AN INVESTIGATION INTO THE ACCURACY AND RELIABILITY OF SKULL-PHOTO SUPERIMPOSITION IN A SOUTH AFRICAN SAMPLE

BY

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Submitted in fulfillment of the requirements for the degree of Doctor of Philosophy

in the Health Sciences Faculty

University of Pretoria

Pretoria

2011

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DECLARATION

I declare that this thesis is my own unaided work. It is being submitted for the degree of Doctor of Philosophy at the University of Pretoria, Pretoria. It has not been submitted before for any degree or any examination in any other University.

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24th day of June 2011

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Abstract

One of the aims of forensic sciences is to determine the identities of victims of crime. In some cases the investigators may have ideas as to the identities of the victims and in these situations, ante mortem photographs of the victims could be used and identities established through skull-photo superimposition. The aim of this study was to evaluate the accuracy of a newly developed digital photographic superimposition technique on a South African sample of cadaver photographs and skulls, from the Pretoria Bone Collection.

Forty facial photographs were selected and for each photograph, 10 skulls (including the skull corresponding to the photograph) were used for superimposition. The investigator did not know which of the 10 skulls corresponded to the photograph in question. The skulls were scanned 3-dimensionally, using a Cyberware™ Model 3030 Colour-3D Scanhead scanner. Once scanned, the raw data for the skulls were 'cleaned' using Cysurf™ programme. The photographs were also scanned for superimposition in the 3D Studio Max programme. Superimposition in 3D Studio Max involves a morphological superimposition, whereby a skull is superimposed over the photograph and assessed for a morphological match. Superimposition using selected anatomical landmarks was also performed to assess the match.

A total of 400 skull-photo superimpositions were carried out using the morphological assessment and another 400 using the anatomical landmarks. In 85% of cases the correct skull was included in the possible matches for a particular photograph using morphological assessment. However, in all of these cases, between zero and three other skulls out of 10 possibilities could also match a specific photograph. In the landmark based assessment, the correct skull was included in 80% of cases. Once again, however, between one and seven other skulls out of 10 possibilities also matched the photograph. When using the morphological and landmark assessments combined, 97.5% of correct skulls were included in the list of possibilities, but between one and seven false positives per case were found.

This study indicates that skull-photo superimposition has limited use in the identification of human skeletal remains, but may be useful as an initial screening tool. Corroborative techniques should also be used in the identification process.

Abstrak

Een van die doelwitte van forensiese wetenskap is om die identiteit van slagoffers van misdaad te bepaal. In sommige gevalle het die speurders ‘n idee van die identiteit van die slagoffer en in sulke gevalle kan voordoodse fotos van die oorledene gebruik word om deur middel van skedel-foto-superimposisie die slagoffer te identifiseer. Die doelwit van hierdie studie was om die akkuraatheid van 'n nuwe digitale foto-superimposisie tegniek op 'n Suid-Afrikaanse groep van kadawer fotos en skedels uit die Pretoria Beneversameling te evalueer.

Veertig fotos van gesigte is gekies en vir elke foto is 10 skedels (insluitende die foto wat ooreenstem met die skedel) gebruik vir superimposisie. Die navorser het nie geweet watter van die 10 skedels ooreenstem met die betrokke foto nie. Die skedel is met 'n Cyberware™ Model 3030 Colour-3D Scanhead in drie dimensies geskandeer. Na skandering is die rou data van die model met Cysurf™ sagteware skoongemaak. Die fotos is ook geskandeer vir superimposisie met die 3D Studio Max program. Superimposisie in 3D Studio Max behels 'n morfologiese superimposisie, waar die skedel oor die fotos geplaas is en geëvalueer is vir morfologiese ooreenstemming. Superimposisie met die gebruik van geselekteerde anatomiese landmerke is ook gedoen om die ooreenstemming te evalueer.

'n Totaal van 400 skedel-foto-superimposisies is gedoen met gebruik van morfologiese evaluasie en ‘n verdere 400 is gedoen met gebruik van anatomiese landmerke. In 85% van die gevalle was die korrekte skedel ingesluit in die moontlike ooreenstemmings met ‘n spesifieke foto, waar morfologiese evaluering gedoen is. Maar, in al hierdie gevalle kon tussen nul en drie ander skedels uit 10 moontlikhede ook met ‘n spesifieke foto ooreenstem. Met die gebruik van die landmerk assessering, was die korrekte skedel in 80% van die gevalle ingesluit. Maar weerens, het tussen een en sewe ander skedels uit 10 moontlikhede ook met ‘n spesifieke foto ooreengestem. Waar die morfologiese en landmerk evaluasie tegnieke gekombineerd gebruik was, was 97.5% van die korrekte skedels ingesluit in die lys van moontlikhede, maar daar was tussen een en sewe vals positiewe per geval gevind.

Hierdie studie dui daarop dat skedel-foto-superimposisie beperkte aanwending vir die identifikasie van menslike oorskot het, maar wel nuttig kan wees as ‘n aanvanklike siftingsmetode. Stawende tegnieke moet ook gebruik word in die identifikasie proses.

Acknowledgments

There are many people who have made the completion of this PhD possible. I would firstly like to thank my supervisor Professor Maryna Steyn. Her guidance and advice throughout the writing of this dissertation is greatly appreciated. I would also like to thank Professor J. H. Meiring for his support for the duration of this project.

A big thank you must go to Ericka L'Abbe from the Department of Anatomy, University of Pretoria for her encouragement and support as well for helping me get journal articles when needed.

I am also hugely grateful to my boss Professor Jeanine Vellema and my colleagues in the Division of Forensic Medicine and Pathology, University of the Witwatersrand for their continued support and encouragement for the entire duration of this project. Jeanine always allowed me the time to carry out my research when necessary and listened to me "whine" about the difficulties always steering me in the right direction- for this I am eternally grateful.

Theunis Briers from the South African Police Services spent time with me initially allowing me to sit in with him whilst carrying out superimpositions for the Police so that I may learn how the technique is carried out in South Africa.

I would like to thank Andre du Plessis from the Video Production Department at the University of Pretoria who took an active interest in my research and spent precious time with me during his working hours establishing the superimposition technique and then teaching me the basics of the 3D Studio Max programme.

I am very grateful for the time Dr. Norman Sauer and his colleagues and students afforded me when I visited Michigan State University in March/April 2006. Dr. Sauer assisted me by teaching me how skull-photo superimposition is carried out in the USA and allowed me to observe cases being analysed in the laboratory. Dr. Sauer and his students welcomed me and treated me as one of their own making me feel like I have a family in the USA who I may visit again at any time.

Karen Bredenkamp and Petrie Marais from Ergotech trained me in scanning my skulls 3-dimentionally and were always available providing the assistance needed so that this project ran smoothly. I am very grateful for their time and efforts.

A big thank you must go to Alison Bentley from the Research Office at the University of the Witwatersrand for the courses she included me in so that the writing of this dissertation may go smoothly. This was particularly helpful, inspiring me to carry on when I thought I had no more in me.

To my friends Hellen Georgakis and Tanya Augustine for being there throughout all my studies always offering support and encouragement as well as reading rough drafts for this dissertation, thank you. I must also thank Carrie Bach, a new work colleague who has listened to me and assisted me when needed, I am very grateful for this.

I must thank my brother-in-law Kelvin du Preez for his help with editing images during the course of this project.

And finally the biggest thank you must go to my immediate family. Sadly, my father was only able to watch me start this project, however his advice helped me realise where I want to be...I will never forget that Daddy. To my mother who never faltered with her encouragement for me to keep reaching for my dreams...thanks Mum. To my twin sister Annwyn and younger sister Lee-Anne, thank you for being a constant shining light in my life and for helping me to keep my inner flame burning! To my husband Sean who has watched me finish one degree and start and finish another two after that, thank you for always being part of my research and particularly for spending time sitting with me assisting me with the 3D Studio Max programme...your patience was greatly appreciated. To my step daughters, Victoria and Emily, thank you for keeping me smiling! And finally, to my precious little daughter Allegra, you have made me the happiest person alive. Thank you for being so patient while mommy sits behind her “puter” working. I love you!

The University of Pretoria, the NRF and a NAVKOM grant provided financial support.

This thesis is dedicated to my mother (my rock) Giuditta Margaret Stafne and my late father Leif Manual Boyde Stafne (1949-2005), who helped me reach this point through their endless support and encouragement during my life.

A man ceases to be a beginner in any given science and becomes a master in that science when he has learned that he is going to be a beginner all his life.

A man should look for what is, and not for what he thinks should be.

Robin G. Collingwood & Albert Einstein

Chapter 1: Introduction

1.1. General

On the 30th May 2006 at 15h30, a gentleman collecting fire wood in a veldt in Moffat Park in the South of Johannesburg came across some bones. Not sure whether the bones were that of an animal or human, he contacted the South African Police Services (SAPS). The SAPS then contacted the Johannesburg Forensic Pathology Service who confirmed that the skeletal remains were indeed those of a human and not an animal. The site was cordoned off and the body was exhumed the following day (1, 2).

On the 1st of June, a post mortem examination was performed on the remains. The main post mortem examination findings were that the remains were those of a young adult, black female found in a grave measuring approximately 1.68 m in length and 45 cm to 50 cm in depth. The grave was covered with bricks and the soil was dry and contained a small amount of refuse material. The area in which the body was found had recently been burnt a in veldt fire (Figures 1.1 and 1.2) (1, 2).

Figure 1.1. Scene where the body was found. Note the burning in the area. **

Figure 1.2. Close up picture of how the body was observed in the shallow grave. **

** **Footnote:** Ethical clearance was obtained for this study (Ethics clearance number 32/ 2006), but in order to protect the identity of the individuals (cadavers) in the photographs, the ethics committee stipulated that only parts of faces may be revealed due to the sensitive nature of these images. For this reason, complete images of the individuals used in this study will not be shown anywhere. However, in this introduction section, unedited South African Police Service case images have been used without an attempt to protect the identity of the individual in the photographs, as this case has been finalized in the legal system. It was also agreed that the crime scene photographs would be used without editing in this thesis, but not used in any publications which may potentially arise from this study.

The deceased was found lying on her left side with her left arm under her body. A portion of her right arm and right ribs had been scorched. Signs of insect activity were evident on the remains and large amounts of maggots were present which were collected for further evaluation. A red school blazer was found with the deceased and partially covered her head. The skeletal remains had minimal decomposed, saponified tissue over the entire body. The skull was covered with long African hair with a head band over the vault of the skull. The skull and mandible were intact, all dentition was present, the hyoid bone was intact and the long bones that were identified showed no signs of ante mortem injury. Scorched remains of the right arm, hand, thoracic ribs and ilium were present (Figures 1.3 and 1.4) (1, 2).

The pathologist estimated that the remains were those of a black female, approximately between the ages of 16 and 20 years with an estimated living stature of 1. 65 to 1. 68 metres tall. Cause of death could not be ascertained due to the advanced stage of decomposition of the remains. The remains were sent to the anthropologists at the Department of Anatomy, University of Pretoria for Anthropological examination and an attempt to determine identity (1).

On analysis, the anthropologist established a similar demographic profile to the pathologist: a black female between the ages of 16 and 23 years with an estimated living stature of 162 cm. The anthropologist also found a peri-mortem fracture to the right tibia which probably occurred at the time of the young female’s death (1, 2).

Personal items such as the red school blazer and a key found in the blazer pocket were used as leading factors in the efforts to identify the young female. The school which had the red blazer as part of their uniform was contacted to enquire about any missing learners.

They confirmed that a learner was in fact missing and the possible identity of the deceased was thus investigated.

Figure 1.3. The appearance of the remains after removal from the shallow grave.

Figure 1.4. The victim lying on her left side, skeletonised, with African hair present.

A photograph of the missing young schoolgirl was obtained and skull-photo superimposition was performed on the skull, in order to establish identity (Figure 1.5) (1).

Figure 1.5. Results of the skull-photo superimposition (left) and a recent school photograph of the young girl shortly before her murder (right).

Figures 1.6 – 1.8 show the process of skull-photo superimposition as it is carried out to establish whether the skull and photograph match. A mixing device is used to provide the image of the skull and photograph together, with different sweeping manoeuvres to see if features of the skull and face are a match.

The biological mother of the missing schoolgirl was also approached for a DNA sample which was provided. Comparative DNA analysis and skull-photo superimposition proved the identity of the human remains to be those of the missing schoolgirl, beyond any doubt (1, 2).

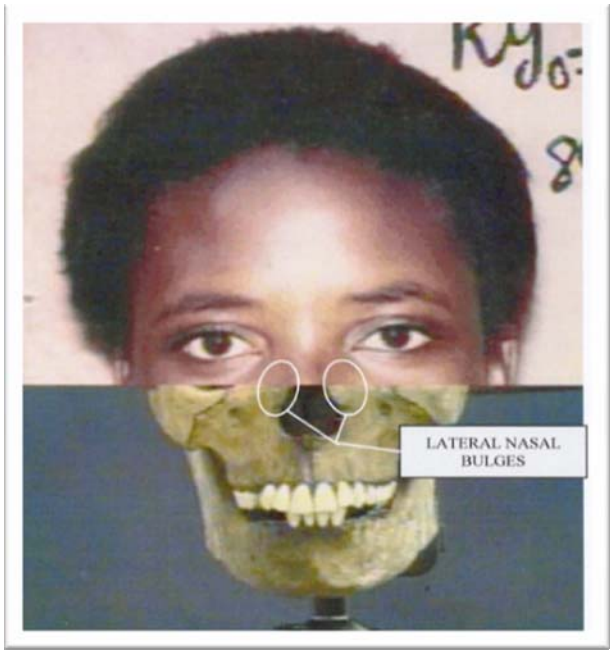


Figure 1.6. Results of skull-photo superimposition- top to bottom sweep identifying areas that match.

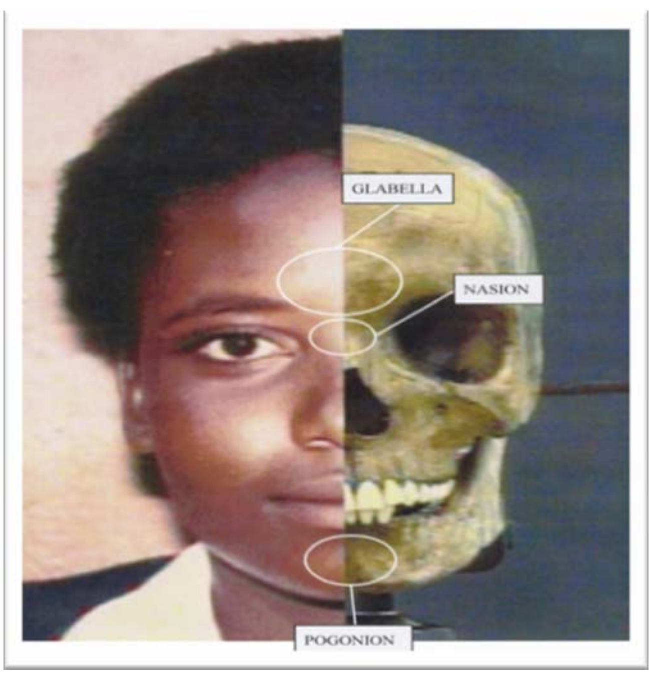


Figure 1.7. Results of skull-photo superimposition- left to right sweep midline identifying areas that match.

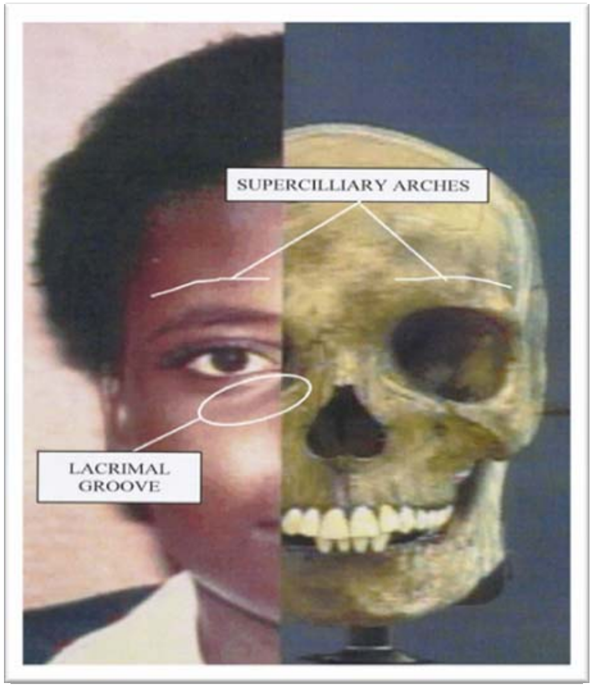


Figure 1.8. Results of skull-photo superimposition- left to right sweep lateral one third of face identifying bony areas that match.

Sadly, this young girl had been one of the five victims of the “Moffat Park Serial Murderer” Gcnumuzi Richard Makhwenkwe who was convicted of 11 counts including rape, murder and robbery with aggravating circumstances. This girl had been Makhwenkwe’s third victim and it was after the discovery of her remains (two bodies with similar manners of concealment had been found previously) that the SAPS suspected a serial murderer on the prowl. Makhwenkwe was ultimately identified as the Moffat Park serial murderer as he had murdered one of his ex-girlfriends and her boyfriend and with the help of a witness, it was established that he was the last person she was seen alive with. He confessed to all five murders and was able to point out the locations where he disposed of the remains. He also confessed to raping two women prior to these murders, but not to murdering them (1, 2).

As can be seen above, numerous areas of forensic scientific investigative processes were utilised in the identification and prosecution of Gcnumuzi Richard Makhwenkwe as well as the identification of his victims. Of particular importance here was the use of comparative DNA analysis and skull-photo superimposition to identify this particular victim. Only the remains of the schoolgirl victim were skeletonised- the remains of the other four victims were at varying stages of decomposition, but visual facial identifications could still be done. This case illustrates the use of skull-photo superimposition and the role it can play in identifying unknown victims of crime, particularly where other forensic scientific comparative identification techniques cannot be utilised, due to lack (or absence) of comparative samples.

One of the aims of forensic sciences is to rebuild crime scenes so as to establish the sequence of events that led up to the investigation (3). When the crime scene involves a victim that is deceased, the investigator needs to establish who the victim was and the circumstances leading to the victim's death. There are, however, cases where the remains are skeletonised and so the determination of the identity of the victim is more difficult. Forensic anthropologists have to rely on skeletal characteristics to determine the identity (4).

When skeletal remains are found the first fact that needs to be ascertained is whether the remains are those of an animal or human. Once it is confirmed that the remains are human, the anthropologist or pathologist is tasked with developing a demographic profile of the deceased that can potentially be matched to a missing person's profile. Here the anthropologist plays a key role. If the possible identity of the human remains cannot be determined, then a potential crime cannot be investigated. This is of particular importance in South Africa where hundreds of unidentified bodies (including skeletonised remains) who may have been victims of homicidal crimes, are buried as paupers every month (5). When skeletal remains are located, it is the role of the anthropologist to try and establish the identity of the individual(s). The post mortem interval must also be estimated and the bones of the skeletonised remains must be anatomically identified. A biological profile is established for the set of remains which should include the sex of the individual, their stature, their age and their population affinity. These features give authorities a broad idea of who to look for when investigating the missing person's profiles. Factors of individualisation are features that can be seen with the remains which provide clues to the exact identity of the individual. Dental records, old or healed trauma on a bone and dental mutilations are specific to an individual and therefore assist with the identification (5). The skull with facial features could also be used as a factor of individualisation. Therefore where two or more sets of remains are present, skull-photo superimposition could be used to identify specific individuals.

In most countries ante mortem dental records or DNA are used to identify victims (6-8). However, should these be unavailable or unsuccessful (9) other methods should be used. Skull-photo superimposition is an additional method that could be used to identify skeletal remains (or to exclude persons) based on the individual characteristics that can be observed from the skull. In such cases the investigators need to have an idea as to the possible identity of the victim. Ante mortem photographs are then used in order to try and establish identity, or to exclude individuals (10). This is done through skull-photo superimposition. In this procedure, the photograph of the suspected victim is superimposed over the skull. Video and photographic equipment is used in order to establish whether the particular skull and skeletal remains are those of the individual in the photograph (10-12). Photographic superimposition has proved to be highly valuable in the identification process of skeletonised remains (13, 14).

The basis for craniofacial identification is the distinctive individuality of the human skull (15). The reliability of identifying a skull as belonging to a particular person increases when there are unique characteristics or irregularities on the skull.

Morphological and metric analyses are initially carried out on the skull (where possible), in order to establish general demographic characteristics such as sex and age. These findings are then combined and assessed to obtain a preliminary identity before the superimposition is done (16). The use of craniometric points has further aided in craniofacial identification. These craniometric points have been used in conjunction with a coordinate system to provide detailed information about the distances, angles and spatial relationship between these points. This has enabled the matching of a skull to a photograph as well as the comparison of two skulls to assess any similarities that may be evident (15).

There are two techniques that have been used to carry out facial feature identification from the skull, namely skull-photo superimposition and facial reconstruction or facial approximation. Facial reconstruction is a method which utilises the knowledge of facial anatomy and skin tissue thicknesses, whereby clay is used to build up the facial profile of a skull (17). This, however, can only be used to draw the public's attention in order to obtain initial clues as the identity of the person, and cannot be used as proof of identity in court. Skull-photo superimposition uses a skull or image of a skull or x-ray, onto which an ante-mortem photograph of the suspected deceased individual is superimposed to examine whether there is a match between the facial features and the anatomical landmarks (11, 18, 19). The anatomical landmarks of the skull need to align with the size and configuration of the photograph in order to make a match. Disparities between anatomical landmarks, size and configuration can also be seen, so that the individual can be eliminated as being the suspected victim (13, 14).

Photographic superimpositions of areas of the maxillary bone and dentition can also be carried out to determine whether there is a match in the dentition, should no other bone fragments be available. This was effectively done in a case of an air force pilot whose plane crashed in Vietnam, where the maxillary remains (minus teeth) provided identification (20).

Due to problems with personal identification in South Africa (5, 21) and high crime rates, this procedure is commonly used in this country. Although some reports on reliability have been published (6, 15, 22-26) its accuracy has never been tested in a consistent manner and also not on a South African population. Questions that may arise in presenting this type of evidence in court, would include issues of the reliability and accuracy of the technique, i.e. what the possibilities are that a positive match might in fact not be positive, what the possibilities are that a negative result (exclusion) might indeed have been a match, and how many other individuals could have been positively matched to a particular skull/photograph.

1.2. Aims and objectives of the study

The objectives of this study are to establish the accuracy of the skull-photo superimposition technique on a South African sample in order to determine whether the technique is suitable for use in the South African legal system. This study will also evaluate whether carrying out the technique digitally enhances the technique and make it faster to perform than the current method as used in South Africa.

The aims of this study are:

1. To carry out skull-photo superimpositions using computer software to digitize the technique, to assist in minimizing the difficulties with the orientation, sizing and the time taken to achieve this. This is very similar to the technique currently used in South Africa, however, it will be an improved technique which is totally computer based.
2. To establish firm criteria (similar to how finger printing is carried out) that confirm a match or a non-match between a skull and photograph and aims to eliminate

subjectivity in the method. This will be done through comparing landmarks on the skull and photograph.

3. To establish the possibilities of false positive identification and false exclusion, using a large number of superimpositions. These superimpositions will include both skulls that match a particular photograph and skulls that do not match a particular photograph.
4. To compare the accuracies of superimposition done by traditional morphological matching and a landmark based approach.
5. To establish criteria for a best-practice procedure that can be used in future superimpositions in South Africa and elsewhere around the world so that consistent procedures are used for the technique worldwide.

1.3. Hypothesis

The following hypothesis will be tested: Skull-photo superimposition can be done reliably using a computerized technique, including a morphological and landmark based method, to a level of accuracy where no false positive or false negative matches between photographs and skulls occur.

This hypothesis will be rejected should there be more than 1% of false positive or false negative matches between photographs and skulls.

1.4. Importance of the study

This study is an attempt to focus on skull-photo superimposition as carried out in South Africa and to develop the methodology so that it is faster, more efficient and most importantly, has levels of accuracy that are defendable in court. The study will assist in the quantification of reliability of the method, in order to provide a court of law with firm statistics on what the chances are to reliably identify a person from his photograph. The importance of this study is in highlighting and quantifying the reliability of the technique and in showing how it can provide scientists with the statistical knowledge required to present skull-photo superimposition in the legal system.

Chapter 2: Literature review

2.1. Trends in forensic anthropological identification

Forensic anthropology is a branch of physical anthropology that deals with skeletonised human remains in a forensic context. More specifically, "it is the scientific discipline that focuses on the life, the death, and the postlife history of a specific individual, as reflected primarily in their skeletal remains and the physical and forensic context in which they are emplaced" (27). The use of skeletal biology in medico-legal investigations began in the 19th century. Thomas Dwight was dubbed the father of forensic anthropology, along with H. H. Wilder, Jeffries Wyman and Oliver Wendell Holmes. These four men are claimed to have established the field of forensic anthropology as it is known today. Their training was in a mixture of anatomy and zoology. Two of the men were involved in murder trials where they testified, giving evidence in court based on their "qualifications" (28).

It is however thought that George Dorsey (1868 – 1931) was the first fully qualified forensic anthropologist. He acquired his PhD in anthropology in 1896 and was only the second man to receive a PhD qualification in anthropology. Later in his career, Dorsey published on the implications of the human skeleton in medico-legal investigations and was also called as an expert witness (even though he had had no formal osteological training) in the famous Luetgert murder trial. Mr Adolph Luetgert owned a sausage factory and was having marital difficulties with his wife Louisa. His wife disappeared under suspicious circumstances, and only 6 days later did Mr. Luetgert report his wife missing. The Police were suspicious of Mr. Luetgert and his sausage factory- a bad smelling vat was found which supposedly contained potash, fat, tallow and bone scrapes, to make soap to clean the factory. When investigated further, bone fragments, two rings (one a gold wedding ring with the letters 'L L' engraved on the inside) and a corset stay were found in the vat. After two trials, Mr. Adolph Luetgert was found guilty and sentenced to life in prison. The chain of custody was heavily debated as it was thought that what was found was not handled correctly. Dorsey was the first anthropologist to testify in an American criminal trial, although his testimonies were questionable and controversial, which ultimately resulted in him leaving his academic appointments and his position at a museum (28).

Early in the twentieth century, researchers such as Ales Hrdlička were consulting on forensic cases, although the forensic work was not their primary interest. With the onset of World War II, the need for guidelines on human identification became the task of the anatomists, the most prominent of the time being T. Wingate Todd, a professor at Western Reserve University Medical School, who made significant contributions with skeletal age markers. Wilton Marion Krogman was prominent in the twentieth century in the development of physical anthropology and is also the very first author of a textbook in physical anthropology, published in 1962 (28). There was significant development and expansion of the field in the 1960's, resulting in the formation of a separate section within the American Academy of Forensic Sciences in 1971. The Physical Anthropology section of the academy came about in 1972. In 1977, the American Board of Forensic Anthropology was created under the Physical Anthropology section of the Academy (28, 29).

The investigation of human rights brought a new facet to the field. A violent dictatorship that began in Argentina in 1976 finally came to an end in 1983. During the time that the dictatorship continued in Argentina, many people went missing. Anthropologist Clyde Snow travelled to Argentina to consult and assist in the recovery of the missing or disappeared people. Unmarked graves were being investigated, but with the lack of experience evident, Snow realised that training was necessary to acquire forensic evidence from these graves. A small group of students was trained by Snow, which ultimately resulted in the formation of the Argentine Forensic Anthropology Team in 1984. This team became involved in the exhumation of graves and the documentation of human rights abuses and they are still continuing their work today (28-30). Similar situations existed in other countries at the same time as Argentina. Countries such as Uraguay, Bolivia, Chile and Boznia- Herzegovina were similarly affected by violent dictatorships resulting in human rights abuses that were investigated after the dictatorships ended uncovering mass graves where individuals needed identification (31). Solla *et al.*(32), has published on cases were individuals went missing during the dictatorial era in Uraguay, were the bodies were finally identified through the use of anthropological analysis including skull-photo superimposition and DNA comparison (31, 32).

In the last decade of the twentieth century, a system of Mortuary Operational Response Teams (DMORTS) was established in the USA, which includes practising forensic anthropologists. The DMORT system falls under the National Disaster Medical System (NDMS). The DMORT teams include specialities such as Anthropologists, Pathologists, Odontologists and X-ray specialists, to name a few. The 10 DMORT teams have been in operation in American National disasters involving flooding, bombing, air disasters and hurricanes. In the aftermath of the World Trade Centre Disaster in 2001, all 10 teams were deployed simultaneously for the first time (28).

Forensic anthropology is also becoming an increasingly popular field of specialisation in South Africa. With the disturbing statistics on violent crime and death in the country, the need for this speciality is becoming ever more important. The discovery of deceased human bodies and skeletonised remains is a frequent occurrence in South Africa, further accentuating the need for such a discipline. Not all cases involve skeletal material. Regularly, cases present where the body is found and the identity of the individual is never determined. In Gauteng alone, more than 2000 bodies are buried annually where the identity of the individual was never established. This has led to an increase in research in the field of Forensic Anthropology, which includes developing identification standards for South African populations as well as alternative methods of identification. Research in Forensic Anthropology in South Africa has been carried out since the 1940's and includes researchers such as Washburn, DeVilliers, Lundy and Feldsman, Kieser, Loth, Henneberg, Işcan and Steyn (4, 5, 29, 33-35) as well as Bidmos and Asala (36, 37) and Dayal (38) and L'Abbe (39) who is also the first South African diplomat of the American Board of Forensic Anthropologists (ABFA).

Cattaneo (40) explains that while anthropologists primarily deal with human skeletal remains, what is often requested is at the broadest end of the spectrum of the anthropological field, including human physiognomy. The field is developing dramatically and becoming multidisciplinary, with collaborative research with other specialists taking place. The need for the development of standards in facial reconstruction and identification is further highlighted because identification using methods such as skull-photo superimposition are becoming more and more widely used across the world (40). This means that methods used need to be standardised so that they are used consistently around the world.

2.2. The history of craniofacial identification and photographic superimposition

As early as 1883, it was realised that superimposition techniques could lead to identification by carrying out a comparison of the skull with a photograph of the deceased. By studying the skull, a forensic scientist is able to make deductions about the appearance of the face of the deceased (41). Scientists such as Welcker (1883), His (1895), Schaaffhausen (1875, 1883) and von Froriep (1913) played major roles in craniofacial identification. Their studies involved analyses of soft tissue thickness, and the relationship that exists between the soft tissue of the face and the skull (41, 42). Therefore the literature on facial reconstruction and skull-photo superimposition often overlap because these techniques are so closely related and very similar.

In the past, portraits, busts and death masks were used in order to establish the identity of an individual. However, with the advent of photography, many new possibilities for identification arose. A French criminologist, Alphonse Bertillon (April 24, 1853 – February 13, 1914), attempted to develop a method which made use of "a system of description and characterisation" (41) which could be used with photographs for identification and which he called "Bertillonage". The Bertillonage method was also later adapted and improved (Stadmuller, 1932 adapting Welckers method to be used with Bertillonage (41)) by enlarging the photographs to be used in the analysis. Attempts were then made to match the photographs with photographs of the skull by using the same focal length at a standard distance, as was used in the Bertillonage method (41, 43).

Bertillon was a French police officer (criminalist) and biometrics researcher who developed a system of description and classification through the use of anthropometry and in so doing, created an identification system based on physical measurements which he took of the head and body. The measurements were used to develop a system of identification that would apply to one person only and would thus be specific to that individual. The system was ultimately found to be inconsistent, because often the measurements were being taken by different police officers who would take their measurements differently. It was also established that measurements taken of individuals with similar phenotypes, such as identical twins, would be identified as a single individual. The principle on which this system of measurements for identification purposes was based was inherently flawed because the methodologies used were subjective and not standardised and therefore other methods of identification were investigated.

When the practice of fingerprinting came into being in 1892, the use of the Bertillon method came to an end and fingerprints were subsequently used for personal identification. Although the Bertillonage method was discredited, Bertillon made other contributions to forensic techniques such as document examination and using galvanoplastics to preserve footprints and ballistics.

There were technical problems with the early methods of skull-photo superimposition- the most important being problems with the photography. When a photograph is available, the skull has to be placed in the same orientation as in the picture. If enlargements to life size had to be made, a point of reference was needed in the photograph to accurately apply this technique. In 1935, Brash and Smith carried out a successful photographic superimposition in the famous Ruxton murder case. Buck Ruxton, a medical practitioner had murdered his wife and her maid and had gone to considerable lengths to prevent the identification of their remains by removing their eyes, teeth and large portions of skin from their faces (44). A photograph of the deceased (Mrs. Ruxton) was available and within the photograph a point of reference could be used in order to successfully enlarge the photograph and carry out the superimposition (7, 41, 44, 45). The superimposition process involved overlaying a negative of the skull over a photograph of Mrs Ruxton in life. The skull and photograph had be scaled to the correct size and orientated so that facial traits were accurately aligned. In the photograph, Mrs. Ruxton wore a diamond tiara which was used as the point of reference for the scaling of the images (42). Outline drawings were made of the skull and face in the photograph and then superimposed.

Another famous case receiving much attention was the Dobkin case which occurred in London in 1942. Skeletonised remains were found in the cellar of a previously bombed Baptist Church. There was a great deal of speculation about the remains possibly being those of a victim of a German blitz raid. However, pathologist Keith Simpson analysed the remains and suggested that the remains could possibly belong to a lady by the name of Rachel Dobkin who had been reported missing for 15 months. Skull-photo superimposition was carried out using an ante mortem photograph of Rachel Dobkin and very compelling similarities were found. Rachel Dobkin's husband was subsequently found guilty of her murder and the truth was discovered: Mr Dobkin had murdered his wife and placed her remains in the cellar of the bombed church to deceive authorities (42).

There was also an unusual case that occurred in Yugoslavia in 1976 where a scientist was tasked with identifying skeletal remains. The identification of these remains was carried out for religious purposes to positively identify a nun who had been buried in a communal grave. A series of superimpositions were carried out including six skulls from the grave, where the correct skull and remains were selected. Corroborative evidence aided further in the positive identification: the remains showed evidence of lesions on the spine which corresponded to the medical history of the nun (44).

The problem that was noted with the older methods was that if life sized photographs were not used for the superimposition, the result was that one skull may match photographs of different people (3). Gruner and Reinhard cited by Gruner (41) attempted to overcome these problems. They devised a method which used lines, drawings and marking points, taking into account the soft tissue thicknesses, to position a skull in the same orientation as in a photograph. This was done without having to determine the natural size, enlarging or calculating angulations, rotations or tilting. Gruner and Reinhard's method was modified and adapted by Helmer and Gruner (46, 47) to include the use of video superimposition equipment. This method was also modified by Leopold in 1978, which made use of a large format camera and a projection screen between the skull and the camera (41).

The first case study in South Africa on skull-photo superimposition was published in 1986 (48). A skeleton including the skull with mandible was found in a shallow grave along with a firearm and ammunition. Potential identifying documentation in the form of a South African identity document was found with the remains. Although the identity document was found in close relation to the remains, one cannot assume that it belonged to the individual without proof. The identity document photograph, which was passport sized, contained an unsmiling face of an individual taken slightly from the left (48). The method of superimposition included making a life sized black and white print of the photograph. The area of the eyes in the orbits of the skull were faded or "whited out" so as not to produce a shadow effect in the print. The skull was then photographed at six different angles onto colour transparency film to match angles seen in the photograph. An overhead projector with a zoom lens was then placed at a right angle to the print, which was fixed to a vertical surface, at a distance so that the skull was projected as a life sized image. All six transparencies were projected individually onto the fixed vertical image so that the best match of morphological features between the transparency and image was obtained (48).

The results obtained from this case study indicated that the skeletal remains were those of the individual in the identity document photograph, but the authors did state that the identification was not indisputable, but rather "consistent with, but equivocal" (48).

Modernised techniques were developed and older techniques modified, with the advance of video monitors and video animation compositors. Clyde Snow was the first American scientist to make use of video cameras for photograph superimposition (24, 41, 42, 46, 47). This method included two video cameras that took pictures of the skull and the photograph independently. The photographs were then sent to a video animation compositor or mixer and superimposed over one another on monitors. The intensity of the picture could be varied and strict control of the proportions was achieved (41). As the technique has developed over the years, the technique itself became less important than the main problem of accurately matching a skull to a photograph. It is important to note that superimposition is not about trying to "fit" the skull into a photograph of an individual's head, but rather an attempt to assess the match of the skull to the face in a photograph.

The introduction of electronic equipment has aided in the simplification of the skull-photo superimposition technique and video superimposition is currently the method used in South Africa (Briers, pers. comm.). This method makes use of a video recording camera(s), a mixing device, equipment for holding the skull and sometimes computer software to help carry out and evaluate the fit of the superimposition (8, 10-12, 18, 19, 22, 25, 26, 44, 46, 49-55). A study done in 1994 by Austin-Smith and Maples tested the reliability of skull-photo superimposition. The authors used three skulls of known identity and compared them to 97 lateral and 98 anterior view photographs. It was found that the chances of having a false positive identification using lateral shots were 9.6% and using anterior shots was 8.5%. However, when using the lateral and anterior shots combined, the chances of a false positive were reduced to 0.6%. This study was done without using anterior dentition to aid with magnification and orientation. An increase in the sample size could have improved the study; however, as more skulls would have been used for comparisons to photographs, this may have resulted in a higher rate of false positives (24).

Bajnóczky and Királyfalvi (22) developed a technique that used a computer-based method to check the results of superimposition. In this study, one skull and two photographs were used for comparison. One photograph was of the person from whom the skull was derived and the other photograph was of an individual whose appearance resembled that of the test cases' photograph appearance. Pairwise comparisons were carried out using points that were marked on the skull, photographs and monitor, for 'afterwards' and 'before' conditions. In principle, the study made use of landmarks on the skull, face and monitor to assess how well the landmarks matched when conducting the superimposition. The materials and methods of this study are very vague, however, it can be deduced that a mathematical model was utilised as a means of determining the match between the points. Another study carried out by Nickerson *et al.* (45) studied the various methods of superimposition, from Static Photographic Superimposition to Video Camera Superimposition to Digital Photographic Superimposition. The study made use of landmarks as suggested by Chai *et al.* (11) and digitised 3-dimensional scans of skulls to carry out superimpositions. This is similar to the current study, with the use of the landmarks. However, Bajnóczky and Királyfalvi (22) made use of a less complicated method of determining a match between the points they used in their study. They found differences between the "afterwards" and "before" conditions but claimed that the differences could have resulted from errors made with the measurement techniques or from non-identity. Again, this paper is very vague in explanation, but it was recognised that the errors in the measurement techniques are probably due to incorrect positioning and/or inaccurate marking in the "afterwards" and "before" conditions, as the study claimed. They also added that differences could have been due to comparisons of a 2-dimensional shape with a 3-dimensional shape, soft tissue thickness and the photographic process. The authors described this method as reproducible and a as a means of "filtering out" any false positives that may occur. However, they did not describe statistics of how this method has been tested and of the chances that false positives may occur, since the study was carried out as a means of reducing only the false positive rate.

Shahrom *et al.* (25) also made use of computer aided superimposition and tested various techniques of carrying out superimpositions, ranging from cheaper methods to more expensive ones. Facial reconstruction was carried out on the skull of a complete skeleton found in a woodland area. Video superimposition was also carried out when photographs of the suspected individual were used. A cheaper method involving video-transparency superimposition was also carried out. The identity of the victim was confirmed through dental records. They conclude that while photographic superimposition could have a very useful role in identification purposes, the method should not be overestimated and should be used in conjunction with other corroborative evidence. Shahrom *et al.* (25) furthermore state that this method is useful when no other means of identification are available. Dorion (6) also found that skull-photo superimposition is more helpful in exclusions than with positive identifications.

A second of only two case studies reported in South Africa was published in 2000 (21). Two badly decomposed bodies were found in the Mpumalanga province in December 1996 and January 1997. One of the individuals was found with a South African identity document in close relation to the body and the other body had been tentatively identified by the clothing. Skull-photo superimposition was carried out on both skulls. Both skulls also featured unusual anomalies; one skull featured an under bite, whilst the other had ante mortem tooth loss of both central upper incisors. These features assisted in the identification of both individuals. The issue of the use of dentition is also raised in this paper, however, it is noted that due to generally poor dental record keeping in South Africa, it is very rare that dental records are available to assist in the identification of skeletal remains (5, 21).

