistical significance of the Procrustes Analysis. Conversely, it can be argued that using Procrustes Analysis may not be the best method to capture perceptual similarity in the assessors especially in an unfamiliar scenario, which is discussed below. This appeared to be reflected in case study 3, where, Procrustes Analysis did not capture perceptual similarity in the assessors in an unfamiliar scenario but it appeared to do so in a familiar set up.

Familiar vs. Unfamiliar Scenario

As discussed in Chapter IV, for the most part familiar faces are recognized with little effort, and changes in expression or viewpoint pose no real problem, even from very low quality images. However, people are not so good at recognizing or matching, unfamiliar faces (Hancock et al 2000).

The above scenarios are especially significant since the assessors in the present study evaluating the reconstructions were not familiar with the subjects, and hence when they were asked to *match* the reconstructions to the ante-mortem (target) photograph by using resemblance tests, this was not the same process that occurs when the general public is asked to potentially “identify” someone that they know (Ellis et al 1979; Burton et al 1999; Hancock et al 2000), see also *Facial saliency of different features In Chapter IV Psychology of Facial Recognition*).

Unfamiliar scenarios are not a true representation of the forensic situation, where the facial reconstruction of the subject will potentially aid with the recognition and hence the identification process, by somebody known to them. It may therefore be argued that the unfamiliar testing scenario may adversely compromise the true positive identification rates of facial reconstructions especially in a face pool set-up when compared to a forensic situation, (Stephan and Henneberg 2001).

However, whilst, it would have been more appropriate to study recognition and identification of facial reconstructions in a familiar scenario, it would have been of course very difficult and unethical to achieve this in the present study, since people who are extremely familiar with the victims are often family or very close friends who would be further traumatized by complicating their bereavement process (Vanezis M. and McGee 1999: Stephan and Henneberg 2001; Stephan and Arthur 2006). This was especially true in the present study because of the sensitive and delicate nature of the work, especially since the individuals in the study did not die in natural circumstances, but rather in sudden, unexpected and disturbing scenarios, and sometimes even involving homicide investigations. However, there are some examples in the literature where such tests could, or have been conducted by using a living individual as the basis for facial reconstruction. Neave (Prag and Neave 1997) for example, was provided with a copy of a skull made from CT scans of a volunteer's head using a computer-controlled laser-cutting technique, a process known as stereo-lithography (Hjalgrim et al 1995). The resulting reconstruction produced from this copy was reported to be sufficiently similar to the individual for Neave to recognize the volunteer. Although very promising, however, this was not conducted on a large scale to be definitive. *(See also Figure 3.8 in chapter III, to see an example where 3-D computerised facial reconstruction of the Iceman was performed by the present author using a stereo-lithograph of the mummified skull).*

It would be most interesting to conduct a large study to evaluate this familiar scenario based on CT scans of skulls from living persons. However, because there is some radiation risk involved in scanning subjects, it would be necessary to address the ethical and safety issues involved. This research therefore, may be incorporated with other diagnostic procedures, such as CT scans obtained from patients already undergoing maxillo-facial surgery. Nevertheless, at the time the present study commenced, the present author had no access to CT scans of skulls of living persons, and digitising them into the then existing software was not viable, practical or ethical.

Although resemblance ratings studies (Krogman 1946; Suzuki 1973; Helmer et al 1993; Prag and Neave 1997; Stephan 2002a; Wilkinson and Whittaker 2002) and the modified resemblance ranking tests described here, suffer to some extent from the fact that assessors are unfamiliar with the targets; this is to some extent modified through the use of *resemblance tests* rather than *recognition* measures. In a study by Stephan and Henneberg (2006) despite apparent similarity of the facial reconstruction to the target individual, tests indicated that *recognition* frequencies of that facial reconstruction were low when tested in a face pool study (presented in both simultaneous and sequential face array), and consequently the authors concluded that high resemblance does not necessitate recognition. Consequently, they indicated that, had the facial reconstruction in their study been advertised to the public, it *may* have resulted in successful recognition for whatever reason, probably as a result of chance, and not to a specific and purposeful facial recognition, given the results of their recognition frequencies.

However, the authors fail to note that the tests on facial *recognition* frequencies in the face pool study were performed by assessors that were *unfamiliar* with the photographs of both the target and non target individuals. By contrast, if the facial reconstruction had been publicized in the media, then the reconstruction could have been potentially identified by someone *familiar* to the target individual that resembled the facial reconstruction. Interestingly, although the reconstruction received low *recognition* frequencies in the face pool set up, the same reconstruction received high *resemblance* ratings by the assessors, indicating that the perceptual similarity using resemblance tests may not be as adversely compromised in an unfamiliar scenario as much as *recognition* frequencies are when tested in a face pool set up.

The E-Fit™ criteria in the present study

The addition of E-Fit™ features in the context of the present study, compared with the use of kits such as Identikits, Photofit, CD-Fit™ and E-Fit™ as described in Chapter IV, Psychology of Facial Recognition in the section *Facial Features and Configuration,* is significantly different. The systems described there are used differently, for example, individual features are pieced together without taking into consideration the interrelationship or configuration between these features; eyewitnesses are asked to select from a number of sets of eyes, noses, mouths, etc. in order that they might conjure up an image with a reasonable likeness to the suspect, instead of a more holistic approach. Memory of faces is more holistic than just individual features that are put together as a jigsaw puzzle to construct a face, as advocated by the kits used in this fashion. It was also demonstrated that the interrelationships or configuration between the features are just as important as the features themselves, and that when facial features are left unchanged, but the distances between them are altered, even subtly, this can have a dramatic effect on the appearance of a face (Hosie et al 1988).

However, the E-Fit features applied to the facial reconstructions in the present study such as adding "opened eyes", is different because the morphology of the original features and the configuration between features on the facial reconstructions are respected when adding the E-Fit features to them.

The implications of adding E-fit features onto a facial reconstruction, as in the present study, is significant, not only with regard to respecting the configuration between features and the morphology and dimensions of these features, but the *colour* of some these characteristics and *style* and *texture* regarding the E-Fit hair feature is also important.

For example, even in a familiar forensic scenario, the implications of soft tissue features in the forensic facial reconstruction set up may compromise the recognition process by confusing the general public who would otherwise, potentially, "identify" someone that they knew, had it not been that the eyes and hair were the *wrong* colour or the hairstyle was totally different on the reconstructed image or model compared with the target individual (Wilkinson 2004).

Similarly, Stephan and Henneberg (2006) found that when they produced two photographs of the same reconstruction, one without hair and eyebrows and one with *inaccurate* hairstyle and texture in comparison to the target individual's photograph, although both photographs of the facial reconstruction scored similar and high resemblance rating results, the facial reconstruction without hair tended to be rated higher with regard to perceptual similarity compared to the facial reconstruction with *inaccurate* hair; indicating that adding *inaccurate* hair style and type/texture can reduce the resemblance rating results even when added on the same reconstruction and even, potentially compromise the recognition/identification process in a familiar scenario.

Some of the factors that influenced the assessors' reconstruction choices in experiment 1 also seemed to apply to the assessors' selection of E-Fit images in experiment 3. For example, some E-Fit choices were made on a more holistic approach of resemblance/perceptual similarity matching, as advised. Some, however, like in the assessors' reconstruction assessment, made their E-Fit choices on specific shapes of soft tissue feature(s) alone, e.g. *shape* of the lips, noses, ears, and one assessor even mentioned that one of the reasons for their choice of E-Fit was that the hair on that image looked more like the hair on the target individual's photograph, even though all the E-Fit features were as identical (as possible) on all the four E-Fit images in that case study.

The ante-mortem photographs

Experiment 1

As discussed in chapter V, although the author had access to the ante-mortem photographs in each case study, they were not used for the preparation of experiment 1, i.e. the selection of the ten facial templates for producing the reconstruction stage (see above - *Selection of the facial templates and their limitations)***.**

Subsequently, once the preparation stage of experiment 1 was completed, each of the ante-mortem photographs was briefly examined in order to be able to reproduce, as closely as possible, the correct corresponding (frontal) viewpoint of the ten reconstructions to the target photograph in each case study. This was important not only because it was important to control as many variables as possible, but also because the equivalent viewpoint between the ante-mortem photograph and the ten corresponding reconstructions needed to match as closely as possible before any evaluations by the assessors could be made. As discussed in the section *viewpoint,* in chapter IV, *Psychology of Facial Recognition,* recognition or matching is compromised when the view point differs between the two images to be examined, especially when presented in an unfamiliar scenario, such as the present study.

Experiment 2

In experiment 2, the Procrustes Analysis testing, there was no requirement for the handling of the ante-mortem photographs; the only requirement for the Procrustes Analysis in this experiment was the mathematical comparison of the skull to the ten facial templates in each of the case studies.

Experiment 3

The ante-mortem photographs were crucial in this experiment, since the E-fit hair feature was replicated from the target ante-mortem photograph in four of the selected reconstructions per case study, as discussed before in the previous chapters. Since the E-fit hair feature was as identical as possible in all four of the E-Fit images in each of the case studies, this controlled as many variables as possible, and allowed the assessors to concentrate more on the facial form and features (see study by Helmer et al (1993) in the section below *Reliability, validation, and success* for similar comparisons with the present study).

With regard to implementing the "identical" E-Fit "opened" eyes feature on the four E-fit images per case study, this was more of the result of respecting the dimensions and morphology of the reconstructed eyes rather than simulating the eyes from the ante-mortem photograph.

Experienced versus inexperienced observers

Given the reasons for the assessors' reconstruction and E-Fit choices, it is possible that these results may have been different had the observers in the present study been more *experienced* at viewing these images and were more familiar with facial reconstruction techniques. Stephan and Henneberg (2006) argue that whilst current facial reconstruction methods are widely recognized as "last resort techniques" it may be that observers have no realistic idea of what criteria they should be basing their decisions on and this may contribute to decreased facial reconstruction success. On the other hand, it may be that assessors who are more familiar with facial reconstruction techniques and appreciate their strengths and weaknesses/limitations may be able to identify the reconstructed faces more accurately than lay individuals, for they know what to look for and what to use in their identification decisions. For example, as discussed, it is well appreciated that the shape of the nose and particularly nasal tip and shape of the vermillion borders of the lips cannot be predicted well on the reconstructed faces Stephan and Henneberg (2006). Expert observers may therefore know which features to use and which features to pay *less* attention to, if they are made aware of what these methods can realistically achieve.

This was the rationale that the present author had in mind in the present study when advising the assessors at what features to pay more attention to and which characteristics to pay less attention to in both the reconstruction and E-Fit assessments experiments, experiments 1 and 3 (Appendix 2 Figures 2.1; 2.2).

It was undoubtedly difficult for *inexperienced/lay individuals* to fully appreciate the criteria used in facial reconstruction especially, in an unfamiliar scenario, particularly when comparing the ante-mortem photograph of the target individual to ten facial reconstructions (exp 1), or to four E-fit reconstructed images (exp 3) which can only have varied levels of similarity to the ante-mortem photograph.

Undoubtedly, this aspect of experienced versus inexperienced observers requires further attention. If prior experience does influence accuracy, then rates could be improved by training viewers.

Reliability, validation, and success

Attempts to assess the accuracy of facial reconstructions have been made by various investigators in the field. There was a great deal of early scepticism regarding the reliability of facial reconstruction in establishing identity (Suk 1935, Brues 1958). Montagu (1947) went as far as to voice such concern, that he felt facial reconstruction could do ‘real harm’ and should be abandoned. As techniques and knowledge improved, facial reconstruction was granted more credibility by some investigators (Krogman 1943; Stewart 1979; Rathbun 1984).

Until recently facial reconstruction techniques had not been subjected to any systematic evaluation or testing. One of the main problems with 3-D reconstructions is the quality of the results and the replication. It is of course necessary to have a degree of replication for the purpose of scientific reliability.

The first attempts at scientific testing were by Snow et al (1970) and the results were sufficiently encouraging to renew interest in the field. In an innovative experiment, Snow et al (1970) asked volunteers to compare clay reconstructions performed on two skulls with ante-mortem photographs of those subjects and six others of the same sex, age and ancestry. These participants were then asked to pick the closest match to the photograph for each of the two reconstructions. Results were varied: whilst 26% chose the correct photograph for the first subject, a 67 year old female, 67% chose the correct photograph for the second individual, a 36 year old male. Vanezis et al (1989) compared a computer generated 3-D facial reconstruction with that created by the sculpture technique. They showed that the computer method for reconstructing a face is not only feasible but has the advantage over the manual technique of speed and flexibility. Nevertheless, the technique was found to be far from perfect. Further facial thickness data needed collecting and the method required evaluation using both known controls skulls and later unknown remains.

Gerasimov (1971) reported that virtually all of approximately 140 reconstructions carried out could be identified. Snow et al (1970), Gatliff and Snow

(1979) claim a 70% success rate, and Caldwell (1981) reported a 50% success rate. Krogman (1946), Gerasimov (1949), Ilan (1964), Suzuki (1973), Rathbun (1984), Rhine (1984), and Phillips et al (1996) reported other successful cases. Whilst Haglund and Reay (1991) have found that facial reconstruction had not been useful in identifications made during the Green River investigation, the authors nevertheless, felt that this may have been due to the difficult circumstances surrounding the case.

Similarly, Helmer et al (1993) implied that the success rate could be due to the particular circumstances and other findings associated with the case, rather than the quality of the facial reconstruction. This led to a double blind trial in which two independent examiners reconstructed 12 skulls. These reconstructions were evaluated by comparing them to each other and to photographs of the individuals. During the course of the experiment, it became apparent that each reconstructor developed his own personal style of reconstruction. The results were varied: 38% of the reconstructions showed close resemblance to the original, 17% approximate resemblance, and 42% slight resemblance. In one case there was no resemblance at all. The reconstructions reflected the age, sex, and facial profile of the individuals. However, features such as mouth and eyes were more inconsistent in their accuracy, whilst the nose was reconstructed, for the most part, approximated to close resemblance.

The most consistent area of agreement in resemblance was found to be in relation to the facial profile. Marked characteristics on the skull relating to age, body constitution or illness were the most easily reproduced. The authors finally remark that all available information on the identity of the individual should be used to ensure a realistic and accurate reconstruction. This includes hair length or form, facial hair, any illnesses, lifestyle and social standing.

However, Helmer et al (1993) conceded that without hair information, the accuracy of the reconstructions may not only have been further reduced, but the authors also report that a replica without hair has a very limited resemblance to most individuals. Therefore, all the 24 facial reconstructions in their study had hair types and styles that bore very good similarity to their respective target individual.

Some have suggested that hair style and hair type may in some cases be retouched later by some artists/scientists after the identification was made to make the facial reconstruction appear more accurate (Tyrrell et al 1994; Stephan and Henneberg 2001).

Similarly, it is implied by Stephan and Henneberg (2001) that by adding hair to the reconstructions in the Helmer et al (1993) study that very closely resembled that of the target photographs, that the hair was therefore replicated from the corresponding photographs, and that this in some way was a flawed procedure because this naturally improved the accuracy of the reconstructions. Whilst, one appreciates that adding the correct and accurate hair style and type on a reconstruction undoubtedly improves perceptual similarity (Stephan and Henneberg 2006), nevertheless, when one controls this variable in all the corresponding reconstructions per skull, such as in this study by Helmer et al (1993), then this is valid under these circumstances. Perhaps the authors' mistake was not to clarify this and to assume one took this for granted.

The study above by Helmer et al (1993) follows similar principles to the present study, where, the same hair styles and type were replicated from the target ante-mortem photograph to each of the four corresponding reconstructions per case study, in order to minimise any variables between the resulting four E-fit images, thus allowing the observer to concentrate on the facial form and facial features.

In a more comprehensive test, Stephan and Henneberg (2001) used a face pool comparison method to test the accuracy in facial reconstruction instead of the usual resemblance ratings technique. The authors tested this by assessing whether building faces from dry skulls are recognized above chance rates. Four skulls were reconstructed using four commonly used methods of facial reconstruction: i) 2-D drawing American facial reconstruction, ii) 2-D computer "FACE" assisted American facial reconstruction, iii) 3-D sculpting American facial reconstruction and iv) 3-D sculpting combination facial reconstruction. The resulting sixteen facial reconstructions were judged by 37 assessors of varying ages. The aim of the experiment was for the assessors to attempt to identify the target individual of each facial reconstruction from a face pool of ten photographed faces. Only one facial reconstruction resulted in true positive identification rates above chance at statistically significant levels. It was concluded from these results that it is rare for facial reconstructions to be sufficiently accurate to allow identification of a target individual above chance. The results of 403 incorrect identifications made out of the 592 identification scenarios showed in this experiment that facial reconstruction should not only be considered a highly inaccurate and unreliable forensic technique, but also suggest that facial reconstructions are not very useful in excluding individuals to whom skeletal remains may not belong. Given the large number of false positives and the identification of many non-target individuals (70% of all non-target individuals) the authors report that evidence from this experiment supports suggestions from others (e.g. Gatliff 1984; Caldwell 1986) that facial reconstruction should not be used to positively identify individuals but only be used to prove tentative identification when all other methods have failed. However, an important point to note is that the reconstructor had little experience at the time of the conducted study.

Furthermore, Stephan and Henneberg (2001) concede, that the identification rates of target individuals, from a few face pool comparison studies, although rather low, have tended to be above chance. It was therefore, concluded that although facial reconstruction techniques despite being inaccurate, may actually work.

In addition, and this is a very important point, since potentially it only requires *one* person to believe they recognize the facial reconstruction and report it to the appropriate law enforcement agencies for a tentative identification to be made, the facial reconstruction technique may therefore be useful by promoting interest and narrowing the field for further identification techniques to be used. In this experiment by Stephan and Henneberg (2001), thirteen of the sixteen facial reconstructions (81%) could therefore be potentially positively identified in a forensic situation since they were identified by at least one individual. Before commencing and being part of the present study, this was probably the scenario with regard to case studies 3 and 4 when their respective facial reconstructions aided with their identification after appearing on Crimewatch UK.

Following this principle, where 81% could therefore be potentially positively identified as quoted by Stephan and Henneberg (2001) above, in theory the actual percentage could be higher in a forensic situation, since the above testing was performed in an unfamiliar scenario, where the assessors were not familiar with the target and non-target photographs; whereas, in a true forensic situation, facial recognition/identification is performed in a familiar situation, where the individual is well known to friends and relatives.

Moreover, Stephan and Henneberg (2001) and Stephan (2002a) claim that since successful facial reconstruction depends on the facial reconstruction being *recognizable* as the target individual, then face pool comparison appears to be a more reliable method of assessing the accuracy of facial reconstructions than resemblance ratings; since resemblance ratings measure the similarity between the reconstruction and the target individual and not the ability of the target individual to be “recognised” from a group of faces, it is claimed therefore that resemblance ratings is not to be an optimal test and may even, be flawed.

However, these conclusions are rather tenuous because it may have been more decisive to include in their studies - in addition to the face pool setup testing - the assessors' evaluation of the resemblance rating between the reconstruction and the corresponding target individual in each instance. In this manner more objective comparisons could have been made between the two different modes of testing the accuracy of facial reconstructions, as was the situation in their latter studies (Stephan and Henneberg 2006; Stephan and Arthur 2006).

Additionally, it is claimed that resemblance studies do not account for the facial reconstructions resemblance to non-target individuals, which may be in theory greater than the target individual's.