Another case in South Africa occurred where skull-photo superimposition was used in a case of suspected murder, in the state against P. Henning in the Pietermaritzburg High Court in 1999. Henning was accused of murdering his farm worker in 1996 and dumping the body in a river. One of Henning's farm labourers had gone missing around the same time Henning was seen to dump 'something' in the river. A skull had washed out downstream from where Henning was believed to have dumped the body and there was great difficulty in identifying the skull as being that of the farm labourer who went missing and was last seen with Henning. Skeletal analysis conducted on the skull (only) by anthropologists at the University of Pretoria's Department of Anatomy established that the skull belonged to a black male adult, approximately

35 years or older- although the age estimation was difficult as only suture closure could be used to establish age. The skull also had a supernumerary upper incisor and a relatively small neurocranium with prematurely fused cranial sutures. All these features can be seen to be factors of individualisation to identify the remains of belonging to a specific individual. Inspector Briers from the South African Police Services carried out skull-photo superimposition and found the skull to match the photograph supplied of the missing farm labourer. In this case the labourer was unfortunately an orphan and therefore comparative DNA evidence could not be used to identify him. The procedure of skull-photo superimposition was used in court along with the supernumery tooth as factors of individualisation to specifically identify the skull as belonging to the missing farm labourer. The identity was accepted by the court and Henning was found guilty (Steyn, pers. comm).

A case study done in India in 2001 aimed to enhance the reliability of the technique. The paper states a previously established 91% rate of positive identification with the use of skull-photo superimposition. They stressed the need for reliability of the technique, because a 91% rate of positive identification reduces confidence in using the technique in court. They suggested a method called “cranio-facial morphanalysis” to correlate the differences in shape of a face (photograph) and skull. The authors introduced an anthroposcopic method of assessing correlations between the face in a photograph and a skull. The study made use of 15 male and 15 female skulls with their corresponding facial photographs. The authors suggested that the use of the cranio-facial morphanalysis together with skull-photo superimposition could improve the reliability of the technique. While the authors claimed that using cranio-facial morphanalysis in conjunction with skull-photo superimposition strengthened the result of the skull-photo superimposition technique, they also stated that the technique cannot claim a definite match or identification of a skull. They did, however, find the technique helpful in the prevention of mismatching and false identification among their samples (23).

Al-Amad *et al.* (56) described a technique of identification using superimposition of ante mortem and post mortem examination dental records using special features of Adobe Photoshop®. The use of dentition was highlighted due to its survival in harsh conditions, however it is noted that the ante mortem dental records need to be available in order for this technique to be practical. As mentioned above this is problematic in South Africa due to poor or often no dental records existing- nevertheless, the method has value as a supplementary or corroborative means of identification if available (56).

Since the inception of the photo superimposition technique, many different methods of carrying out the procedure have been considered, with major developments having occurred in the last 10 to 15 years. The use of computer equipment has enhanced the technique significantly. Digital photographic superimposition allows the process to be faster too. The questions of the reliability of the technique will always remain. The use of computerised or digital software has improved the skull-photo superimposition technique; however, many laboratories employing the technique still make use of the method using video cameras and animation compositors. The practice of skull-photo superimposition will be discussed further in sections below, along with more detailed assessments of the accuracy of the technique and its applicability in court.

2.3. Skull-photo superimposition: How the technique is carried out in the United States vs. South Africa

Literature reports have focused on how to carry out, as well improve the superimposition technique. This includes the analyses of soft tissue thickness, placement or position of the skull, the size adjustments of the skull in relationship to the facial outline, as well as the relationship of the anatomical landmarks to the overlying soft tissue. Knowledge of these techniques and a good ante mortem photograph are critical in order to carry out the comparison (24), and will be discussed in detail below.

The practice of skull-photo superimposition in the United States and South Africa is very similar. The notable differences in the techniques are that in the United States tissue depth markers are employed to assist with skin tissue thickness and a computer is used to capture the final image. The equipment includes a video camera(s), a video mixer, a TV monitor and a video cassette recorder. In the United States, two video cameras are used to film the skull and photograph independently and then the computer captures the superimposed image. In South Africa, one video camera is used to film the skull and photograph independently, with the help of the mixing device to store the images separately to be used for the superimposition (21, 26).

Some time was spent at Michigan State University in East Lansing in the US by the investigator. A short internship was undertaken to learn the methods of the skull-photo superimposition procedure as it is carried out there. Their superimposition process starts with placing skin tissue thickness markers on the skull. They then make use of a "dynamic orientation process" to align the skull correctly with the photograph. This involves placing the ante mortem photograph under one video camera so that the image fills the screen of the monitor. The skull with tissue depth markers is placed under the second camera. Using the mixing device and the TV monitor, the skull image is sized so that it is the same size as the image of the face. When the skull and photograph are correctly aligned and sized, the cranio-facial proportions of the skull and photograph are assessed. This is carried out by adjusting the skull manually so that the skeletal landmarks of the skull match up with landmarks on the face in the photograph. Ideally, the best method to align the skull and photograph is to align them at the landmark porion. Porion on the skull is established by placing ear-buds into the external auditory meati of the skull, which would match up with the left and right tragi of the ears. Next, the Whitnall's tubercles are aligned with the left and right ectocanthion points on the face. The Whitnall tubercle is a bony eminence on the zygomatic bone located on the lateral margin of the left and right orbits (Sauer, pers. comm.) (26).

The above steps are imperative to establish the correction angles of inclination and declination, so as to match the angle in the photograph. Following this, the subnasal point of the skull is aligned with the subnasal point of the face in the photograph. The next step is to align gnathion on the skull, with the identical point on the face in the photograph. This "dynamic orientation process" is described to be very challenging and time consuming. Much time is spent making sure that the adjustments for size and alignment between the two images are done accurately, so that the process is carried out correctly.

If landmarks from the skull and photograph are not aligning, then it could be an indication that the skull and photograph are not of the same individual. In the final step of the skull superimposition process an overall evaluation of the morphological features of the face and skull is made. This is done by following the Austin-Smith and Maples (24) list of morphological requirements to establish a match as a guideline. Their guidelines stipulate that 12 morphological features in the frontal view of the skull and photograph should correlate in the superimposition process. It is noted that some of the 12 features may not be seen in the photograph due to the presence of hair. These features are summarised in Tables 2.1 and 2.2 below. Once the assessment between photograph and skull is carried out, considering all morphological features and craniometric landmarks, conclusions regarding the inclusion or exclusion of the skull and photograph are made (26).

Due to the inconsistencies and inaccuracies noted in the literature (6, 15, 22-26), practitioners in the United States have adopted a policy of using skull-photo superimposition only for exclusion in court. Therefore the identification of skeletal remains is made through the use of dental identification as well as skull-photo superimposition for exclusion purposes i.e. trying to exclude a skull as belonging to a photograph (26).

In South Africa the superimposition process is commenced by filming the ante mortem photograph. This image is then stored in the mixing device for later use. The skull is placed on a skull stand with sticks placed into the external auditory meati. The skull is then filmed with the video camera. With the use of the mixing device, the photograph image is displayed onto the TV monitor and outline drawings of morphological features of the face are made with a non-permanent marker.

Table 2.1. Table of requirements of a lateral consistent fit between skull and face (taken from Austin-Smith and Maples (24))

	Lateral view requirement

1.	The vault of the skull and the head height must be similar.
2.	The glabellar outline of both the bone and the soft tissue must have a similar slope although the line of the face does not always follow the line of the skull exactly. There must be slight differences in the soft tissue thicknesses that do not relate to nuances in the contour of the bone.
3.	The lateral angle of the eye lies within the bony lateral wall of the orbit.
4.	The glabella, nasal bridge, nasal bone area is perhaps the most distinctive. The prominence of the glabella and the depth of the nasal bridge are closely approximated by the soft tissue covering this area. The nasal bones fall within the structure of the nose and the imaginary continued line, composed of lateral nasal cartilages in life, will conform to the shape of the nose except in cases of notably deformity.
5.	The outline of the frontal process of the zygomatic bones can normally be seen in the flesh of the face. The skeletal process can be aligned with the process seen in the face.
6.	The outline of the zygomatic arch can be seen and aligned in those individuals with minimal soft tissue thickness.
7.	The anterior nasal spine lies posterior to the base of the nose near the most posterior portion of the lateral septal cartilage.
8.	The porion aligns just posterior to the tragus, slightly inferior to the crus of the helix.
9.	The prosthion lies posterior to the anterior edge of the upper lip.
10.	The pogonion lies posterior to the indentation observable in the chin where the orbicularis oris muscle crosses the mentalis muscle.
11.	The mental protuberance of the mandible lies posterior to the point of the chin. The shape of the bone (pointed or rounded) corresponds to the shape of the chin.
12.	The occipital curve lies within the outline of the back of the head. The area is usually covered with hair and exact location may be difficult to judge.

Using the mixing device, the image of the skull and photograph are displayed on the TV monitor simultaneously. The skull is aligned and sized with the photograph using the sticks in the external auditory meati to match the tragi of the ears.

Table 2.2. Table of requirements of a frontal consistent fit between skull and face (taken from Austin-Smith and Maples (24))

	Frontal view requirement

1.	The length of the skull from bregma to menton fits within the face. Bregma is usually covered with hair.
2.	The width of the cranium fills the forehead area of the face.
3.	The temporal line can sometimes be distinguished on the photograph. If so, the line of the skull corresponds to the line seen on the face.
4.	The eyebrow generally follows the upper edge of the orbit over the medial two-thirds. At the lateral superior one-third of the orbit the eyebrow continues horizontally as the orbital rim begins to curve inferiorly.
5.	The orbits completely encase the eye including the medial and lateral folds. The point of attachment of the medial and lateral palpebral ligaments can usually be found on the skull. These areas align with the folds of the eye.
6.	The lacrimal groove can sometimes be distinguished on the photograph. If so, the groove observable on the bones aligns with the groove seen on the face.
7.	The breadth of the nasal bridge on the cranium and surrounding soft tissue is similar. In the skull, the bridge extends from one orbital opening to the other. In the face, the bridge spreads between the medial palpebral ligament attachments.
8.	The external auditory meatus opening lies medial to the tragus of the ear. The best way to judge this area is to place a projecting marker into the ear canal. On superimposition, the marker will appear to exit the ear behind the tragus.
9.	The length and width of the nasal aperture falls outside the borders of the nose.
10.	The anterior nasal spine lies superior to the inferior boarder of the medial crus of the nose. With advanced age the crus of the nose begins to sag and the anterior nasal spine is located further superiorly.
11.	The oblique line of the mandible (between the bucinator and the masseter muscle) is sometimes visible in the face. The line of the mandible corresponds to the line of the face.
12.	The curve of the mandible is similar to that of the facial jaw. At no point does the bone appear to project from the flesh. Rounded, pointed, or notched chins will be evident in the mandible.

Once the skull and photograph are correctly aligned and sized, the cranio-facial proportions of the skull and photograph are assessed. This is carried out by adjusting the skull manually so that the skeletal landmarks of the skull match up with landmarks on the face in the photograph. The task of adjusting the skull to the image in the photograph is challenging and tedious, and can take up to several hours.

The line drawings made on the TV monitor assist with the matching process. The line drawings can show morphological features on the monitor when the image in the photograph is not clear because of the mixing of the images of the photograph and skull. A morphological comparison between the skull and the face in the photograph is then carried out to assess whether the skull matches the face in the photograph and thus a decision on whether the skull matches the photograph is made. Aspects of the superimposition technique explained above have been published (21), however elements of the above description of the skull-photo superimposition technique result from personal observations during sessions spent at the laboratory observing how the technique is carried out.

Although there are inconsistencies noted in the literature (6, 15, 22-26), South Africa has adopted an inclusion policy for the use of skull-photo superimposition in court. Therefore the identification of skeletal remains can be made through the use of skull-photo superimposition for inclusion purposes i.e. establishing whether the skull belongs to the face in the photograph or not (21, 48).

2.4. The accuracy of skull-photo superimposition

Since the establishment of the photographic superimposition technique, various scientists have examined the procedure in order to improve and assess the accuracy of the results (8, 10-12, 19, 24). Many authors believe the inclusion of teeth improves the accuracy of the result obtained, as matching a photograph (where teeth are visible) to a skull (where teeth are still in their sockets) is far easier and more accurate. Matching the dentition from a photograph to the dentition on a skull, aids in the magnification process and confirms a definite match or elimination depending on how the other anatomical landmarks fit (7). If dentition is available, an attempt is made to match them to ante mortem dental records. However, in many cases no dentition is available and photographic superimposition is carried out using other anatomical landmarks to determine whether there is a match (7, 10, 24).

Since the development of the technique of photographic superimposition, the accuracy of the technique has not been stringently tested. Most of the initial studies around photographic superimposition focused on the development of better techniques and equipment with which to carry it out (8, 10-12, 18, 19, 22, 24, 25, 48, 49, 51-54, 57). Few studies have been carried out that tested the accuracy and scientific validity of the technique. One of the first studies was carried out on an American population in the early 1990's by Austin-Smith and Maples (24) as discussed above, which found that the chances of having a false positive identification using lateral shots were 9.6% and using anterior shots, 8.5%. However, when using the lateral and anterior shots combined, the chances of a false positive were reduced to 0.6%.

Aulsebrook *et al*. (58), around the same time as Austin-Smith and Maples (24), conducted a survey on skull-photo superimposition and facial reconstruction. They discussed the validity of the superimposition technique citing authors Cocks and Brown (44) who were trying to achieve a method of objectively "quantifying a comparison" (58). The idea of Cocks and Brown was to make use of points or measurements that could be used on the skull as well as a face or photograph. However, another accuracy problem is encountered in this method, because the repeatability of the points or measurements is difficult and in turn could affect whether false positives or false negatives are identified (58). Grüner (41) and Aulsebrook *et al.* (58) additionally did studies to calculate the distinctiveness of the human skull and they concluded that skulls were as individual and distinct to a particular person as a finger print. Aulsebrook *et al.* (58) agree with Işcan's (29) opinion that skull-photo superimposition should be used in addition to other identification techniques as corroborative evidence. They also cite De Vore's (1977) work which claims that skull-photo superimposition should be used for exclusion purposes rather than inclusion purposes. Both Dorion (6) and Shahrom *et al.* (25) believe that while photographic superimposition may enhance the process of identification, it should be used in conjunction with other evidence, as misidentifications have been reported in the past. The suggestion is to use the technique along with definitive corroborative evidence such as dental records (where available) or other forms of evidence, such as a biological profile that matches the remains in question.

Jayaprakash *et al.* (23) also elucidate the use of skull-photo superimposition as an identification tool, and mention a previously published 91% accuracy rate. They declare that this technique is not "wholly reliable" (p. 121), and suggested a new technique called "cranio-facial morphanalysis", as described above. This was also found to be not completely reliable with the authors using the statement that "the skull could very well have belonged to the person seen in the photograph" (p. 136). The legal implications of such a statement will be further discussed below.

Although court systems have accepted skull-photo superimposition as an identification tool all over the world, not all court systems use the tool in the same manner. Whilst some use the technique to include an individual (i.e. to identify him/her) other courts use the technique to exclude individuals. In both South African case studies mentioned previously, the identity of the individual was suspected, and corroborative evidence was available. In the earlier study the individual was found with a South African identity document along with other evidence in the shallow grave. The identity document photograph was used to determine his identity. In the second study published, two individuals were found in separate locations. One individual was identified tentatively by his clothing and a photograph was obtained, and the other individual had a South African identity document found in close relation to the remains. In all three cases the technique was used to identify the remains (21, 48).

Fenton *et al.* (26) were tasked with identifying the comingled remains and personal effects of some hikers which were discovered in remote area of desert near a southern Arizona town. Through the combined efforts of authorities in the United States and Mexico, it was established that the remains in question were those of five individuals of Mexican origin. The authors described their technique using a "dynamic orientation process" to correctly align and size the skull and photograph for the superimposition process. The idea of carrying out this process is to exclude a skull from possibly matching the photograph. If the skull cannot be excluded, then it suggests that it represents the individual in the photograph. It is noted that the technique is not used in the same manner around the world. The only validity studies that have been done were in the United States, India and also China (23, 24, 53). However, none have been conducted in South Africa, even though the technique is frequently used.

2.4.1. The role of photography in skull-photo superimposition and identification

Redsicker (59) explains that in the field of forensic photography, the photographer's work is scrutinized not for its artistic content but rather the accuracy with which it depicts the topic of interest. The depth of field of a photograph becomes important in crime photography where crime scenes have to be photographed. The depth of field is defined as the area which appears in focus from the foreground to the background. For an overall series of crime scene photographs, a greater depth of field is needed as opposed to a situation where specific detail is needed from a e.g. a shoe impression or blood spatter mark (59). The depth of field becomes very important if being used for skull-photo superimposition. Variation in the technique of the photography i.e. the distance from the camera or the angle of the camera can produce variations which may not be normally observable between two identical images.

Eliášová and Krsek (60) describe distortions that can occur with photographs and how this may influence the accuracy of skull-photo superimposition. The process of superimposition makes use of a 2-dimensional image which is superimposed onto a 3-dimensional object. The image has many factors that contribute to the distortions, such as the conditions whilst the photograph is being taken as well as intrinsic and extrinsic parameters of the camera (60). Although the authors claim that that they are able to explain the distortions through the use of a mathematical model, one must question whether the person carrying out the superimposition will be able to put the model to use, as deeper understanding of photography and mathematics is required for this. This further highlights the problems when making use of skull-photo superimposition as a sole tool for the identification of skeletal remains, since misidentifications could occur based purely on a photograph that contains these distortions.

2.4.2. The use of anatomical/ craniofacial landmarks in skull-photo superimposition

Anthroposcopy is a method of assessing the body's build by visual inspection. Visual assessment is a very old method which is still being used in medicine today. It is not very consistent due to the subjective nature of the method. Anthropometry involves the measurement of elements of the human body. These are more objective and more consistent and thus more reliable. Anatomical / craniometric landmarks have been indentified on the human face / skull for the purposes of taking anthropometric measurements. Anthroposcopy is used to observe and identify physical characteristics such as landmarks on the face of an individual (61, 62). Both anthropometry and anthroposcopy play roles in the technique of skull-photo superimposition.

Anatomical landmarks can play an important role in the identification of an individual when being used in photography and camera surveillance. Modern techniques of studying the face for the purposes of identification in the forensic context include techniques that use metric analyses (measurement), morphological analyses (shape of the features) and superimposition, which this study is testing. So these techniques can be used to compare two photographs, a face and a photograph as well as a skull and a photograph (63).

Various studies have aided the process of identification through the use of anatomical / craniofacial landmarks and the measurements that can be made using these landmarks- the measurements and (or) proportions that are obtained from the photograph or camera evidence can be used to successfully identify the perpetrators of crime. This form of identification, also termed 'facial image identification', can be done morphologically, anthropometrically and also through superimposition (14). The morphological method uses proportions and features of the face such as the eyes, eyebrows, eyes, nose, ears and lips with classification systems that have been published. An anthropometric analysis is based on indices which have been calculated from facial dimensions, but also include ear or nose shape and hairstyle etc. Superimposition is suggested as a method of comparing the two images of facial dimensions in an attempt to carry out a facial comparison. Examples of this anthropometric analysis are used in the application of access control systems as well as the well known facial identification system "Identikits". Anthropometric analysis and "Identikits" are especially useful with the large amount of identity document fraud that occurs in South Africa and elsewhere (53, 63).

The use of anatomical landmarks in skull-photo superimposition was introduced to be employed in conjunction with the superimposition technique, in order to rule out the possibility of false positives or false negatives. This has been one of many suggestions to better the accuracy of the technique (15, 24). This is of particular importance to this current study, as the literature discussed highlights the problems with regard to angles in photographs, distortions in photographs / images and poor quality photographs. It stresses the importance of developing a technique with which to identify individuals from photographs that is accurate and repeatable. As mentioned by Roelofse *et al.* (63), the use of anatomical landmarks is important in the identification of individuals from photographs, and this also holds true for superimposition.

2.4.3. Forensic sciences, evidence and the legal system

Scientific evidence is claimed to be "fact or opinion evidence that purports to draw on specialized knowledge of a science or relies on scientific principles for its value" (64). Expert testimony that is given in court is based on technical, scientific and / or other specialized knowledge which has been acquired by an individual who is qualified to testify based on the experience they have gained in their daily duties. An expert is someone recognized by the legal system that may be called upon to describe the evidence as well as its significance to the case being presented. Rules have been formulated in the court systems that establish who is qualified as an expert witness, what aspects of the case they may provide testimony on and whether this testimony is in fact reliable (64).

It is important to note that a "lay" witness may only provide evidence on observed facts, and may not offer any opinions regarding those facts. A "lay" person is someone who has demonstrated an aptitude to perceive, recall and recount their own knowledge truthfully. An expert witness is defined as "[a] person who, through education or experience, has developed skills or knowledge in a particular subject, so that he or she may form an opinion that will assist the fact finder" (64). Therefore an expert witness has experience beyond the general understanding of the public. The expert testimony has the role of assisting the jury so that factual conclusions regarding evidence can be made.

There are also rules regarding the admissibility of the evidence that may be provided in the legal system. The concern with the evidence being offered in court is that the testimony of an expert witness has the ability to mislead the jury. Therefore the court has to ensure that the expert testimony is “based on facts or data, is the product of reliable principles or methods, and that the experts’ conclusions are reliable and relevant” (64-66).

There are two major approaches to expert opinion in court; these are the *Frye* approach and the *Daubert* approach. Each of these approaches applies different rules to the presentation of scientific evidence in court. The *Frye* approach was the original method whereby scientific evidence was reviewed. The *Frye* standard requires that the scientific principle used had “gained general acceptance in the specific field” before the principle could be used for expert testimony. This rule creates great difficulties when applied to the use of “new” scientific evidence, due to the fact that evidence based on a science that is developing or a science that is very novel may not be considered as “generally accepted”. While this standard is not used in many places anymore, it is still used in some jurisdictions in the US (64).

The *Daubert* standard is originally stated (in its entirety) as follows: "If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise" (27, 66). The standard is based on a two part test namely reliability and relevance that must be employed, when the evaluation of scientific evidence is carried out. The test also includes questions on whether the scientific theory had been subjected to testing, to peer review and to publication, whether the theory has a potential rate of error and whether the technique is generally accepted. The major difference between the *Frye* and *Daubert* theories is that the *Frye* standard is only concerned with the admissibility of scientific evidence in court. The *Daubert* standard, however, requires participation from the court in evaluating the relevance of the scientific theory to the facts being presented in a case (64, 66).

The *Daubert* criteria were introduced into the courtroom in order to try and eliminate "pseudo-science" type evidence, which is evidence presented by an expert witness, based purely on the expert witness' anecdotal or personal experience in the field and not on the results of tried and tested techniques or validation studies (Steyn, pers. comm.). This has changed the field of Forensic Anthropology greatly, not only in terms of what research is carried out, but also how it is carried out.

The South African legal system has its roots in Roman Dutch Law which has been developed over the years into the legal system as we know it today. Statutory laws on the other hand, are developed by the South African legislative body and are passed by Parliament. These Statutory Laws include the *Births and Deaths Registration Act, 1992 (Act no. 51 of 1992)*(67) and the *Inquests Act, 1959 (Act no. 58 of 1959)* (68), which respectively provide for the registration of births and deaths of individuals, as well as investigations into the circumstances and causes of unnatural deaths (69). The *Criminal Procedure Act, 1977 (Act no. 51 of 1977)* (70) is another Statutory Law which provides for the processes in criminal proceedings relating to the prosecution of crimes in South Africa.

Common Law includes Roman-Dutch Law and is developed and built up from previous court cases and the decisions made in those court cases, i.e. legal precedent. In this manner, court proceedings are based on legal rules and principles developed from prior Higher court decisions also known as Case Law. In South Africa, murder, culpable homicide and theft for example, are Common Law offences in which Statutory Laws are used. A Common Law offence such as murder will be investigated by the police, following which evidence will be presented at a criminal trial led by a state prosecutor, for the purposes of verdicts and sentencing. Civil trials involve the infringement of an individual's rights for which that individual seeks redress, where the State plays no role (69).

In South Africa, the legislative aspects of the performance of medico-legal autopsies are governed primarily by the *Inquests Act, 1959 (Act no. 58 of 1959*) (68), where such autopsies and ancillary investigations then form part of the police's investigative processes into unnatural deaths. Medico-legal autopsy and ancillary forensic evidence may then be presented at Inquest courts and / or at criminal trials, for the purposes of conveying the medical and forensic scientific evidentiary findings relating to circumstances, causes and mechanisms of death (69). The *National Health Act, 2003 (Act No. 61 of 2003) "Regulations Regarding the Rendering of Forensic Pathology Service"* (71, 72) define clearly who may perform and / or contribute to a medico-legal post mortem examination in sections 16 and 17, under the heading: *"Practitioners authorised to conduct post mortem examination"* viz. *"16. A post mortem examination must only be performed by an authorised person who has been appointed by the Head of Department for this purpose."* Furthermore, it states in section 17 that *"17. An authorised person may consult with other qualified professionals and request such professionals to participate in the post mortem examination and contribute to the further examination of such a body."* These Regulations (72) also define who this *"authorised person"* is, namely that *"an authorised person means a medical practitioner registered as a forensic pathologist or forensic medical officer in terms of the Health Professions Act, 1974 (Act No. 56 of 1974)* (73)*, to perform post mortem examinations or autopsies on a body and appointed in terms of regulation 16 of these regulations"* (as above). In terms of sections 19 and 20 of these Regulations, *"19. ….. an authorised person may submit for examination, or cause to be submitted for examination, any tissue, fluid, object, or thing related to a body, to an authorised institution, for purposes of establishing the cause and circumstance of a death of a person or for furthering the administration of the processes and administration of justice."* and *" 20. An authorised person is the only person who has the authority to decide to dissect a body, remove or cause to be* *removed, any part, organ or contents of a body for a special investigation"*. The implications of these extracted sections are clear, in that even when skeletonised remains are to be examined, such cases first have to be admitted to the relevant regional Forensic Pathology Service Mortuary, before being referred by an "authorised" medical practitioner to e.g. an (Forensic) Anthropology Division, for further anthropological investigations as may be required. These usually include as the top and most frequent priority, to determine the identity of the deceased. It must also be noted that these Regulations also define what is to be understood under "unnatural deaths" namely: *"For the purposes of the medico-legal investigation of death, the following shall be deemed to be deaths due to unnatural causes-*

(a) any death due to physical or chemical influence, direct or indirect, or related complications;

(b) any death, including those deaths which would normally be considered to be a death due to natural causes, which in the opinion of a medical practitioner, has been the result of an act of commission or omission which may be criminal in nature: or

(c) where the death is sudden and unexpected, or unexplained, or where the cause of death is not apparent".

Skeletonised remains frequently belong to the categories stipulated in (a) and (c) of these definitions and as thus, need to be fully investigated from a medico-legal perspective, to establish in as far is possible, circumstance and cause of death, together with the identity of the remains.

The scope of practice for forensic pathologists in South Africa is further outlined in the *"National Code of Guidelines for Forensic Pathology Practice in South Africa"* (74), as authored and published by the "National Forensic Pathology Service Committee", referred to in Section 37 of the *Regulations Regarding the Rendering of Forensic Pathology Service of the National Health Act, 2003 (Act no. 61 of 2003)* (71, 72, 74). According to the *"National Code of*

Guidelines for Forensic Pathology Practice in South Africa", Forensic Pathology Service has as its primary objective *"the rendering of a medico-legal investigation of death service that serves the judicial process."* In addition, it states that *"it is essential that standardised and uniform protocols and procedures are followed nationally, rendering objective, impartial and scientifically accurate results."* If these standardised processes are not adhered to, doubt may be cast on the reliability and relevance (in accordance with the *Daubert* criteria described above) of the forensic medical or scientific evidence presented to the courts (Vellema, pers. comm.).

The term "forensic evidence" may be used to describe the manner in which information is presented to the courts and includes verbal evidence (e.g. witness testimony), documentary evidence (e.g. autopsy reports) and physical / tangible evidence (e.g. objects like bullets) (75). In South Africa, documentary forensic evidence can be submitted to the courts by means of an Affidavit, which is a written statement wherein the person swears under oath to the truth contained in the statement; or a Solemn Declaration which is similar to the Affidavit, but no oath is taken. The investigation into the cause of death involves the medical practitioner who may be called upon to give evidence in court in 4 ways: 1) as a defendant in civil or criminal action; 2) as a witness of fact e.g. armed robbery; 3) as a professional witness e.g. treatment of a case in casualty; and 4) as an expert witness who is seen in the eyes of the law as an individual who, through education, training and experience, possesses knowledge beyond that of a lay person. In a courtroom setting, expert witnesses are called upon to ensure that complex scientific principles are understood by lay persons, but they are also frequently expected to give "opinion evidence" based on experiential conclusions drawn from factual findings (69, 75). The practice of how scientific evidence is presented in court in South Africa differs from the *Daubert* and *Frye* standards, but does include aspects from both standards. In Chapter 24 of the *Criminal Procedure Act, 1977 (Act no. 51 of 1977)* (70), aspects pertaining to the presentation of evidence in court are covered, but none specifically pertaining to scientific requirements for "newer" e.g. forensic sciences-related expert witness testimony. This illustrates an area in the legal system in South Africa where more consideration is needed.

The standard used for the admissibility of evidence in court has serious implications for the use of skull-photo superimposition. The expert testimony on the technique of skull-photo superimposition would not be accepted in court if the *Frye* standard were used for the admissibility of evidence, because, as stated before, the *Frye* standard requires that the scientific principle is generally accepted in the field. Although skull-photo superimposition may be accepted as a means of identification, the methods and the accuracy of the technique are still developing and therefore could not be used as admissible evidence for expert testimony, as it is not a "generally accepted "and agreed upon method in the scientific community. The *Daubert* standards are generally employed around the US for the admissibility of evidence in court. This is important with regard to the skull-photo superimposition technique since the technique, as mentioned previously, is not used consistently around the world. In South Africa, skull-photo superimposition is currently accepted by the legal system for the identification of skeletal remains. Therefore, consideration is needed in the South African setting to develop more specific legislative criteria for the minimum standards of scientific testing of techniques, so that they comply with the scientific objectives of relevance, repeatability, accuracy and reliability.

Skull-photo superimposition is a generally accepted method for the identification of skeletal remains even though the reliability of the technique is still questioned by some scientists and the technique is used differently around the world. It is very important to note that the technique is constantly being developed further, to achieve improved methods that are more valid and reliable (26, 64, 66, 76). Results from the practice of skull-photo superimposition consistently show that it is a valuable technique for the identification of skeletal remains;

however results presented in the literature consistently indicate that the technique should be used for the purposes of exclusion, rather than as a primary identification method.

2.4.4. Skull-photo superimposition for exclusion or inclusion purposes

Exclusion or the "failure to exclude" is presented as being a "safer" means with which to use skull-photo superimposition for identification purposes. Exclusion is a means of identifying skeletal remains through the use of skull-photo superimposition, by excluding any other skull/ set of remains as belonging to the individual in the photograph. The "failure to exclude" method is better used in closed (mass) fatality cases which means there are a known number of remains, the identities of the individuals are known, and all that is required is to match the skeletal remains to a specific missing person. By not excluding skeletal remains as belonging to a specific individual, it suggests that the remains belong to that individual, and therefore a positive identification can be made (26).

Fenton *et al.* (26) clarify their approach as being similar to other literature where skull-photo superimposition seldom yields a positive identification. By beginning their superimposition with the assumption that the skull and photograph belong to the same individual, Fenton *et al.*, (26) are able to reject their initial assumption when differences in proportions or anthropometric landmarks are discerned. If, however, very few substantial differences can be observed, then they conclude that the skull and face in the photograph may indicate the same individual.

As already noted, this differs to the technique as practised in South Africa. The manner in which the legal system operates is also different and more lenient in South Africa, where it pertains to minimum scientific standards for the presentation and acceptability of scientific evidence. It would seem that stricter and clearly defined legislative parameters for the presentation of scientific evidence by expert witnesses are needed in South Africa. *Daubert* requires that scientific theories are repeatable and have validation. Currently, this cannot be said for skull-photo superimposition in South Africa. The questions regarding the accuracy of the technique and the differences in the methodologies of the skull-photo superimposition techniques around the world encouraged the present study.

Chapter 3: Materials and methods

3.1. Introduction

In this study, crania and post-mortem photographs of individuals were used in order to carry out superimpositions. Crania were converted into 3D images with the use of a 3D scanner. Skull-photo superimposition was then carried out using 3D Studio Max software. This section will thus outline the materials and methods needed to achieve this.

3.2. Materials

The crania/ skulls that were used for this study were obtained from the Pretoria Bone Collection (PBC), Department of Anatomy, University of Pretoria.

3.2.1. The Pretoria Bone Collection

The PBC was started in 1943 initially as a teaching aid for medical, dental and health care students. In 2000, this collection was reorganized to include a student aid collection and a research collection. The research collection offers a wealth of information on physical traits and variations seen within skeletal material, such as "the physical characteristics of individuals originating from diverse geographic regions, sex differences, age and nutritional status" (39). It has been suggested that this collection can assist researchers with studies on contemporary remains.

The PBC sources the remains in one of two ways: donations and unclaimed bodies. In accordance with the *Human Tissue Act, 1983 (Act no. 65 of 1983)* (77), anyone in South Africa may donate his/her body or tissues for the purposes of medical training or therapy and research (39, 77). Under the act, the remains of a destitute individual which are unclaimed for burial by a spouse, relative or friend within 24 hours after the death may be donated to an institution such as a University for medical research, at the discretion of the inspector of Anatomy of that area. Between 50 and 100 bodies (unclaimed and donated) are received by the University of Pretoria each year, mainly from surrounding hospitals i.e. Kalafong or Mamelodi, and occasionally the Steve Biko Academic Hospital (previously the Pretoria Academic Hospital) (39). The benefit of this process is that the PBC has clear and accurate records of the individuals received from the various hospitals, such as the age of the individual, their sex and their ancestry. Therefore the research carried out using the PBC reflects standards for a South African population. A spouse, relative or known friend may later claim a previously unclaimed body with proof of relationship to the deceased or with an authorization order obtained from a magistrate (39, 77). Currently the collection consists of 1131 skulls, of which 812 are complete post-cranials and 399 are incomplete post-cranials (L'Abbe, pers. comm.).

The collection has cadaver photographs available, which are taken of the individuals on arrival at the Department of Anatomy, which thus include facial photographs reflecting the ancestry and sex of the deceased persons. In this way the demographics of each cadaver is documented for future use as white, black or coloured/mixed ancestry and male or female. The majority of the photographs were initially taken with an Olympus TRIP AF 30 normal 35 mm film camera and lens: DX Olympus 34mm 1:5.6. Some of the later photographs were taken digitally, with a Sony Cybershot, 2.8 megapixel, and Sony lens, f=6,9mm 1:2.8, digital camera. Photographs are taken at the time that the bodies are admitted to the University of Pretoria's mortuary, and thus are post mortem images of a deceased person; no ante mortem or ID book photographs are available for these individuals. All the photographs are catalogued for the purposes of research and these were the images used for this study.

Only anterior view photographs were included in this study. The photographs are taken by the technical staff in the Department of Anatomy, and not by a student or researcher, therefore there has been no standardization, i.e. the photographs are not always of good quality and don't repeat the identical positioning of the head for each photograph. The cadaver photographs are not "ideal" due to the lack of standardization when taking the photograph; however, it is believed that this may represent what could occur in real life where a photograph that is not of good quality is provided by the family of the suspected deceased.

It must be noted that the photographs are of deceased individuals, and therefore the superimposition involved superimposing a photograph of a deceased person over a skull. The superimposition could still be carried out however, where sufficient facial features were visible for the process to continue: i.e. photographs where facial features were poorly reflected were excluded from the study, based on the poor quality of the photograph.

3.2.2. Sample collection

The sample collection involved looking through the approximately 700 photographs available in the PBC. Of these, only 40 were included in the study due to the stringent exclusion criteria used. The final sample consisted of 20 black and 20 white males. Forty photographs of male persons, 20 of which were black and 20 white individuals, were randomly selected. Depending on the quality of the image, a photograph was accepted or rejected as part of the study. As stated above, many of the images could not be included due to their poor quality and some photographs had to be eliminated as the remains had been collected by the family

The catalogues of cadaver photographs were used to select skulls. For the photograph to be selected to be part of the study, specific criteria had to be met. Through a process of elimination using the criteria, 40 photographs were selected. The following criteria were used for selection:

- Only male individuals were selected for the study.
- The quality of the images: The photographs were chosen randomly and included depending on the clarity of the facial features seen in the photograph.
- For each of the 40 selected photographs, the skull matching that photograph had to be available.
- Black and white individuals were chosen.
- Nine skulls plus the skull of the individual in the photograph were selected for the sample. In order to perform blind testing, the nine further skulls together with the matching skull for each photograph were selected from the PBC. The skulls used in the blind testing were matched to the study sample with regards to ancestry and age. If two photographs were used that were of individuals of identical population affinity and similar age, some of the nine skulls that were used for the photograph were used for matching in the second similar photograph. This resulted in fewer skulls requiring scanning to make up the samples.
- This resulted in approximately 150-170 skulls being 3-dimensionally scanned to make up the scan sample for each photograph.

Ethical clearance was obtained for this study (Ethics clearance number 32/ 2006), but in order to protect the identity of the individuals (cadavers) in the photographs, the ethics committee stipulated that only parts of faces may be revealed due to the sensitive nature of these images. For this reason, complete images of the individuals used in this study will not be shown anywhere. In the introduction section of this thesis, unedited South African Police Service case images (**) have been used without an attempt to protect the identity of the individual in the photographs, as this case has been finalized in the legal system. It was also agreed that the crime scene photographs would be used without editing in this thesis, but not used in any publications which may potentially arise from this study.

3.3. Methods

The study was carried out in three stages. In the first stage the technique of matching the skull to the photograph was developed. This involved scanning photographs to have digital copies of them as well as scanning skulls 3-dimensionally for the superimpositions technique. These were then matched/ overlaid using computer software. This process involved some practice and repetition. This newly developed technique was then used to carry out stages two and three. In the second stage a morphological matching of skulls and photograph was carried out and in the third stage a landmark-based computerized matching of skulls and photographs was carried out.

3.3.1. Stage 1

3.3.1.1. Photograph capturing procedure:

Photographs were uploaded using a Canon CanoScan LiDE 20 scanner. Photographs were digitally trimmed to remove unnecessary imagery- the images were cropped so that only the head and face could be seen. The cadaver number (which appears above the person in the photograph) was also digitally removed from the photograph. This was to ensure anonymity for the investigator during the study as well as to protect the identity of the individual. The new cropped image was saved separately with its original cadaver number to be used in 3D Studio Max software. The skulls were initially scanned according to the cadaver number assigned to the remains and were then later renamed in a new folder to be used in the 3D Studio Max program. This was done so that anonymity could be ensured.

3.3.1.2. Skull scanning procedure:

Once the 40 skulls of the individuals for which photographs were available, as well as the additional 150 skulls that would be used in the blind testing were selected, they were scanned using a Cyberware™ Model 3030 Colour 3D Scanhead scanner located at Ergotech in Centurion, Pretoria (Figure 3.1).

Skulls including articulated mandibles were scanned (making provision for the temporo-mandibular joint cartilage). Prestik™ was used to aid with the articulation of the mandible onto the skull and to represent the temporo-mandibular cartilage. The skulls of the white individuals proved problematic due to the fact that many of the mandibles and maxilla were edentulous. In cases such as these, the Prestik™ was used in the temporo-mandibular joint as well as a piece of Prestik™ (approximately 2 cm in thickness) between the maxilla and mandible to account for teeth (where dentures were probably worn). This 2 cm thickness was estimated based on measurements taken from skulls with teeth in the upper and lower jaw (Figure 3.2).