In contrast, however, to Stephan and Henneberg (2001) and Stephan (2002a) findings, Wilkinson and Whittaker (2002) concluded that resemblance ratings are in fact an accurate method for facial reconstruction assessment. Five reconstructions were produced by Wilkinson and a photographic face pool of ten individuals of similar age, sex and ethnic origin was set up including the five targets. Fifty assessors chose the face from the face pool that most resembled each reconstruction; the same assessors were then asked to rate the reconstructions as a resemblance of the target individuals using a five-point scale, from no resemblance to great resemblance. In this study a 'foil' comparison was included, where the photograph of the individual was not the target, but an unrelated face from the face pool. The overall similarity ratings for the reconstructions and the target individuals were 14% great, 42 close, 28% approximate, 14 % slight and 2% no resemblance. The foil comparison was rated as 48% slight and 40% no resemblance. All five reconstructions were rated as close overall resemblances to the identified individuals.

One of the problems with resemblance techniques such as rating tests mentioned elsewhere, and resemblance ranking testing as in the present study, is that it is still rather a subjective evaluation of perceptual similarity, where different observers have different apparent reactions to the same reconstruction (see also section above *Experienced versus inexperienced observer).* The method of face pool identification was therefore developed to assess the accuracy of facial reconstruction techniques because, it was felt that assessors tended to look for errors rather than similarities in the reconstruction when comparing it to the target individual (Wilkinson 2004).

In their study above, Wilkinson and Whittaker (2002) also assessed the accuracy of facial reconstructions using a face pool set up. Five reconstructions were produced using five juvenile skulls between the ages of eight and eighteen by employing tissue depth data from White British children (Wilkinson 2002). A photographic face pool of ten juvenile white females was set up, which included the five target individuals. The fifty assessors were asked to select the face that most resembled each reconstruction from the face pool. The five reconstructions were all correctly identified as the most frequently chosen face from the face pool, with the mean hit rate of 44%, and all hit rates well above chance (10%). Consequently, Wilkinson and Whittaker concluded that it was possible to create a good likeness of an individual following the Manchester method of facial reconstruction.

Similarly, Van Rensburg (1993) used 11 judges to attempt to identify 15 reconstructions in a face pool set up. The author used the unorthodox method of employing death masks for comparisons with the reconstructions. A total of 40% (33% above chance) of the reconstructions were correctly identified when direct comparison was made between one death mask with one reconstruction at a time; and 17 % (10% above chance) were correctly identified when comparisons were made using one reconstruction with all the death masks. 12% above chance were correctly identified when comparisons were made between all the reconstructions and all the death masks, with 19% above chance for the average correct identification.

Nevertheless, face pool studies have some disadvantages of their own, for example, the photographs used in a face pool study have to stand up to various biases; such as: (i) the images may be biased, e.g. there may be slight variation in resolution or pose that may cause the assessors to chose one photograph more than the other photograph; this is referred to as type I bias (Stephan and Henneberg 2006); and (ii) the selected distracter faces/foils might be biased, e.g. if the distracters are highly dissimilar to the target individual, the target face may be disproportionately selected in comparison to the other faces, and since the plausibility of the distracter faces/foils is extremely low then these foils may effectively not be functional; referred to as type II bias (Stephan and Henneberg 2006).

Furthermore, face pool comparisons (Snow et al 1970; Stephan and Henneberg 2001; Stephan 2002a) are disadvantaged since the assessors are often unfamiliar with the target individuals. Unfamiliar scenarios, as discussed above are not a true representation of the forensic situation, where potentially, the facial reconstruction of the subject/victim is recognised by somebody well known to them. It is basically, a different process when recognition/identification occurs in a familiar scenario, to that of an unfamiliar situation such as that of a face pool study, where, the assessors are selecting a facial image in an array of photographs including the target individual and distracter faces /foils to correspond to the facial reconstruction. Even in the context of high quality images, research shows that matching unfamiliar faces is difficult (Kemp et al 1997; Bruce at al 1999), even when viewpoint and facial expressions are closely matched (Bruce et al 2001).

It may therefore, be argued that the unfamiliar testing scenario may adversely compromise the true positive identification rates of facial reconstructions compared to those in a forensic situation. Therefore, face pool studies/face array cannot claim to be true *recognition* tests, as has been the case in some studies (Stephan and Henneberg 2001; Stephan and Arthur 2006; Stephan and Henneberg 2006), unless the face pool study is conducted in a familiar scenario, where the target individual and distracter faces/foils are known to the assessors. *Recognition* of the facial reconstruction implies being identified by someone well known to the target individual. This may have a bearing on the fact that, although some studies (Stephan and Arthur 2006; Stephan and Henneberg (2006) demonstrate that facial reconstructions receive favourable resemblance ratings, they may not however, be correctly *recognized* above chance rates.

Although resemblance ratings studies (Krogman 1946; Suzuki 1973; Helmer et al 1993; Prag and Neave 1997) and the modified resemblance ranking technique, as in the present study, suffer to some extent with the familiar/unfamiliar scenario since assessors are unfamiliar with the target individual, however, they are not being asked to "identify/recognise" the facial reconstruction of the subject from a group of photographs (face pool) but merely indicate the similarity between the photograph of the individual with a reconstruction/s. (See *Suggestions for future research* points no's 3 and 6).

Basically there are three scientific issues that need to be addressed in order to establish reliability, validation, and success in facial reconstruction. First reliability refers to the accuracy of the results, and is an area in which some progress has been made in relation to how different experimenters in the field can produce a similar face from the same skull. For example in some cases two different experimenters using the same methodology have produced similar results. However, in several experimental cases, similar faces (from different skulls) have been replicated by the same experimenter (Quatrehomme and Işcan 2000). Since the same techniques of facial reconstruction produced different identification results for different skulls, Stephan and Henneberg (2001) found it difficult to assess which method was best in a face pool study when comparing four different methods of facial reconstructions: - 2-D drawing American facial reconstruction; 2-D computer "FACE" assisted American facial reconstruction; 3-D sculpting American facial reconstruction and 3-D sculpting combination facial reconstruction. It may be that different methods of reconstruction are optimum in different cases. In their study Stephan and Henneberg (2001) found that only the 3-D sculpting American method produced true positive identifications at a statistically significant rate above chance, and therefore, may be considered more accurate in contrast to the other techniques in their study. However, of those tested, the 3-D sculpting combination method was the only technique to produce identifications of all target individuals, and thus may be considered superior despite the fact that target faces were not recognized above chance rates and many non-target individuals were identified. (NB three-dimensional computer generated reconstruction techniques like the present study were not included in the report by Stephan and Henneberg 2001).

Secondly, validation refers to the faithfulness of the results where the aim is to achieve a "good" resemblance between the deceased during life and the final reconstruction. This aspect of facial reconstruction has been randomly accomplished and sometimes seems to be inconsistent even with the same experimenter suggesting a 'hit and miss' result (see above for success rates). Not surprisingly, there seems to be more successful identification cases published in the literature (Suzuki 1973; Cherry and Angel 1977; Gatliff and Snow 1979; Rathburn 1984; Perper et al 1988; Philips et al 1996; Prag and Neave 1997; Farrar 1997; Stoney and Koelmeyer 1999) compared to cases with limited to no success cases in identification (Haglund and Reay 1991; Prag and Neave 1997). It may be that success cases are given more attention, while many cases that have had no conclusive results go unreported. However, this second validation issue with regards to reliability and how *successful* a facial reconstruction is may be due, in part, to the reasons given below in the third measure of success.

The third issue and level measure of success is the 'usefulness' of the facial reconstruction in generating the lead in identification of the person in question. To further compound the meaning of 'success' in the facial identification scenario, there have no doubt been facial reconstructions that have helped lead to identification without clearly resembling the deceased (Haglund 1998). The resemblance does not in some cases seem to be critical for identification to occur. It may be that the additional information presented with the reconstruction to the public yielded a clue to the actual identity of the person in question, such as hair, jewellery, and clothes found at the scene. It would therefore, seem that ‘success’ can be achieved even with poor resemblance between the facial reconstruction and the deceased. Conversely, a reconstruction bearing close resemblance to the deceased may not stimulate leads to identification; a facial reconstruction resemblance success may be an investigative identification failure (Stephan and Henneberg 2006).

Lack of identification of the facial reconstruction when publicised in the media may be due to a number of reasons, for example, the deceased may be from a different area and insufficient exposure to the target population in the news by the media was the problem (Ubelaker 1992; Haglund 1998).

Furthermore, in the ‘success’ cases reported above by practitioners in the facial reconstruction field it is not always clear if the ‘successes’ were due to the facial reconstruction stimulating the identification process or that the identification would have occurred anyway regardless of the role of the reconstruction. According to Neave (1980) *‘It appears that success of facial reconstruction depends as much upon the circumstances pertaining to the subject under investigation as it does upon the accuracy of the technique’*. Similarly, Gatliff and Snow (1979), report that “*this difference in success rate seems to be more of a function of the general interest of the public and press than of the quality of the reconstruction itself*”. Examples of such circumstances are: in newly missing persons where public awareness is not high for stimulating leads for identification; or a previous attempted lead that has finally resulted in identification; or even inadequate investigation procedure prior to the facial reconstruction to stimulate interest and lead to a potential identification. Other issues that may influence identification are the demographics of the deceased, such as the exposure of the victim to the rest of the community. For example if the deceased was a recluse or transient or very mobile then identification becomes very difficult even in a large target population. Similarly, elderly males of low socioeconomic class where circumstances suggest death was accidental or natural do not evoke a lot of public interest at the time of discovery, and even less as time elapses and memories fade when the facial reconstruction is circulated (Gatliff and Snow 1979). On the other hand somebody becoming long established in a community increases the odds for recognition even in a small target population (Haglund and Reay 1991). Similarly, cases involving young female homicide victims whose clothing or dental work suggest they came from a more affluent socioeconomic status than average receive a wider and attentive audience which increases the chances of recognition (Gatliff and Snow 1979). Clearly, wider dissemination of the reconstructed image through the various mass media will increase the chances of identification. However, if the person disappeared as a child and is not found dead until later in adult life, then the likelihood of recognition is slim, even when a great deal of attention is received from the media (Vanezis et al 2000). Furthermore, the size of the population of missing persons is relevant to the success of recognition. For example, if there are only a few missing persons in a small community, then the chance of success are much greater than where there is a large number of missing persons to choose from in a large metropolis. Occasionally, relatives or others who knew the deceased may, for various reasons, not wish to come forward (Vanezis et al 2000).

Another important issue with respect to the success of a facial reconstruction by leading to a positive identification may be due more to the psychological implications of facial recognition rather than to morphological *accuracy* of the reconstructed face. For example relatives and friends sometimes report that the reconstructed image did not look like the victim because it had a smiling expression and in reality the victim never smiled, or the victim had very distinctive dimples, which cannot be predicted from the skull morphology. This is why the present author prefers a slightly open mouth to a smiling face to exhibit these unique characteristics or anomalies in facial reconstructions (*See also Chapter IV, Psychology of Facial Recognition and footnote 1 in chapter III).*

Similarly, issues that can further compromise the success of the facial reconstruction being positively identified (in a familiar scenario) are the complex areas of predicting the colour of the features on the face such as hair and eyes, unless, information is presented at the scene to suggest otherwise, such as persisting hair being found on the body. This is why the present author prefers to exhibit the final reconstructed images in greyscale and not in colour which can complicate the recognition and the identification process. For example the reconstructed image may be as morphologically and cephalometrically faithful to the skull as possible but the recognition/identification process may be compromised because the eye or hair colour was not quite right according to relatives. Wilkinson (2004) agrees with this and she states that an observer may think he recognises the individual, but then thinks, '*Oh, it can't be Uncle Bob because he had blue eyes.*'

Similarly, aspects like ponderal status and pilosity are difficult to predict because of the continual changes in these areas due to ageing, disease and personal preference. (Quatrehomme and Işcan 2000). *See also "Preliminary collection of data for facial reconstruction."*

Lastly, researchers such as Rhine (1984) have expressed views in relation to the legal implications of facial reconstructions and discuss how their work was admissible in demonstrating the chain of evidence to the court. In relation to the status of facial reconstruction in court, it is appreciated that it is an investigative tool which facilitates identification and goes no further. Therefore its use as evidence should be limited to demonstrating the continuity of the investigative process by demonstrating how a putative identification is achieved by recognition of the reconstructed face which then paves the way to a definitive identification using confirmatory methods such as DNA profiling or dental records (Vanezis et al 2000).

In conclusion, as discussed at length previously regarding the lack of knowledge of the exact relationship between the skull and corresponding soft tissue at every single point, it is acknowledged by most that facial reconstruction is not an *absolute* science but necessitates the employment of some artistic licence and a degree of subjectivity to produce the final results (Gatliff 1984; Stephan 2003b).

Furthermore, traditional methods used in facial reconstruction techniques to predict some facial features such as, ear height (Farkas et al 1987), eyeball projection (Stephan 2002b; Wilkinson and Mautner 2003), mouth width (Stephan 2003; Wilkinson et al 2003), position of the superciliare (Stephan 2002c), and nose projection and pronasale position (Stephan et al 2003; Rynn and Wilkinson 2006) position have been shown to be unreliable when tested. Some have even expressed such strong objections as to state that in the light of these findings, it does not seem surprising that facial reconstruction may be an inaccurate technique that rarely achieves its objective of purposeful identification of the target individual (Montague 1947; Stephan and Henneberg 2001; Stephan et al 2003).

However, it may be that facial reconstruction may achieve success through methods other than facial recognition, such as, background information (Haglund and Reay 1991), or chance (Stephan and Henneberg 2001). It may even be, that the actual facial reconstruction helps to promote public interest in the case, which in turn may promote extra leads without the facial reconstruction necessarily, being recognised (Ubeleker 1993; Stephan 2003; Stephan et al 2003)

However, one does carry a certain responsibility with this principle because it is feared that once the ‘wrong’ face is presented to the public then the true identity may not be achieved because they are mislead and may even result in a misidentification (Vanezis et al 2000). Nevertheless, if the general characteristics of the deceased (age, sex, ancestry, build, height, ante-mortem health status and personal artefacts) are presented through the mass media to the general public, then there is a greater opportunity for determining identification (Quatrehomme and Işcan 2000).

The future of facial reconstruction techniques

As discussed above, it has become more evident that facial reconstruction is based on only a small set of number of known relationships. Some practitioners have suggested that these are probably inadequate for reconstructing a complete face that is representative of the individual to whom the skull belonged (Gatliff 1984; Stephan 2003b Stephan et al 2003; Stephan and Henneberg 2006). Therefore, if faces built from skulls are to closely represent the target individuals it is clear that further work is needed in order to derive a comprehensive understanding of the natural soft-to hard-tissue relationships.

For reasons of versatility, speed and accessibility, three-dimensional (3D) computer techniques will probably become the method of choice for reconstructing faces from skulls; furthermore they enable easily made indirect measurements (for example, measures that pass through bone planes); the calculations of many variables in a very short time (Stephan et al 2003).

Research using the present 3-dimensional computerised laser facial reconstruction techniques (using the same hardware as the present study but with older software), was conducted by a colleague, Gonzalez-Figueroa (1996). The author used 19 casts of unidentified Chilean persons. The facial reconstructions were then compared with 22 photographs of the missing persons believed to be those belonging to the casts of the original skulls. The facial reconstructions were then compared by computerised anthropometry and photogrammetry, as well as using perceptual similarity/resemblance between the reconstructions and the photographs. Finally, DNA sampling from skeletal remains and relatives was used to try and confirm identification. It was shown that the facial proportion indices were statistically significantly different in 45% of the cases and not statistically different in 55% of the cases. Although showing some promise, the results were not conclusive. It has to be noted, however, that the researcher did her best under very difficult circumstances, using photographs of victims and casts of the missing persons sent over from Chile, which were of very poor quality.

Wilkinson (2004b) describes a ‘virtual’ sculpture as a method of computerised facial reconstruction. The skull surface is imported into the Freeform program as an STL file from surface scans, CT scans or X-rays. Tissue depth pegs are attached on the skull surface at the appropriate anatomical sites using a computerised measuring tool in a similar way to the manual method. This is also similar to the present study’s method of locating the tissue thicknesses pegs on the digitised skull. Pre-existing eyeball shapes are placed in the orbits at the appropriate position and depth; facial muscles, which can be altered in shape and size by utilising 3D deformation tools, are then placed on the skull from a bank of facial muscles and parotid glands. Ears and noses produced from surface scans can be imported onto the model and customised to relate to the bony structure of the skull. Muscles and features can be sculpted and the final sculptural stage is the addition of a skin layer over the muscle structure, whilst adding the appropriate subcutaneous fat and skin layers. Finally aesthetic finishing touches are added, such as hair, eye and skin colour. Although this technique is computerised, it follows the methodology, as the title implies, that it imitates the manual technique of clay facial reconstruction. However, it should have the advantages of versatility, speed and accessibility like some other computerised techniques. Results published by Wilkinson et al (2006) suggest that this computerised modelling system for facial reconstruction produces a recognizable individual, with good levels of accuracy and reliability; the greatest errors were exhibited on the nasal tip and ears for the male reconstruction and the nasal alae and ears for the female reconstruction in their pool study. However, these features have traditionally been problematic for facial reconstruction practitioners as discussed elsewhere in this chapter. Interestingly, the authors suggest that the results of this study may be more successful than in previous computerised studies because the surface scan models in the face pools were very similar in appearance to the facial reconstructions, thus forcing the observers to compare morphology when attempting to identify the target individual from the face pool without becoming distracted by skin tones and textures (Bruce et al 1991). This highlights an interesting point regarding the present study where, although all the ten facial reconstructions in experiment 1 and the four E-Fits in experiment 3, were all of very similar appearance to each other, they were not similar to the photograph of the target individual in each case study in terms of skin tone and texture; this might have distracted the assessors when making their choices in the study.

Additionally, some novel computer techniques are being pioneered which claim to remove much of subjectivity of manual reconstructions, such as the introduction of new software tools, for instance, Reality Enhancement/Facial Approximation by Computational Estimation (RE/FACE), which uses models derived from the CT scans and do not require manual measurements or placement of landmarks (Turner et al 2005). The authors claim that because this method does not require tissue-depth tables and can be tailored to specific racial categories by adding CT scans it removes much of the subjectivity of manual reconstructions. However, the remaining issues for validation for this research with regards to quantitative and qualitative measures are yet to be established.

Similarly, Vandermeulen et al (2006) present a fully automated procedure for craniofacial reconstruction, using a database of reference head CT scans. All reference images are automatically segmented into head volumes (enclosed by the external skin surface) and bone/skull volumes, both represented by a single distance transform (sDT) map. The reference skull sDTs are (non) linearly warped to the target skull sDT and this warping is applied to all reference skin sDTs. A linear combination of warped reference skin sDTs is proposed as the reconstruction of the external skin surface of the target subject. Although the results on the pilot reference database (N=20) show the feasibility of this approach, however, further investigations are required to proof the validity of the concept, as acknowledged by the authors themselves.

Another technique(Claes et al 2006), proposed by the same group of authors as the latter study above is a statistical model of combined soft tissue-depths (De Greef et al 2005; 2006) and complete facial surfaces, which can be used for 3D computerized forensic facial reconstructions. This study by Claes et al (2006) is not too dissimilar to the author’s present study; however, Claes et al (2006) claim that they reduce the template bias by using a flexible statistical model of a dense set of facial surface points, combined with an associated sparse set of skull-based landmarks. This statistical model is constructed from a facial database of (N=118) individuals and limits the reconstructions to statistically plausible outlooks. The statistical face model was learned from a database of complete 3D facial surfaces with 52 skull-landmarks and the tip of the nose, by applying principal component analysis (PCA). The result of this PCA is a geometrically averaged facial template, which is calculated together with a correlation-ranked set of statistically independent modes of principal variations.