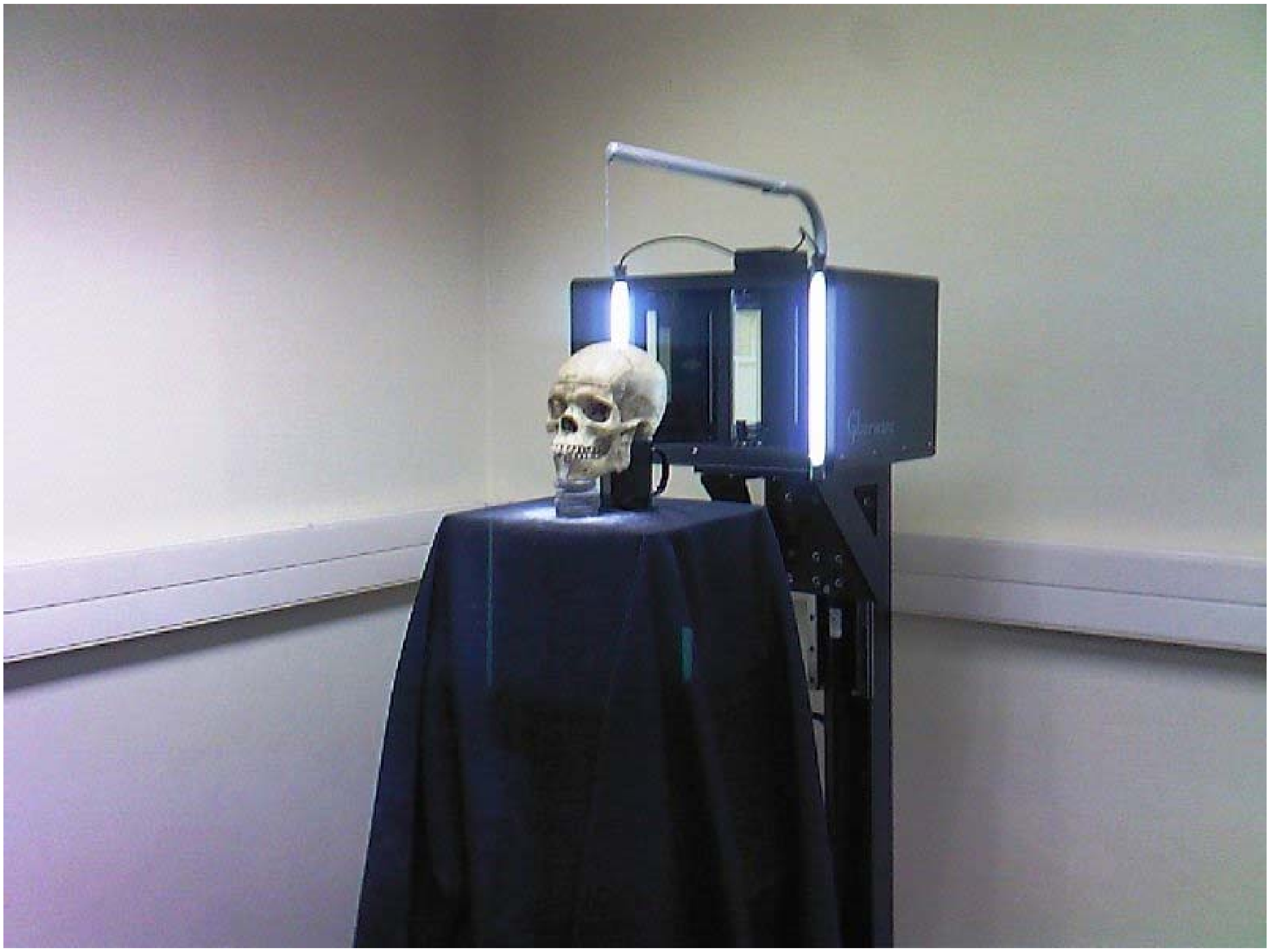


Figure 3.1. The process of 3D scanning a skull

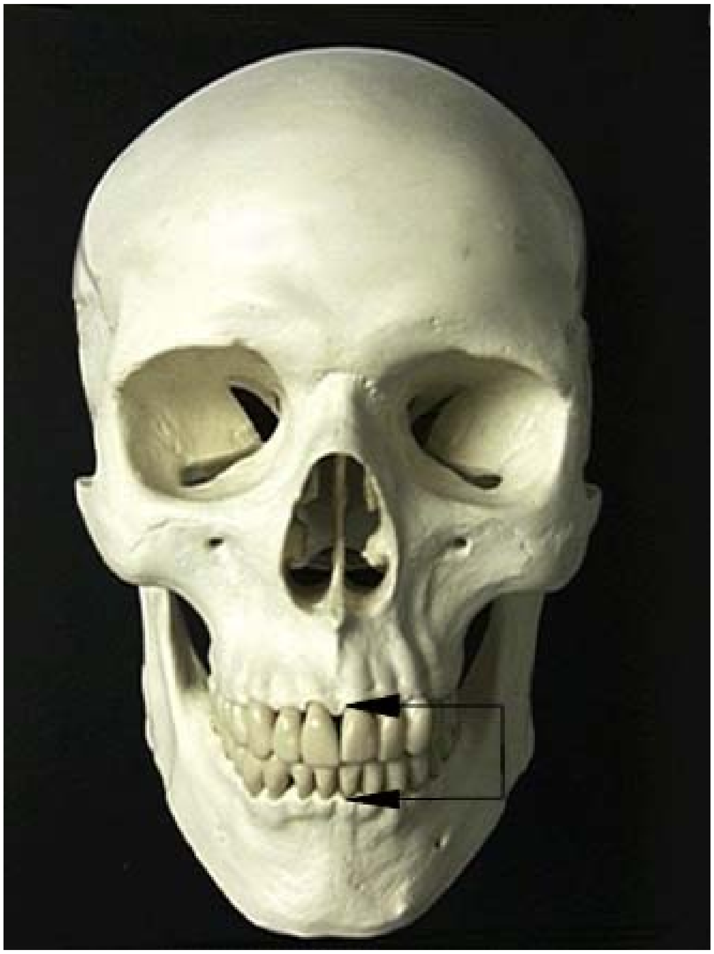


Figure 3.2. The measurement used to estimate the distance between the mandible and maxilla in an edentulous skull. The measurement is shown with the arrows.

Once the skulls had been scanned, a three dimensional image was obtained. These images were then edited and reduced in size in the Cysurf™ software located on the computer at Ergotech. The editing involved opening the raw data image and "cleaning" it, using functions of the Cysurf™ program. This included de-spiking the image (i.e. removing areas of spiking on the image which is extra unnecessary data picked up by the scanner), voiding (or erasing) unnecessary areas that were picked up during the scanning process (i.e. areas within the orbits which were not needed); filling areas of the scan which were not picked up during the scanning process (some curved surfaces were not picked up properly) and finally smoothing the image. The cleaning process does not in any way alter the image or the original anatomy of the skull. This image was then reduced in size by 50% to be used in 3D Studio Max. No sections of the image or quality of the image are sacrificed in the decimation (size reduction) process. The decimation process is absolutely necessary in order for the image to be small enough to use in the 3D Studio Max program. These images were then further utilized in the 3D Studio Max program.

3.3.1.3. Development of skull-photo superimposition technique:

In this part of the study 10 photographs were matched to the 3D scans of their own skulls, in order to develop and refine the technique in 3D Studio Max- initially skulls and photographs were matched morphologically similar to the method used by the SAPS. Using this method, corresponding landmarks were then placed on the photographs and the 3D scans, and it was established how many of the dots representing primary and secondary landmarks should overlap exactly and/or touch in order for a match to be positive. Details of how this was carried out will be explained under 3.3.3.1. The aim for this stage was to "practice" the techniques that were necessary to carry out stages 2 and 3.

3.3.2. Stage 2 of the skull-photo superimposition study:

This stage analyzed how well the photographs matched the/a skull 3D scan based purely on morphology and whether one or more match between a photograph and skull (in effect 3D image of a skull) were obtained. Photographs of each of the 40 individuals were matched to 10 skulls each (the selection of which was explained previously). This stage was based on a visual morphological assessment of the goodness of the fit, and is similar to the current method used in photographic superimposition by the South African Police Service (Briers, pers. comm.) as well as the list of requirements of a frontal consistent fit between skull and face from Austin-Smith and Maples (24) as tabulated in Table 2.2.

3.3.2.1. Superimposition procedure:

Working in the 3D Studio Max program involved importing the photograph image (in .jpg format) as well as the skull image (in .obj format) into the program (Figure 3.3).

3D Studio Max is a software program that makes use of shapes and the manipulation thereof possible. The photograph itself is a flat image and had to be imported onto a shape to be viewed in 3D Studio Max.

Figure 3.3. The imported images in 3D Studio Max. The scanned image of the skull is shown on the left, and the photograph of the matching individual on the right.

The 3D Studio Max software program operates by providing a view of an image or object from four different perspectives/ views i.e. front, top, lateral and perspective. These four views enable the user to manipulate or rotate an image or object at random whilst at the same time being able to see the image or object from four different views at the same time (Figure 3.4).

For the purposes of this study, the “front” view was primarily used to ensure that the proportions of the photograph and skull were correctly maintained.

The stage 2 superimposition steps were as follows:

1. The skull and photograph were imported into the 3D Studio Max program.
2. The skull and photograph were adjusted to the same proportion and size.
3. The skull and photograph were moved over each other for the assessment to be carried out.
4. The morphological match was carried out based on the morphological features of the skull and photograph.

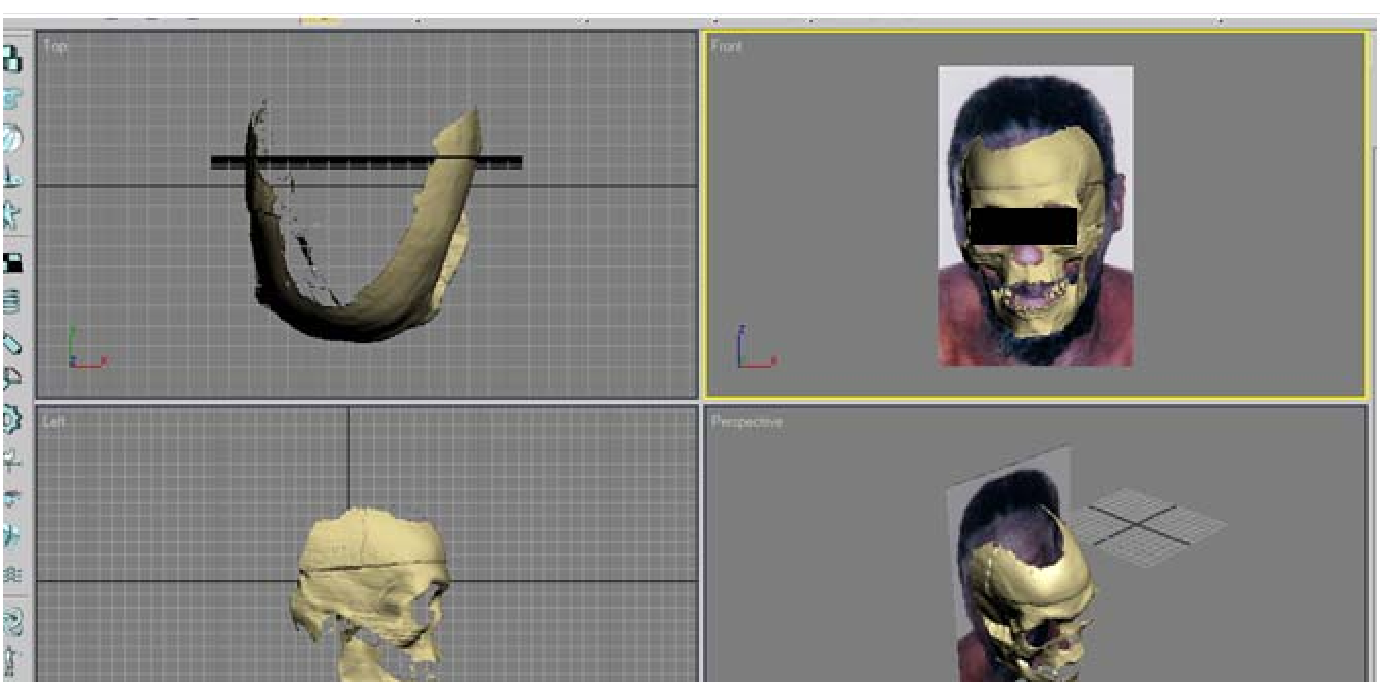


Figure 3.4. The four views seen in Studio Max. The top right view is the view used to carry out the superimposition. Whilst movements are made in the top right view, the same movements can be seen in the other views but from a different perspective i.e. from the top, or from the side (laterally).

For this stage a simple morphological match was carried out in order to determine whether the skull and its morphological features belong to the individual in the photograph. This was carried out using the list of requirements of a frontal consistent fit between skull and face from Austin-Smith and Maples (24) as shown in Table 2.2, for example did the morphological features of the face match with the features of the skull (Briers, pers. comm.). Dimensions such as nasal height, upper facial height and bizygomatic breadth were also considered when attempting to match the skull to the photograph. Each of the 10 skulls for one individual photograph were analyzed in this way following the above steps.

The only difference between this method and the current method used by the SAPS is the fact that an image of the skull in the form of a 3D scan was used, instead of a video image. This should make no real difference to the outcome of the superimposition.

3.3.3. Stage 3 of the skull-photo superimposition procedure:

In this stage 40 photographs were matched to 3D scans of 10 skulls each. This stage was firmly based on how well / exactly the craniofacial landmarks/points matched. No subjective judgments were made on whether the skull and photograph matched. The match between photograph and skull was made based on matching criteria for each landmark used as described fully in 3.3.3.3. The technique used here was similar to the technique used by Bajnóczky and Királyfalvi (22), where they made use of points and compared before and afterwards conditions when attempting to match two photographs to one skull as explained in the literature review.

3.3.3.1. The craniofacial landmarks:

Craniofacial landmarks have been used in this study in order to allow for objective assessment of a match between a photograph and a skull. Figures 3.5 and 3.6 show an anterior and lateral view of the skull with craniofacial landmarks, with full definitions of each of the landmarks in Tables 3.1 and 3.2 (78-80).

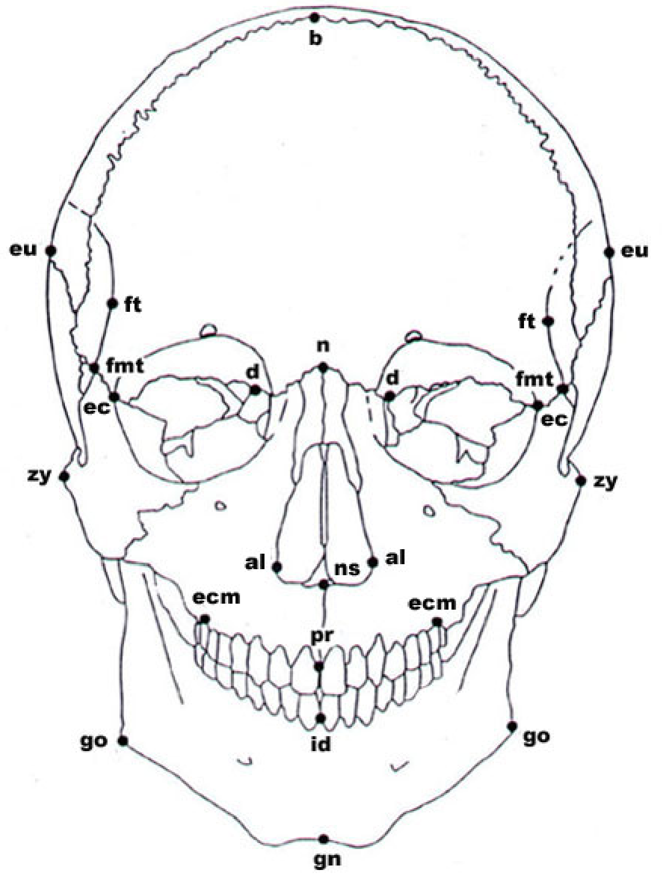


Figure 3.5. Anatomical landmarks of the skull/ craniometric landmarks (anterior view) (78-80). The landmark abbreviations and the full name of the landmark are explained in Table 3.1.

Table 3.1. Landmark abbreviation and landmark complete name which provide explanations to Figure 3.5.

Landmark abbreviation	*Landmark name*
Al	Alare
B	Bregma
D	Dacryon
Ec	Ectochonchion
Eu	Eurion
Fmt	Frontomalare temporale
Ft	Frontotemperale
Gn	Gnathion
Go	Gonion

Id	Infradentale
N	Nasion
Ns	Nasospinale
Pr	Prosthion
Zy	Zygion

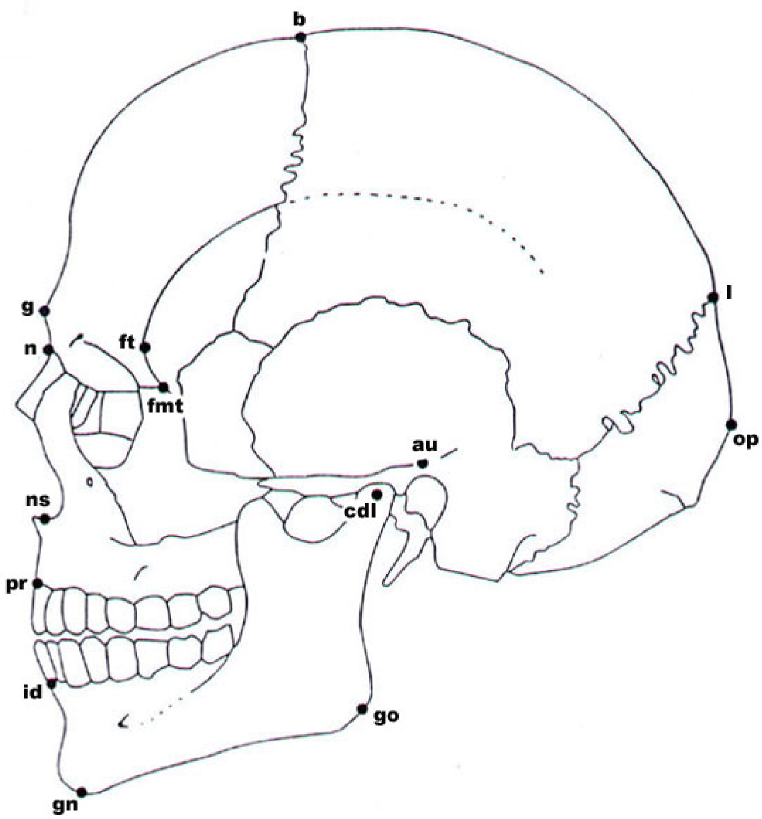


Figure 3.6. Anatomical landmarks of the skull/ craniometric landmarks (lateral view) (78-80). The landmark abbreviations and the full name of the landmark are explained in Table 3.2.

Table 3.2. Landmark abbreviation and landmark complete name which provide explanations to Figure 3.6.

Landmark abbreviation	*Landmark name*

Au	Auriculare
B	Bregma
Cdl	Condylion laterale
Fmt	Frontomalare temporale
Ft	Frontotemperale
G	Glabella
Gn	Gnathion
Go	Gonion
Id	Infradentale
L	Lambda
N	Nasion
Ns	Nasospinale
Op	Opisthocranion
Pr	Prosthion

It is important to take note that the craniofacial landmark on the surface of the skull may not have the same corresponding orientation as it would on the surface of the skin. As used by Farkas (62), for the purposes of this study, the cranial landmarks will be described as “bony” landmarks, and the skin surface landmarks will be described as “soft” landmarks henceforth. These are further described in Tables 3.3 – 3.5. The bony landmarks are accurately identified because the exact positioning of the landmark can be seen. The identification and placement of soft landmarks on the skin requires experience and so can be difficult for beginners. Raijion (81) has also had similar findings in his study where he explains that landmark identification on the face of an individual is more of an art than science and is often tedious and time consuming and the success thereof is based on one’s previous experience. Some soft landmarks are easier to locate and place; however, the task is generally a challenge (62).

For this study, orientation landmarks, primary landmarks and secondary landmarks were selected from the list of available landmarks (Figures 3.5 and 3.6).

<u>Orientation Landmarks</u>

Orientation landmarks were selected to assist with the orientation of the skull to the photograph. These were selected as they were landmarks easily identified on both the face and the skull and therefore it was felt that these landmarks could be used to align photograph with skull with a high degree of accuracy. The orientation landmarks ensured that the skull was correctly aligned and sized with the photograph so that the process of determining a match could follow. These were thus used as a baseline. The orientation landmarks are described in Table 3.3. A total of four orientation landmarks were thus used, as the ectocanthion is a paired landmark.

Primary Landmarks

Primary landmarks were selected because they are easily identifiable, firm landmarks. They were described as "primary" because they are clearly visible on both a skull and face, should match completely and the soft tissue overlying the landmark does not vary much between individuals. These landmarks are described in Table 3.4. This totals five landmarks, as dacryon and frontotemperale are paired landmarks.

Table 3.3. Orientation landmarks. The description of the landmark on the skull (bony landmark) and the corresponding soft tissue landmark is given. The bony tissue landmarks are based on Martin and Saller (78) and Knussman (79) as translated in Moore-Jansen et al. (80).The soft tissue landmarks are based on descriptions from Farkas (62).

Landmark	Abbreviation	Description	
		Bony Landmark	Soft Landmark
Ectocanthion	Ec	The area where the palpebral ligament attaches (right and left).	The area on the orbit (lateral) where the top and bottom eyelid meet at the bony margin.
Subnasal point	Ns	The point where the lower margins of the nasal aperture meet to form the nasal spine.	The point where the nasal septum meets the skin of the upper lip.

Nasion	N	The intersection of the nasofrontal suture with the midsagittal plane.	The uppermost point of the nasal bridge where the nasal bridge meets the skin of the forehead.

Secondary Landmarks

The secondary landmarks are those which are somewhat more difficult to locate and may also be influenced by the amount of soft tissue overlying them. They are somewhat arbitrary, but are nevertheless helpful in matching a skull and a photograph- for example, the bony landmark of gnathion should always be inside/ above the soft tissue landmark, even though the exact soft tissue thickness may vary between individuals. Similarly, the bony nasal aperture should fall inside the alae etc. these landmarks are generally more challenging to position and interpret exactly, particularly with the soft landmark placement. These landmarks are described in Table 3.5 seen below. This totals seven landmarks, because gonion, zygion and alare are paired landmarks.

Table 3.4. Primary landmarks. The description of the landmark on the skull (bony landmark) and the corresponding soft tissue landmark is given. The bony tissue landmarks are based on Martin and Saller (78)and Knussman (79)as translated in Moore-Jansen et al. (80).The soft tissue landmarks are based on descriptions from Farkas (62).

Landmark	Abbreviation	Description	
		Bony Landmark	Soft Landmark
Glabella	G	The most forward projecting point in the midline of the forehead at the level of the supra-orbital ridges and above the nasofrontal suture.	The slightly protruding area between, but slightly above the supraciliary arches.
Dacryon	D	The point on the medial wall of the orbit, at the junction of the lacrimomaxillary suture and the frontal bone.	The point on the orbit (medial) just below nasion and to its right and left.

Fronto-temperale	Ft	The most medial point on the incurve of the temporal ridge.	The narrowest point on the temple (right and left) area when looking at the face anteriorly.

Table 3.5. Secondary landmarks. The description of the landmark on the skull (bony landmark) and the corresponding soft tissue landmark is given. The bony tissue landmarks are based on Martin and Saller (78)and Knussman (79) as translated in Moore-Jansen et al. (80).The soft tissue landmarks are based on descriptions from Farkas (62).

Landmark	Abbreviation	Description	
		Bony Landmark	Soft Landmark
Gonial angle	Go	The midpoint of the angle of the mandible between the body and the ramus- the angle of the mandible on the skull should be within the angle of the mandible on the photograph.	The area where the bony prominence of the angle of the mandible is visible (right and left).
Gnathion	Gn	The lowest median point on the lower border of the mandible.	The middle most and lowest point on the chin.
Zygion	Zy	The most lateral point on the zygomatic arch.	The most lateral point on the bony ridge of the cheek bone (right and left).
Nasal aperture width/ Alare	Al	The most lateral point on the nasal apertures.	The lateral point where each ala of the nose meets the skin of the philtrum and cheek.

Altogether 16 craniofacial landmarks were used to match the photograph to the/a skull.

3.3.3.2. Procedure for superimposition using landmarks:

The stage 3 superimposition procedure comprised of the same 40 photographs and 10 skulls used in stage 2 and proceeded as follows:

1. The skull and photograph were imported into the 3D Studio Max program.
2. The skull and photograph were adjusted to the same proportion and size without distorting it.
3. A rough morphological match was carried out so as to orient the skull and photograph. As a baseline, it was ascertained that the eyes fitted into the bony orbits. The skull and the photograph were then separated so that the landmarks could be placed on each of the photograph and skull.
4. The orientation, primary and secondary landmarks (Tables 3.3, 3.4 & 3.5) were then placed on the skull and photograph and grouped (i.e. landmarks on the skull move with the skull and landmarks on the photograph move with the photograph).
5. The skull and photograph were then moved over each other for the match. The match was made by ensuring the orientation landmarks from the photograph and from the skull all touched or overlapped, so as to make 100% sure that the orientation of the skull and the photograph are identical.
6. The relative positions of the other landmarks were then assessed. Specific criteria had to be met for there to be a match between the primary and secondary landmarks. These criteria are described below.
7. Skin tissue thicknesses were taken into account using skin tissues thicknesses developed from a South African sample (82). At the time of the study, skin tissue thicknesses were not available for a South African female sample; therefore only males were included in the study.

3.3.3.3. Criteria for matching of landmarks between the skull and photograph

The criteria for what defines a match between the bony landmark and the soft landmark for the primary and secondary landmarks are described in Tables 3.6 & 3.7.

In summary for stage 3 the match was carried out using only the craniofacial landmarks. The skull and photograph were first adjusted to be the same size. Orientation landmarks were then added to both photograph and skull and both were orientated using morphological features and the orientation landmarks. The skull and photograph were then separated and primary and secondary landmarks were added. Once all primary and secondary landmarks were added, the landmarks of the skull and photograph were then superimposed over each other. The orientation landmarks were forced to fit each other and the match of the primary and secondary landmarks were then assessed.

Table 3.6. Criteria for matching of primary landmarks (anterior view)

Landmark	Criteria for match
Glabella	Landmarks must touch or overlap on both the skull and photograph**.**
Dacryon	Landmarks must touch or overlap on both the skull and photograph**.**
Frontotemperale	Landmarks must touch or overlap or the landmark of the skull can be inside/ medial to the landmark of the photograph by a distance no greater than the width of a landmark*.

* The width of a landmark is approximately 1. 5 mm in diameter.

It was proposed that the primary and secondary landmarks should touch, overlap or one landmark could be medial to another for the photograph and skull to be determined a match.

Table 3.7. Criteria for matching of secondary landmarks (anterior view)

Landmark	Criteria for match
Gonial angle	Landmarks on both the skull and photograph must touch, overlap, or the landmark on the skull must be inside/ medial to the landmark on the photograph by a distance no greater than the width of a landmark.
Gnathion	Landmarks on both the skull and photograph must touch, overlap, or the landmark on the skull can be superior to the landmark on the photograph by a distance no greater than the width of a landmark.
Zygion:	Landmarks on both the skull and photograph must touch, overlap, or the landmark on the skull must be inside/ medial to the landmark on the photograph by a distance no greater than the width of a landmark.
Nasal aperture width/ Alare	Landmarks on both the skull and photograph must touch, overlap, or the landmark on the skull must be inside/ medial to the landmark on the photograph by a distance no greater than the width of a landmark.

Stages 2 and 3 were conducted blindly. Due to the number of skulls involved in the study, it was not possible that a skull from one stage could be memorized for matching a specific photograph in the next stage. The skulls were also renamed, further ensuring the blindness of the study.

Using the criteria described above, it was then assessed if none of the skulls, one of the skulls or more than one of the skulls matched with the photograph in question. Therefore a total of 10 superimpositions per photograph were carried out, totaling 400 superimpositions overall for each of stages 2 and 3. From the 800 superimpositions thus done, it was then calculated what the accuracy was, as well as the chances of making a false positive (skull and photograph incorrectly judged as being a match) or false negative (skull and photograph match, but was not matched during the procedure) diagnosis.

3.4. Repeatability study

A repeatability study was carried out to test whether the placement of the landmarks in the landmark based matching technique was accurate. For this study 10 photographs and their matching skulls were used as in stage 1 of the study. The landmarks on each particular skull were compared to the landmarks placed on that same skull, but these were allocated a few months later. This was done to ascertain to what degree of accuracy the positioning of the landmarks may differ if placed on separate occasions.

As mentioned previously, the investigator was aware that the placement of the landmarks on the skull would be more accurate than on the photograph. This procedure tests the investigator's ability to place landmarks accurately on the same position time and time again. The validity of the study was dependant on the investigator being able to reliably place landmarks. The same matching criteria used to match skull to photograph as used in stages 2 and 3 were used again to assess a match or non-match. Therefore no statistics could be used to assess the repeatability, as the descriptive matching criteria were used for assessment.

3.5. Statistical analysis

Using the data obtained from the 800 superimpositions, (40 photographs each superimposed on 10 skulls for both stages 2 and 3), the chances for obtaining false positives and false negatives were determined. This involved calculating the percentages of skulls correctly and incorrectly matched to their corresponding photograph. This was done separately for stages 2 and 3 of the study, in order to assess the accuracy of the two methods used. For each of the two stages, the following calculations were done:

1. Out of the 40 possible correct matches, how many were positively matched to their skull?
2. In how many cases were the correct skulls not matched to their photograph (i.e. a false negative)?
3. For each of the 40 photographs, how many of the nine remaining skulls (excluding the true positive) also matched particular skull i.e. "false" positives?
4. What was the success rate with the two techniques combined- how many skulls were positively matched overall using the two techniques combined?
5. Is there a difference between the reliability of the two techniques? A Fishers Exact Probability calculation was used to determine whether there is a statistically significant difference between the results from stage 2 and stage 3, in order to establish whether one method is better to use than the other.

Chapter 4: Results

There were three stages to this study. Stage 1 involved refining the techniques with which to carry out the superimpositions for stages 2 and 3. Stage 2 involved carrying out a morphological, computerized match of a photograph with 10 skulls each. This included the actual matching photograph and nine others of the same sex, ancestry and approximate age. There were 40 photographs and therefore 400 superimpositions were carried out for stage 2. Stage 3 involved a landmark based computerized matching of a photograph with 10 skulls. Once again this included the actual matching photograph and nine others. There were also 40 photographs and therefore 400 superimpositions for stage 3, totaling 800 superimpositions overall for the study.

4.1. Stage 1

In stage 1 the development and refinement of the technique took place. Ten photographs with their matching skulls were used for this purpose. The same 10 skulls were also used again in stages 2 and 3- the blind nature of stages 2 and 3 were maintained even though these 10 skulls were used again due to the fact that there was a significant time difference between the superimpositions of stage 1 and stages 2 and 3, as well as the fact that many skulls were being used in stages 2 and 3 ensuring it was impossible to remember a specific skull. For these 10 photographs, morphological and landmark based assessments were considered. As mentioned previously in the materials and methods section, stage 2 will analyze how well the photographs matched the/a skull 3D scan based purely on morphology and whether one or more matches between a photograph and skull (in effect 3D image of a skull) are obtained. This stage will be based on a visual morphological assessment of the goodness of the fit, and is similar to the procedure that is currently used by the South African Police Service. Stage 3 will be a landmark based matching, beginning with a rough morphological match for the purposes of orientation and sizing. This involves moving the skull and photograph over each other in the 3-dimensional software package. The skull and photograph will then be separated and the chosen landmarks added and compared. During stage 1, details of how to actually conduct these two procedures were worked out. The orientation, primary and secondary landmarks that would be needed for stage 2 were established (see materials and methods). After it was established which landmarks would be used, the skull and photograph were then moved over each other and the orientation landmarks forced to fit. The positions of the other landmarks were assessed and a decision as to whether the skull and photograph matched was made (see materials and methods for matching criteria). In other words, it was established how the landmarks should be orientated relative to each other in order to constitute a positive match. The placement of the landmarks and the repeatability of the placement of landmarks were also determined.

The morphological matching of skull and photograph involved importing the skull and photograph images into the software package. The skull and photograph were moved around over each other to find the best possible fit to establish a match. Features of the face in the photograph were matched to the same feature on the skull.

Soft tissue thicknesses were considered during the matching procedure. Because soft tissue thickness data for the South African population are minimal, published South African data as well as international data for soft tissue thicknesses were considered when morphologically matching features of the face in the photograph to features of the skull (82, 83). Phillips and Smuts (84) have noted that black males and females have noticeably thicker soft tissue throughout their entire face when compared to the South African mixed ancestral groups. They further discuss the fact the mixed ancestral groups have soft tissue thicknesses that are also distinct from the American white population and go on to highlight the use of soft tissue thicknesses developed for a specific sample when making use of soft tissue thicknesses. Stephan (85) has been able to show that the commonly used mouth-width prediction guidelines are not accurate and has suggested that previously used mouth width prediction guidelines are not accurate either. The most accurate guidelines are that the mouth width is equal to the distance between the medial borders of the iris (85). Stephan (86) conducted a study which attempted to predict nose projection and pronasale/ nasospinale position and also found that the methods employed were not always accurate. The author goes on to state “many prediction guidelines exist in facial approximation for determining the soft-tissue features of the face, and the reliability of each is generally unknown” (86).

Because of these inaccuracies noted in the literature, the methods employed at the SAPS skull-photo superimposition laboratory as well as at the USA Michigan State University anthropology laboratory where the investigator spent time with experts conducting superimpositions were used. In the USA laboratory, teeth were available on the photograph and skull to match, size and orientate the two images together, therefore allowing all features of the face to correlate with each other after which a match or non-match was established. The soft-tissue depths were cut and applied to the skull at the various landmarks as indicated by Taylor and Gatliff (83) and then the superimpositions were carried out. The soft-tissue landmarks were used to compare the fit of photograph to skull as the markers provided a method to assess how much soft-tissue was present at any point for comparison with the edge of the face in the photograph. In the South African laboratory at the SAPS, the methodology of the policeman conducting the superimpositions was noted for use in this study. One of the features used was the area where the eyelids meet laterally- this should correspond with the Ectocanthion landmark on the middle of the lateral border of the orbit. This matching and orientating criteria as well as the soft tissue thicknesses (as used in the USA) were considered when superimposing the photograph over the skull so that a match or non-match could be established (Briers, pers. comm.). The aim when carrying out the superimpositions morphologically was that when the photograph was placed over the skull, the eyes on the photograph should fit within the orbits of the skull and the area where the two eyelids meet laterally should correlate to the Ectocanthion landmark. The lips should meet just above where the teeth from the maxilla and mandible meet. Other features such as the contours of the mandible on the photograph should fit with the contours seen on the mandible of the skull and the nose should fit over the nasal aperture with each nostril an equal distance from the Alare landmark laterally (Figure 4.1).

The features as described for Figure 4.1 were assessed for each of the 10 superimpositions carried out morphologically and a process of matching a skull to the photograph was developed.

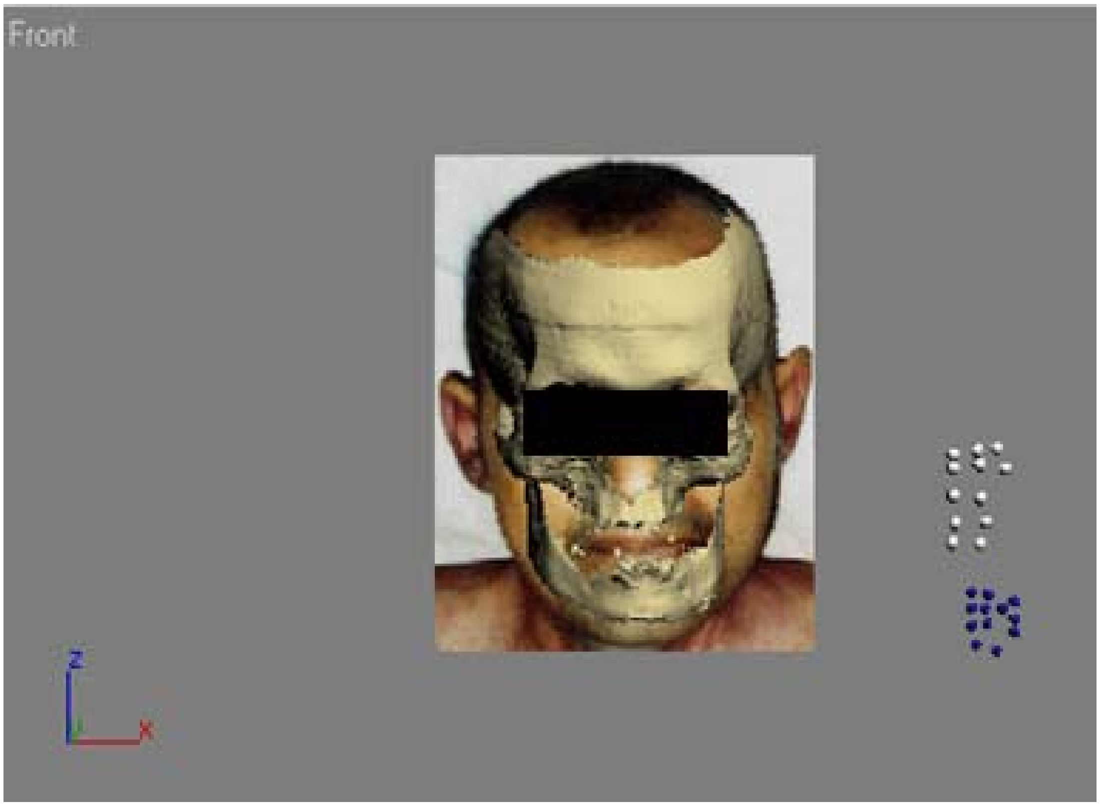


Figure 4.1. The morphological match of a photograph and skull. Note the contours of the skull fit within the face of the photograph, the eyes fit within the orbits, the nose fits over the nasal aperture and the contour of the mandible follows that of the jaw line in the photograph.

These features would be considered for the morphological superimpositions going forward for stage 2. Should these features be found to match/ fit, it would be determined that the skull and photograph are a match. Should these morphological features be found not to correlate, it would be decided that the skull and photograph are not a match.

During preparation for stage 2 it was found that the objectivity of the procedure was not as straightforward as first contemplated. This technique needs to be studied and internalized, with ample understanding and experience required for it to be done effectively. Working through these first 10 superimpositions taught the investigator what to look for morphologically, so that a better understanding was gained in order to be able to carry out the technique effectively. There is therefore a degree of subjectivity when carrying out the superimposition procedure based on morphological features. The additional use of the more objective landmark based matching technique will thus improve the overall objectivity of the technique.

This superimposition procedure for stage 3 began with establishing how to place landmarks and how to size and orient the photograph and skull to match each other with the landmarks now added. A great deal of practice with placing the landmarks in the same position repeatedly was needed. Therefore the development of this procedure began with a few landmarks on the photograph and skull and practicing how to place the landmarks and place them repeatedly. Figure 4.2 illustrates one of the initial landmark based matching procedures where the skull was matched to the photograph.

Orientation, primary and secondary landmarks were not yet established. At this stage the only concern was to accurately and repeatably position the landmarks. From this point orientation, primary and secondary landmarks were developed. Orientation landmarks would be landmarks based at the centre of the face and were established as being the easiest to consistently match between the photograph and skull with minimal soft tissue thickness influence. Therefore, these landmarks would have to match each other when orientating the skull to fit the photograph. The landmarks that were selected as orientation landmarks were ectocanthion (left and right), subnasal point and nasion. Primary landmarks were then selected and these were landmarks that may be slightly more difficult to locate and place repeatedly because some of the landmarks were more laterally located on the face and possibly more influenced by soft tissue thicknesses in those areas. An important consideration for the use of these landmarks was the fact that some of these landmarks may not always overlap each other exactly, due to the fact that they can vary with soft-tissue thicknesses in those areas. Secondary landmarks were then selected to further aid in the matching process.

Figure 4.2. Landmark based matching of skull and photograph using 10 landmarks: practice with placing the landmarks and matching skulls to photographs using landmarks. The blue dots are the photograph landmarks and the white dots are the skull landmarks.