In some ways, the techniques and software of Claes et al (2006) are similar to those used in the present study (Vanezis et al 2000). Skull-based landmarks of the template model are fitted to the corresponding landmarks indicated on a digital copy of the skull. However, the mathematical warping process differs, where they use a "minimal bending thin-plate spline (TPS)-based deformation". Furthermore, the authors in this study have used PCA to obtain an *average* facial template to act as the mask and reconstruct over the skull obtained. However, like the previous computerised studies, and as stated by the authors themselves (Claes et al (2006), although this technique shows promise, it still needs to be further validated and improved in some areas.

It would seem that the above 3D computerised techniques, although, pioneering in their own right and showing great promise, nevertheless, still need further improvement and validating before they become established as the method of choice for reconstructing faces from skulls.

Conclusions drawn from Experiment 4

Further work was carried out involving anthropometric comparisons as discussed in Chapter V.

Matching landmark lines between images appeared to be only of limited value due to the images not being aligned at exactly the same viewpoint and to a certain extent, the magnification. It should be appreciated that the thesis was based on recognition and was not an anthropometric study. Therefore precise alignment of viewpoints was not a requirement of the study. Hence using the same data from the study, although images were in the frontal view, they were not aligned to the accuracy acceptable for an anthropometric study as there was no requirement to so. It would appear that, although there is some correspondence between the discrepant distances and the first and second ranked reconstructions, no firm conclusions could be drawn from this technique and therefore does not help us to understand the way observers made their choices. Further tests would need to be carried out (beyond the scope of the thesis) to reach any firm conclusions.

Proportion indices results also reflected similar issues. However, there appeared to be some correspondence between the Procrustes Analysis' first and second order (from the four reconstructions chosen by the observers: ranks 1, 2, 3 and 10) and the proportion indices. Further tests (beyond the scope of the thesis) would be needed to be carried out to reach any firm conclusions.

It is not possible therefore to draw any definitive conclusions as to whether there was any relationship between the further anthropometric work carried out and the observers' best three (and last reconstruction choice), or with the Procrustes Analyses ranking order of the same four reconstructions in each of the case studies.

Conclusions

1. From the results obtained in this study, there is insufficient evidence to reject the Null Hypothesis (Ho), which states that: ***Having met the anthropological criteria for a given skull, whichever of the facial templates that conform to these criteria chosen from the database to be reconstructed over the skull, the final reconstructed faces do not show sufficiently discriminatory differences between them. Thus, there is no effect on the identification process, regardless of the appearance of the reconstructed image or, secondly, of the image which upon which facial features have been added, using the E-FIT system.*** Since the correlation between the ranks of the assessors' reconstruction choice and the ranks of the Procrustes Distances (Analysis) in each case study are not statistically significant. Nevertheless, a number of interesting observations have been made generally as discussed below.

2. Although not statistically significant, as mentioned above, it would seem however, that in some of the case studies, the mathematical approach using Procrustes Analysis does seems to capture *some* perceptual similarity in human observers.

3. There appears to be good agreement in most of the case studies between the two psychological resemblance tests using the two different sets of assessors in experiment 1 and 3 (reconstruction choice and reconstruction/E-Fit choice, respectively).

4. An electronic identikit system such as E-Fit, although not statistically significant, appears to improve perceptual similarity in human observers, provided the limitations of adding facial features are addressed. With regard to the present study, this may be because E-Fit features may have "humanised" the facial image, thus forcing the human eye to look at the image in a more holistic way, rather than concentrating on just specific isolated areas on the face, and as observed, it is actually very difficult to identify faces when only the three-dimensional shape is presented (Bruce et al 1991).

5. Taking into account all the aspects of this study, one obvious setback, which undoubtedly had an effect on the outcome of the results, was that the assessors were examining and comparing unfamiliar faces. It would have been desirable to use reconstructions of persons known to the assessors rather than asking them to assess unfamiliar persons. Using observers in an unfamiliar set-up probably contributed to having such a diverse spread of the results. It should be appreciated that, although the study was designed in this way for practical and ethical reasons, it nevertheless does not truly reflect the real operational forensic scenario.

6. The study involved an assessment of facial reconstruction using 3-D computer graphics, comparing psychological resemblance testing with a mathematical approach. This technique thus makes it possible in theory, to choose the closest available cephalometrically facial template for the reconstruction. However, this technique uses a more holistic matching and this did not necessarily take into account individual differences of isolated features. Furthermore, as stated elsewhere, recognition/matching is a much more complex process and even a face which may be generally morphologically similar to the person in life may not capture perceptual similarity in human observers, especially in an unfamiliar scenario. It is not certain that recognition/identification will always occur even when the facial reconstruction bears good resemblance to the target individual (Stephan and Henneberg (2006), although, this was tested in an unfamiliar setting. It may therefore be that perceptual similarity in assessors using resemblance tests conducted in an unfamiliar scenario may not be the best way to assess the statistical significance and accuracy of the Procrustes Analysis. Consequently, Procrustes Analysis may not be the most appropriate method to capture perceptual similarity in human observers.

7. The present study was conducted to reflect normal forensic practice of pre-selecting the most *typical* and *standard* facial templates to act as the base for facial reconstruction in the same way that other computer software programs *average* a final facial template. However, it would also have been possible, although it would not have reflected forensic practice, to have used ten very *diverse* facial templates within the anthropological category dictated by the

skull to examine if Procrustes Analysis captured perceptual similarity in assessors.

8. Given the reasons for their reconstruction and E-Fit choices, one wonders whether, had the assessors been more *experienced* at looking at these images, and were more familiar with facial reconstruction techniques, would the results perhaps have been any different. It was undoubtedly difficult for *inexperienced/lay individuals* to fully appreciate the criteria used in facial reconstruction, especially, in an unfamiliar scenario, particularly when comparing a directly positively identified ante-mortem photograph of the target individual to ten facial reconstructions (exp 1), or to four E-fit reconstructed images (exp 3) which can only have varied levels of similarity to the ante-mortem photograph. Observers therefore will only know which features to use and which features to pay *less* attention to, if they are made aware of what these reconstruction methods can realistically achieve. Undoubtedly, this aspect of experienced versus inexperienced observers demands further attention, because if it does have an effect on the concepts of facial reconstruction techniques, then accuracy rates could be improved by educating the public as to what facial reconstruction techniques can and cannot realistically achieve.

9. No firm conclusions can reached from the further anthropometric work carried out to assess whether there was a relationship between facial measurements and observer choices, since the thesis was based on recognition studies and images were not formatted for anthropometric assessment.

10. Finally, it is important to define the factors affecting the outcome of facial reconstructions in terms of their probability of success in identification. Such factors include the efficiency in the investigation of missing persons, demographic factors, lifestyle of deceased, etc., as discussed above.

Suggestions for future research

1. A study using *experienced* observers who are more familiar at looking and appreciating the strengths and limitations of facial reconstruction techniques – such as the ones mentioned below in point 2 - when assessing the accuracy of facial reconstruction.

2. An investigation to assess the very complex relationship between some soft tissue facial features and how they correlate with the underlying skull, such as the *shape* of the nose and nasal tip and *shape* of lips, and how they affect the outcome of the reconstruction and consequently how it captures perceptual similarity in human observers in an unfamiliar scenario and ultimately recognition and identification in a familiar set up. With regard to the present study's software, provisions should be considered to include a *virtual* anatomical landmark to indicate the tip of the nose (Claes et al 2006) and nasal projection and not rely on existing landmark sites on the skull and the corresponding facial template sites alone to predict this projection. This can be accomplished by perhaps being guided by some of the existing canons to predict the nasal tip. However, although this may give a better indication of the nasal projection on the final reconstruction, unfortunately, this will not give a better suggestion regarding the *shape* of the pronasale.

3. A study using assessors that may be familiar with the subjects in question, e.g. a study based on CT scans of skulls from living persons. This aims to test the recognition by familiarity of the subject in question by friends and relatives. However, because there is some radiation risk involved to the subject undergoing the CT scans, since a number of good CT scans need to be obtained for this purpose, therefore, this research, may be incorporated with other diagnostic procedures, such as CT scans obtained from patients undergoing oral and Maxillofacial surgery.

4. A larger study to further assess the value of Procrustes Analysis in forensic facial reconstruction in a *familiar* scenario, such as incorporating the study

based on CT scans of skulls from living persons, as mentioned above in *point (3).* If proved successful, Procrustes Analysis may then be used initially to refine the choice of facial template(s) and exclude extreme shapes rather than as a check to assess closeness to the already selected faces.

5. Similar to the above suggested study with regard to facial template selection, another investigation to be considered is one using principal component analysis (PCA), to establish the most statistically *suitable* facial template for the purpose of 3-dimensional computerized facial reconstruction. The statistical face model is learned from a database of complete 3D facial surfaces with all the existing skull-landmarks and the tip of the nose, by applying principal component analysis (PCA). The result of this PCA is a geometrically *averaged* facial template, which is calculated together with a correlation-ranked set of statistically independent modes of principal variations or face-specific deformations that capture the major changes or differences between facial outlooks and their skull-based landmarks in the database (Claes et al 2006).

6. Another examination to be considered is testing and evaluating the facial reconstructions in a face pool set-up (Stephan and Henneberg 2001), where the target photograph is included amongst other photographs (foils) that do not belong to the individual. This is to establish if and how often the target photograph is selected in each case study as a match to the reconstruction(s). As resemblance techniques do not account for the facial reconstructions' resemblance to non-target individuals, which may be greater in theory, than the target's photograph. However, unlike previous face pool studies using unfamiliar scenarios (Stephan and Henneberg 2001, 2006; Stephan and Arthur 2006), the present author is suggesting performing the face pool study in a familiar set-up, for example, incorporating the circumstances mentioned above in point 3, which will have more significance at establishing how *accurate* and how *successful* the recognition/identification process is in a familiar set-up; in theory, a face-pool study performed in a familiar scenario should imitate as closely as possible a forensic situation, especially if undertaken in a *sequential* face array rather than a *simultaneous* testing as in the previous face pool studies. Research in eyewitness identification from lineups has been shown that

although not greatly affecting the rate of correct identifications, sequential face array set ups were found to dramatically reduce the number of false positive identifications (false positives). It has been proven in experimental studies that such testing has the effect of forcing the witness to make a judgment on each member of the parade in turn. (Wells et al 1998; Davies and Valentine 1999; Stephan and Henneberg (2006).

7. Future anthropometric research, which is beyond the scope of this study, could possibly shed further light on the relationship between the observers' recognition study, Procrustes Analysis and 2-D anthropometric measurements.

Section III

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Appendices

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Appendices

Appendix 1

Soft Tissue Thicknesses
and
Cranio-Facial Landmarks

Figure A 1.1
Soft tissue thicknesses at Cranial Landmarks

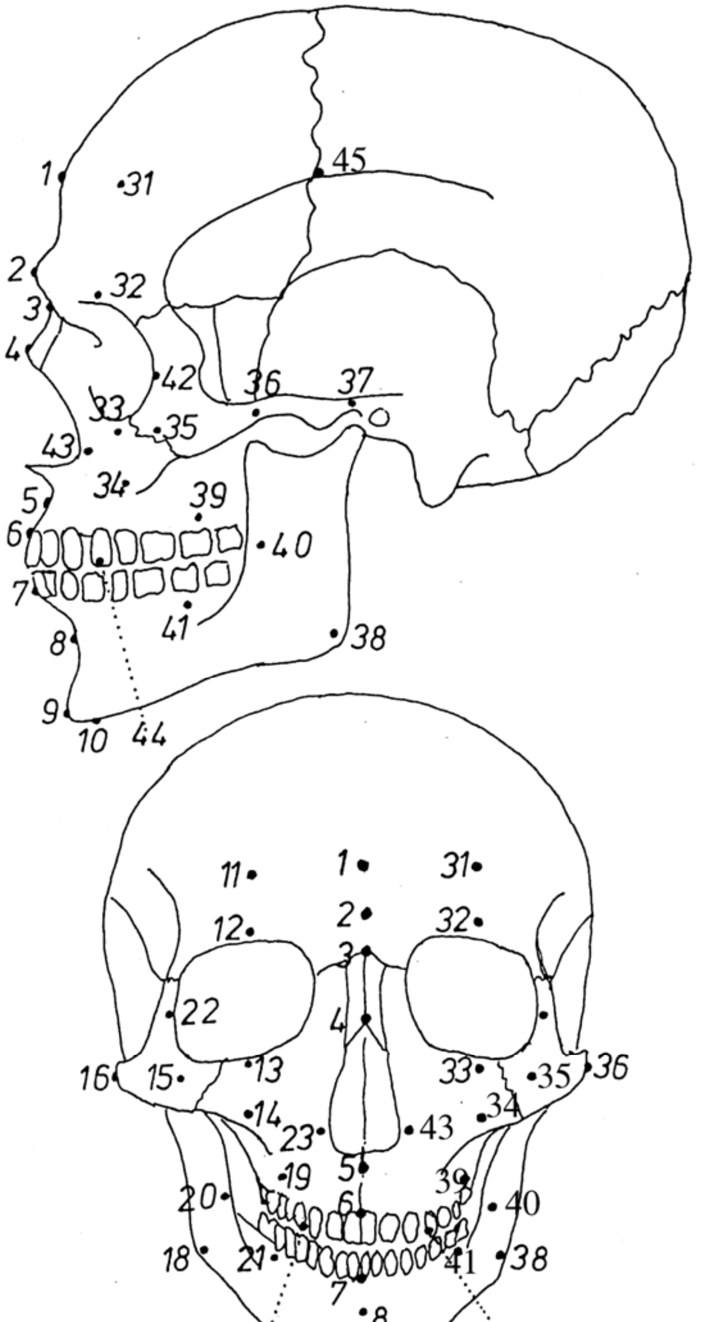


Figure A1.2
Facial Landmarks

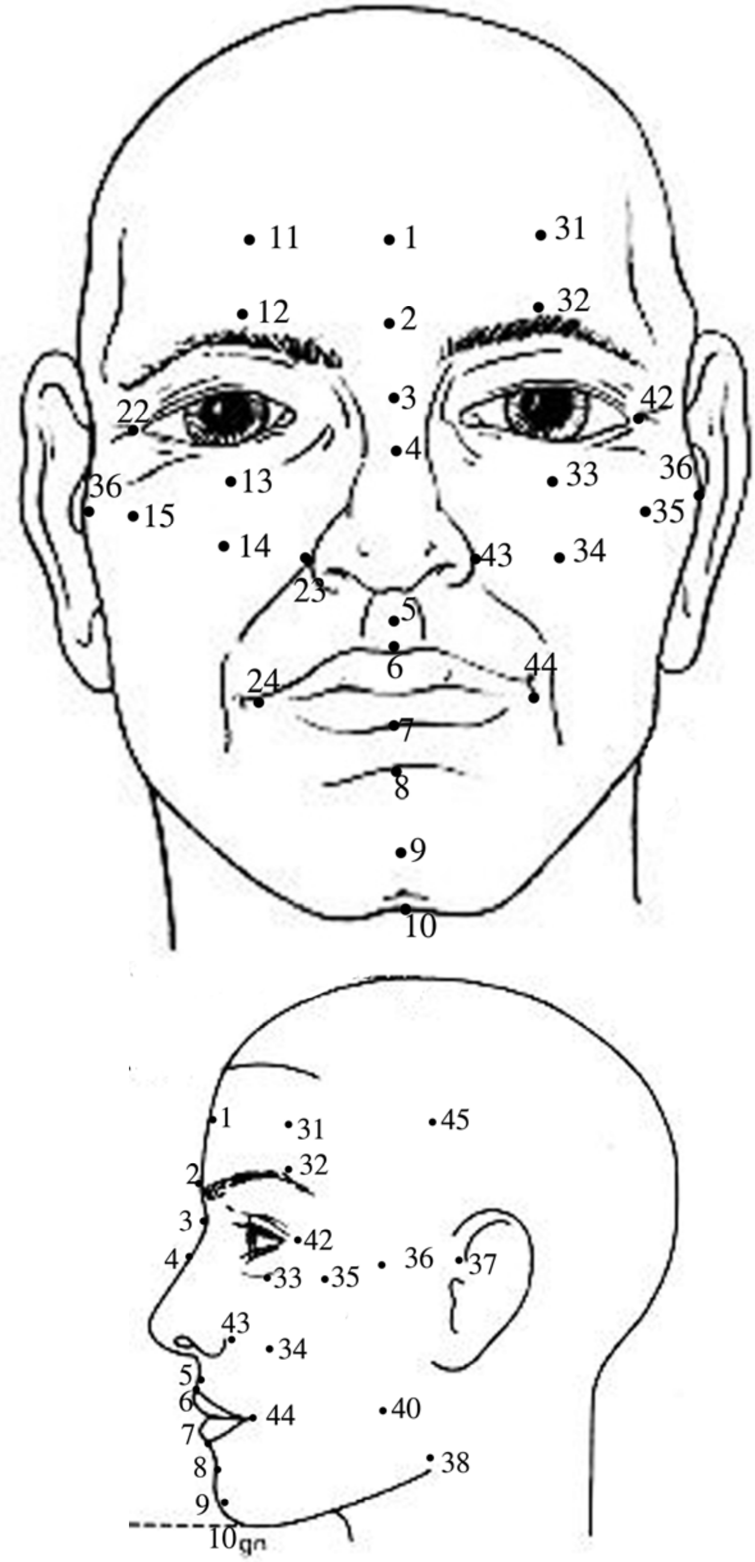


Figure A1.3

Female Caucasian Soft Tissue Thicknesses at Cranial Landmark Locations

(Thin, average and obese thicknesses in mm; after Rhine and Moore 1982; Helmer 1984)

Mark1.ID=1
Mark1.Name=Supraglabella
Mark1.Thicknesses: thin=2.50 average= 3.50 obese= 4.25

Mark2.ID=2
Mark2.Name=Glabella
Mark2.Thicknesses: thin=4.00 average=4.75 obese=7.50

Mark3.ID=3
Mark3.Name=Nasion
Mark3.Thicknesses: thin=5.25 average=5.50 obese=7.00

Mark4.ID=4
Mark4.Name=Rhinion
Mark4.Thicknesses: thin=2.25 average=2.75 obese= 4.25

Mark5.ID=5
Mark5.Name=Subspinale
Mark5.Thicknesses: thin=5.00 average=8.50 obese=9.00

Mark6.ID=6
Mark6.Name=Supradentale
Mark6.Thicknesses: thin=6.25 average=9.00 obese=11.00

Mark7.ID=7
Mark7.Name=Infradentale
Mark7.Thicknesses: thin=8.50 average=10.00 obese=12.25

Mark8.ID=8
Mark8.Name=Supramentale
Mark8.Thicknesses: thin=9.25 average=9.50 obese=13.75

Mark9.ID=9
Mark9.Name=Pogonion
Mark9.Thicknesses: thin=8.50 average=10.00 obese=14.25