Some difficulty was experienced initially with the identification and placement of some of the landmarks due to the various soft-thicknesses, however as more superimpositions were conducted, the process became easier. An attempt was made to use more landmarks rather than fewer, as this would be more beneficial for the study. Matching the landmarks, particularly where they did not touch but were in close vicinity, also caused problems. Ascertaining how close the landmarks needed to be in order to constitute a positive match was difficult, because even though it was known that these 10 cases should match their photographs, the positioned landmarks did not always match completely. Eventually it was decided that the landmarks could be the size of the point used (1. 5 mm diameter) away from each other (i.e. not touching but within 1. 5 mm away from each other) in order for those landmarks to be deemed a match.

The process of matching would proceed as follows: the photograph and skull would be matched morphologically first for orientation and sizing; the skull and photograph would then be separated and the landmarks located and placed; then the skull with landmarks would be moved over the photograph with its landmarks to establish the match between the landmarks. The matching criteria for the primary and secondary landmarks are listed in the materials and methods and include criteria such as:

- The landmarks must touch: the circumference border of the one dot must be in contact with the border of another dot.
- The landmarks much overlap: the circle shape of one dot must overlap with the circle shape of another dot
- The landmarks can be inside the other with a distance of no more than 1. 5mm apart: the dot of the skull landmark may fall approximately 1. 5 mm medially from the landmark on the photograph. This was done to allow for soft-tissue thicknesses which were a constant consideration whilst carrying out the superimpositions.

The match between landmarks with the skull and photograph visible (group match) was assessed (Figure 4.3), as well as the landmarks with skull and photograph not visible (dot match) (Figure 4.4).

Figure 4.3. Group match. The match between photograph and skull using the landmarks- with the skull and photograph visible. The blue dots are the photograph landmarks and the white dots are the skull landmarks.

The matching of these first ten skulls with their associated photographs was carried out effectively. The morphological matching and the use of the landmarks for matching were done with sufficient precision in order to proceed with stages two and three where the exact accuracies could be determined.

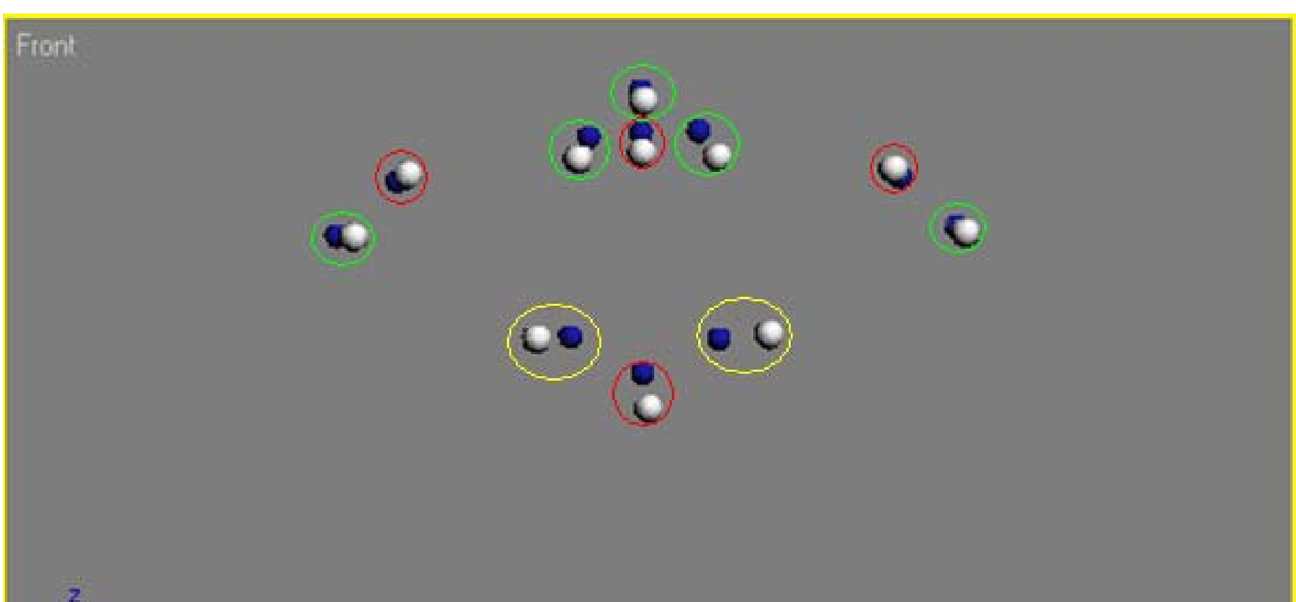


Figure 4.4. Dot match. The match between photograph and skull using the landmarks- with the skull and photograph not visible. The blue dots are the photograph landmarks and the white dots are the skull landmarks. The red circles indicate the orientation landmarks, the green circles indicate the primary landmarks and the yellow circles indicate the secondary landmarks.

4.2. Stage 2

Stage 2 involved the morphological assessment of 40 photographs with 10 skulls each. Four hundred superimpositions were carried out in total for this stage. Of the 40 photographs that were assessed, six false negative results were obtained. Thus six of the 40 photographs were not matched to their correct skulls, and the correct skull was not included at all as a possible match. This is equivalent to a 15% false negative rate for the morphological assessment component of the study. Of the 40 photographs assessed, 34 (85%) were positively matched to their actual skull, but so were 69 other skulls. This is equivalent to a 17.3% false positive rate (69 / 400 superimpositions). Out of the 400 superimpositions (69/400) 17.3% could thus not be excluded as a possible match. Table 4.1 shows the results from the morphological assessment. The cases highlighted in yellow are the cases where the correct skull was matched to the photograph. In the 'matching skulls' column it can be seen which of the skulls, out of a total of 10 were matched to the photograph. The correct skull is also indicated in one of the columns. The number of incorrectly matched skulls (false positives) is also indicated in the last column. Therefore, the table illustrates the number of positive matches (how many skulls could be regarded as a positive match to a particular photograph which are highlighted with yellow) and the number of false negatives (which are the non-highlighted cases where the correct skull was not matched to its photograph and thus not included in the list of possibilities for that photograph).

Examples of a positive match and a non-match are shown in Figures 4.5 and 4.6. Figure 4.5 is a positive match as indicated by the arrows; (a) the width of the cranium fills the forehead area of the face, (b) the curve of the mandible is similar to that of the facial jaw, (c) the orbits completely encase the eye including the medial and lateral folds, the width of the nasal aperture falls outside the borders of the nose (24) and (d) the width of the zygomatic bones on the photograph as well as the fleshy areas of the cheek fall over the zygomatic bones on the skull.

Figure 4.6 is a non-match as the features of the face do not match the features of the skull as indicated by the arrows. The angle of the mandible (a) falls outside the contour of the skull and the cranium is too small to fit the contour of the head and scalp areas (b) on the photograph. The zygomatic bones of the skull are also too narrow to be a positive match to the photograph (c).

A possible reason why the six correct skulls were falsely excluded from being a match could be due to the quality of the photograph and the quality of the 3-dimensional scan.

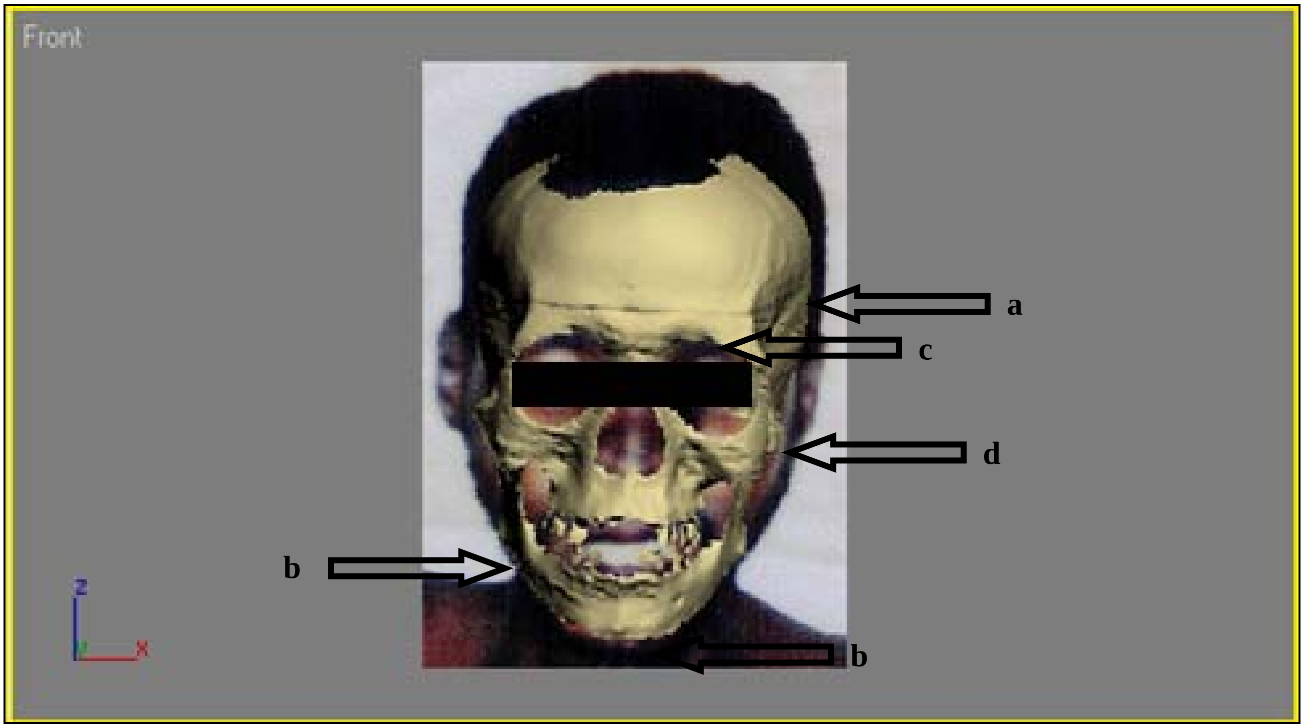


Figure 4.5. 6231 Skull ‘g’ Morphological matching. This superimposition is an example of a positive match for stage 2 of the study. Arrow (a) indicates the width of the cranium filling the forehead area of the face, (b) indicates that the curve of the mandible is similar to that of the facial jaw, (c) indicates that the orbits completely encase the eye including the medial and lateral folds and (d) indicates that the width of the zygomatic bones on the photograph as well as the fleshy areas of the cheek fall over the zygomatic bones on the skull

It was found that the features of the skull and photograph are not very easily observable whilst carrying out the superimposition and therefore, a match might not be made, as the “matching” or correlating features are not observable in the software program where the superimposition was being carried out. The overall quality of the 3-dimensional scan and photographs were found to be problematic during the entire superimposition process. This is addressed further in the discussion section.

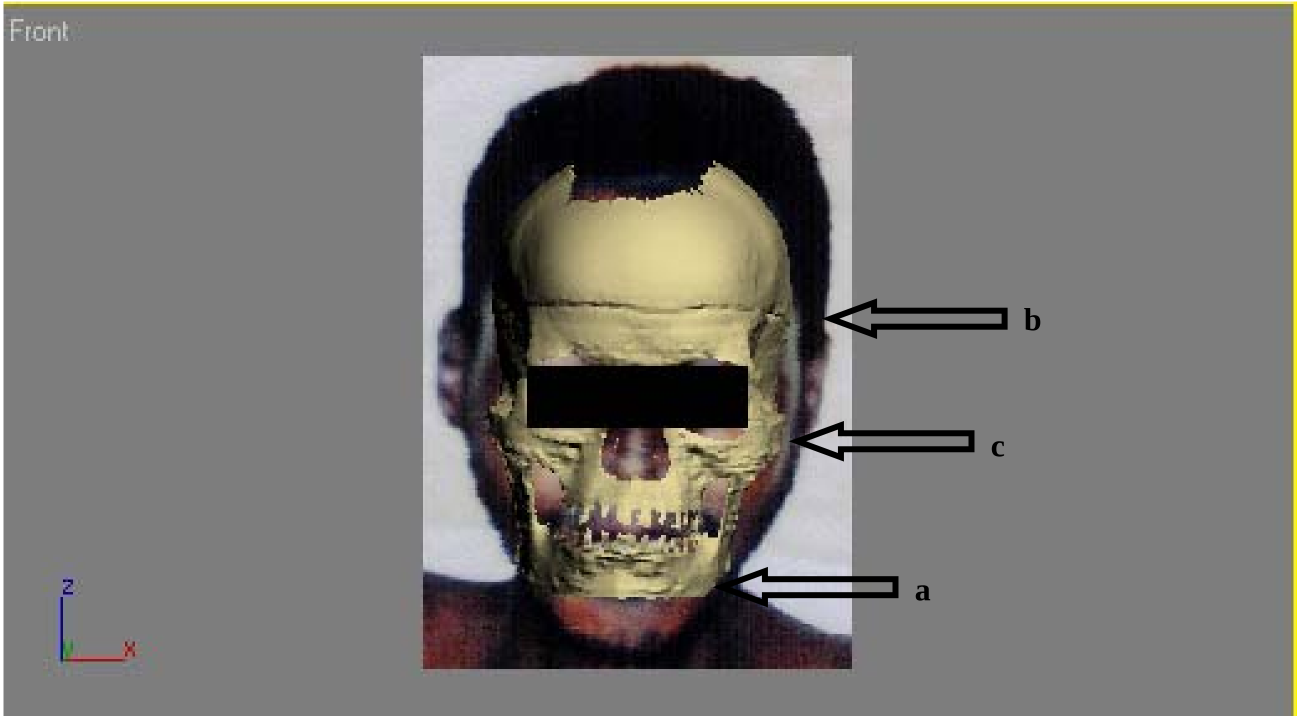


Figure 4.6. 6231 Skull ‘h’ Morphological. This superimposition is an example of a non-match for stage 2 of the study. Arrow (a) indicates that the angle of the mandible falls outside the contour of the skull (b) indicates that the cranium is too small to fit the contour of the head and scalp areas, and (c) indicates that the zygomatic bones of the skull are also too narrow to be a positive match.

Table 4.2 summarizes the results of this stage of the study. From this table it can be seen that there was only one case where the correct skull, and only the correct skull, was matched with its photograph (indicated in purple). For all others, one to three other skulls also matched the photograph. On the other hand, it can also be said that six to nine skulls could be excluded per photograph, although in six cases it also excluded the correct skull.

Table 4.1. Results of morphological assessment: positive matches. The cases where the correct skull was included in the list of possibilities are highlighted in yellow.

Photograph number	***Matching skull/s***			***Correct skull***	***Number of incorrect skulls matching photograph***
6142	e	i	j	i	2
6231	g			g	0
6325	d	j		j	1
6280	f	h	i	i	2
6281	c	f	j	j	2
6219	e	j		j	1
6228	d	f	i	i	2
6264	d	g	i	g	2
6306	i	d		g	2
6307	b	e	j	j	2
6288	g	e		i	2
6310	c	j		j	1
6292	e	i	b	i	2
6301	b	h	a	j	3
6305	j	i		j	1
6309	j	i		j	1
6323	a	e	i	i	2
6325	i	j		i	1
6314	f	e		e	1
6367	i	j	h	j	2
6374	c	f	j	j	2
6391	a	i	j	j	2
6207	a	c	i	a	2
6269	a	b	i	a	2
6218	c	f	g	g	2
6248	c	i	g	c	2
6317	f	h		f	1
6327	a	c	f	c	2
6371	b	f		b	1
6376	a	e	g	g	2
6381	d	e		d	1
6385	j			f	1
6299	a	g		a	1
6283	j	g		a	2

6242	c	d	g	g	2
6210	d	g	i	i	2
6230	h	i		g	2
6253	c	h	j	h	2
6316	c	f		c	1
6220	a	b	e	e	2
Total number of other skulls matching photograph					**66**

Table 4.2. Summary of results of morphological assessment. The cases where the correct photograph was not included in the list of possibilities are highlighted in blue. The case highlighted in purple is the only case where only the correct skull was matched to its photograph.

Skull number	***Skull and photograph match***	***Other matching skulls***	***Skulls excluded***
6142	Yes	2	7
6231	Yes	0	9
6325	Yes	1	8
6280	Yes	2	7
6281	Yes	2	7
6219	Yes	1	8
6228	Yes	2	7
6264	Yes	2	7
6306	No	2	8
6307	Yes	2	7
6288	No	2	8
6310	Yes	1	8
6292	Yes	2	7
6301	No	3	7
6305	Yes	1	8
6309	Yes	1	8
6323	Yes	2	7
6325	Yes	1	8
6314	Yes	1	8
6367	Yes	2	7
6374	Yes	2	7
6391	Yes	2	7
6207	Yes	2	7
6269	Yes	2	7
6218	Yes	2	7
6248	Yes	2	7
6317	Yes	1	8
6327	Yes	2	7
6371	Yes	1	8
6376	Yes	2	7
6381	Yes	1	8
6385	No	1	9
6299	Yes	1	8
6283	No	2	8

6242	Yes	2	7
6210	Yes	2	7
6230	No	2	8
6253	Yes	2	7
6316	Yes	1	8
6220	Yes	2	7
Totals		**66**	**300**

4.3. Stage 3

Stage 3 involved the landmark based assessment of 40 photographs with 10 skulls each. Four hundred superimpositions were also carried out for this stage. Table 4.3 illustrates the results of this phase of the study. In this table, the highlighted skull samples (yellow) are the samples in which the skull was included as a possible correct match to its photograph. The non-highlighted rows indicate the cases where the correct skull was not included as a possible match to its photograph. Of the 40 photographs, 32 positive matches were achieved, which is equivalent to an 80% positive identification rate. However, between one and seven other skulls were also matched to the same photograph in cases where the correct skull was matched to its photograph- between one and seven skulls could thus not be excluded as possibly belonging to the photograph. Out of the 400 superimpositions, 128 could not be excluded as a possible match which is equivalent to a 32% false positive rate. Of the 40 photographs that were assessed, eight false negative results were obtained. That is, eight of the 40 photographs were not matched at all to their correct skulls. This is equivalent to a 20% false negative rate for the landmark based assessment component of the study.

Table 4.4 summarizes the results. It also shows how many other skulls from the sample of 10 skulls used for the superimposition also possibly matched the photograph. It must therefore be noted that although an 80% positive identification rate was achieved, this was not achieved by matching only the correct skull to the photograph. In fact, with the landmark based assessment method, there were no cases where the single correct skull was exclusively identified as belonging to the individual in the photograph, as was found in the morphological assessment method.

Examples of a positive match and non-match are shown in Figures 4.7 to 4.10. Fig. 4.7 is an example of a positive match.

Table 4.3. Results of landmark-based assessment: positive matches. The cases where the correct skull was included in the list of possibilities are highlighted in yellow.

Skull number	***Matching skulls***	***Correct match***	***Number of other skulls matching photograph***
6142	a b h i	i	3
6231	b f g	g	2
6325	g i j	j	2
6280	c i	i	1
6281	d e	j	1
6219	c	j	1
6228	c d g i	i	3
6264	b c d f g h i	g	6
6306	d g i	g	2
6307	b e j	j	2
6288	b c i	i	2
6310	c d f j	j	3
6292	b c e f i j	i	5
6301	e j	j	1
6305	h j	j	1
6309	a b e f j	j	4
6323	b d h i j	i	4
6325	h i	i	1
6314	d e f	e	2
6367	g h i	j	3
6374	a b	j	2
6391	a b e h i j	j	5
6207	c i	a	2
6269	a b c e f h j	a	6
6218	e f g	g	2
6248	a e f h i j	c	6
6317	a d f h j	f	4
6327	a f h	c	3
6371	a b c d f h i	b	6

6376	a c e g i	g	4
6381	b c d e f h i	d	6
6385	e f i j	f	3
6299	a b d f g	a	4
6283	a f g i	a	3
6242	c f g	g	2
6210	a b d e f g h i	i	7
6230	h i	g	2
6253	a b c d h	h	4
6316	b c f j	c	3
6220	a c e f h	e	4
Total number of other skulls matching photograph			**127**

Table 4.4. Summary of results of landmark-based assessment. The cases where the correct skull was not included in the list of possibilities are here highlighted in blue.

Skull number	*Skull and photograph match*	*Other matching skulls*	*Skulls excluded*
6142	Yes	3	6
6231	Yes	2	7
6325	Yes	2	7
6280	Yes	1	8
6281	No	2	8
6219	No	1	9
6228	Yes	3	6
6264	Yes	6	3
6306	Yes	2	7
6307	Yes	2	7
6288	Yes	2	7
6310	Yes	3	6
6292	Yes	5	4
6301	Yes	1	8
6305	Yes	1	8
6309	Yes	4	5
6323	Yes	4	5
6325	Yes	1	8
6314	Yes	2	7
6367	No	3	7
6374	No	2	8
6391	Yes	5	4
6207	No	2	8
6269	Yes	6	3
6218	Yes	2	7
6248	No	6	4
6317	Yes	4	5
6327	No	3	7
6371	Yes	6	3
6376	Yes	4	5
6381	Yes	6	3
6385	Yes	3	6

6299	Yes	4	5
6283	Yes	3	6
6242	Yes	2	7
6210	Yes	7	2
6230	Yes	2	8
6253	Yes	4	5
6316	Yes	3	6
6220	Yes	4	5
Totals		**127**	**240**

It can be seen that morphologically the skull and photograph match each other following the list of requirements of a frontal consistent fit between skull and face from Austin-Smith and Maples (24) as tabulated in table 2.2. This, however, was not a prerequisite for the landmark based match to take place. This stage began with orientating and sizing the skull and photograph so that angles and proportions were equal for both images.

Figure 4.7 illustrates the images of both the skull and photograph with landmarks present. Figure 4.8 illustrates the matching of the landmarks where the skull and photograph are hidden so that just the landmarks may be assessed. Figures 4.7 and 4.8 show that all the landmarks are in very close proximity to each other with the only notable differences being with the frontotemperale landmark (ft) (left and right as indicated with arrows) and the gonial angle (go) (on the left as indicated by the arrow). The primary landmarks ectocanthion (ec) (left and right), nasion (n) and subnasal point (ns) all match according to the criteria stipulated. The primary and secondary landmarks glabella (g), dacryon (da) (left and right), frontotemperale (ft) (left and right), gonial angle (go), gnathion (g), zygion (zy) (left and right) and alare (al) (left and right) all match according to the criteria stipulated. The notable differences in the frontotemperale landmarks and the left gonial angle landmark are possibly due to skin tissue thicknesses which must be considered when matching of skull and photograph is carried out. The gonial angle landmark does fulfill one of the criteria of being 1.5 mm away from each other in the photograph and on the skull. The use of fronto-temperale as a landmark when conducting superimpositions in future should be avoided. In most cases when a match was established, this landmark proved difficult to match using the defined criteria. The fact that a 3D object is being superimposed over a 2D object may have contributed to the differences noted. All the landmarks for the skull and photograph matched according to the matching criteria (with the exception of fronto-temperale), thus establishing a match- this skull and photograph are the correct matching skull and photograph.

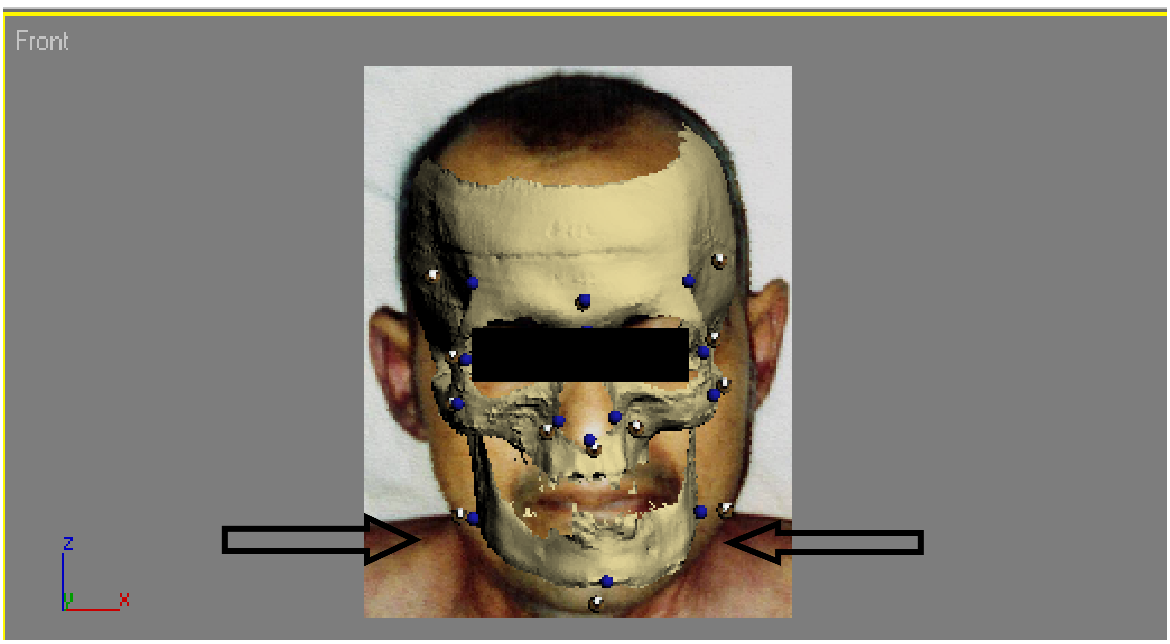


Figure 4.7. Photograph of case 6264, matched to skull 'g'. This superimposition is an example of a positive match. The photograph and skull with their landmarks are all visible in this image- the blue landmarks are from the skull and the white landmarks are from the photograph. The arrows indicate the landmarks where differences were noted.

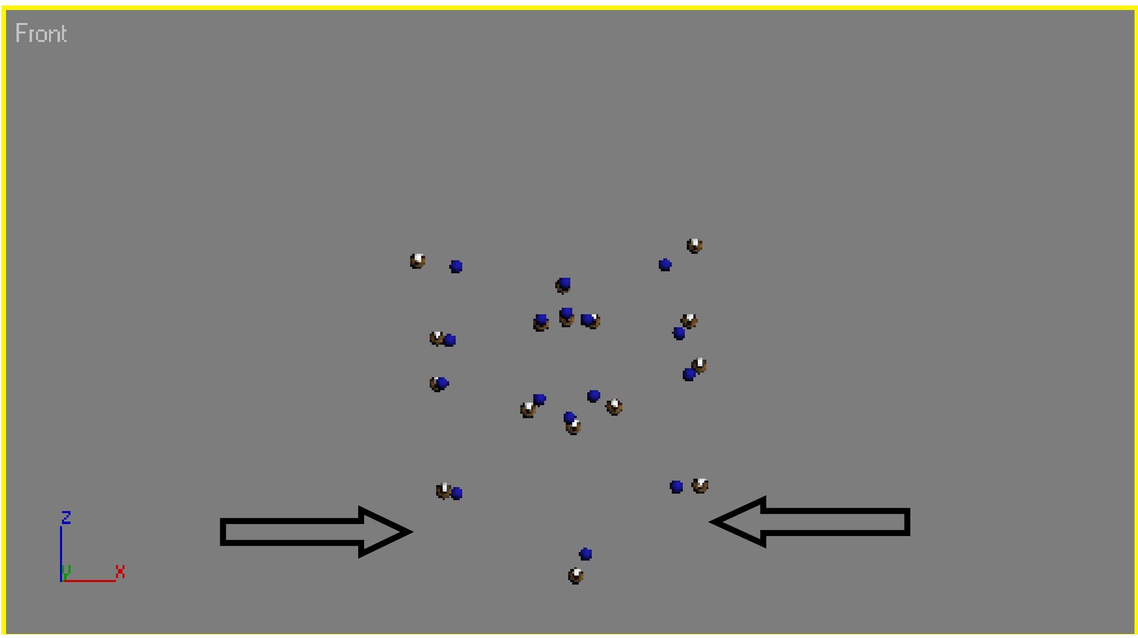
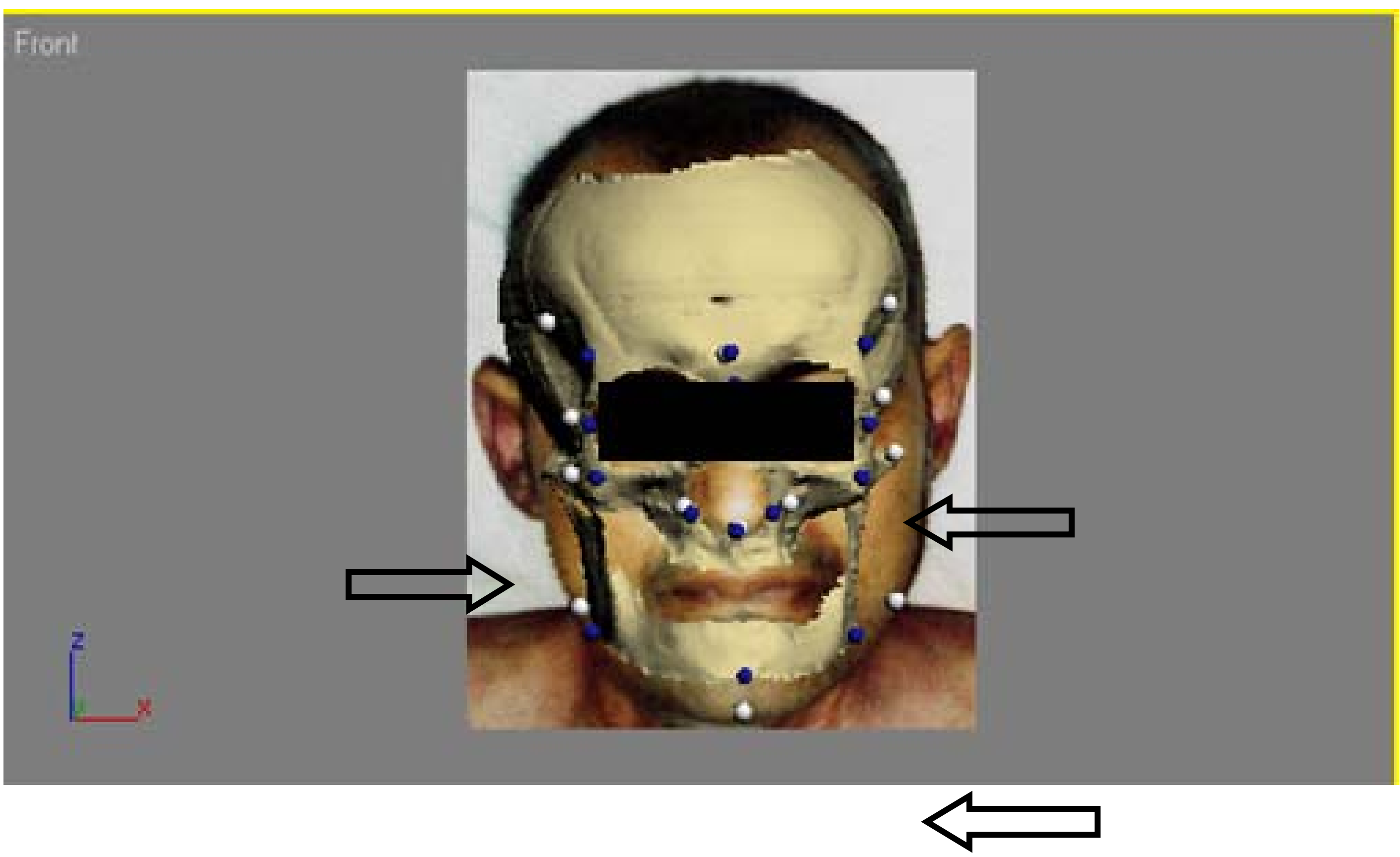


Figure 4.8. Dot match of case 6264 and skull g. This figure shows the superimposition with the skull and photograph removed so that an assessment of the landmarks or 'dots' could be made. This image is an example of matching landmarks. The arrows indicate the landmarks where differences were noted.

Figures 4.9 and 4.10 are examples of a non-match. In Fig. 4.9 the skull and photograph with landmarks present is shown. Figure 4.10 show the matching of the landmarks with the skull and photograph hidden so that just the landmarks may be assessed for the match. It can be seen that the orientation landmarks match each other and the primary and secondary landmarks are in very close proximity to each other, however, there are notable differences as noted with arrows in frontotemperale (left and right), zygion (left), gonial angle (left) as well as gnathion landmarks in this superimposition.

These landmarks do not match the criteria as stated in the materials and methods and differ in distance by more than 1.5 mm from each other, therefore resulting in a non-match.



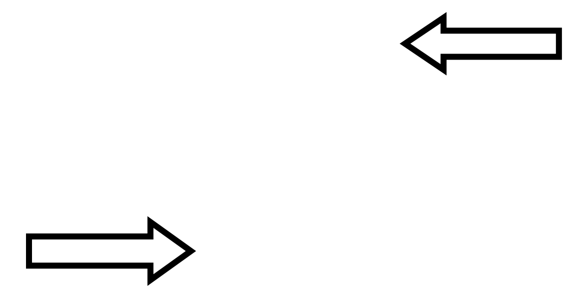


Figure 4.9. Photograph of case 6264, matched to skull ‘a’. This superimposition is an example of a non-match for stage 3 of the study as indicated by the differences in the landmarks shown by the arrows above. The photograph (white dots) and skull (blue dots) with their landmarks are all visible in this image.

For the landmark based assessment it is important to note that 16 landmarks were selected for the matching process in the study. In some photographs, 16 landmarks could be clearly seen and assessed; therefore, for example 15 out of 16 or 16 out of 16 of the landmarks could possibly match each other. However, there were photographs where all the landmarks were not visible because of the angle of the head in the photograph and consequently only 14 or 15 landmarks could be seen and assessed, resulting for example in 13 out of 14 or 14 out of 15 landmarks which could match each other.

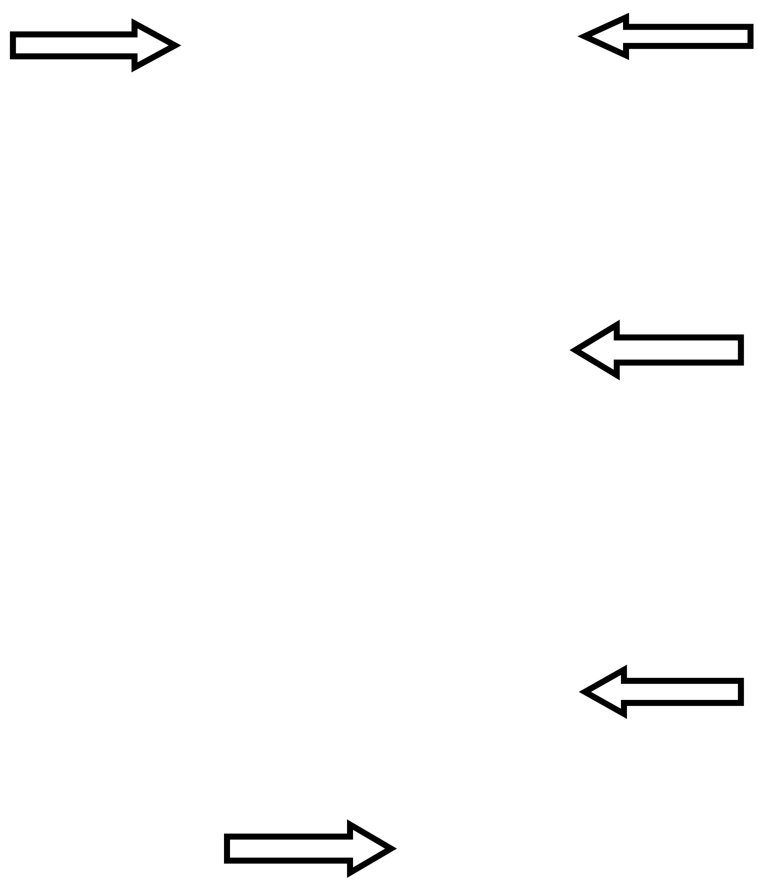


Figure 4.10. Dot match of case 6264 and skull 'a'. This figure shows the superimposition with the skull and photograph removed so that an assessment of the landmarks or 'dots' could be made by the investigator. This image is an example of a non-match between the landmarks of the skull and photograph as many of the landmarks as indicated by the arrows do not fit the criteria for matching each other- they are too far apart.

4.4. Comparison of stage 2 and stage 3 results

As noted above, an 85% positive identification (34 out of 40) rate was obtained for stage 2 and an 80% rate (32 out of 40) for stage 3. A Fishers Exact Probability calculation was performed to test whether there was a significant difference between the results of the two stages. A p-value of 0, 77 was obtained, showing no significant difference between the two results and therefore no significant difference in the accuracy between the two stages, which had been carried out independently of each other. However, the number of falsely matched skulls ranged between one and three for Stage 2 (a total of 69 false positive matches), and this increased to 128 false matches for Stage 3. This shows that although there is no difference between the two principles of identification in skull-photo superimposition, the morphological assessment may be a better method with which to carry out the technique since the false negative rate was lower in the morphological assessment when compared to the landmark based assessment.

It should be emphasized that in Stage 2 at least one correct skull was solely and positively matched to the photograph. This was not the case in the landmark based assessment as there were no skulls that were correctly and exclusively matched to a photograph.

In six of the cases the correct skull was not included as a possible match in the morphological assessment, whilst in the landmark based assessment, the correct skull was not included in eight cases. This is equivalent to a 15% false negative rate for the morphological assessment and a 20% false negative rate for the landmark based assessment of skull-photo superimposition. Therefore, seen in isolation, the morphological assessment was the better method with which to carry out the superimpositions. The Fishers Exact Probability indicates no difference in the positively matched results; therefore either method could be used to carry out the superimpositions. However, overall, the morphological method was better as it had a higher positive match rate, had a lower false positive match rate and a lower false negative match rate. Most importantly the morphological technique was simpler and faster to carry out than the landmarks based assessments and therefore, considering everything, can be said to be the better method with which to carry out the technique.

4.5. The overall success of using stage 2 and stage 3 combined

As previously established, 85% and 80% positive identification rates were obtained for stages 2 and 3 respectively. Stages 2 and 3 were carried out separately for this study and the results were reported on separately. However, when reviewing the results in combination, a different picture emerged.

When the results from stages 2 and 3 were combined, it was established that only one photograph of the 40 was not matched to its correct skull (Table 4.5 highlighted in red). Therefore, the combined use of stages 2 and 3 resulted in a 97.5% positive identification rate using this digitized matching technique. The false negative rate for the two techniques combined is 2.5 %. Table 4.5 illustrates the results of the two techniques combined. It shows the photograph number with the number of skulls matching the photograph for the morphological assessment and the number of skulls matching for the landmark based assessment. The cases highlighted in yellow for both the morphological and landmark based assessment indicate the cases where the correct skull was matched to the photograph and the corresponding numbers show how many other skulls where matched to the photograph too i.e. the false positive cases. This shows that the morphological and the landmark based assessment techniques yield results that are completely independent but do overlap with each other. The case highlighted in purple is the only sample in the morphological assessment where only the correct skull was matched to the photograph.

Table 4.5. Combined results of stage 2 and stage 3. The cases where the correct skull was included in the list of possibilities are here highlighted in yellow. The cases where the correct skull was not included in the list of possibilities are here highlighted in blue. The case highlighted in purple is the only case where only the correct skull was matched to its photograph and the case highlighted in red is the only case for both morphological and landmark based assessment where the correct skull was not matched to the photograph.

Skull number	***Other skulls matching photograph (morphological)***	***Other skulls matching the photograph (landmark based)***
6142	2	3
6231	0	2
6325	1	2
6280	2	1
6281	2	2
6219	1	1
6228	2	3
6264	2	6
6306	2	2
6307	2	2
6288	2	2
6310	2	3
6292	1	5
6301	3	1
6305	1	1
6309	1	4
6323	2	4
6325	1	1
6314	1	2
6367	2	3
6374	2	2
6391	2	5
6207	2	2
6269	2	6
6218	2	2
6248	2	6
6317	1	4

6327	3	3
6371	1	6
6376	2	4
6381	1	6
6385	1	3
6299	1	4
6283	2	3
6242	3	2
6210	2	7
6230	2	2
6253	2	4
6316	1	3
6220	3	4
Total number of positive matches	**69**	**128**

In the morphological assessment five skulls (highlighted in blue) were not correctly matched to the photograph and similarly in the landmark based assessment, seven skulls were not correctly matched to the photograph i.e. the false negative cases. The case highlighted in red indicates the only case where the correct skull was not matched to its photograph in both the morphological and landmark based techniques- overall, six cases were not correctly matched in the morphological assessment and eight cases were not correctly matched in the landmark based assessment.

The number of skulls incorrectly matched to the photograph for one procedure may be higher for one assessment technique than the other and the false positives in each of the columns are not always the same individuals. Therefore, using the morphological assessment and landmark based assessment techniques independently, but combining their results, may reduce the number of false positives overall for the procedure.

Even more beneficial when combining the results of the two assessment techniques, is that the number of false negatives may be reduced. Table 4.6 summarizes the overall results from the study. This further corroborates that the combination of the two techniques is beneficial to the manner in which superimposition is carried out. Individually, the morphological and landmarks based results show lower positive match rates and higher false negative match rates. The overall false positive match rate is reduced with the techniques combined. The false positive matches for the two techniques combined were calculated as an average of the false positive matches from both the morphological and landmark based assessments. The false negative match for the two techniques combined was calculated by subtracting the positively matched cases from 100 and working out the percentage. One could argue that by combining the two techniques / assessments, the number of false positives and false negatives could increase, however, from this study it can be seen that by combining the results of the two techniques, the average of the false negative matches is better overall than looking at the false negative matches independently. The same cannot be said for the false positives which are higher when the two techniques are combined however; this highlights the fact that using the two stages together is more beneficial than using one stage on its own. Therefore, these results indicate that by performing the two techniques independently and combining their results, will be a means of filtering out the false negatives and false positives so that the correct match can be made more easily.

Table 4.6. Summary of overall results from the two different techniques used as well as the two techniques combined.

	Positively matched cases	***False positive matches***	***False negative matches***
Morphological technique	85%	17.3%	15%
Landmark based technique	80%	32%	20%
Morphological and Landmark combined	97.5%	53.6%	2.5%

Using both of these two techniques can thus be seen as the manner in which to proceed, as this aids the overall process by reducing the false negative matches and increasing the number of positively matched skulls and photographs. This establishes that the technique of skull-photo superimposition can still be a valuable tool to use in efforts to identify skulls where identities are suspected and for which photographs are available.

4.6. Repeatability study

A repeatability study was carried out to test the placement of the landmarks in the landmark based matching technique. This was seen to be one of the potential areas of error. Ten photographs and their matching skulls were used, as in stage 1 of the study. The repeatability study involved matching a skull to its previously matched skull and a photograph to its previously matched photograph using the landmarks to establish that the location and placement of landmarks in the landmark based matching that took place earlier were identical in procedure to the procedure at the start of the study. This means that the repeatability study assessed the placement and reliable placement of the landmarks at a later stage (see appendix C).

Once again it is very important to take note that in some cases fewer landmarks had to be used for some of the photographs due to the angle of the face in the photograph. As a consequence, in some cases 16 landmarks were seen and assessed, but there were also photographs where only 15 or 14 landmarks could be assessed. This may have contributed to an overall lower average of points matching that was calculated for those photographs where fewer landmarks could be used.

The matching criteria for the repeatability study were the same criteria used for the morphological and landmark based assessment components of the study. The results obtained for this assessment was an 86. 8 % positive match rate for matching the photographs and a 98.1% positive match rate for the matching of skulls. In other words, the investigator was able to place the landmarks on the photograph with an accuracy of 86.8% and on the skull with an accuracy of 98.1%. This is important for this study as the placement of the landmarks and the ability to repeatedly place them accurately is crucial to the outcome of the study. As mentioned previously, the placement of the landmarks on the photograph and the placement of the landmarks on the skull are somewhat different. The skull landmarks are exact and easily seen; however, the landmarks on the photograph are often not easily seen and can vary due to variations in the soft tissue and how they are observed and perceived in the photograph. The lower accuracy rate obtained with the facial photographs is thought to be mainly due to the poor quality of some of the photographs used in the study, but may also be due to the fact that placing landmarks directly on the bone is more exact than locating and placing the landmarks on the photograph. As already stated by Farkas (62) the placement of landmarks on the face is a difficult procedure and accuracy could relate to the length of time or experience the individual placing the landmarks has. This will be expanded on in the discussion section.

4.7. Difficulties experienced with the results

As stated above, some of the landmarks proved to be continuously difficult to place on the photographs specifically. The fronto-temperale and gnathion landmark were especially difficult to locate and place with a sense of accuracy. It is believed that because the superimposition consists of a 2-dimensional shape being superimposed over a 3-dimensional shape, the fronto-temperale landmark may not have been placed accurately and consistently on the photograph and therefore some of the superimpositions were determined a match based on the matching criteria with the exception of the fronto-temperale landmark. Gnathion also proved problematic due to the mouth being open in some of the photographs. In cases where the mouth was open in the photograph, the gnation landmark was ignored and the match was done based on the rest of the landmarks using the specified matching criteria. As previously clarified, the ease of placement of a landmark on the bone cannot be compared to placement of the identical landmark on the soft tissue of the face. Again, because some of the photographs contained faces where the mouth was open, the process was even more difficult. The open mouth posture was impossible to replicate whilst scanning the skulls 3-dimensionally therefore all skulls were articulated and scanned in the Frankfurt horizontal plain with the mandible articulated. In cases where the skull was completely edentulous, the mandible was articulated as described in the materials and methods using a piece of Prestik™ to obtain the best articulation as would be observed in the living individual. This is further discussed in the discussion.

Appendix B illustrates the results for the landmark based matching. It shows the correct skull with the photograph and whether the skull was correctly matched to the photograph and why. As noted in these pictures, the quality of the cadaver photograph in some cases was poor which exacerbated problems with the matching procedure. One will also notice in these pictures and pictures shown previously in the results that the "dots" used to carry out the matching procedure appear to be different sizes. The dots are actually of equal size for each image, however, the 3D Studio Max program has functions which allows one to centre and enlarge the objects viewed in the four views of the program. These functions were used when capturing the image for comparison later due to the improved view of the image, particularly where the photograph was of poor quality. For each of the superimpositions, the same "dots" were used and the identical procedure was carried out to ensure the consistency of the method for the study.

Chapter 5: Discussion

5.1. Summary of results

This study proceeded in three stages. In stage 1 the techniques with which to carry out the superimposition for stages 2 and 3 were refined. Stage 2 involved carrying out a morphological match of a facial photograph with 10 skulls each, while stage 3 comprised a landmark based computerized matching of a facial photograph with 10 skulls each. There were 40 photographs and therefore 400 superimpositions were carried out each for stage 2 and stage 3, totaling 800 superimpositions overall for the study.

Stage 2 involved the morphological assessment of 40 facial photographs with 10 skulls each. Of the 40 photographs, 34 positive matches were achieved, which is equivalent to an 85% positive identification rate. However, a 17.3% false positive rate was found for the morphological assessment component of the study, as 69 other skulls were also matched to the photographs. Of the 40 photographs that were assessed, six false negative results were obtained, which is equivalent to a 15% false negative rate. The false negative results are the superimpositions carried out where the correct skull was not matched to the photograph.

Stage 3 involved the landmark based computerized matching of 40 facial photographs with 10 skulls each. Of the 40 photographs, 32 positive matches were achieved, which is equivalent to an 80% positive identification rate. However, a 32% false positive rate was found for the landmark based assessment component of the study, as 128 other skulls were also matched to the photographs. Of the 40 photographs that were assessed, eight false negative results were obtained, which is equivalent to a 20% false negative rate. The false negative results are the superimpositions where the correct skull was not matched by the photograph.

A Fishers Exact probability calculation was performed to test whether there was a significant difference between the positive identification rates of the two stages (85 % and 80% respectively). A p-value of 0.77 was obtained showing no significant difference between the two results and therefore no significant difference in the accuracy rates between the two stages. One can reason from this result that only one of the stages is necessary to assess whether a skull possibly matches the individual in the photograph. This has implications going forward, as much time could be saved doing one method as opposed to doing both. In addition, stage 2 (the morphological assessment) was a less complicated technique to perform than stage 3 (the landmark based assessment) which has implications for time taken and therefore potentially also the costs involved.

When the results from stages 2 and 3 were combined, however, it was established that only one photograph of the 40 was not included as a possible match to its correct skull and therefore, a 97.5% positive identification rate was obtained overall. This has significant implications and indicates that the outcomes of skull-photo superimposition can be improved when stages using different techniques are employed to identify a single skull. Therefore, using one technique to establish the identity of a skull in conjunction with an additional technique to corroborate the findings of the other technique enhances the reliability and accuracy of these techniques.

It must be noted that stage 3 was more complicated than stage 2, but both stages made use of the same equipment which is not usually used in South Africa to carry out skull-photo superimposition. The new digitized technique was utilized in both stage 2 and stage 3. The equipment included a computer, specialized software to carry out the skull-photo superimpositions, and specialized equipment and software to scan the skulls 3-dimensionally in order to obtain 3D images of the skulls. The computer and software to carry out the superimpositions were already in possession of the investigator and the University of Pretoria, but the scanning equipment and software needed to obtain 3D images of the skulls, required the assistance of an ergonomics company who regularly carry out work of this nature. However, the same result of obtaining a 3-dimensional image of the skull can be obtained when a CT scan of the skull is carried out and additional computer software is used to render the CT scan into a 3-dimensional image. This method at the time proved to be far more expensive and therefore impractical for use in the study.

A repeatability study was also conducted to ensure that the methods used to place the landmarks on the skulls and photographs were carried out in a repeatable manner. An 86.6% rate of repeatability was obtained for placement of the landmarks on the photographs and a 98.1% rate of repeatability was obtained for placement of the landmarks on the skulls. As expected the matching of the landmarks on dry skulls had a higher accuracy rate than the matching of landmarks on the photographs, due to the difficulty of locating and placing the landmarks on soft tissue. This will be discussed further below.

Techniques used in South Africa and the U.S.A. were assessed and compared. Although considerable research has been done in other areas of the world such as Japan and China, the investigator is familiar with the technique as applied in South Africa and the U.S.A., as some time was spent at Michigan State University during a short internship. Research in other areas of the world was thus taken into account, but the main focus was on comparing the techniques as applied in South Africa and the United Sates.

5.2. Limitations of the study

5.2.1. Photography

For this study facial photographs were used, but at best, the overall image quality of the photographs was not superior because the photographs were of cadavers and not of living individuals. The Department of Anatomy has record of photographs taken of the cadavers accessioned into their mortuary collection for the use of dissection by medical students since 1997. There has never been a standardized method for taking these photographs and the photographs are taken by the technical staff members, who are not familiar with the use of consistent standards whilst taking the photographs. Therefore, the photographs are not taken in the ideal Frankfurt horizontal plane and often the images are slightly blurred due to poor lighting and / or camera-shake, when the photography is done. The photographs are taken before the cadavers are prepared and stored for dissection by the medical students.

This leads one to the question of whether better quality photographs would have improved the results of the study. For example, where the photographs were blurred, the morphological matching process was quite challenging. Often the outline contour of the face in the photograph could not be clearly seen resulting in the superimposition process being very difficult. Likewise, in the real situation where skeletal remains are found and the identity is suspected, the photograph that may be produced for skull superimposition may also be one of very poor quality because of the angle of the face in the photograph and the fact that an old and/or blurred photograph may be produced. In some ways this makes the study more applicable and relevant, as it covers similar conditions that may present themselves when carrying out the skull-photo superimposition method as the South African Police Services seldom receive a photograph in which the head is photographed in the Frankfurt plane. This photograph would then be the only means with which to carry out the superimposition.

One can also question whether the facial tissue thickness may play a role in the superimposition procedure. A photograph of a living individual versus a deceased individual differs in the fact that particularly with cadavers, skin and superficial tissue thicknesses can be reduced due to the post mortem change of tissue desiccation of the body. Other post mortem influences such as lividity, skin slippage and positional distortion of features have also been noted in most of the cadaver photographs. In severely affected cases, those photographs were excluded from the study due to their unsuitability. The 40 photographs were chosen for the study with the above considerations in mind- the photographs with the fewest post mortem influences were used in this investigation. In the selection process each photograph was thus critically evaluated to ensure that only the best quality photographs were to be utilised.

Other important considerations included the camera angles and distances in the photography processes. From personal experience during an internship at Michigan State University, it was found that the same skull can appear as two completely different individuals depending on the distance it was filmed from, and the same can be said for facial photographs. A skull and photograph were given to the investigator to carry out the superimposition process to assess whether a match could be obtained. The dentition provided evidence that the skull did indeed belong to the individual in the photograph in that the teeth from the skull could be superimposed over the teeth seen in the photograph with a perfect match; however the rest of the skull matching procedure proved to be very difficult and it could not be matched to the face in the photograph. Only through dentition was it thus established that the skull and photograph were of the same individual. The facial photography process was then assessed and tested and some features, such as differences in the distance from the camera when the photograph was taken, were noted. It was then decided to see if the same "mismatching" photography effects could be proved with photography of the skull. The skull was filmed with the camera up close and then again with the camera at some distance away from the skull. The two separate images were then superimposed over each other using the mixing equipment in the same manner as one would when carrying out a skull-photo superimposition. The result was that the same skull could not be superimposed over itself with a positive match being produced. The same skull appeared to look like two completely different skulls i.e. as if the two photographic images were of skulls of two different people.

Photographic techniques and processes are thus very important for the skull-photo superimposition procedure when legal implications pertaining to identity are considered. Eliášová & Krsek (60) have discussed the same problems with differences in camera angles and distances. They have proposed a mathematical model whereby differences in angles and distances from the camera can be overcome through the use of this model. However, one must question the use of this mathematical model in laboratories that carry out skull-photo superimposition. The model is highly mathematical and in depth understanding of photography and mathematics would be required to apply the model for the rectification of possible camera angle and distance distortions. It should be noted that for most cases where actual skull-photo superimpositions are carried out, these distortions may well exist because the distance and angle in photographic techniques are not considered when ante mortem identity- or "family"-photographs of deceased individuals are used. It must be noted that although photographic distortions have been found to play a complicating role in the skull-photo superimposition technique, for the most part, these problems have not been insurmountable. However, these issues should always be considered when certain features of a skull match the photograph (e.g. dentition), but the skull cannot be matched to the photograph. In the USA, the challenging issues surrounding photographic techniques and using mathematical models to assist with superimpositions are not as problematic because in the USA, skull-photo superimposition is usually only carried out as a corroborating evidentiary process in proving identity (26, 27). This is because comparable DNA samples and dental records are almost always available there and are thus used as the principal methods to determine the identity of skeletal remains.

In South Africa however, skull-photo superimposition is usually the only means to identify skeletal remains, because alternative scientifically comparable corroborating evidence such as DNA or dental records (as used in the USA) are most frequently not available here (5). Should cases such as these reach the courts, forensic anthropologists and Police officers who carry out superimposition procedures in South Africa may experience great difficulty in proving that the remains do belong to a specific individual, especially if the proof thereof could put a suspected murderer in jail for life.

Another problem to consider when facial photographs are involved in the determination of identity is the potential problems with accurately identifying an individual in a photograph. People are generally able to recognize each other from facial characteristics; however the scientific validity of the identification of an individual from facial features is being questioned, with studies now being carried out to determine this (63). With the current practice of using "facially identified" photographs for skull-photo superimposition, many more problematic doors could be opened in the scientific identification process.

The use of facial photography in the determination of identity is not new to the field of forensic sciences. Photographs have been used since the mid 1800's to assist with the identification of individuals. However, studies today are aimed at proving the correct identity of the individual in a photograph (63). Therefore, if a photograph of a crime suspect is available, authorities will be asked to prove that the individual in the photograph is indeed the suspect. This has serious implications for the skull-photo superimposition method as a facial photograph of the actual person suspected of being the deceased is needed for the technique to have a positive contribution to a case. Should the situation arise where there are questions regarding the identity of the suspected deceased individual in the photograph, linked to a possible homicide with a murder suspect, this would be a difficult case to try and prove. Despite the fact that the probability of such a scenario is very small, in the forensic sciences all possible legally disputable scientific controversies need to be considered when solving cases of unidentified remains.

5.2.2. The use of landmarks in skull-photo superimposition

The use of anatomical and craniofacial landmarks is not new to science and medicine, as soft tissue landmarks have been used for the purposes of cephalometric analyses and maxillofacial surgeries for at least 20 years. Methods of accurately identifying and locating craniofacial landmarks have been a long standing problem in the field, with techniques of locating these landmarks through grid analyses and digitization being suggested (81, 87). It has involved the joint effort and collaboration of individuals in the medical-, graphical- and computer sciences field. One of the aims of this study was to reduce the subjectivity of the technique when the idea of using landmarks was considered. Aspects to consider when making use of anatomical landmarks in the digitized skull-photo superimposition procedure are:

- How big or small must the landmark be?
- Will the size of the landmark influence the overall results of the study?
- How should the landmarks match for there to be a confirmed match between skull and photograph?
- How many dots should match for there to be a confirmed match between skull and photograph?
- The accuracy of placing the landmark on the same point on the face each time.

All the above points needed to be contemplated with the use of craniofacial landmarks in this study.

The size of the point used as the landmark is a very important consideration. If the landmark is too big, landmarks that do not actually match may match purely because of the size of the landmark. On the other hand, smaller landmarks may not match because the size of the landmark is too small. The landmark size thus has to be large enough for the movement and manipulation of the landmark within the software program, but small enough so that errors due to the size of the landmark could be avoided. The size of the landmark in the 3D Studio Max program is approximately 1.5 mm. There is no scientific reasoning for this particular size, and it was simply chosen because this was the smallest size that could be manipulated in the program. A previous study was performed in Hungary in 1995 (22) which also used landmarks in a similar manner to the method in this study. Their landmarks were used as measuring points in a "before and after situation" for comparison. As mentioned before, the Bajnóczky & Királyfalvi (22) materials and methods are very vague but the overall results of their study present a method of reducing the number of false positives obtained in cases, but they also stress that it should be used in conjunction with the traditional method of video-superimposition. The authors also do not mention the size of the point used to locate the landmarks from where their measurements were made. Further investigation is needed to determine whether a particular size of landmark should be used for this method and whether a particular size is more beneficial or detrimental to the technique.

For this particular study an approximately 1.5 mm "dot" size was used to identify a landmark for comparison on an approximately 50 mm long face as seen in the 3D Studio Max program. This would equate to a 6 mm "dot" to identify a landmark on a living individuals face with a length of 200 mm. Six millimetres would be too big a "dot" size to identify a landmark on a living individuals face for comparison as accuracy levels could then be debated as a match may be made purely because the "dot" is large enough for there to be an overlap of the two landmarks. The use of the "dot" and the size of the dot are aspects that should be further explored in additional studies.

The issue of the proximity of the landmarks is another important consideration. How close the landmarks should be to each other is the most important issue to contemplate for the technique suggested in this study. This may heavily influence the outcome of the skull-photo superimposition procedure i.e. do the skull and photograph match based on the landmarks and how has that match been determined. The matching criteria used were described as: landmarks touching; landmarks overlapping; or landmarks being a landmark space or 3 mm away from each other for a match to be confirmed. These matching criteria were believed to be good for use in this study; however, they are highly influenced by the size of the dot used to locate the landmarks on both the skull and the photograph. If the size of the landmark is appropriate then accurate results will be obtained. Again, as mentioned above the size of the dot used to locate the landmark needs to be further explored to determine at what size the accuracy is due to the landmark being large enough for the "dots" to overlap. Bajnóczky & Királyfalvi (22) conducted the only other accuracy study whereby landmarks were used to assess the accuracy of the technique, however, due to the ambiguity of the materials and methods it was not clear whether the size of the landmarks used in their "before" and "after" situations was of significance in their study. No other study has made use of "dots" as this study has done to compare landmarks on a face and a skull to assess the accuracy of the superimposition procedure. The issue of how many landmarks should match for there to be a confirmed match is another important consideration. At the outset of this study, the investigator aimed to produce a more subjective and reliable method with which to carry out this technique. However, as the study proceeded, it became apparent that objectivity is extremely difficult in some cases. It also became apparent that this procedure is a learned technique, with the investigator developing an eye for the process. The more training and practice of the technique, the better one would be able to carry it out. After much consideration of the landmarks, it was decided that the orientation landmarks would be used to orientate and size the images of the skull and photograph and so those had to be a match. The primary and secondary landmarks would also have to match for a match between photograph and skull to be confirmed. Requirements as stipulated previously would have to be met for the primary and secondary landmarks to match, and therefore for an overall match between photograph and skull to be established.

The method of using a landmark based assessment to assist in determining the accuracy of the technique did not seem to be as beneficial as originally believed. Because the technique is a learned technique and one develops an eye for carrying out a skull-photo superimposition, complete objectivity could not be achieved. As one learns how the technique is carried out, the method of superimposition improves. Currently, a morphological comparison is used when carrying out skull-photo superimposition across the world. This study has shown that by using stages or different techniques to establish the match could improve the accuracy of the results obtained. However, the method of using landmarks to assess a match between a skull and photograph as stated above was not as straight forward as initially believed. Which landmarks to use to carry out the superimposition requires careful consideration as well as the size of the point or "dot' which will identify the landmark. Further research is required in this area to determine what affect these factors could play on the accuracy of skull-photo superimposition.

Placing the landmarks repeatedly was a further consideration for the study. If the landmarks could not be repeatedly placed, then the results of the study would not be valid. From the outset of the study, the investigator was aware that placement of the landmarks on the skull would not be as problematic as those on the facial photographs, as the skull landmarks are easily located and observable landmarks. Placement of the landmarks on the face in the photograph would prove far more difficult because the bony landmarks are covered by soft tissues. As already stated, the placement of landmarks on soft tissues is not new. Surgeons make use of landmarks on the skin of face in surgeries that involve facial reconstruction, particularly where facial features have been distorted through accidents or congenital malformations (62). For this reason a repeatability study was carried out on images of both the skull and photographs. The results of the repeatability study prove that landmarks can be repeatedly placed on the skull with a good level of accuracy. However, a lower accuracy was achieved for the placement of landmarks repeatedly on the photograph as compared to the skull landmarks (86.8 vs. 98.1%). One may question whether the ability to accurately place the landmarks on the photograph is good enough for the study and good enough to prove to a court of law that the technique is accurate enough to confirm the identity of skeletal remains. The techniques used by plastic surgeons as described by Farkas (62) could be explored to determine the methods they use to locate and place landmarks and whether their techniques may assist in the determination of placing landmarks accurately for the purposes of skull-photo superimposition.

Other methods of facilitating the skull-photo superimposition processes have been presented in the literature, and include equipment to hold the skull for orientation (10), X-rays (49), a system of grids and lines (12) and more recently software packages (18, 25). The study conducted by Bajnóczky & Királyfalvi (22) is the only one making use of anatomical landmarks for the purposes of not only aiding in the overall superimposition process, but also for improving the reliability of these processes. Publications on the improvement of skull-photo superimposition methods are plentiful, yet research on the reliability of the techniques and the legal ramifications thereof, is extremely sparse, therefore highlighting the necessity for further study in this area.

This study has been able to show that the technique of skull-photo superimposition in a South African sample can be done with some level of accuracy and can assist in determining the identity of skeletal remains. However, further investigations are needed in the location and placement of landmarks on the soft tissue of the face which may improve the accuracy of the landmark based technique and improve the overall accuracy. In addition, this study has indicated that using different stages to carry out the superimposition technique may also be beneficial to the reliability of the technique.

5.2.3. The scanned images of the skulls

The skulls were all scanned with the Cyberware™ Model 3030 Colour 3D Scanhead scanner located at Ergotech in Centurion, Pretoria. It became evident as the study proceeded that the calibration of the equipment influenced the scanning quality. Some of the scans took a great deal of effort to carry out to ensure that all the surfaces of the skull were scanned with a high quality. Other scans were easier to carry out as the scanner was able to read all surfaces of that skull better- this may be due to the fact that the angles on these easier skulls were such that the scanner was able to scan / read these surfaces better. The scanning procedure included 'dusting' the skull with Maizena, a white corn flour, so that the scanner was able to read all the surfaces of the skull. On occasion, the skull had to be dusted and scanned repeatedly, as all the surfaces of the skull had not been scanned effectively- these were the skulls that were more difficult to scan. The difficulty could be due to the fact that the Maizena was not evenly distributed over the surface of the skull and as mentioned above, the angles of these skulls may have been such that the scanner was not able to read the surface effectively. The scanner reads surfaces at 90º to the beam very well; however, angular or curved surfaces are scanned poorly or not at all. Therefore, a face which was more angular was more difficult to scan than a face which was less angular.

The scanner was also only able to scan a portion of the frontal bone of the skull but in all scans the frontal-parietal areas of the skull were missing due to the fact that this surface was curved and therefore not able to be scanned by the scanner.

The company Ergotech was approached to do the scanning because at the time the study was started, it was the only viable option. All other methods investigated were either too expensive, or the images produced were so large in size that they could not be manipulated on a standard desktop computer. The other methods of obtaining a 3D scan of a skull such as CT scanning the skull, also required additional software to render the scanned skull into a 3D image which could then be viewed on the computer. These additional software packages were all too expensive and too difficult to obtain. In the few years since the study started, new techniques of scanning skulls to obtain 3D images have become available. Free software is now also available which can be downloaded from the internet and used to manipulate the skull and the facial photograph to carry out the superimpositions. Had the investigator been in a position to benefit from these new software programmes, better quality 3-dimensional scans could have been used with better software to carry out the superimpositions. For example, the investigator could have obtained a CT scan of the skull and made use of the programme 3D Doctor to then render the CT scan into a 3-dimensional image of the skull. The image file produced from using a CT scan and rendering the CT scan a 3-dimensional image through the use of 3D Doctor produces a far better quality image would have been a better for the study. This can be seen in Figures 5.1 and 5.2, which illustrate a scan of a skull which has been CT scanned and then rendered into a 3-dimensional image from the 3D Doctor package as opposed to a skull obtained from the scans carried out at Ergotech.

If these improved 3D skull scanning methods had been available at the time of the initiation of this study, the results of this investigation may possibly have been somewhat better.

The method used in this study is still better than the manual technique currently used as the digital method in the long run is more beneficial as permanent records can be kept of the superimpositions, the technique takes less time to carry out and the technique may be taught to additional observers who may then carry the technique at different forensic sciences investigation centres.

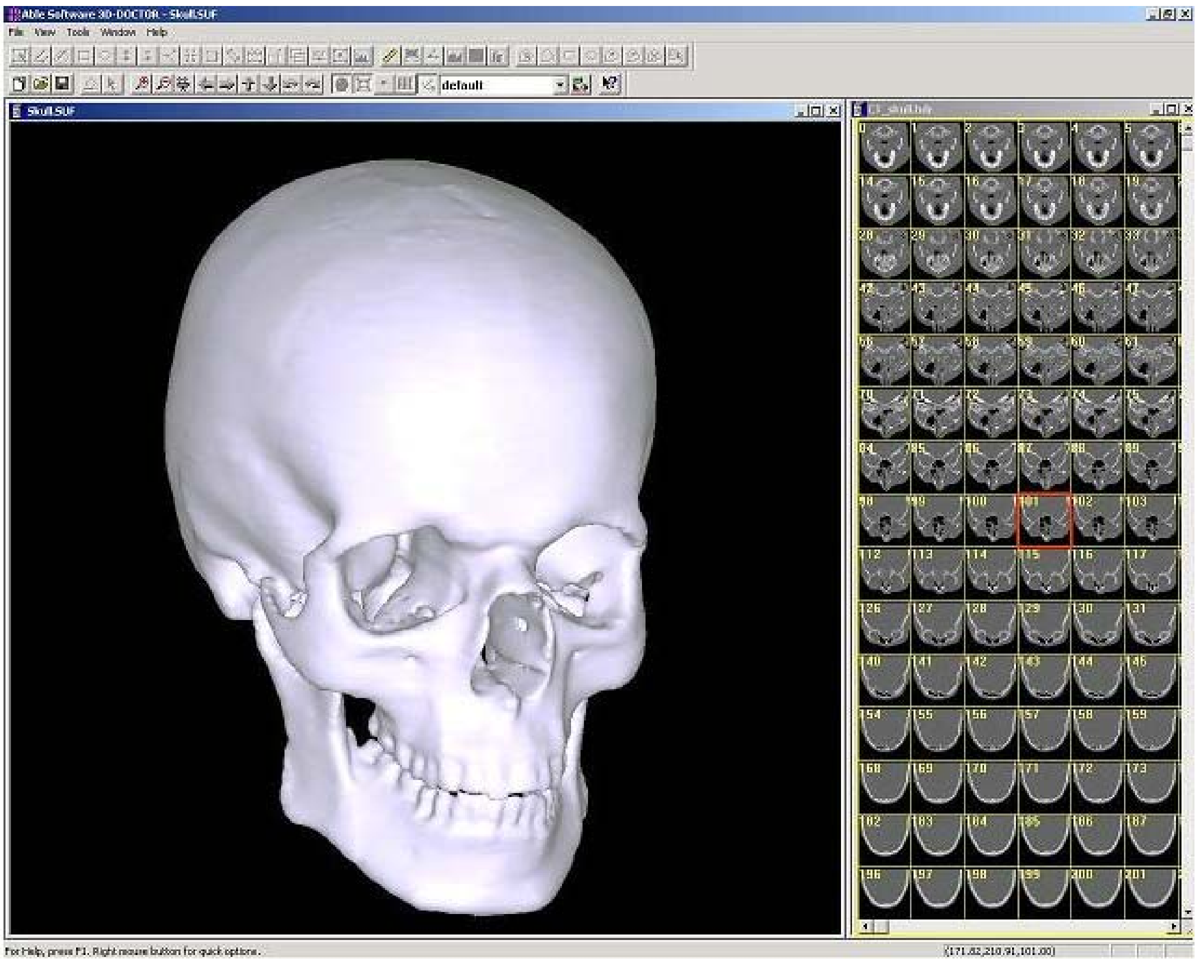


Figure 5.1. 3-dimensional image of a CT scanned skull which has been rendered a 3-dimensional image in 3D Doctor.

Moreover, a better quality scan which is now available may improve the results of the study as better detail on the skull can be seen to match it to a photograph. It should be noted that the current manual method should not be viewed to be less subjective or produce better results than the methods described in this study as the subjectivity of the method will remain an inherent problem in the technique. This study aimed to prove a reliability which is done by carrying out a morphological superimposition and corroborating the results from that with a landmark based superimposition. As already mentioned the quality of the photographs which were used in the study were not good, but this contributed significantly to highlighting what could happen in real life situations, where photographs of poor quality are likely to be produced with which to carry out superimpositions.

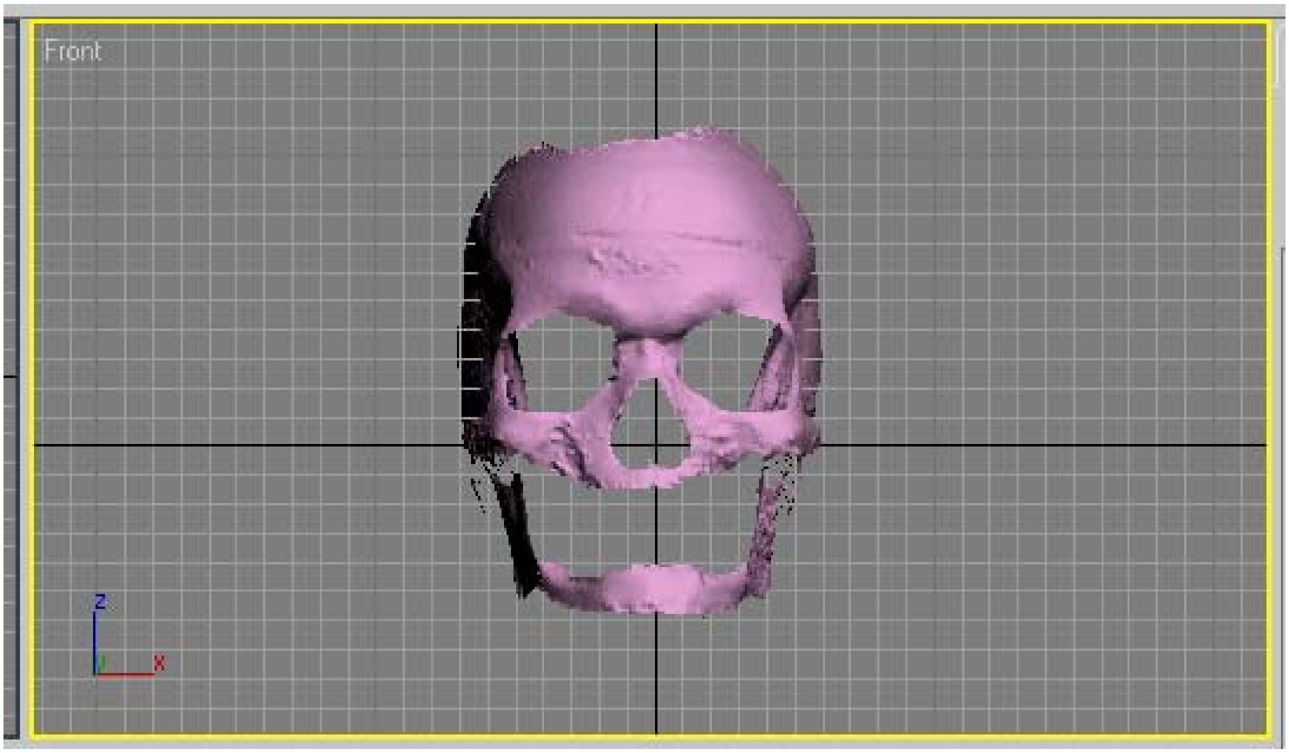


Figure 5.2. 3-dimensional image rendered from a 3D scan at Ergotech viewed in 3D Studio Max.

Should a similar study be undertaken today with the new technology that has become available (now at an affordable cost), the results of this study could possibly improve. However, the false positive and false negative results obtained still cast doubt as to whether a definitive one-on-one skull-photo superimposition can be done with reliability.

The overall problem of the quality of the scan and photographs may have also contributed to the fact that in most cases, more than one skull was matched to the photograph. Again, this is because the features of the skull and photograph were not easily observable. Although Schimmler *et al*,(15) state that the individuality of the human skull is crucial in identification, the possibility of features of two or more skulls being similar does exist. Schimmler *et al.*(15) also clarify that a human skull can be identified through the uniqueness of features of the skull "if the possibility of confusing it with another skull is very low" (pp89).

Again this can be investigated by using a better quality 3-dimensional image of a skull for superimposition in a sample to evaluate the accuracy of matching the correct skull to its photograph, as well as the number of false positives and negatives. The investigator when trying to establish the technique during stage one of the study did investigate the use of 3D Doctor images, however, no superimpositions could be done using the 3-dimensional image as 3D Studio Max could not cope with the size of the image produced from 3D Doctor. This method was then abandoned, however it was noted that the quality of the 3D skull image was very good and therefore should better 3-dimensional software become available, it should be investigated to establish if better results may be produced.

5.2.4. The manual method and the new 3-dimensional method: a comparison

The development of superimposition methods has been described in the literature review. It relates how the method started and what the technical improvements were until now, where the process as it is currently used today around the world, mostly makes use of video superimposition techniques (8, 10-12, 18, 19, 22, 25, 26, 49, 51, 53-55). Skull-photo superimposition is still a very manual technique using video cameras and a mixing unit, with the investigator having to make manual adjustments to the skull to manipulate it to try and establish whether a match can be made to the photographic orientation (Briers, pers. comm.)(26). The aim of this study was to test the accuracy of this technique as it is used in South Africa, as well as to develop a digital method with which to carry out this technique.

Testing the accuracy of this technique is highly important since this technique is currently being used in the South African judicial system for the purposes of identification of skeletal remains. The investigator decided to try and digitize the technique not only because its results are used in the courts, but also because the length of time to carry out the procedure often exceeded eight hours and more. It was also believed that by digitizing the technique, the reliability could be improved. This manual technique was studied at the laboratory that carries out video superimposition in both South Africa and the United States to develop insight and understanding as to how to the technique is carried out.

The digital technique used in this study was developed from combining the techniques observed by the investigator in the USA and those used in South Africa and converting the processes into a digital method. This involved scanning a skull 3-dimensionally to obtain a 3D model of the skull and utilising 3D software with which to manipulate the skull and a facial photograph, to assess whether a match could be made. Cost and time implications for both the existing USA and South African practices were assessed before deciding to develop the digital method. The overall costs for performing the techniques as currently done in the USA and South Africa were far higher than the digital method developed by the investigator, due to the costs involved for purchasing the equipment. The costs for the digital method were lower, because the only costs were those of “renting/ using equipment” to scan the skulls 3-dimensionally on Ergotech’s equipment, as all other resources required, such as the 3D software were already available. The digital method is more efficient than the current South African manual mixer method because the 3D software allows for the same technique to be carried out in a much shorter time period. Many avenues to obtain 3-dimensional (3D) scans of the skull were investigated as explained previously, e.g. CT scans and the use of a software package called 3D Doctor, in order to attempt reducing the cost of the technique, but the method use in this study was found to be the most feasible at the time.

5.2.5. The use of edentulous skulls

The Pretoria Bone Collection (PBC) was used for the study because as stated before, actual skulls together with their post mortem facial photographs were available to the investigator. Due to the fact that the photographs were taken after death, the photographic quality was not very good for many of the photographs; however, no other collection of this nature exists in South Africa where there are facial photographs of deceased individuals available to compare with their skulls. A major problem experienced with many of the skulls in the PBC was the edentulous nature of the mandibulae and maxillae. This created problems for the investigator when it came to scanning the skulls. The scanning of a skull was done with the mandible articulated with the skull, so that a representation of the skull as it would be in the photograph was obtained. With the edentulous mandibles and maxillae, the articulation proved very difficult and had to be overcome in order to continue with the scanning. Many methods were considered to overcome this problem. The articulation without the teeth was very problematic and it was decided to use Prestik ™ in the area where the teeth would be to try and hold the mandible and maxilla in place for the scanning of the skull. After noting some measurements of the general size of the dentition between the mandible and maxilla, a 2 cm space was made for all skulls with a piece of Prestik ™ so that the skull and mandible could be articulated for the scanning to take place. The use of the Prestik ™ could be debated at length; however, the investigator noted that it would be the most effective means with which to overcome the problem of absent teeth, as well as to articulate the mandible in a manner which could best replicate the living articulation of the mandible with maxilla. The investigator also noted that should the use of Prestik™ to assist with the articulation of mandible to skull prove to be unreliable, the superimposition of the skull onto the photograph without the mandible present could still proceed. In real life situations it is important to keep in mind that skulls without mandibles are frequently encountered, i.e. the mandibles may have been destroyed, been scavenged or just not been found during the retrieval of the human remains. Research has shown that one can still proceed with skull-photo superimpositions in these situations to try and establish identity and that these superimpositions can be done as effectively as if the mandible were present (19, 54).

In many of the facial photographs the cadavers were photographed with an open mouth. Superimposition in such cases would be very difficult and trying to articulate the mandible with the skull in the same orientation would also be challenging. In these situations, the skull from the maxilla upwards would have to be the focus of the superimposition procedure and not the mandible. Therefore, the superimpositions were not as adversely affected by photographs where the mouths were open or where the skulls were edentulous as the focus of the superimposition was the non- movable face with maxilla. Again it is important to stress that in real life scenarios, the superimposition procedure is one that would need to accommodate many unfavourable situations and the potential use of the Prestik ™ in edentulous skulls was an attempt to do this. Since other studies have shown that superimpositions can be successfully carried out on skulls where the mandible is not present, edentulous skulls and photographs where the mouths were open, were included as samples in this study.

5.3. Skull-photo superimposition: transferability of the technique

Throughout this study it became apparent that this technique is one that is learned and that some experience is necessary. This implies that it can be taught to other individuals, but that it would take some time and effort to master the details. The overall benefits of this technique, either manual or digital, are that any individual can be trained to carry out the technique as effectively as an expert would. This is important to note as it means that more individuals in more forensic sciences centres may be able to carry out this technique. Training would require significant time spent performing the technique including as many superimpositions as possible. The more the technique is practised the better one is able to perform the superimposition. This does imply that at the beginning of the study the investigator may potentially not have been as adept with the technique as when compared to the end of the study. The investigator no doubt became more skilled at applying the technique towards the end, with the result that the first few superimpositions might have produced different and better results had the end-experience existed then. A few of the initial superimpositions were checked once all the superimpositions were complete, and it was noted that there was little difference in the morphological comparison, and a slight difference in the landmark comparison due to the placement of the landmarks. It is thus apparent that although one develops an experienced eye for the technique and how it is performed, it remains a good technique to employ in laboratories to assist in the identification of skeletal remains where identity is suspected.