Mark10.ID=10
Mark10.Name=Gnathion
Mark10.Thicknesses: thin=3.75 average=5.75 obese=9.00

```
Mark11.ID=11
Mark11.Name=Right Frontal Eminence
Mark11.Thicknesse: thin=2.75 average=3.50  obese=5.00

Mark12.ID=12
Mark12.Name=Right Supraorbital
Mark12.Thicknesses: thin=5.25 average=7.00  obese=10.00

Mark13.ID=13
Mark13.Name=Right Suborbital
Mark13.Thicknesses: thin=4.00  average=6.00 obese=8.50

Mark14.ID=14
Mark14.Name=Right Maxillo- Malar (Inferior Malar)
Mark14.Thicknesses: thin=7.00 average=12.75 obese=14.00

Mark15.ID=15
Mark15.Name=Right Malar- Orbit Level
Mark15.Thicknesses: thin=6.00 average=10.75 obese=14.75

Mark16.ID=16
Mark16.Name=Right Zygion
Mark16.Thicknesses: thin=3.50 average=7.50 obese=13.00

Mark17.ID=17
Mark17.Name=Right Supraglenoid
Mark17.Thicknesses: thin=4.25 average=8.00 obese=10.50

Mark18.ID=18
Mark18.Name=Right Gonion
Mark18.Thicknesses: thin=5.00 average=12.00 obese=17.50

  **Mark19.ID=19
Mark19.Name=Right Supra M2
Mark19.Thicknesses: thin=12.00 average=19.25 obese=23.75

Mark20.ID=20
Mark20.Name=Right Occlusal Line
Mark20.Thicknesses: thin=11.00 average=17.00 obese=20.25

**Mark21.ID=21
Mark21.Name=Right Sub M2
Mark21.Thicknesses: thin=9.50 average=15.50 obese=18.75


Mark22.ID=22
Mark22.Name=Right Ectoconchion
Mark22.Thicknesses: thin=4.20 average=5.40 obese=6.60
```

```
Mark23.ID=23
Mark23.Name=Right Alare Level (Supracanine)
Mark23.Thicknesses: thin=9.45 average=11.22 obese=12.90

Mark24.ID=24
Mark24.Name=Right Cheilion Level (Canine-1st Premolar)
Mark24.Thicknesses: thin=13.50 average=18.60 obese=23.70

Mark25.ID=25
Mark25.Name=Right Stephanion
Mark25.Thicknesses: thin=2.00  average=4.00 obese=5.00

Mark26.ID=31
Mark26.Name=Left Frontal Eminence
Mark26.Thicknesses: thin=2.75 average=3.50 obese= 5.00

Mark27.ID=32
Mark27.Name=Left Supraorbital
Mark27.Thicknesses: thin=5.25 average=7.00 obese=10.00

Mark28.ID=33
Mark28.Name=Left Suborbital
Mark28.Thicknesses: thin=4.00 average=6.00 obese=8.50

Mark29.ID=34
Mark29.Name=Left Maxillo- Malar (InferiorMalar)
Mark29.Thicknesses: thin=7.00 average=12.75 obese=14.00

Mark30.ID=35
Mark30.Name=Left Malar-Orbit Level
Mark30.Thicknesses: thin=6.00 average=10.75 obese=14.75

Mark31.ID=36
Mark31.Name=Left Zygion
Mark31.Thicknesses: thin=3.50 average=7.50 obese=13.00

Mark32.ID=37
Mark32.Name=Left Supraglenoid
Mark32.Thicknesses: thin=4.25 average=8.00 obese=10.50

Mark33.ID=38
Mark33.Name=Left Gonion
Mark33.Thicknesses: thin=5.00 average=12.00 obese=17.50

**Mark34.ID=39
Mark34.Name=Left Supra M2
Mark34.Thicknesses: thin=12.00 average=19.25 obese=23.75
```

Mark35.ID=40
Mark35.Name=Left Occlusal Line
Mark35.Thicknesses: thin=11.00 obese=17.00 obese=20.25

**Mark36.ID=41
Mark36.Name=Left Sub M2
Mark36.Thicknesses: thin=9.50 average=15.50 obese=18.75

Mark37.ID=42
Mark37.Name=Left Ectoconchion
Mark37.Thicknesses: thin=4.20 average=5.40 obese=6.60

Mark38.ID=43
Mark38.Name=Left Alare Level (Supracanine)
Mark38.Thicknesses: thin=9.45 11.22 12.90

Mark39.ID=44
Mark39.Name=Left Cheilion Level (Canine-1stPremolar)
Mark39.Thicknesses: thin=13.50 average=18.60 obese=23.70

Mark40.ID=45
Mark40.Name=Left Stephanion
Mark40.Thicknesses: thin=2.00 average=4.00 obese=5.00

** Landmark not generally used. (Only 36 landmarks are commonly used from the above 40).

Figure A1.4

Male Caucasian Soft Tissue Thicknesses at Cranial Landmark Locations

(Thin, average and obese thicknesses in mm; after Rhine and Moore 1982; Helmer 1984)

Mark1.ID=1
Mark1.Name=Supraglabella
Mark1.Thicknesses: thin=2.25 average=4.25 obese=5.50

Mark2.ID=2
Mark2.Name=Glabella
Mark2.Thicknesses: thin=2.50 average=5.25 obese=7.50

Mark3.ID=3
Mark3.Name=Nasion
Mark3.Thicknesses: thin=4.25 average=6.50 obese:7.50

Mark4.ID=4
Mark4.Name=Rhinion
Mark4.Thicknesses: thin=2.5 average=3.00 obese=3.50

Mark5.ID=5
Mark5.Name=Subspinale
Mark5.Thicknesses: thin=6.25 average=10.00 obese=11.00

Mark6.ID=6
Mark6.Name=Supradentale
Mark6.Thicknesses: thin=9.75 average=9.75 obese=11.00

Mark7.ID=7
Mark7.Name=Infradentale
Mark7.Thicknesses: thin=9.50 average=11.00 obese=12.75

Mark8.ID=8
Mark8.Name=Supramentale
Mark8.Thicknesses: thin=8.75 average=10.75 obese=12.25

Mark9.ID=9
Mark9.Name=Pogonion
Mark9.Thicknesses: thin=7.00 average=11.25 obese=14.00

Mark10.ID=10
Mark10.Name=Gnathion
Mark10.Thicknesses=: thin=4.50 average=7.25 obese=10.75

```
Mark11.ID=11
Mark11.Name=Right Frontal Eminence
Mark11.Thicknesses: thin=3.00 average=4.25 obese=5.50

Mark12.ID=12
Mark12.Name=Right Supraorbital
Mark12.Thicknesses: thin=6.25 average=8.25 obese=10.25

Mark13.ID=13
Mark13.Name=Right Suborbital
Mark13.Thicknesses: thin=2.75 average=5.75 obese=8.25

Mark14.ID=14
Mark14.Name=Right Maxillo-Malar (InferiorMalar)
Mark14.Thicknesses: thin=8.50 average=13.25 obese=15.25

Mark15.ID=15
Mark15.Name=Right Malar-Orbit Level
Mark15.Thicknesses: thin=5.00 average=10.00 obese=13.75

Mark16.ID=16
Mark16.Name=Right Zygion
Mark16.Thicknesses: thin=3.00 average=7.25 obese=11.75

Mark17.ID=17
Mark17.Name=Right Supraglenoid
Mark17.Thicknesses: thin=4.25 average=8.50 obese=11.25

Mark18.ID=18
Mark18.Name=Right Gonion
Mark18.Thicknesses: thin=4.50 average=11.50 obese=17.50

**Mark19.ID=19
Mark19.Name=Right Supra M2
Mark19.Thicknesses: thin=12.00 average=19.50 obese=25.00

Mark20.ID=20
Mark20.Name=Right Occlusal Line
Mark20.Thicknesses: thin=12.00 average=18.25 obese=23.50

**Mark21.ID=21
Mark21.Name=Right SubM2
Mark21.Thicknesses: thin=10.00 average=16.00 obese=19.75

Mark22.ID=22
Mark22.Name=Right Ectoconchion
Mark22.Thicknesses: thin=4.50 average=5.50 obese=6.55
```

```
Mark23.ID=23
Mark23.Name=Right Alare Level (Supracanine)
Mark23.Thicknesses: thin=10.10 average=12.35 obese=14.60

Mark24.ID=24
Mark24.Name=Right Cheilion Level (Canine-1stPremolar)
Mark24.Thicknesses: thin=15.30 average=18.50 obese=21.70

Mark25.ID=25
Mark25.Name=Right Stephanion
Mark25.Thicknesses: thin=2.00 average=4.00 obese=5.00

Mark26.ID=31
Mark26.Name=Left Frontal Eminence
Mark26.Thicknesses: thin=3.00 average=4.25 obese=5.50

Mark27.ID=32
Mark27.Name=Left Supraorbital
Mark27.Thicknesses: thin=6.25 average=8.25 obese=10.25

Mark28.ID=33
Mark28.Name=Left Suborbital
Mark28.Thicknesses: thin=2.75 average=5.75 obese=8.25

Mark29.ID=34
Mark29.Name=Left Maxillo-Malar (InferiorMalar)
Mark29.Thicknesses: thin=8.50 average=13.25 obese=15.25

Mark30.ID=35
Mark30.Name=Left Malar-Orbit Level
Mark30.Thicknesses: thin=5.00 average=10.00 obese=13.75

Mark31.ID=36
Mark31.Name=Left Zygion
Mark31.Thicknesses: thin=3.00 average=7.25 obese=11.75

Mark32.ID=37
Mark32.Name=Left Supraglenoid
Mark32.Thicknesses: thin=4.25 average=8.50 obese=11.25

Mark33.ID=38
Mark33.Name=Left Gonion
Mark33.Thicknesses: thin=4.50 average=11.50 obese=17.50

**Mark34.ID=39
Mark34.Name=Left Supra M2
Mark34.Thicknesses: thin=12.00 average=19.50 obese=25.00
```

Mark35.ID=40
Mark35.Name=Left Occlusal Line
Mark35.Thicknesses: thin=12.00 average=18.25 obese=23.50

**Mark36.ID=41
Mark36.Name=Left Sub M2
Mark36.Thicknesses: thin=10.00 average=16.00 obese=19.75

Mark37.ID=42
Mark37.Name=Left Ectoconchion
Mark37.Thicknesses: thin=4.50 average=5.50 obese=6.55

Mark38. ID=43
Mark38.Name=Left Alare Level (Supracanine)
Mark38.Thicknesses: thin=10.10 average=12.35 obese=14.60

Mark39.ID=44
Mark39.Name=Left Cheilion Level(Canine-1st Premolar)
Mark39.Thicknesses: thin=15.30 average=18.50 obese=21.70

Mark40.ID=45
Mark40.Name=Left Stephanion
Mark40.Thicknesses: thin=2.00 average=4.00 obese=5.00

** Landmark not generally used. (Only 36 landmarks are commonly used from the above 40

Figure A1.5

Facial Landmarks

Mark1.ID=1
Mark1.Name=Metopian

Mark2.ID=2
Mark2.Name=Glabella

Mark3.ID=3
Mark3.Name=Nasion

Mark4.ID=4
Mark4.Name=Nasale

Mark5.ID=5
Mark5.Name=Mid-philtrum

Mark6.ID=6
Mark6.Name=Labiale Superius (Upper Lip Margin)

Mark7.ID=7
Mark7.Name=Labiale Inferius (Lower Lip Margin)

Mark8.ID=8
Mark8.Name=Supramentale

Mark9.ID=9
Mark9.Name=Mental Protrubence

Mark10.ID=10
Mark10.Name=Gnathion

Mark11.ID=11
Mark11.Name=Right Frontal Eminence

Mark12.ID=12
Mark12.Name=Right Superciliare

Mark13.ID=13
Mark13.Name=Right Suborbital

Mark14.ID=14
Mark14.Name=Right Maxillo-Malar (InferiorMalar)

Mark15.ID=15
Mark15.Name=Right Malar-Orbit Level

```
Mark16.ID=16
Mark16.Name=Right Zygion

Mark17.ID=17
Mark17.Name=Right Supraglenoid

Mark18.ID=18
Mark18.Name=Right Gonion

**Mark19.ID=19
Mark19.Name=Right Supra M2

Mark20.ID=20
Mark20.Name=Right Occlusal Line

**Mark21.ID=21
Mark21.Name=Right Sub M2

Mark22.ID=22
Mark22.Name=Right Ectocanthion

Mark23.ID=23
Mark23.Name=Right Alare

Mark24.ID=24
Mark24.Name=Right Cheilion

Mark25.ID=25
Mark25.Name=Right Stephanion

Mark26.ID=31
Mark26.Name=Left Frontal Eminence

Mark27.ID=32
Mark27.Name=Left Superciliare

Mark28.ID=33
Mark28.Name=Left Suborbital

Mark29.ID=34
Mark29.Name=Left Maxillo-Malar (Inferior Malar)

Mark30.ID=35
Mark30.Name=Left Malar-OrbitLevel

Mark31.ID=36
Mark31.Name=Left Zygion

Mark32.ID=37
Mark32.Name=Left Supraglenoid
```

Mark33.ID=38
Mark33.Name=Left Gonion

**Mark34.ID=39
Mark34.Name=Left Supra M2

Mark35.ID=40
Mark35.Name=Left Occlusal Line

**Mark36.ID=41
Mark36.Name=Left Sub M2

Mark37.ID=42
Mark37.Name=Left Ectocanthion

Mark38.ID=43
Mark38.Name=Left Alare

Mark39.ID=44
Mark39.Name=Left Cheilion

Mark40.ID=45
Mark40.Name=Left Stephanion

** Landmark not generally used. (Only 36 landmarks are commonly used from the above 40).

Appendix 2

Scanning Forms

Figure A2.1 **Facial Reconstruction Form**

RECONSTRUCTIONS	ORDER OF PREFERENCE 1st	ORDER OF PREFERENCE 2nd	ORDER OF PREFERENCE 3rd
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Name:……....

Age:………………………………………………………………………………………

Sex:………………………………………………………………………………………

Occupation:………………………………………………………………………………

Department:………………………………………………………………………………

Telephone:……………………………………………………………………………..

E-mail:……………………………………………………………………………………

Guidelines for your facial reconstruction choice

In assessing the facial images you should pay particular attention to the general shape of the face, chin, forehead, cheeks and the general overall impression of their combination. Individual features such as the nose, lips and eyes are of lesser importance because the underlying skull provides insufficient information to enable these structures to be accurately reconstructed.

Give reasons for making your choices:

Figure A2.2 E-Fit Form

E-FIT	**PREFERENCE** (GIVE REASONS FOR CHOICE)
1	
2	
3	
4	

Name:……………………………………………………………………………………………………

Age:…………………………………………………………………………………………

Sex:…………………………………………………………………………………………

Occupation:…………………………………………………………………………………

Department:…………………………………………………………………………………

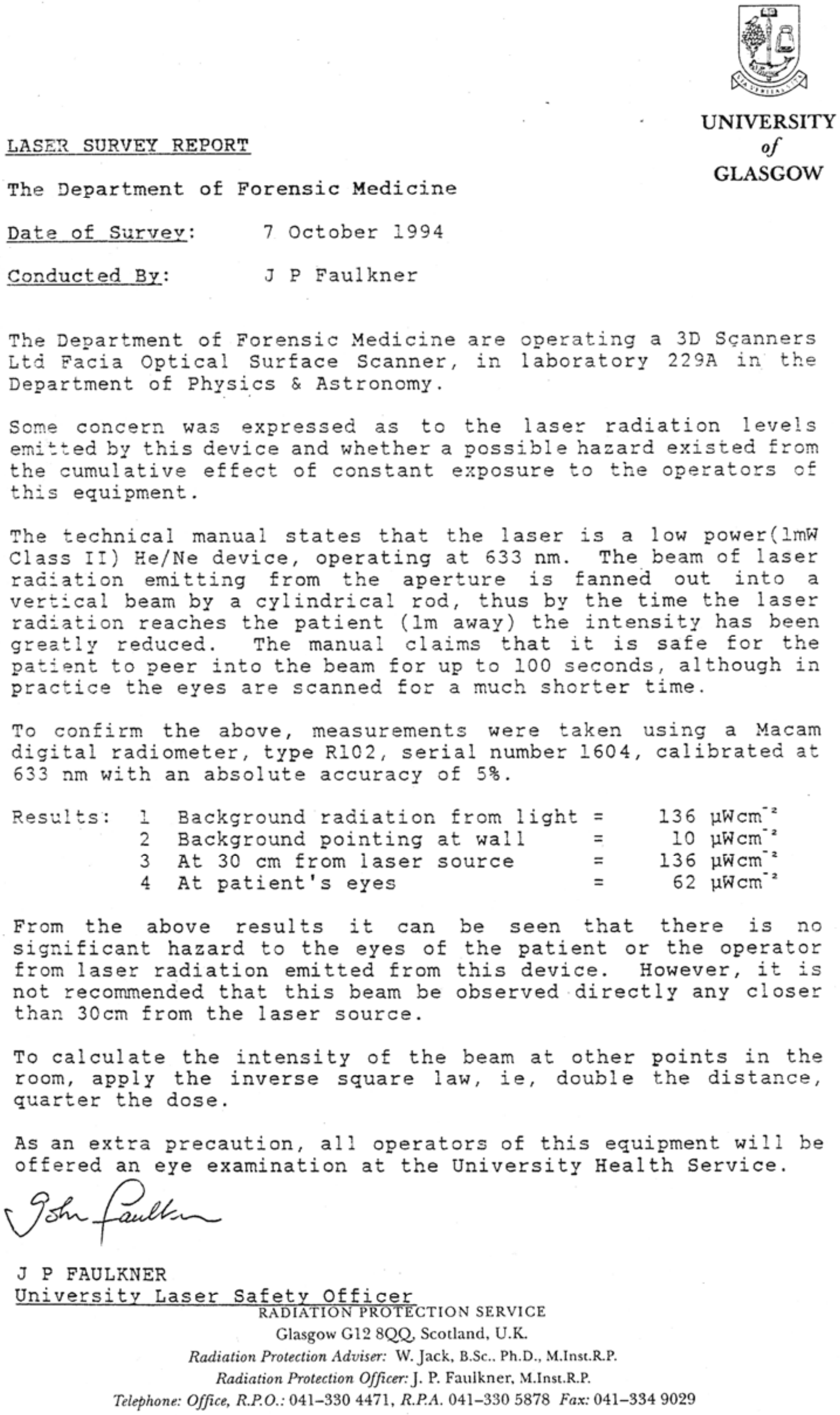
Telephone:………………………………………………………………………………..

Appendix 3

Laser Survey Report

Figure A3. 1

Laser Survey Report



UNIVERSITY
of
GLASGOW

LASER SURVEY REPORT

The Department of Forensic Medicine

Date of Survey: 7 October 1994

Conducted By: J P Faulkner

The Department of Forensic Medicine are operating a 3D Sçanners Ltd Facia Optical Surface Scanner, in laboratory 229A in the Department of Physics & Astronomy.

Some concern was expressed as to the laser radiation levels emitted by this device and whether a possible hazard existed from the cumulative effect of constant exposure to the operators of this equipment.

The technical manual states that the laser is a low power(1mW Class II) He/Ne device, operating at 633 nm. The beam of laser radiation emitting from the aperture is fanned out into a vertical beam by a cylindrical rod, thus by the time the laser radiation reaches the patient (1m away) the intensity has been greatly reduced. The manual claims that it is safe for the patient to peer into the beam for up to 100 seconds, although in practice the eyes are scanned for a much shorter time.

To confirm the above, measurements were taken using a Macam digital radiometer, type R102, serial number 1604, calibrated at 633 nm with an absolute accuracy of 5%.

Results:
1 Background radiation from light = 136 μWcm^{-2}
2 Background pointing at wall = 10 μWcm^{-2}
3 At 30 cm from laser source = 136 μWcm^{-2}
4 At patient's eyes = 62 μWcm^{-2}

From the above results it can be seen that there is no significant hazard to the eyes of the patient or the operator from laser radiation emitted from this device. However, it is not recommended that this beam be observed directly any closer than 30cm from the laser source.

To calculate the intensity of the beam at other points in the room, apply the inverse square law, ie, double the distance, quarter the dose.

As an extra precaution, all operators of this equipment will be offered an eye examination at the University Health Service.

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