5.4. Skull-photo superimposition: Inclusion versus exclusion and the legal ramifications thereof

5.4.1. Inclusion versus exclusion

The processes of skull-photo superimposition and the manner in which they are carried out (manually and digitally) are very important in terms of evidence presentation in a court of law. Fenton *et al.* (26) commented on the consistency of skull-photo superimposition as a tool for the positive identification of skeletal remains, citing Austin-Smith and Maples (24) who claim a 9% possibility of false identification when performing superimposition using unknown human skulls. In their research, Austin-Smith and Maples (24) claimed a 9.6 % false identification rate for lateral view photographs and an 8.5 % false identification rate for anterior photographs. They reported a reduced false positive rate of 0.6 % when the frontal and lateral view photograph of the same individual was compared to a single skull. The Austin-Smith and Maples (24) study is different to the current study in so far as the current study makes use of photographs and a sample of skulls in which one skull belongs to the individual in the photograph. Austin-Smith and Maples (24) made use of three skulls to superimpose over 97 lateral and 98 frontal view photographs. None of the skulls used for superimposition belonged to the individuals in the photographs. The approach to testing the reliability is significantly different from the current study to the Austin-Smith and Maples (24) study. The differences in the approach may result in different outcomes. Should a similar approach be attempted in a South African sample, perhaps different results may be achieved.

Fenton *et al.*, (26) present their opinion that unless dental features can be seen on a photograph, skull-photo superimposition is not the best technique for the use of identification. DNA, fingerprint and X-ray analyses remain better methods to employ for the purposes of identification. Glassman (42) has also stated that should the skull being used for superimposition be incorrectly aligned with the photograph and it is the correct skull, a decision made to a match could be one that concludes in “poor concordance” (42).

Fenton *et al.* (26) discuss their practice of skull superimposition and their dynamic orientation process which starts with the supposition that the skull and photograph belong to the same individual. From there proportions, positioning and anatomical landmarks are used to further corroborate their assumption. If a match cannot be established, then the individual in the photograph is excluded as being the potential identity of the unknown skeletal remains. The technique that Fenton *et al.* (26) employ to carry out their superimpositions has been described in the literature review. Their technique was an important consideration in the development of the techniques tested in this study. Practically, when skull-photo superimposition is used to determine identity, the identity is usually suspected and a superimposition is carried out where the sample would be one skull and one facial photograph. As seen with the Austin-Smith and Maples (24) study, the use of 10 skulls per photograph in this study may have influenced the outcomes of this study i.e. the use of fewer skulls for the sample size may have resulted in fewer skulls "possibly" matching the photograph and therefore a decreased positive match rate or a decreased false positive or false negative match rate. Therefore the sample used and the size has a significant effect on the accuracy values for a study such as this one. Had Austin-Smith and Maples(24) used the same photographs and larger skull sample including skulls that belonged to the photographs, one must question whether the accuracy rates achieved would have been different. In addition, carrying out the procedure for this study as it is done in South Africa i.e. for inclusion purposes, may have also resulted in an increased match rate between skull and photograph and therefore more false positive results. This study illustrated and further highlighted that two skulls may be very similar and that carrying out superimposition through methods of exclusion would be a more accurate and scientifically valid method to apply the technique.

Fenton *et al.*, (26) describe various methods used by the scientific community to carry out skull-photo superimposition such as the use of video cameras, a mixing device and a TV screen for viewing the superimposed images. They state that this technique allows an objective comparison between bone and soft tissue through the use of the features of the mixing device, which include image wiping and fading capabilities. They stress the accurate sizing and orientation of images for the method to work effectively, describing how some studies have attempted to use anatomical landmarks to achieve this. Although anatomical landmarks have been suggested as an aid for orientation for the superimposition process, Fenton *et al.* (26) acknowledge that authors have relied on a positioning method of trial-and-error to find the exact fit for orientation of the skull and facial photograph (24, 26, 41, 88). The same problem existed for the current study. Orientating the skull and photograph in the 3-dimensional software package also proved problematic, but the time taken to correctly orientate the skull and photograph digitally is believed to be a quicker process digitally than doing it manually. The set up of the manual equipment also lends itself to a faster orientation of skull and photograph. The set up as noted in the USA by the investigator was a far more efficient and user friendly setup than the noted setup in the South African laboratory. Therefore there are a few factors that affect the accuracy of the technique and that should be considered when conducting a study of this nature.

5.4.2. The legal ramifications of skull-photo superimposition

Fenton *et al.*, (26) state that the forensic community regard the skull-photo superimposition technique as a reliable method for the identification of human remains and a similar conclusion can be drawn from this study. However, results from the current study suggest that corroborating techniques must be used in the identification of skeletal remains. It was also clear that it may not always be possible to be completely objective when conducting skull-photo superimposition, therefore corroborating results from other techniques used to establish the identity of the remains will always be beneficial.

The objectivity of a scientific technique is of major importance in legal processes. The dual nature of the forensic anthropologist has been described by Işcan (29) and further highlighted by Dirkmaat *et al.* (27). Theses authors describe the role of a forensic anthropologist as being both a scientist and a professional. As scientists they conduct research in their fields so that they have up-to-date methods and techniques with which to establish the identity of skeletal remains. As professionals, they are expert witnesses in the legal system where they have employed their up-to-date methods and techniques and identified a set of skeletal remains and present their findings in court.

With the dramatic changes in the USA legal system that arose out of the *Daubert vs. Merrell Dow Pharmaceuticals* court case, the approaches to research, analysis, and expert witness testimony have been revolutionized. Replicable, reliable, testable scientifically valid methods are now needed in a court of law to justify scientific opinion. This has resulted in legal demands for objective scientific research, which in turn has resulted in significant changes in the way forensic anthropology is practiced. This paradigm shift has effectively redefined the goals of anthropological research, the collection of related evidence as well as the overall analysis of skeletal remains. The result is that further study and research of topics and methods that were previously considered adequate now need to retested, validated and published. It has also required the retesting of results obtained from previous and slightly dated scientific research so that up to date and scientifically valid techniques are used by the science community. In addition, the *Daubert* standards emphasize the methods used for the analysis and testing of scientific techniques and not the experience of the individual providing the testimony. An expert witness who merely has experience is no longer adequate for the presentation of expert testimony in a court of law. The expert witness requires corroborating scientific methods and results from other studies that can aid his/her expert testimony (Steyn, pers. comm.)(27).

This is especially important in cases where skeletal remains are found and scientific techniques are used to establish the identity of the remains. The legal system employed in South Africa is different to the system used in the USA; however, both countries make use of scientifically derived techniques to establish the identity of homicide victims. The USA primarily makes use of the *Daubert* standards for the admissibility of evidence in the court room. The South African legal system is governed by the *Constitution for the Republic of South Africa Act, No. 108 of 1996* (89). The Constitution is the supreme law of the country and contains the Bill of Rights which forms Chapter 2 of the Constitution. As explained previously, murder, culpable homicide and robbery are examples of Common Law crimes which are tried using Statutory Laws such as the *Inquests Act, 1959 (Act no. 58 of 1959)* (68) and the *Criminal Procedure Act, 1977 (Act no. 51 of 1977)* (70), which respectively provide for investigations into the circumstances and causes of unnatural deaths and for the processes in criminal proceedings including the provision of evidence, relating to the prosecution of crimes in South Africa (69). As clarified earlier, the term "forensic evidence" may be used to describe the manner in which information is presented to the courts and includes verbal evidence (e.g. witness testimony, documentary evidence (e.g. autopsy reports) and physical / tangible evidence (e.g. objects like bullets) (75). Investigations into causes of unnatural deaths involve medical practitioners who may be called upon to give evidence in court in a number of ways, but mainly as an expert witness who is seen in the eyes of the law as an individual who, through education, training and experience, possesses knowledge beyond that of a lay person. In a courtroom setting, expert witnesses are called upon to ensure that complex scientific principles are understood by lay persons, but they are also frequently expected to give "opinion evidence" based on experiential conclusions drawn from factual findings (69, 75). The practice of how scientific evidence is presented in court in South Africa differs from the *Daubert* and *Frye* standards, but does include aspects from both standards. In the *Criminal Procedure Act, 1977 (Act no. 51 of 1977)* (70), aspects pertaining to the presentation of evidence in court are covered, but none specifically pertaining to scientific requirements for "newer" e.g. forensic sciences-related expert witness testimony.

From this it can be seen that the South African legal system appears to have gaps pertaining to the rendering of scientific evidence which could cause problems going forward. The *Daubert* standards for the admissibility of evidence in court require that a medical practitioner's experience is not sufficient as evidence if not supported by tried and tested scientific methods. The South African legal system does not specifically mention this and therefore, expert medical practitioners could be requested to testify on their own experiential assumptions or conclusions in court. Such a practitioner would not necessarily be asked to support his/her assumption or conclusion with scientific evidence that has been tested and is repeatable. This is an area in the forensic sciences in general where the South African legal system appears to have some catching up to do.

There are serious implications with regard to expert testimony by forensic experts in the South African legal system as anyone who calls themselves a scientist may present evidence in court without the requirement to demonstrate their expertise in the field. Therefore, anyone who conducts skull-photo superimposition in South Africa may go to court to assist in establishing the identity of skeletal remains without demonstrating that their methods are tried, tested, accurate and have been peer reviewed.

For a technique to be scientifically valid, it should be used consistently worldwide. This is not the case with skull-photo superimposition and in addition, there are differences within the international legal systems making use of the technique as evidence in court. Although the laws of South Africa are not influenced by those of the USA, the principles used there to define what expert testimony is, should be considered and employed by South African forensic scientists and medical practitioners so that consistent and scientifically valid standards are used when preparing testimony for court. By understanding how the legal system works in the USA, South African forensic scientists are better prepared for cases they are involved in. The above illustrates that a single standardised process for the practice of skull-photo superimposition should be agreed upon and implemented world-wide. Therefore when studies are conducted on superimposition processes, they should include similar techniques used and accepted internationally which are being tested and further validated. This will also then ensure that irrespective of which legal system is making use of superimposition to identify skeletal remains, the scientist / anthropologist will have sound scientific evidence that has been tested and is repeatable to corroborate the identification evidence being presented.

A very significant point highlighted by this and previous studies is the manner in which the results of skull-photo superimposition are handled. The USA uses them for exclusion purposes and South Africa uses them for inclusion purposes. The results from this study and recent literature (26) consistently show that the technique is better and more objectively used for exclusion purposes than for inclusion purposes and that it is best used in closed disaster cases where a limited number of individuals of known identity are deceased. Thus all that remains is to match the remains to an identity.

5.5. Future recommendations for the use of skull-photo superimposition in South Africa

With the noted limitations from this particular study, the use of skull-photo superimposition does prove to be a very useful technique. In South Africa in particular, where standard scientific corroborative techniques such as comparative DNA analyses or odontology cannot be used because the DNA samples or dental records with which to make matches simply do not exist, additional methods are required to try and establish an identity. From the results it can be deduced that the addition of landmarks aided the superimposition process in a way whereby the landmark technique can be used as a means of filtering out incorrect matches. By performing the morphological assessment technique followed by the landmark based computerized assessment technique independently and combining their results, the average of false positives and negatives are better overall and the rate of positive identification was improved. Although the results from this study reveal that for every photograph, some false positive results were obtained, this does not represent the situations as they usually occur in forensic cases. When the identity of skeletonised remains is suspected, one or two photographs of the same individual are produced with which to carry out the skull-photo superimposition. In closed cases where there are a number of deceased individuals and the identities of these deceased are known, what remains is to match the identity to the specific remains and this is always corroborated with other anthropological techniques.

This study has added value to the use of superimposition processes in South Africa, because it has shown that there is merit in using the technique as a means to narrow down the identity of unknown skeletal remains, especially when other techniques such as DNA or dentition are not possible. It has also shown that the manner in which South Africa uses the process should be reconsidered for better efficiency and scientific validity and very importantly, that the method needs constant testing to ensure that the best available techniques and equipment are being used for the process. Most important to note from the results of this study is the manner in which skull-photo superimposition outcomes are utilised in South Africa. As already highlighted, the results from the superimposition processes are used differently in South Africa as compared to the USA. The results from this study support the fact that the manner in which skull-photo superimposition is used in South Africa should possibly be revised to adopt the same viewpoint as in the USA, i.e. for the purposes of exclusion rather than inclusion.

Skull-photo superimposition, (manually and digitally) has been shown to be a very useful screening tool in the identification of skeletal remains, which can be used in the initial stages of the identification processes along with other scientific techniques to further corroborate identity. It is also of particular value when no other techniques are available in order to try and establish identity: however, it must be stressed that as many scientific techniques as possible should be used in the determination and corroboration of identity, especially where this may impact significantly on investigative and legal proceedings.

In summary it can be said that this study has made significant contributions to the field of forensic anthropology with respect to the manner in which skull-photo superimposition is carried out. It has also emphasized the need for a consistent scientifically valid and repeatable process to be used world-wide. The study has also highlighted the fact that very few validation studies on skull-photo superimposition have been carried out in the past and that some of those validation studies are currently outdated.

Further research is needed with respect to the techniques utilised in skull-photo superimpositions so that the best methods possible can be selected for superimpositions. This will ensure validation of the methods utilised so that they fulfil the legal requirements of scientifically tested, retested and reliable scientific methodology. At present, if one were called upon by the court to testify on the use of skull-photo superimposition as an identification tool, the current studies to corroborate the repeatability and validity of the technique would create problems. These studies are now dated, and according to the *Daubert* standards, recent scientifically tested and valid studies are needed by an expert witness to corroborate findings where scientific techniques have been used. Therefore, along with this study, similar up-to-date studies are required in other countries on their own population samples, using identical or similar processes of skull-photo superimposition. In this manner, international scientifically and legally acceptable superimposition techniques could be developed to assist in skeletal identification processes, which in turn would contribute significantly towards validation of such findings in the legal system.

With respect to the validation studies that have been done, current and dated, it was found that a 100% positive identification rate has never been established, with the possibility of false positives and false negatives being an ever present reality. This has resulted in much debate as to whether the tool of skull-photo superimposition should be used to assist in identification. This study found similar rates of positive identification to other published studies and concludes that skull-photo superimposition has a very positive contribution to make in the identification of skeletal remains; however, corroborating methods of scientific identification should always be included where possible.

Chapter 6: Conclusions

- The results from this study have shown that using a morphological analysis technique, 85% of skulls were correctly matched to their photograph, however, in these cases between zero and three other skulls also potentially matched the correct photograph. This equates to a 17. 3 % false positive rate for the morphological assessment technique. A 15% false negative rate was achieved for the morphological assessment.
- Using a landmark based analysis technique, 80% of skulls were correctly matched to their photograph, but between one and seven other skulls also matched the photograph. This equates to a 32 % false positive rate. A 20 % false negative rate was achieved for the landmark based assessment.
- It was established that when the results from both the morphological and landmark based techniques were combined, a 97.5% positive match rate was found where the skulls were correctly matched to their photograph. This equates to a 2. 5 % false negative rate overall for the two techniques combined.
- A Fishers Exact probability calculation indicated that there was no significant difference between the individual results from the two techniques, implying that using one technique or the other would give similar or identical results.
- Since the onset of this study, new techniques of obtaining very good quality 3D scans of skulls, as well as new software programmes with which to carry out superimpositions, have been developed. The accuracy rate could possibly be improved, should better 3-dimensional scans be available.

- This study found different results (for the individual stages 2 and 3 separately) to a similar reliability study which was conducted by Austin-Smith and Maples in 1994 (24). This study indicated that the technique is reliable and should be used to assist with the identification of skeletal remains.
- The hypothesis for this study stated that *"skull-photo superimposition can be done reliably using a computerized technique, to a level of accuracy where no false positive or false negative matches between photographs and skulls can occur"*. The decision to reject the hypothesis would be taken if there were more than 1% of false positive or false negative matches between photographs and skulls. For this study, the hypothesis had to be rejected with the 97.5% positive match rate achieved i.e. more than 1% false positive and false negative matches were established for this study.
- Although the hypothesis had to be rejected, it does not imply that the technique cannot be used in the contribution of the determination of identity.
- This study has identified the differences in various areas of the world in the approach to carrying out skull-photo superimposition and has highlighted the need for consistency in the technique.
- The study has also shown that the skull-photo superimposition technique is better carried for purposes of exclusion, as utilised in the USA.
- Further research is needed with respect to the techniques utilised in skull-photo superimposition so that the best methods possible can be selected for superimpositions. This will ensure validation of the methods utilised so that they fulfil the legal requirements of scientifically tested, retested and reliable scientific methodology.
- Along with this study, similar up-to-date studies are required in other countries on their own population samples, using identical or similar processes of skull-photo

superimposition. In this manner, international scientifically and legally acceptable superimposition techniques could be developed to assist in skeletal identification processes, which in turn would contribute significantly towards validation of such findings in the legal system.

- In summary it can be said that this study has made contributions to the field of forensic anthropology with respect to the manner in which skull-photo superimposition is carried out. It has also emphasized the need for a consistent scientifically valid and repeatable process to be used world-wide.

If I have seen further than others, it is by standing upon the shoulders of giants.

Isaac Newton

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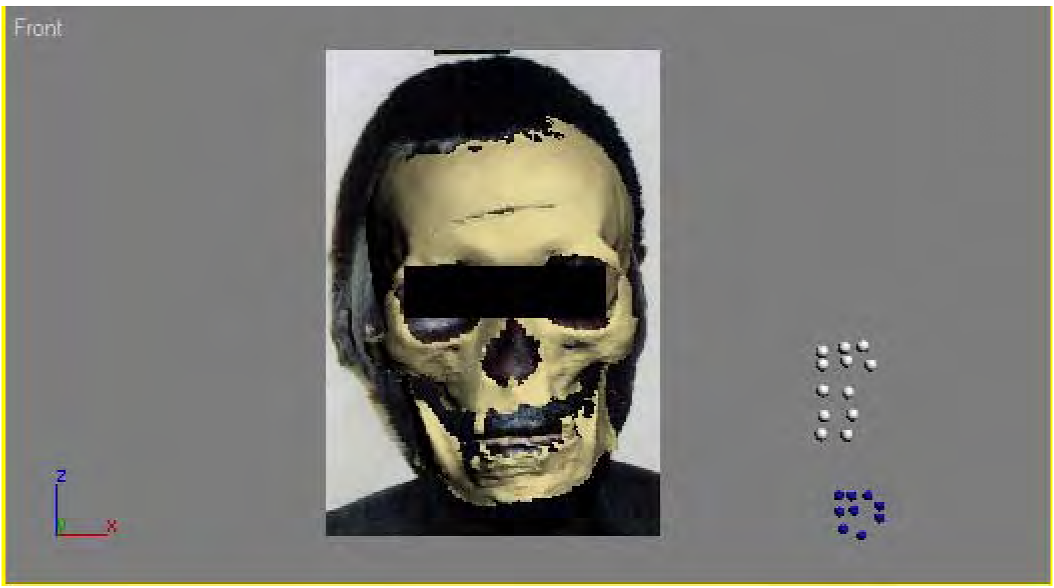
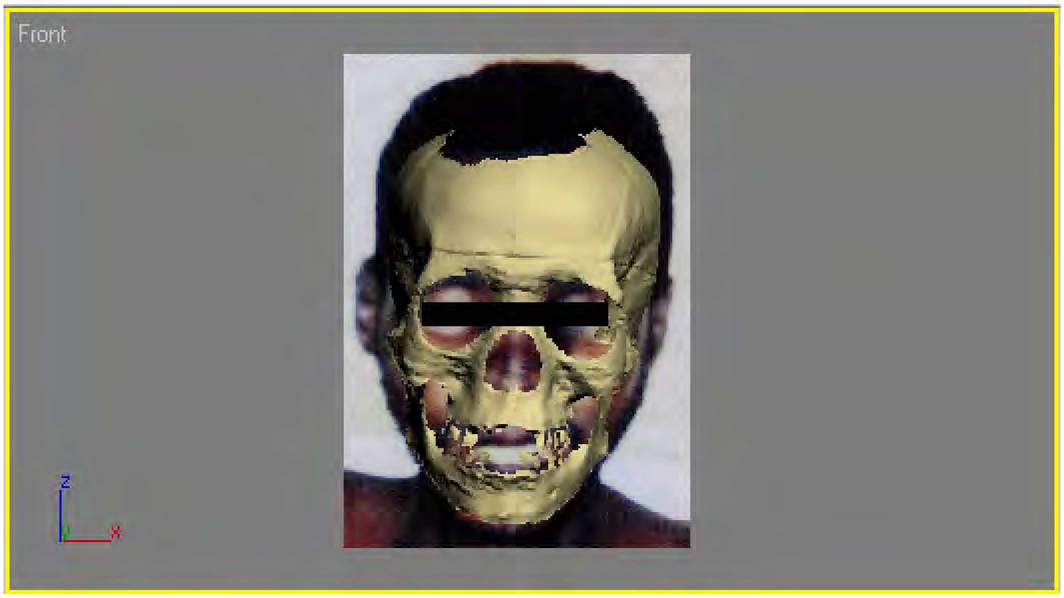
<u>Appendix A: Photographs with their correct skulls (morphological assessment)</u>



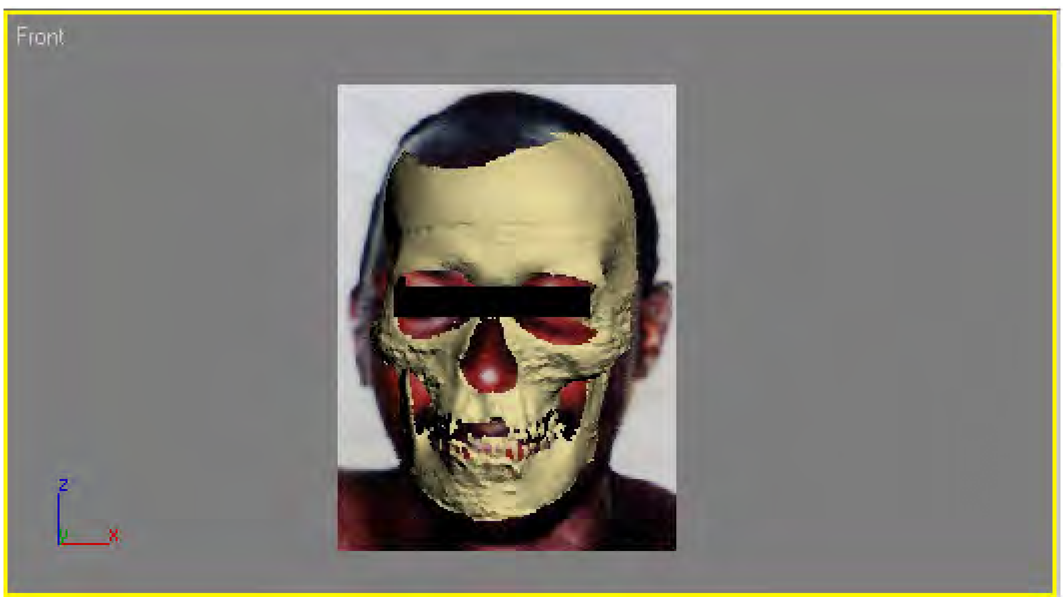
<u>6142 skull i morphological</u>

The correct skull was matched to the photograph.



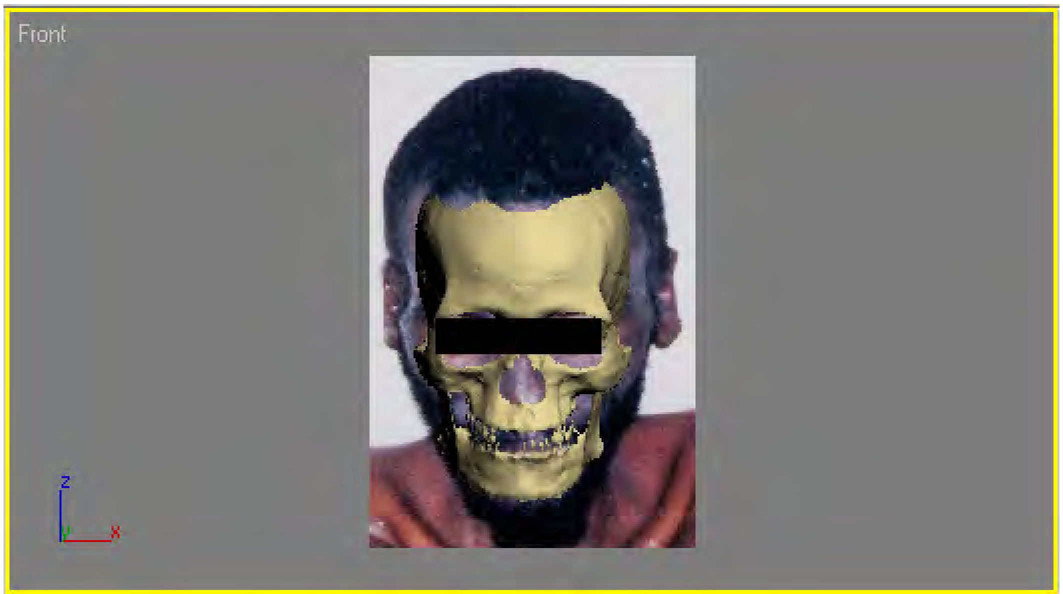
<u>6231 skull g morphological</u>

The correct skull (only the correct skull) was matched to the photograph.



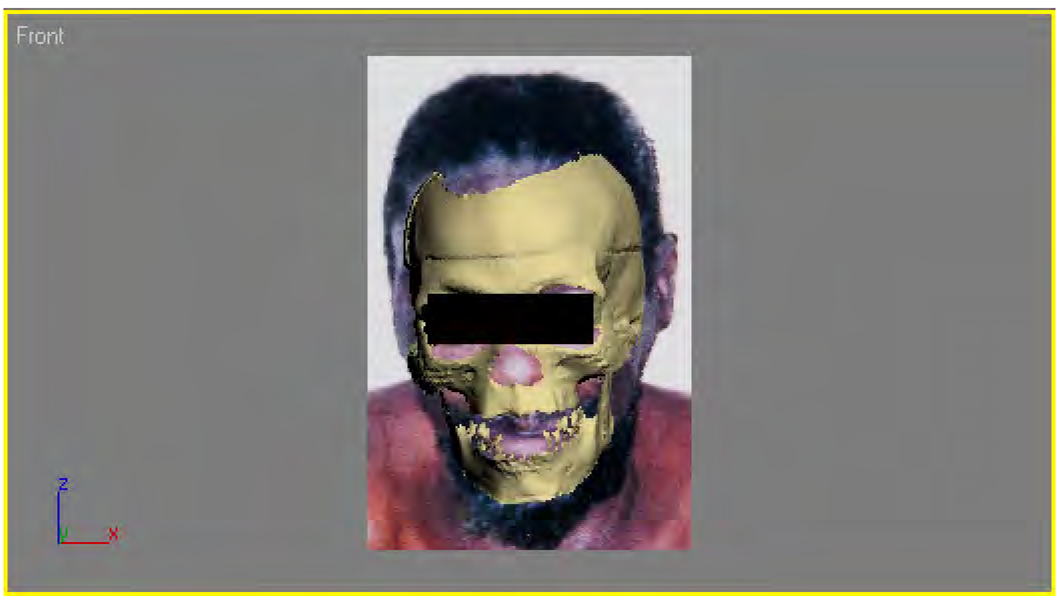
<u>6325 skull j morphological</u>

The correct skull was matched to the photograph.



<u>6280 skull i morphological</u>

The correct skull was matched to the photograph.



<u>6281 skull j morphological</u>

The correct skull was matched to the photograph.

<u>6219 skull j morphological</u>

The correct skull was matched to the photograph. From the scan and photograph it's evident that this individual wore dentures.

<u>6228 skull i morphological</u>

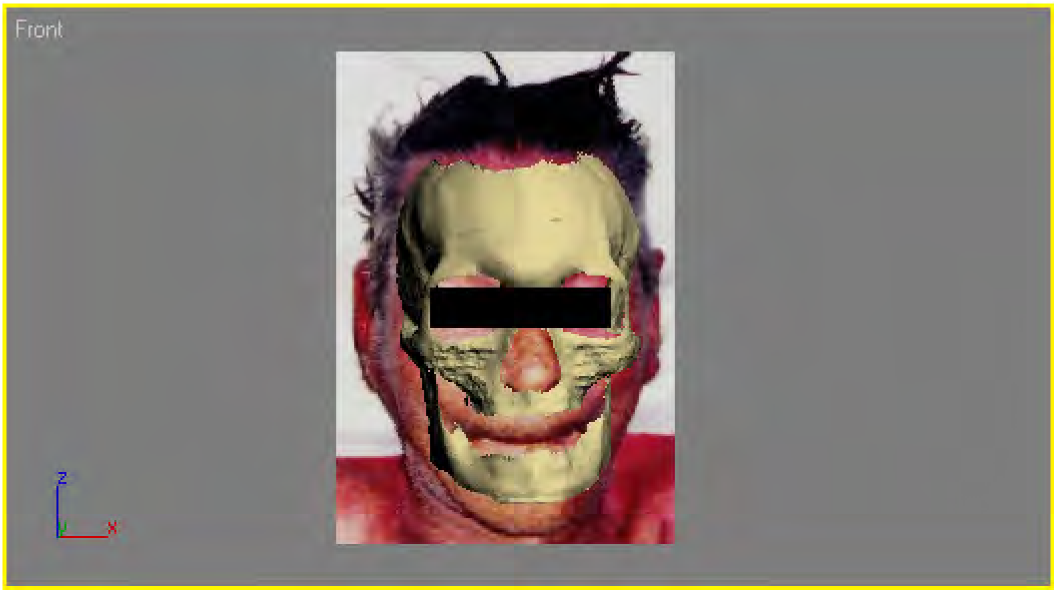
The correct skull was matched to the photograph.

<u>6264 skull g morphological</u>

The correct skull was matched to the photograph.

<u>6306 skull g morphological</u>

The correct skull was not matched to the photograph.



6307 skull j morphological

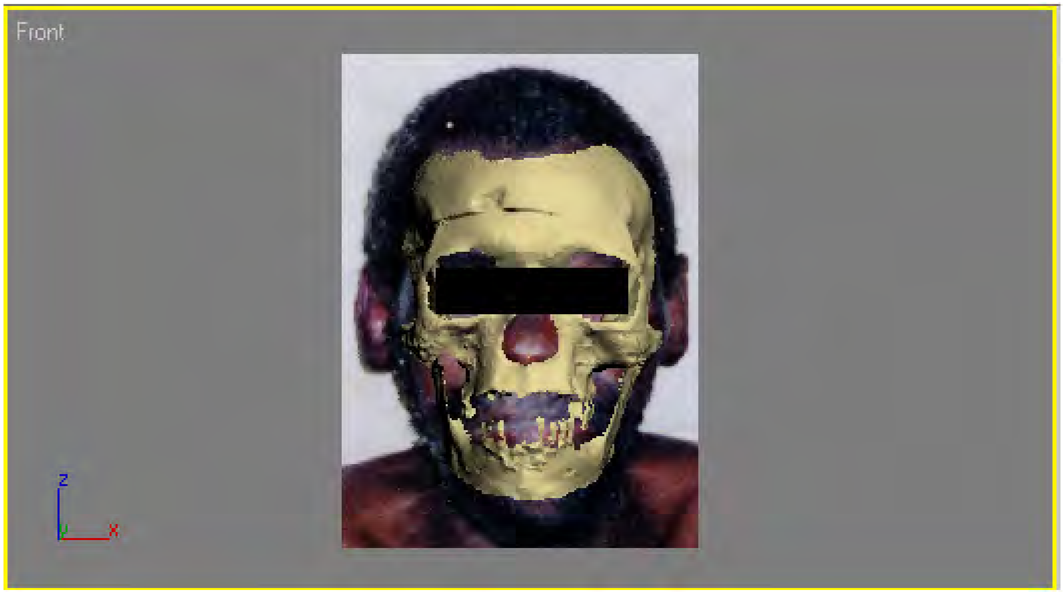
The correct skull was matched to the photograph. The mandibular area was ignored due to the mouth area being problematic- it is evident that this individual wore dentures and distortion of the lip area has occurred with the dentures being removed.

6288 skull i morphological

The correct skull was not matched to the photograph.

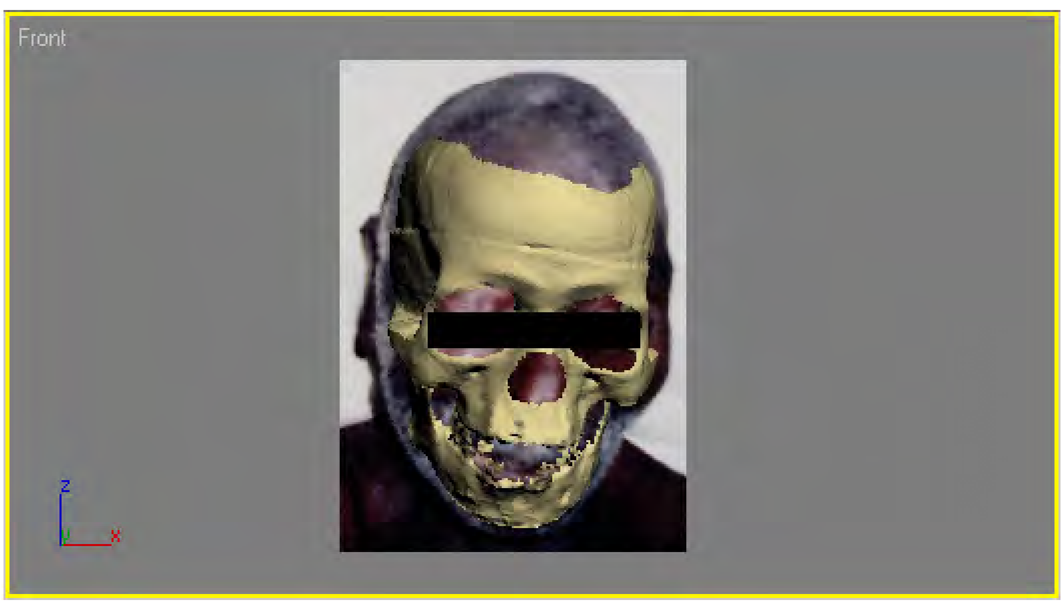
6310 skull j morphological

The correct skull was matched to the photograph. The mandibular area was ignored due to the mouth being slightly open.



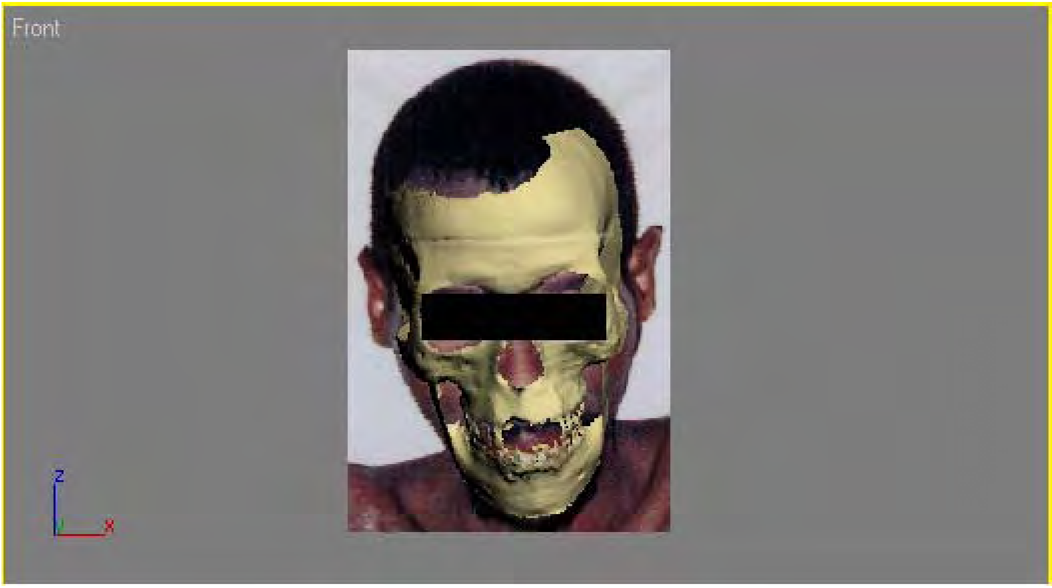
<u>6292 skull i morphological</u>

The correct skull was matched to the photograph.



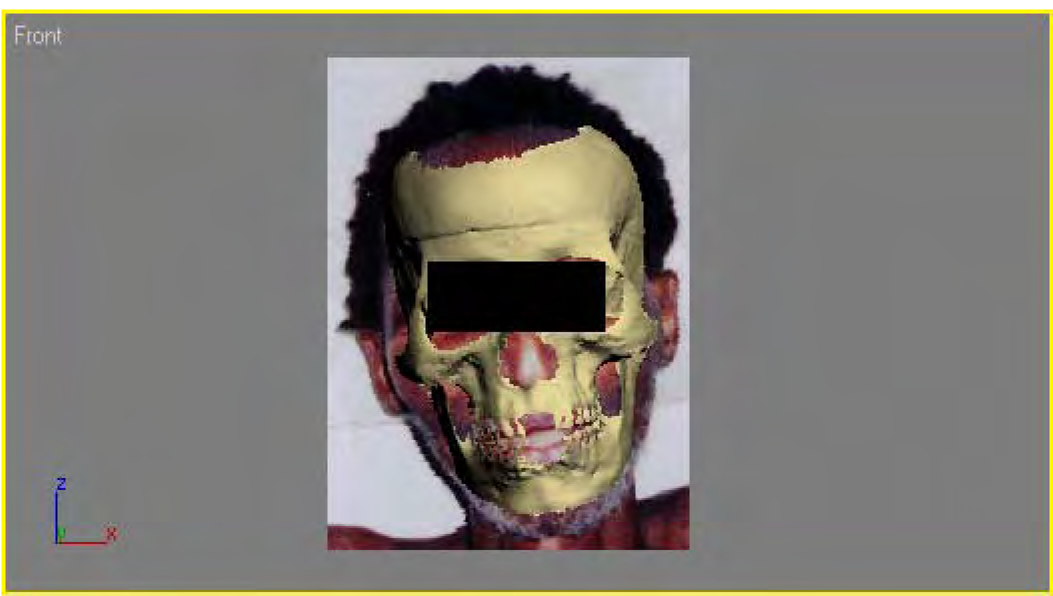
<u>6301 skull i morphological</u>

The correct skull was matched to the photograph.



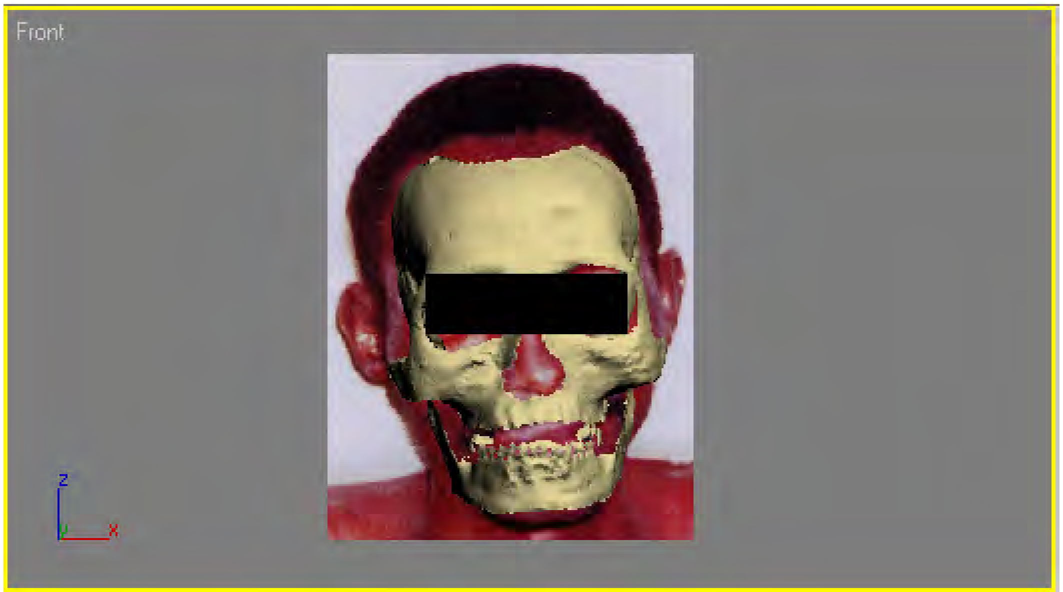
6305 skull j morphological

The correct skull was matched to the photograph.



6309 skull j morphological

The correct skull was matched to the photograph.



6323 skull i morphological

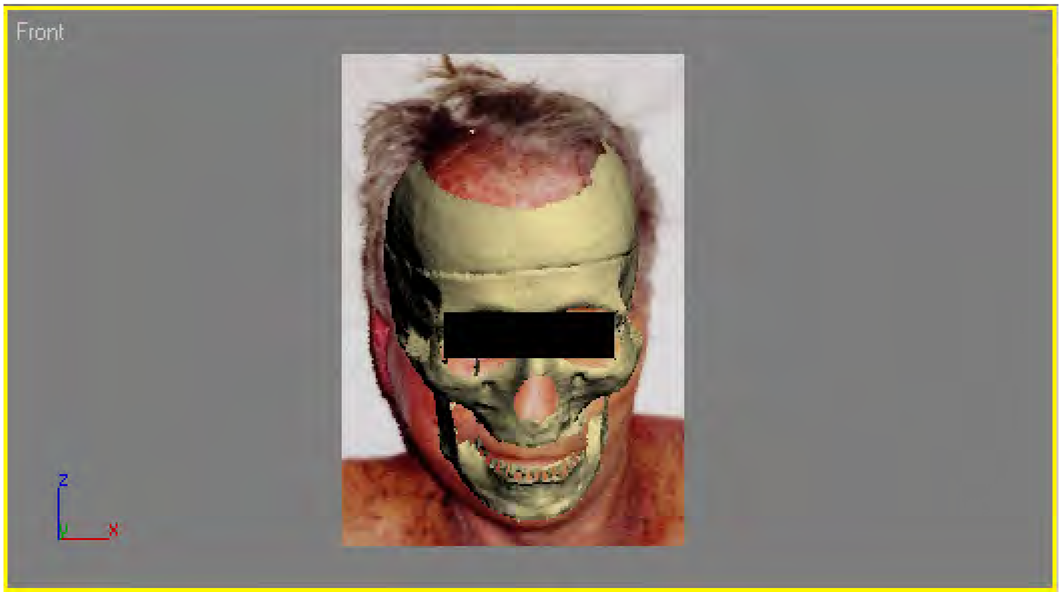
The correct skull was matched to the photograph.

<u>6325 skull i morphological</u>

The correct skull was matched to the photograph.

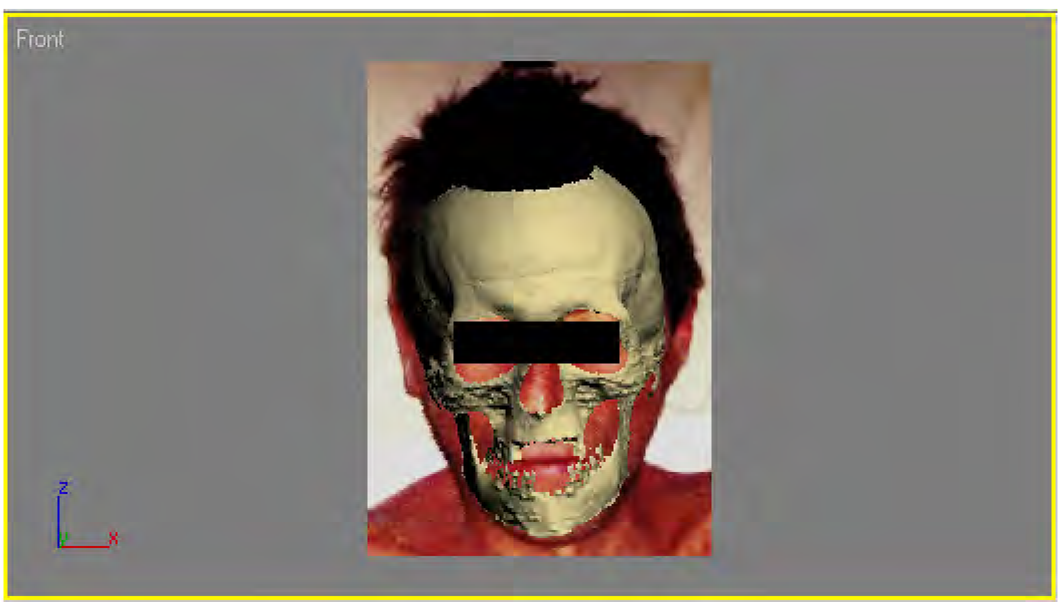
<u>6314 skull e morphological</u>

The correct skull was matched to the photograph.



<u>6367 skull j morphological</u>

The correct skull was matched to the photograph.

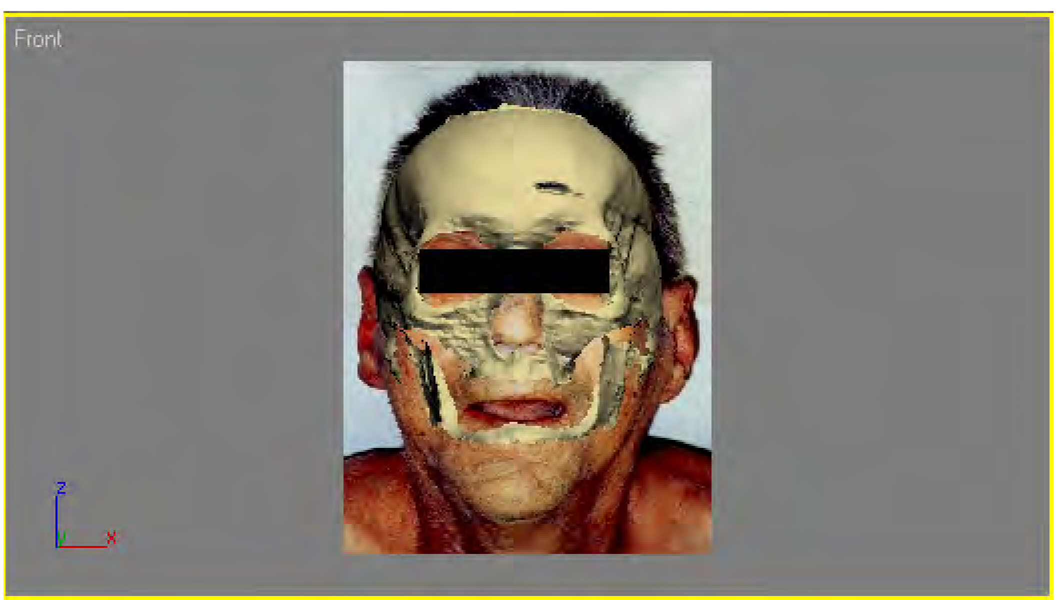


<u>6374 skull j morphological</u>

The correct skull was matched to the photograph.

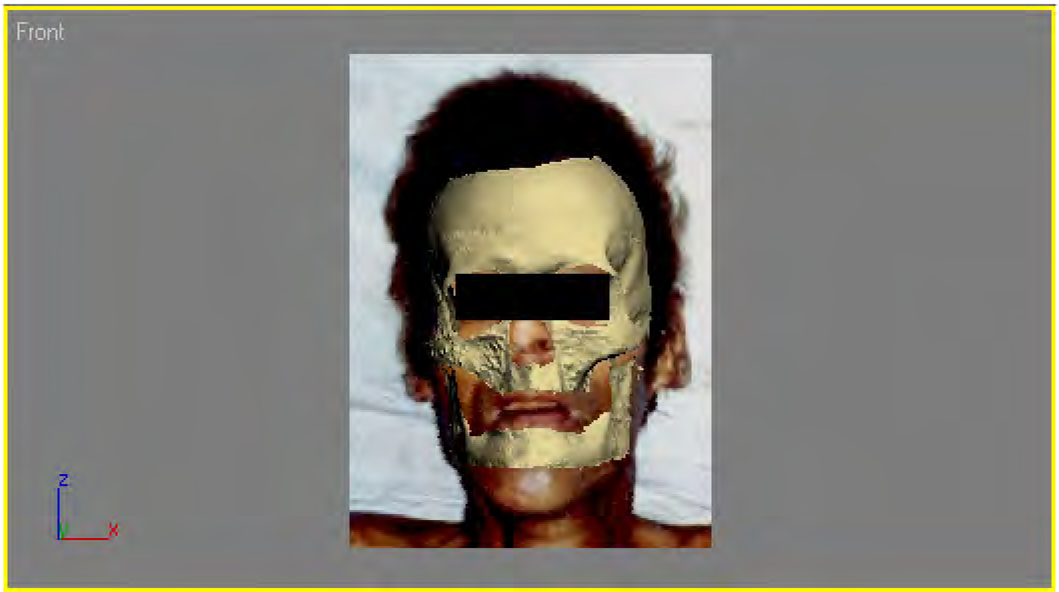
6391 skull j morphological

The correct skull was matched to the photograph.



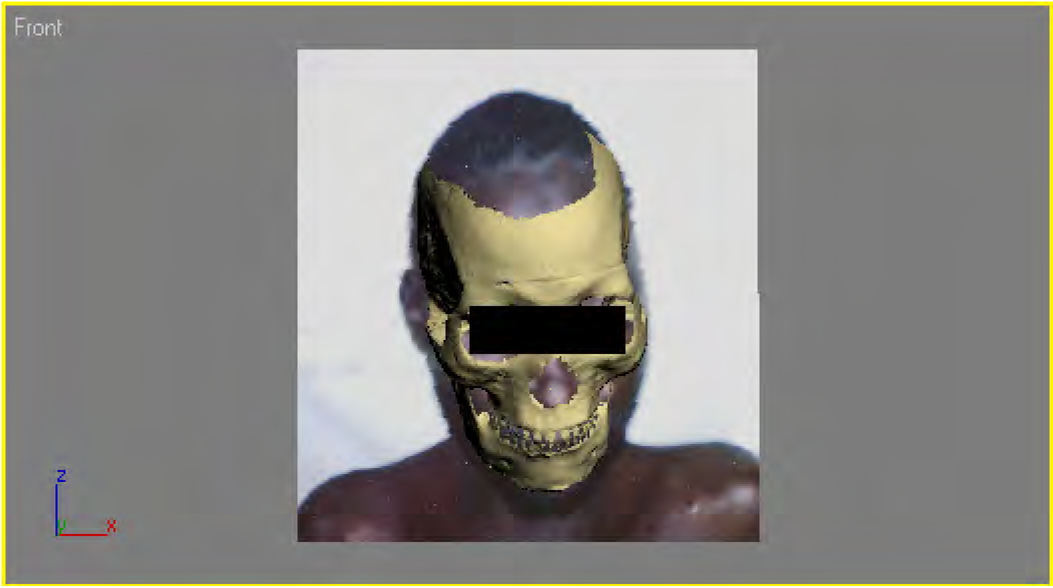
6207 skull a morphological

The correct skull was matched to the photograph. The mandibular area was ignored due to the mouth being open.



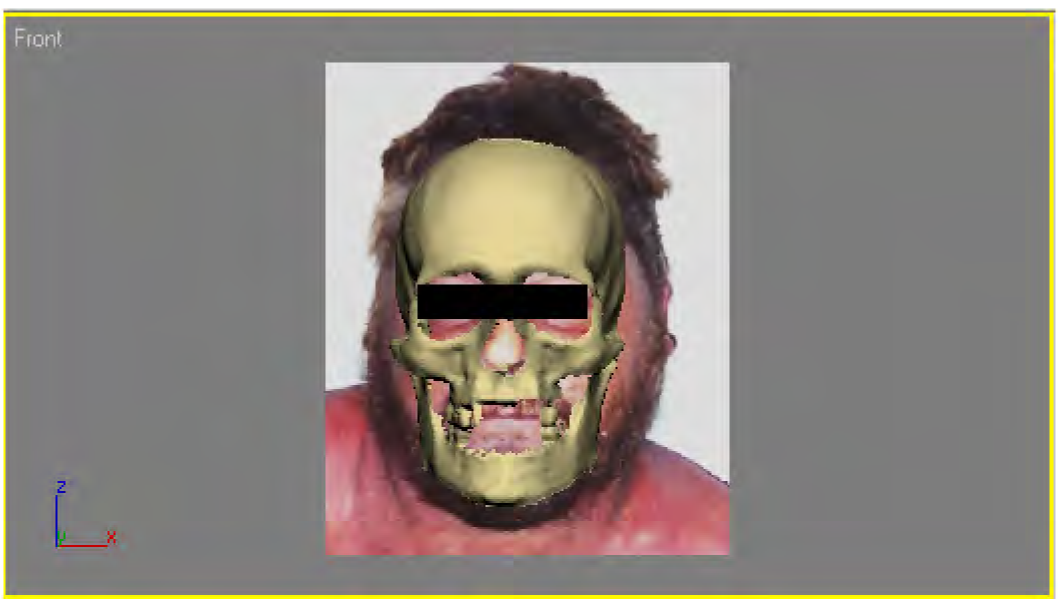
6269 skull a morphological

The correct skull was matched to the photograph. The mandibular area was ignored due to the mouth being open.



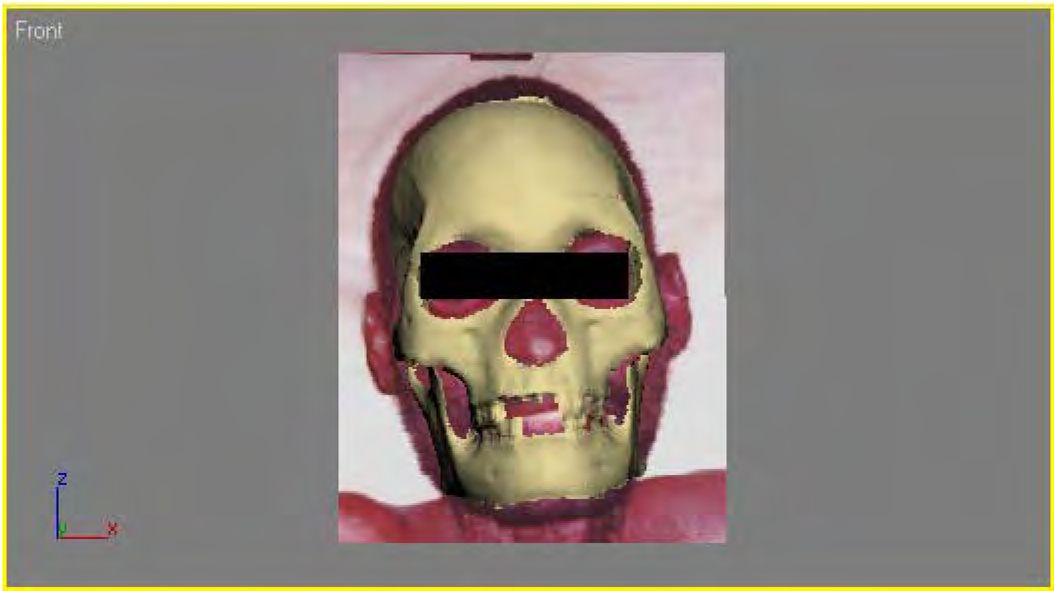
<u>6218 skull g morphological</u>

The correct skull was matched to the photograph.



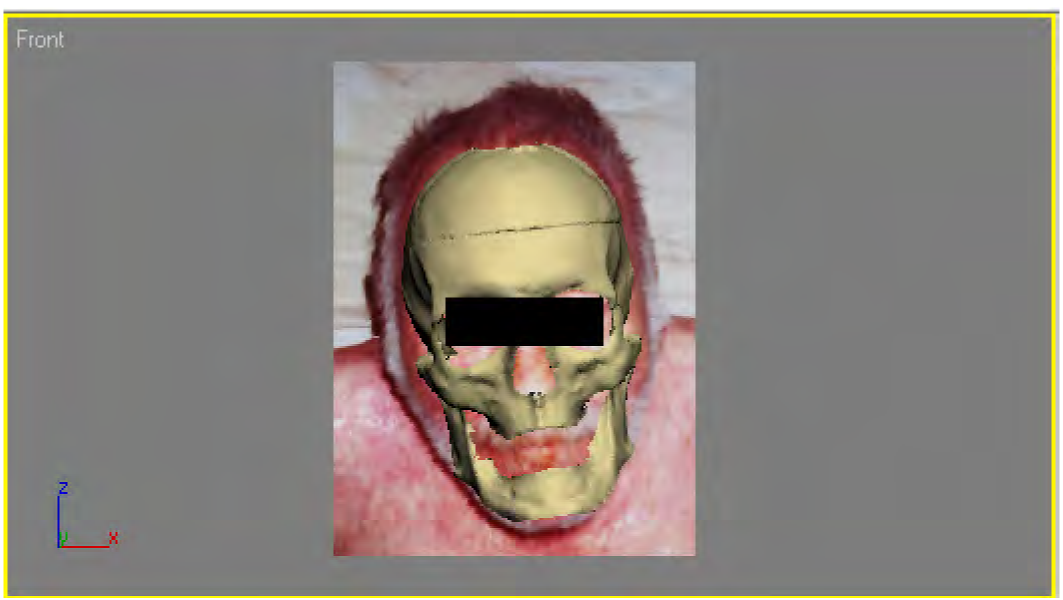
<u>6248 skull c morphological</u>

The correct skull was matched to the photograph.



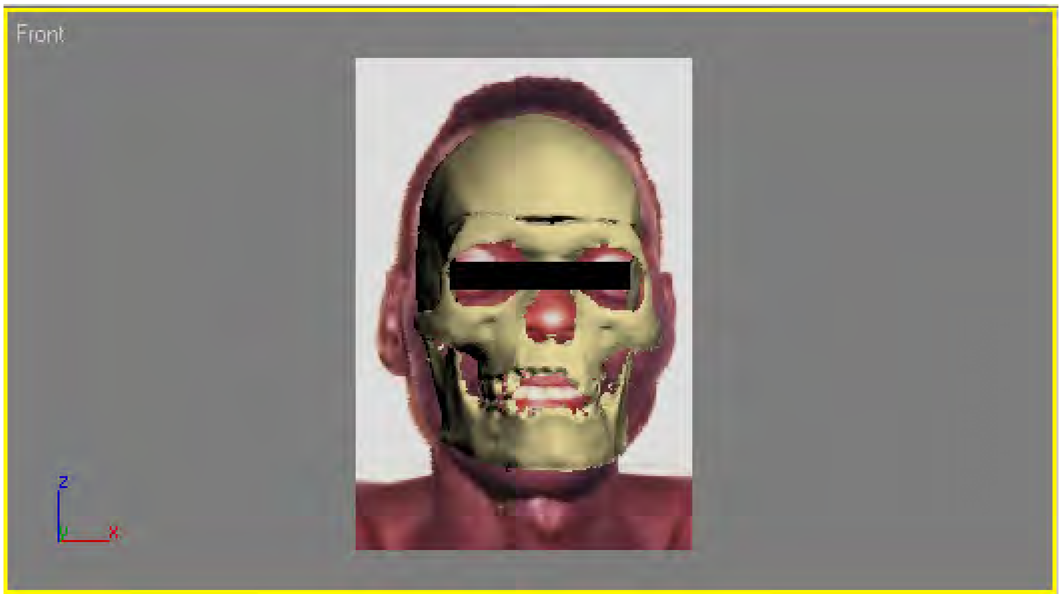
<u>6317 skull f morphological</u>

The correct skull was matched to the photograph.



<u>6327 skull c morphological</u>

The correct skull was matched to the photograph.

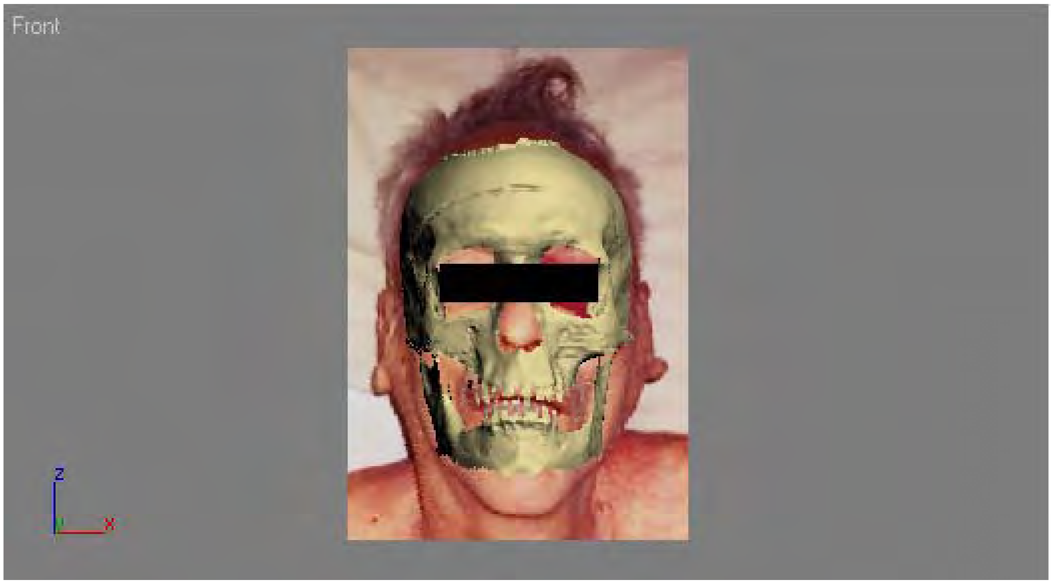


<u>6371 skull b morphological</u>

The correct skull was matched to the photograph.

<u>6376 skull g morphological</u>

The correct skull was matched to the photograph.

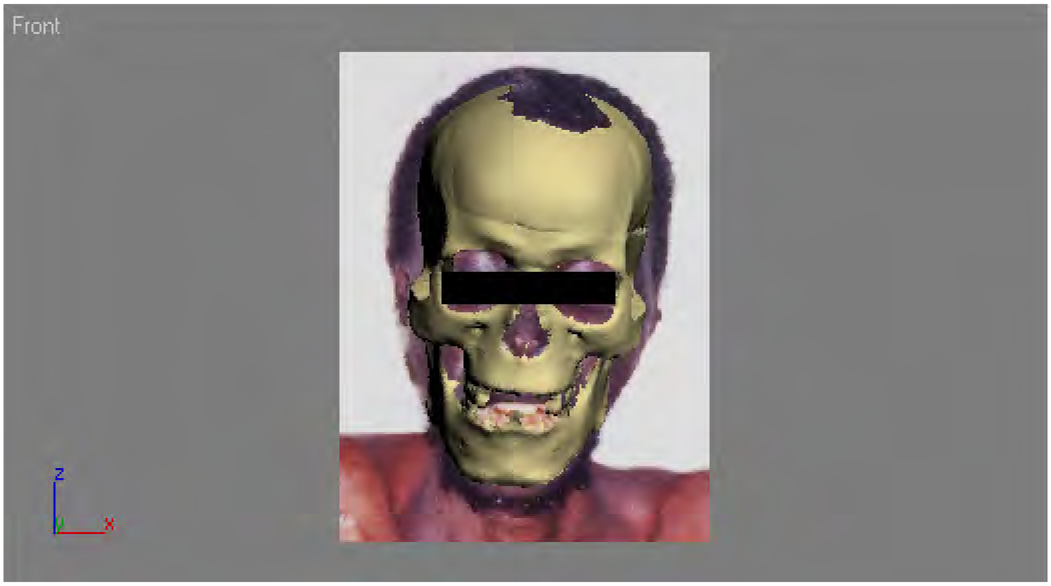


6381 skull d morphological

The correct skull was matched to the photograph. The mandibular area was ignored due to the mouth being open.

6385 skull f morphological

The correct skull was not matched to the photograph.

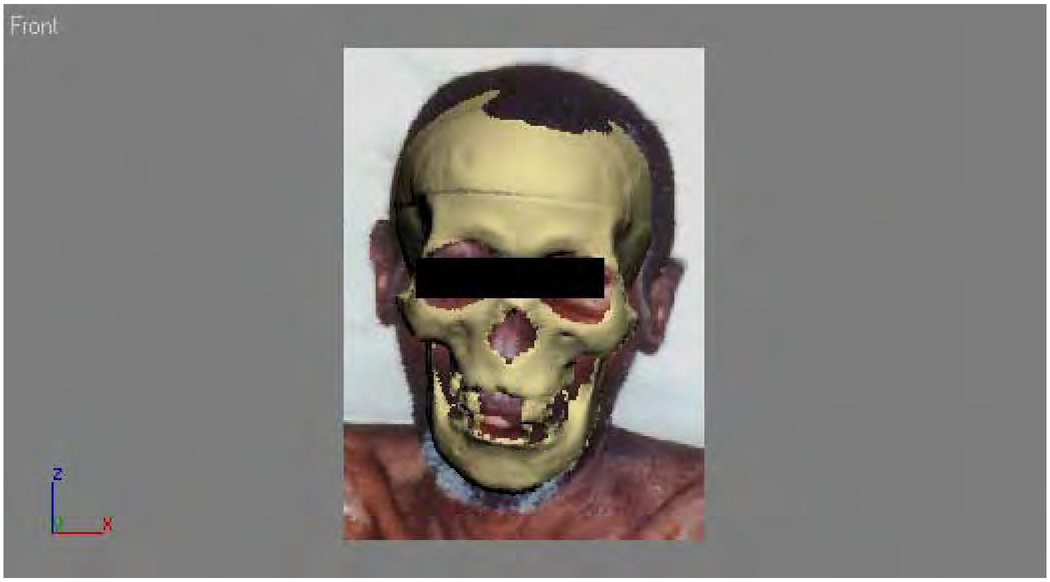


6299 skull a morphological

The correct skull was matched to the photograph.

6283 skull a morphological

The correct skull was not matched to the photograph.



6242 skull g morphological

The correct skull was matched to the photograph.

6210 skull i morphological

The correct skull was matched to the photograph.

6230 skull g morphological

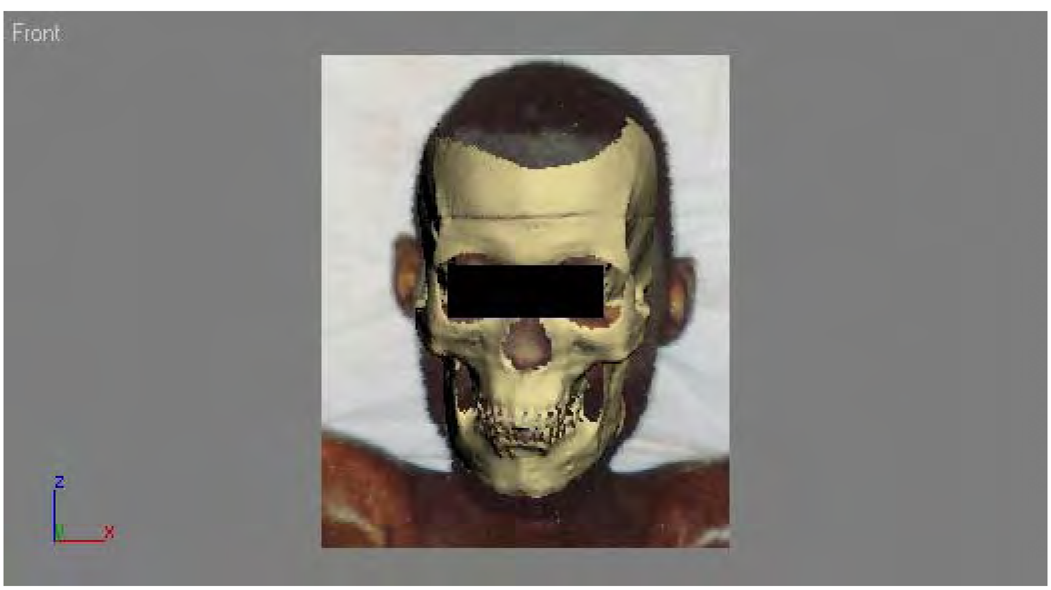
The correct skull was not matched to the photograph.

6253 skull h morphological

The correct skull was matched to the photograph. The mandibular area was ignored due to the mouth being open.

<u>6316 skull c morphological</u>

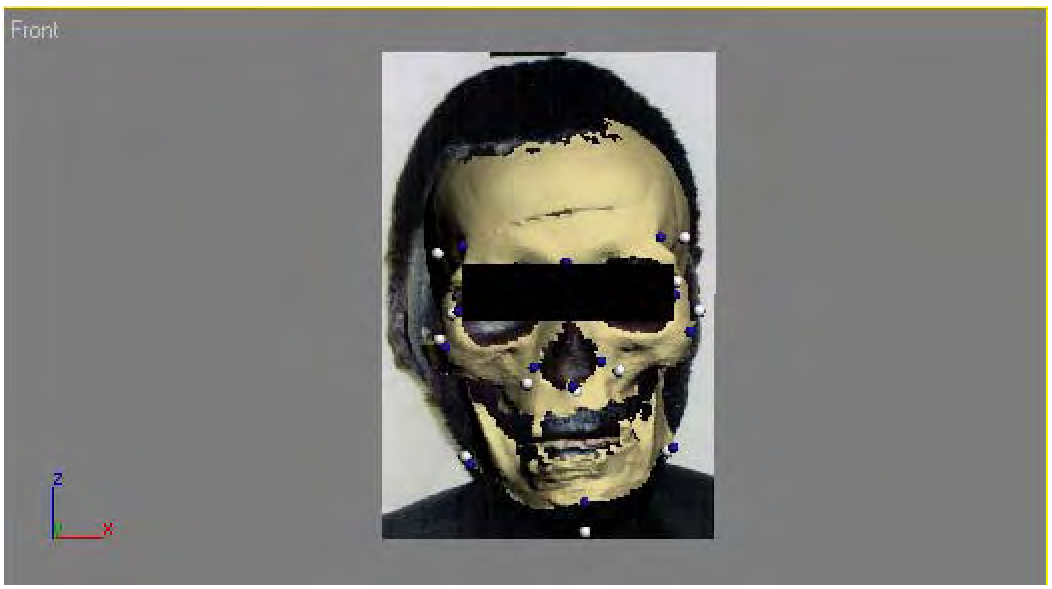
The correct skull was matched to the photograph. The mandibular area was ignored due to the mouth being open.



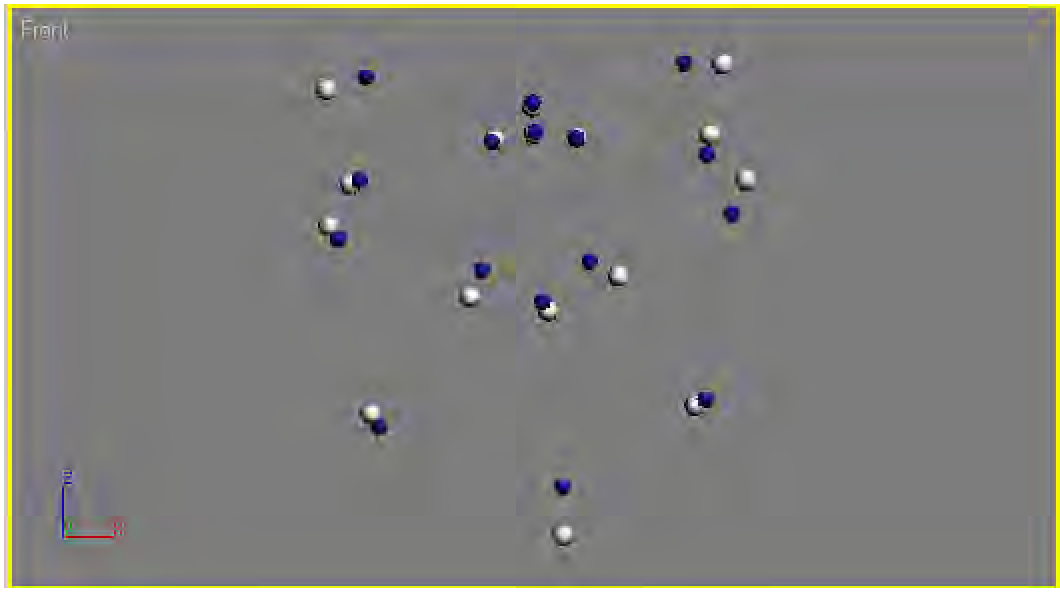
<u>6220 skull e morphological</u>

The correct skull was matched to the photograph.

<u>Appendix B: Photographs with their correct skulls (landmark based assessment)</u>

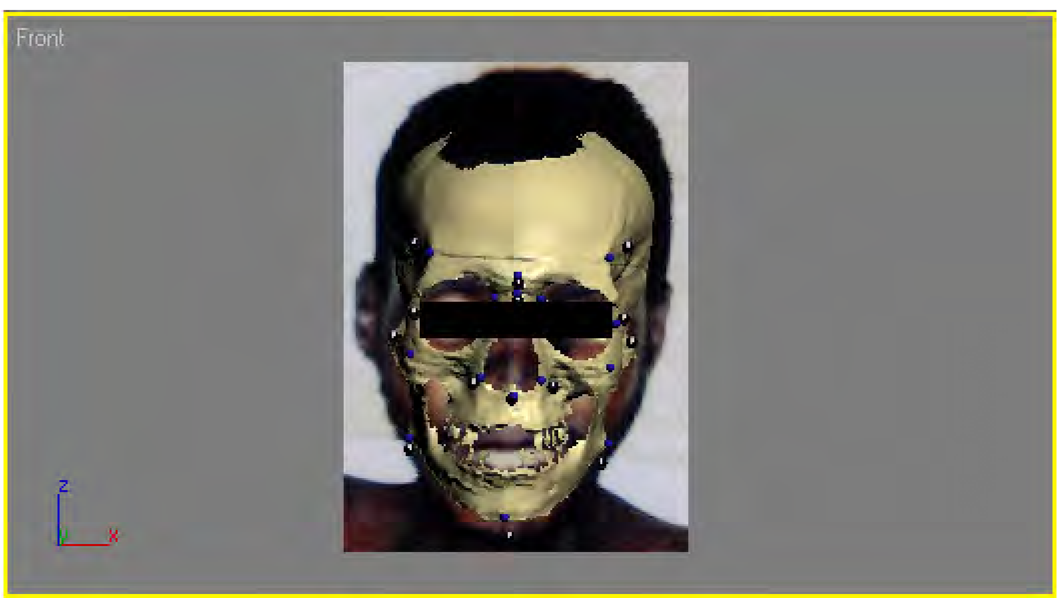


<u>6142 skull i match</u>



<u>6142 skull i dot match</u>

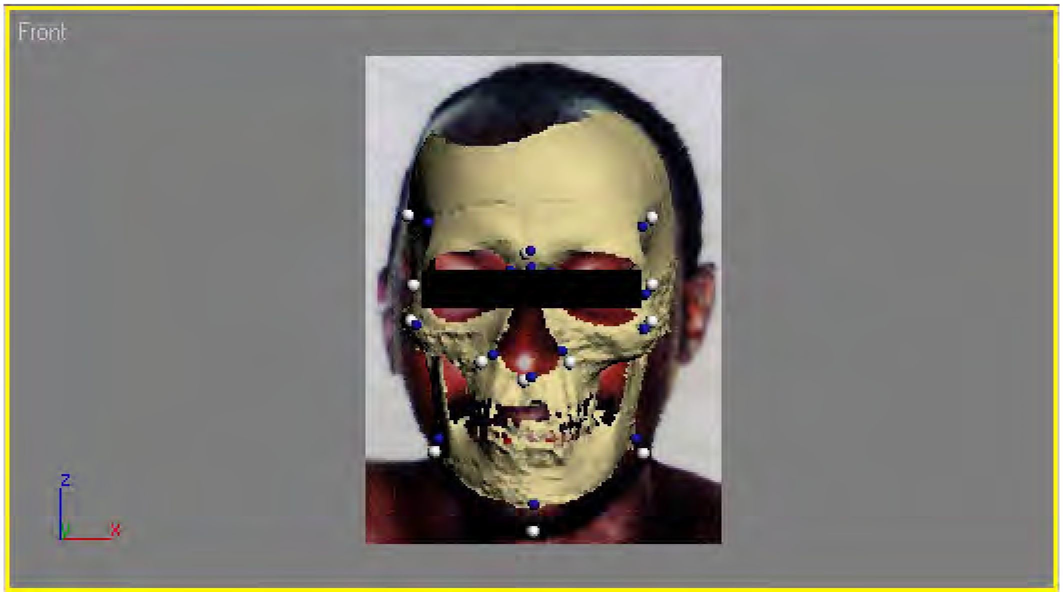
The correct skull was matched to the photograph.



<u>6231 skull g match</u>

6231 skull g dot match

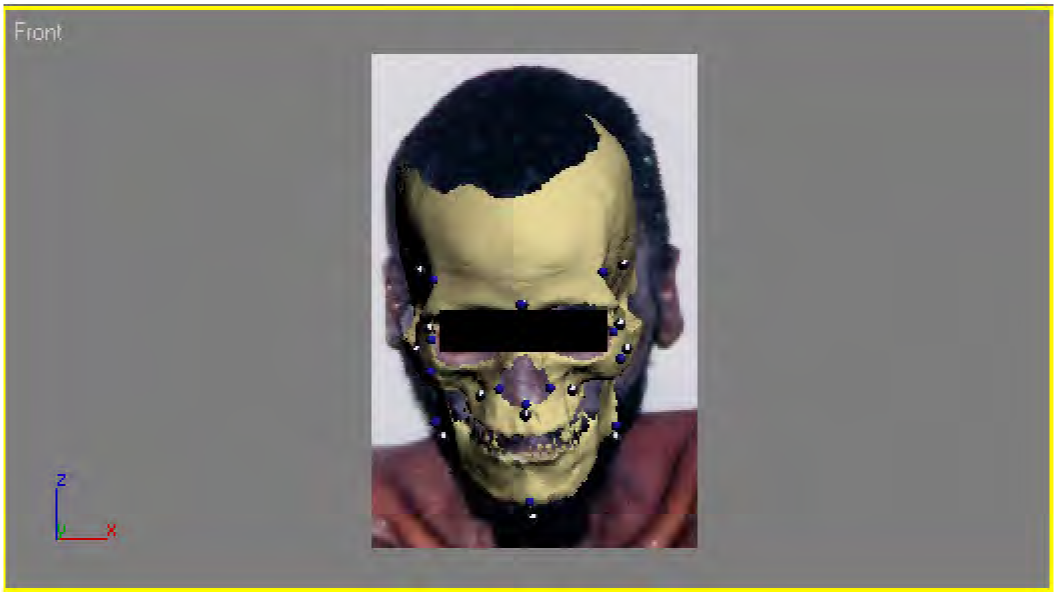
The correct skull was matched to the photograph.



<u>6325 skull j match</u>

<u>6325 skull j dot match</u>

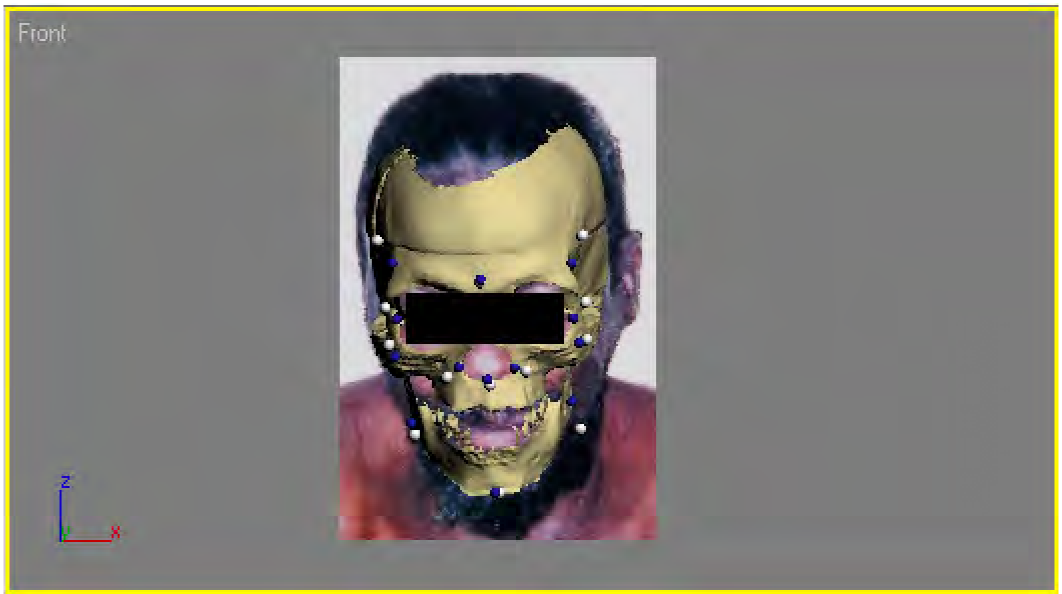
The correct skull was matched to the photograph.



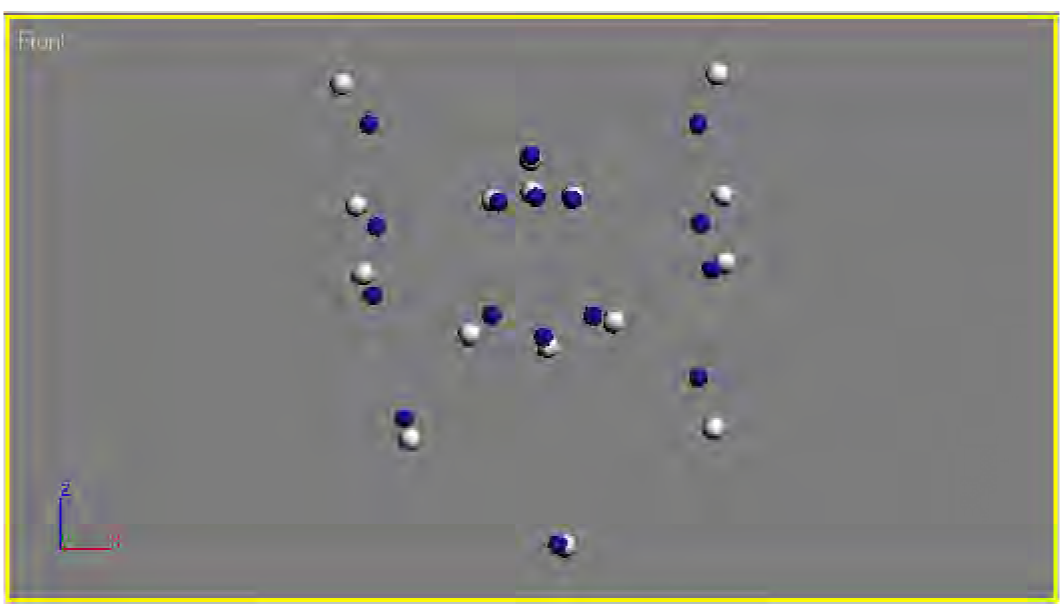
<u>6280 skull i match</u>

<u>6280 skull i dot match</u>

The correct skull was matched to the photograph.



6281 skull j match



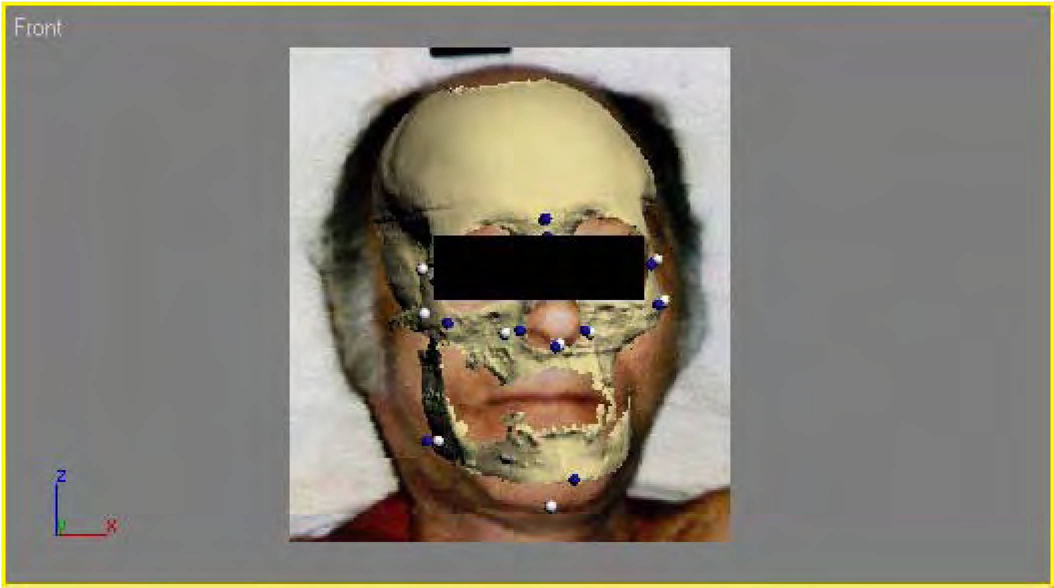
6281 skull j dot match

The correct skull was not matched to the photograph.

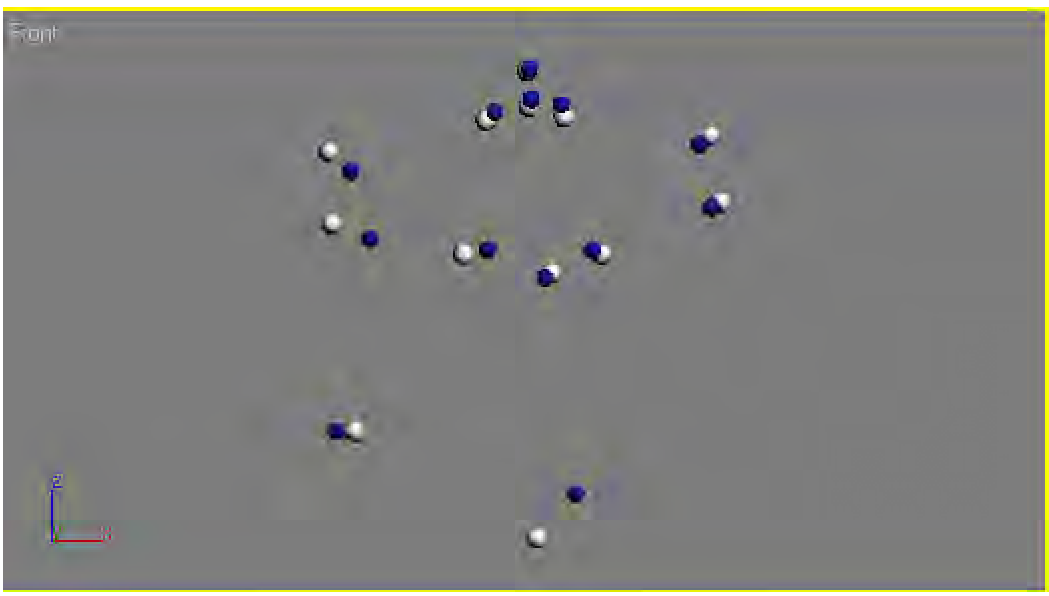
6219 skull j match

6219 skull j dot match

The correct skull was not matched to the photograph.

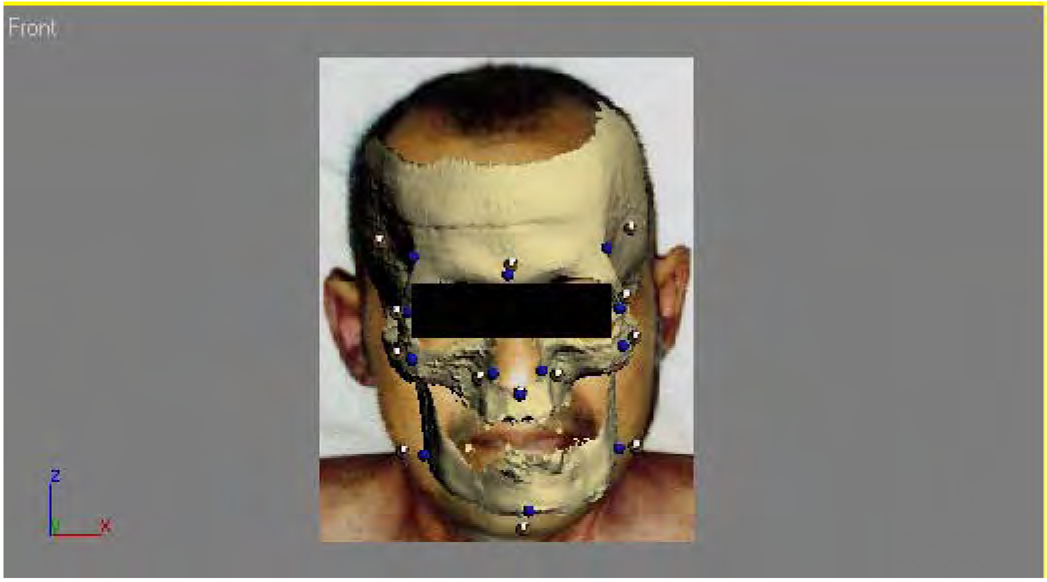


<u>6228 skull i match</u>



<u>6228 skull i dot match</u>

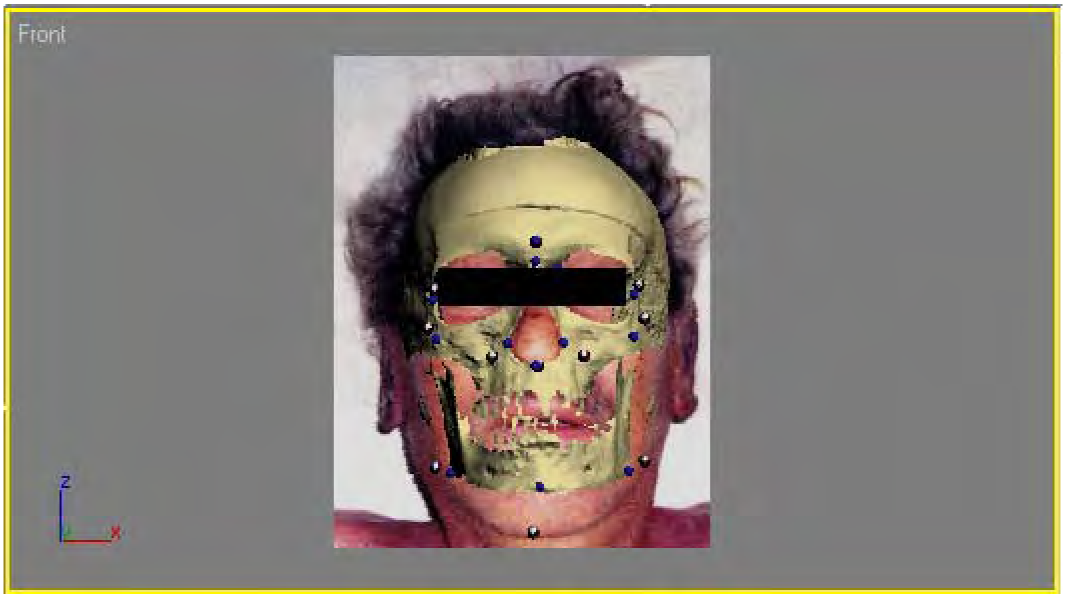
The correct skull was matched to the photograph.



6264 skull g match

6264 skull g dot match

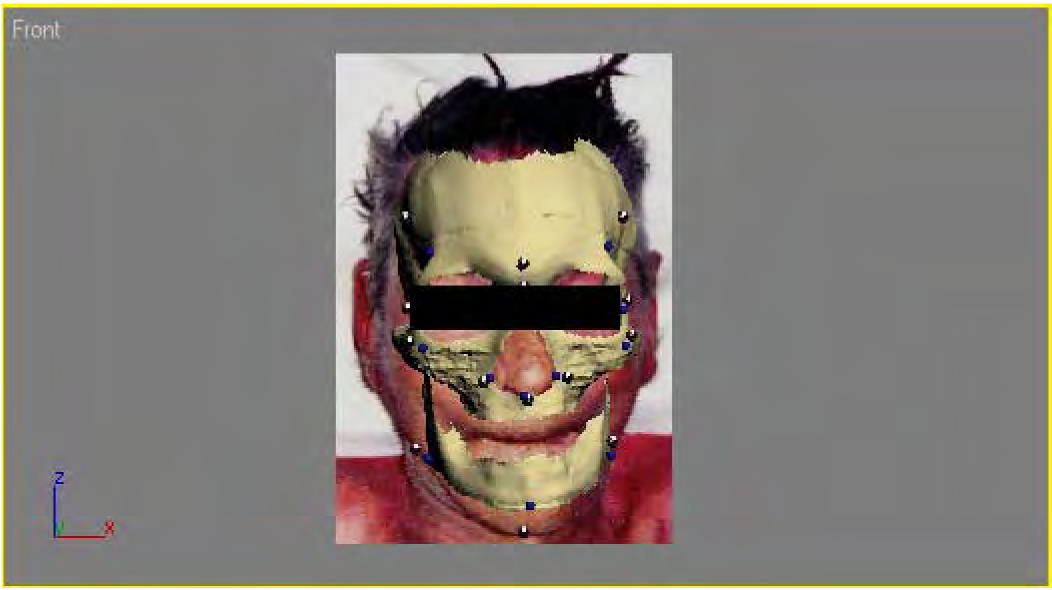
The correct skull was matched to the photograph.



<u>6306 skull g match</u>

<u>6306 skull g dot match</u>

The correct skull was matched to the photograph.

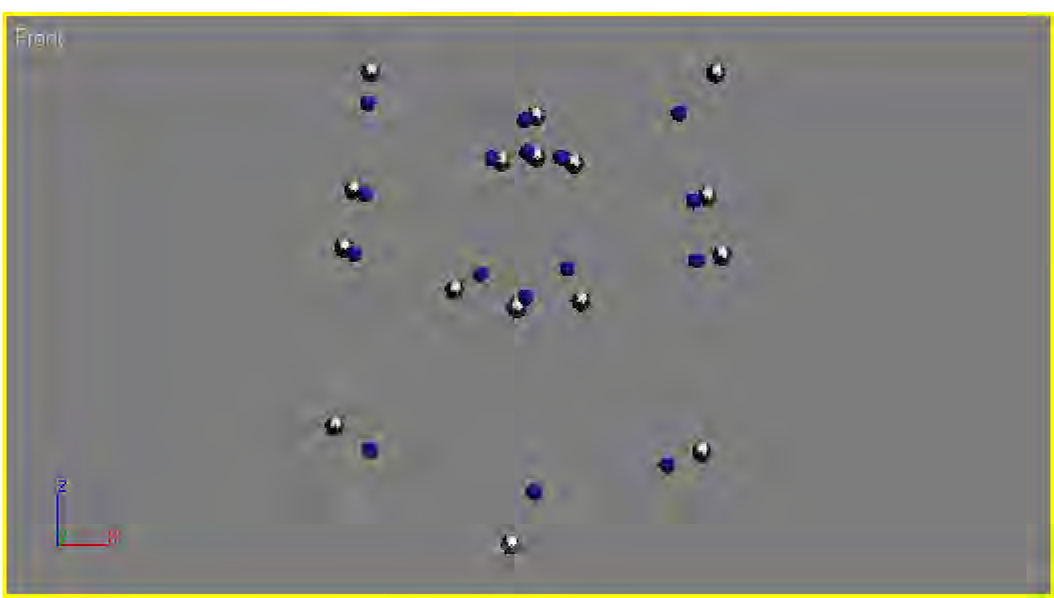


6307 skull j match

6307 skull j dot match

The correct skull was matched to the photograph.

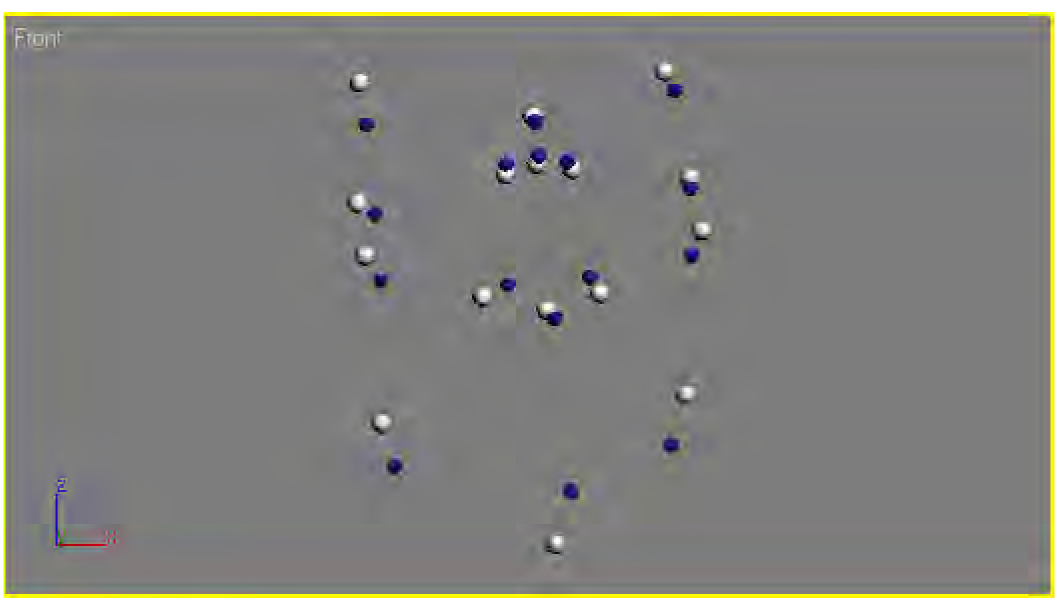
<u>6288 skull i match</u>



<u>6288 skull i dot match</u>

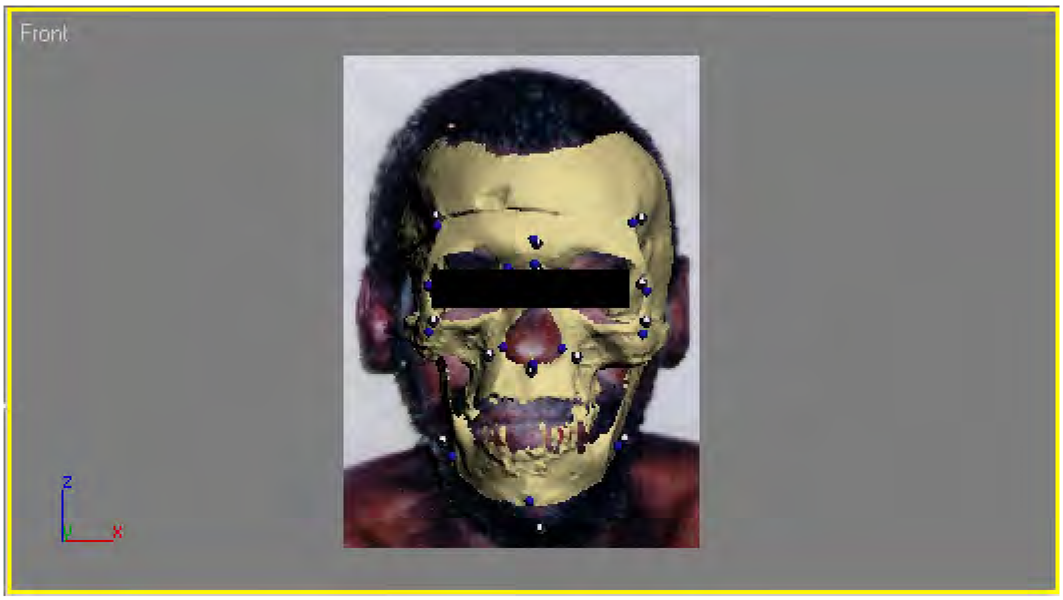
The correct skull was matched to the photograph.

<u>6310 skull j match</u>



<u>6310 skull j dot match</u>

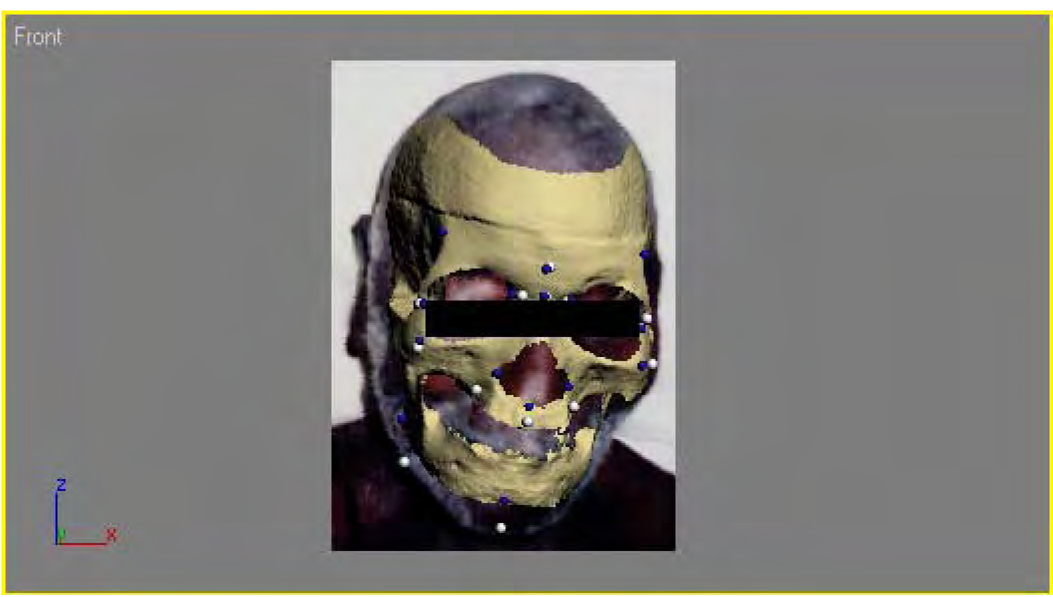
The correct skull was matched to the photograph.



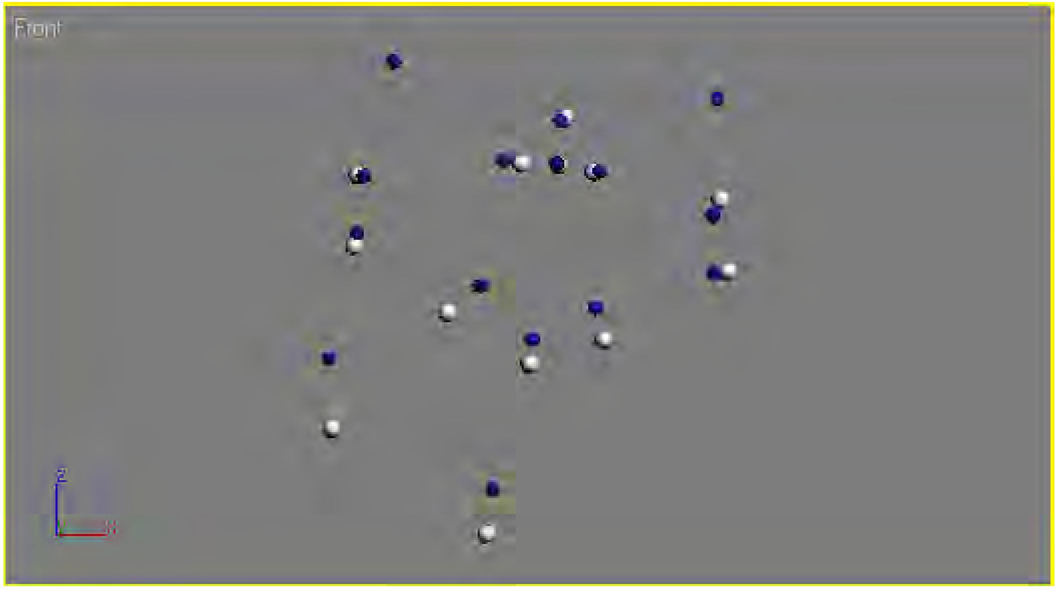
<u>6292 skull i match</u>

<u>6292 skull i dot match</u>

The correct skull was matched to the photograph.

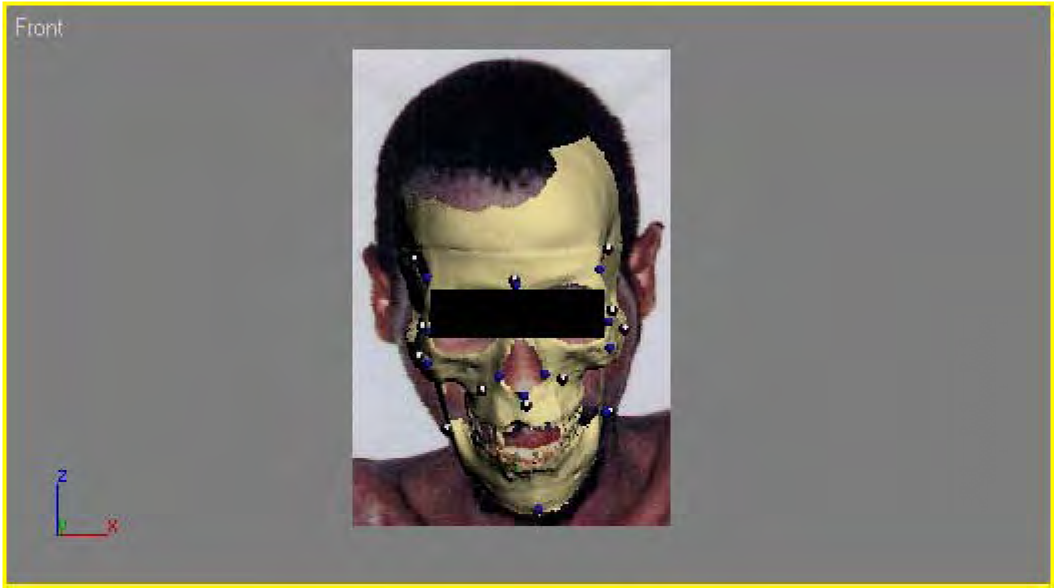


<u>6301 skull j match</u>

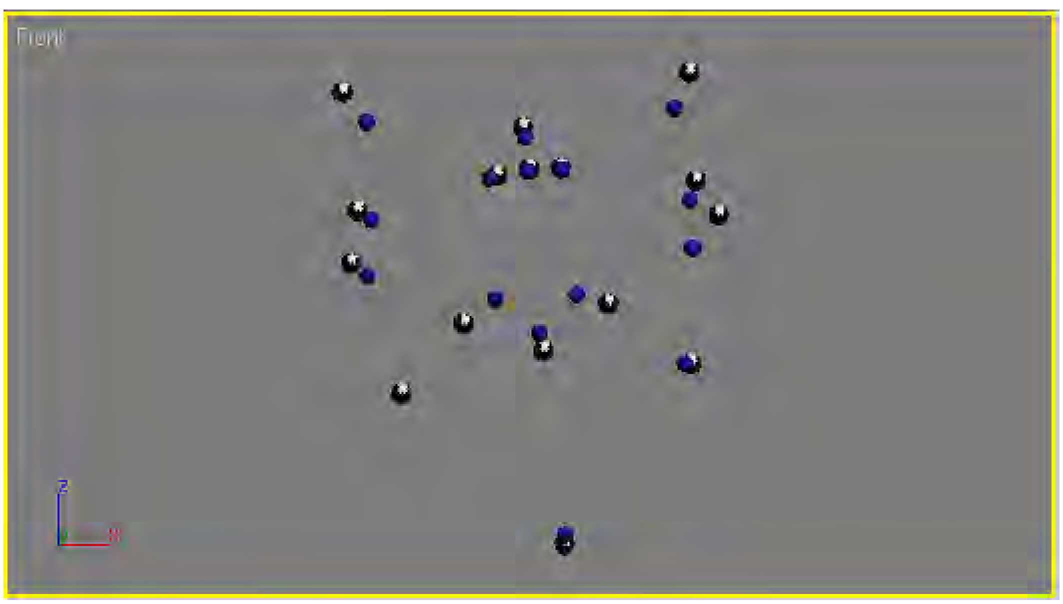


<u>6301 skull j dot match</u>

The correct skull was matched to the photograph.

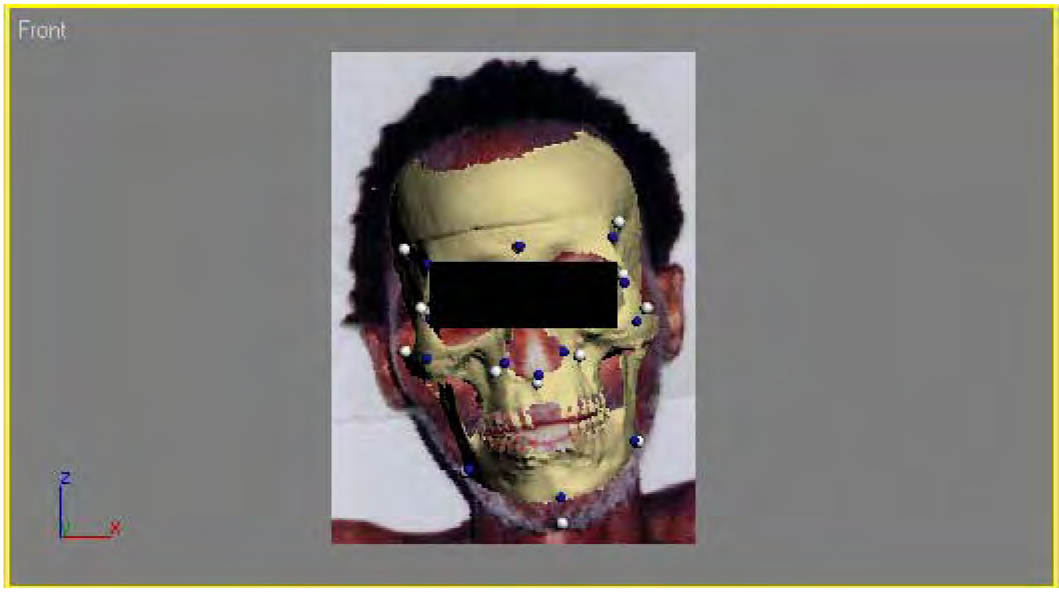


<u>6305 skull j match</u>

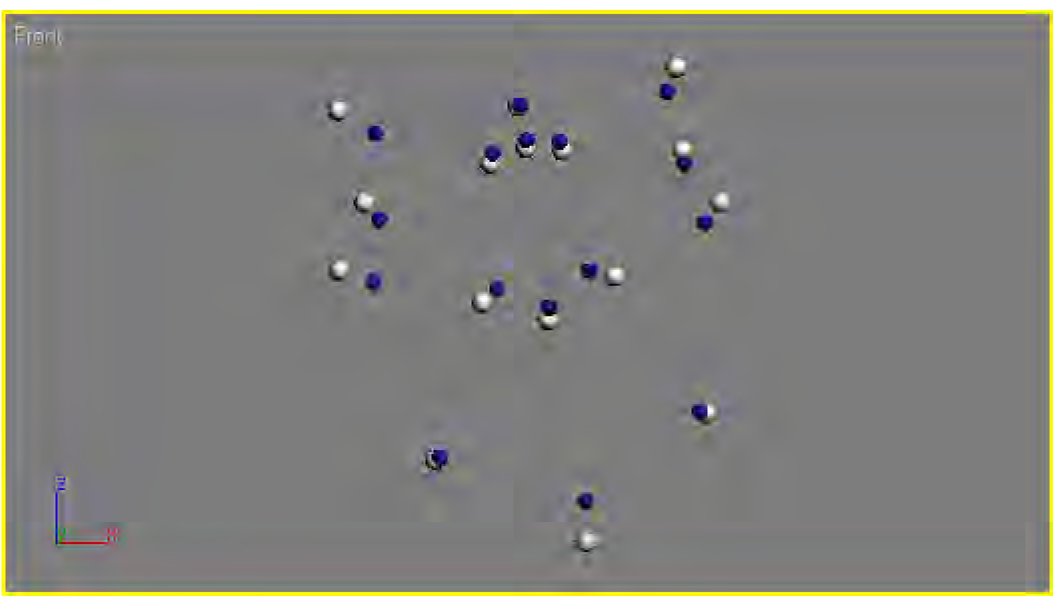


<u>6305 skull j dot match</u>

The correct skull was matched to the photograph.

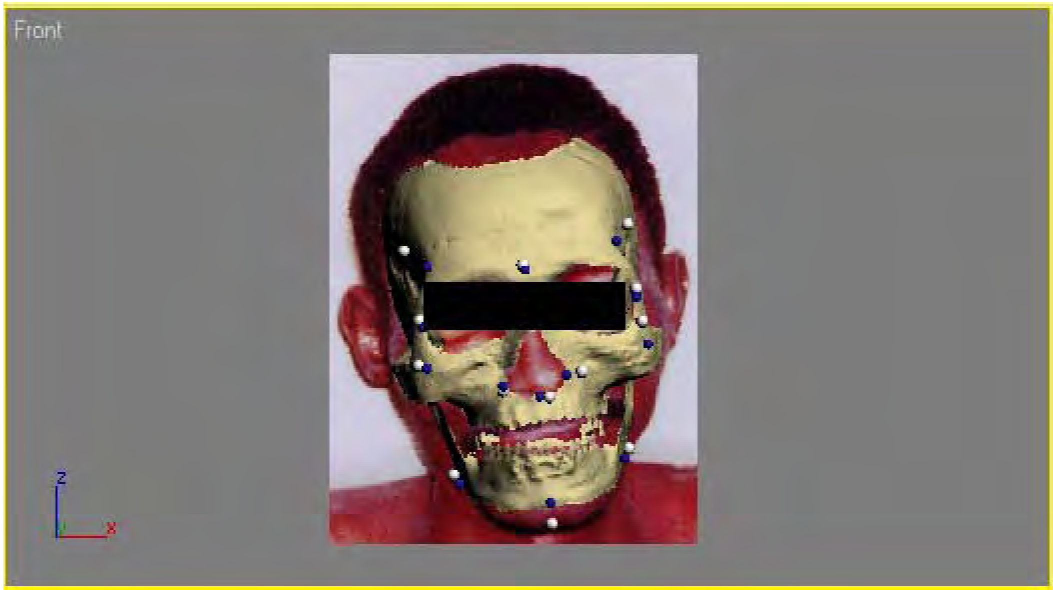


6309 skull j match



6309 skull j dot match

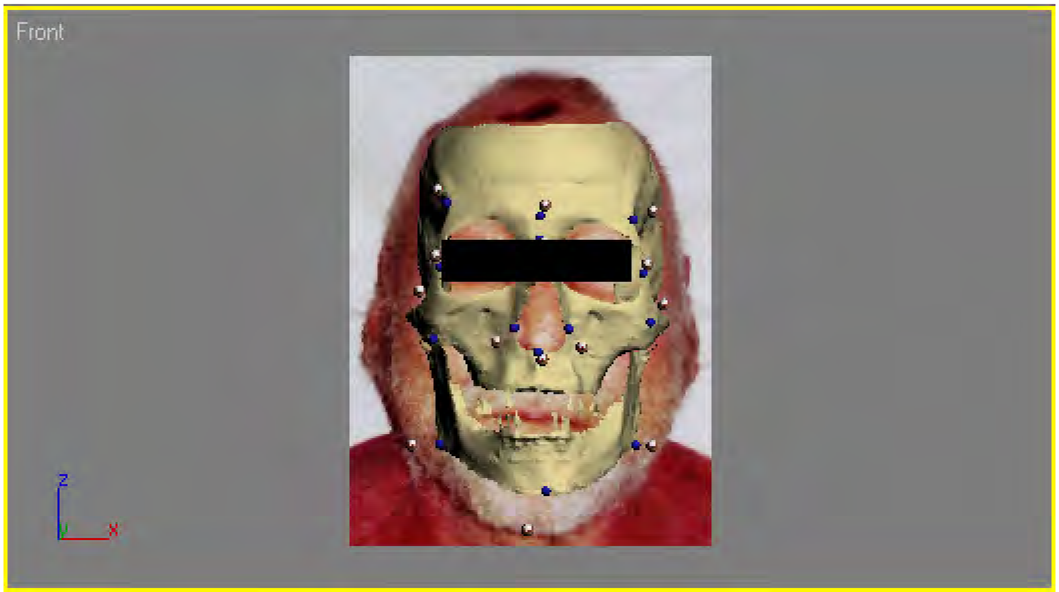
The correct skull was matched to the photograph.



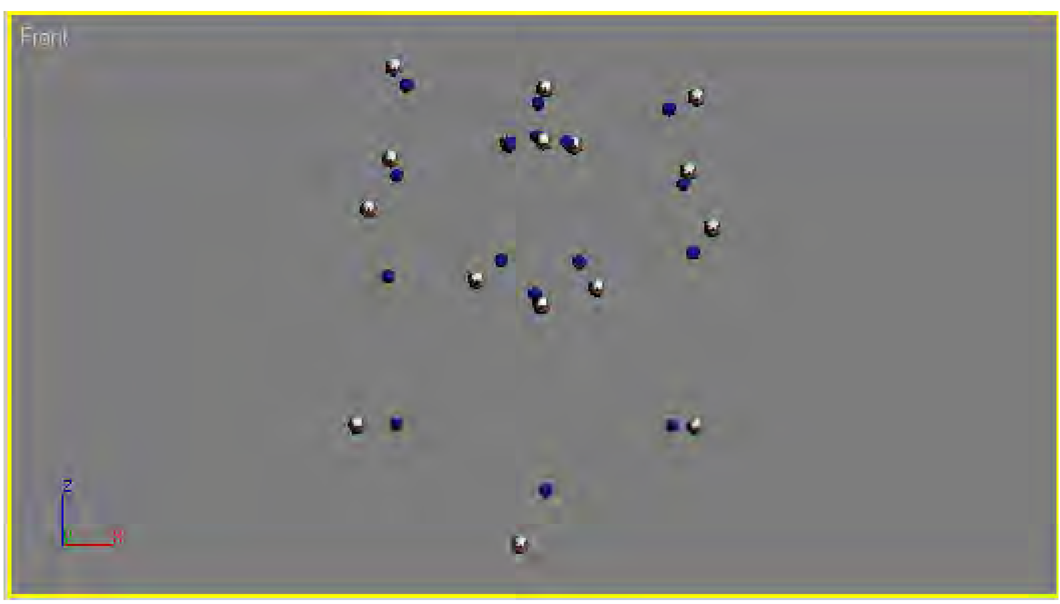
<u>6323 skull i match</u>

<u>6323 skull i dot match</u>

The correct skull was matched to the photograph.

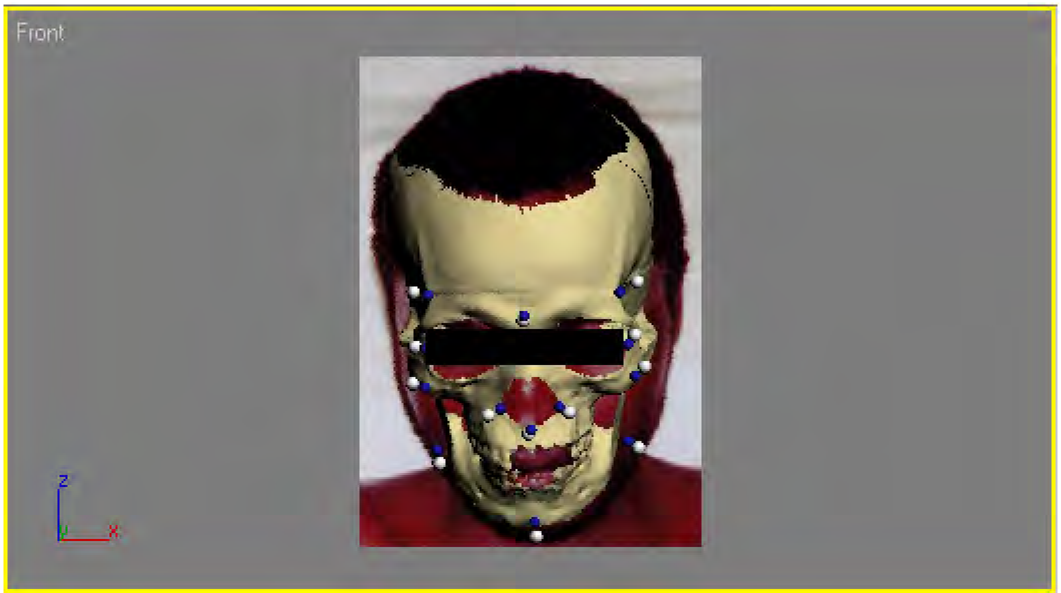


<u>6325 skull i match</u>

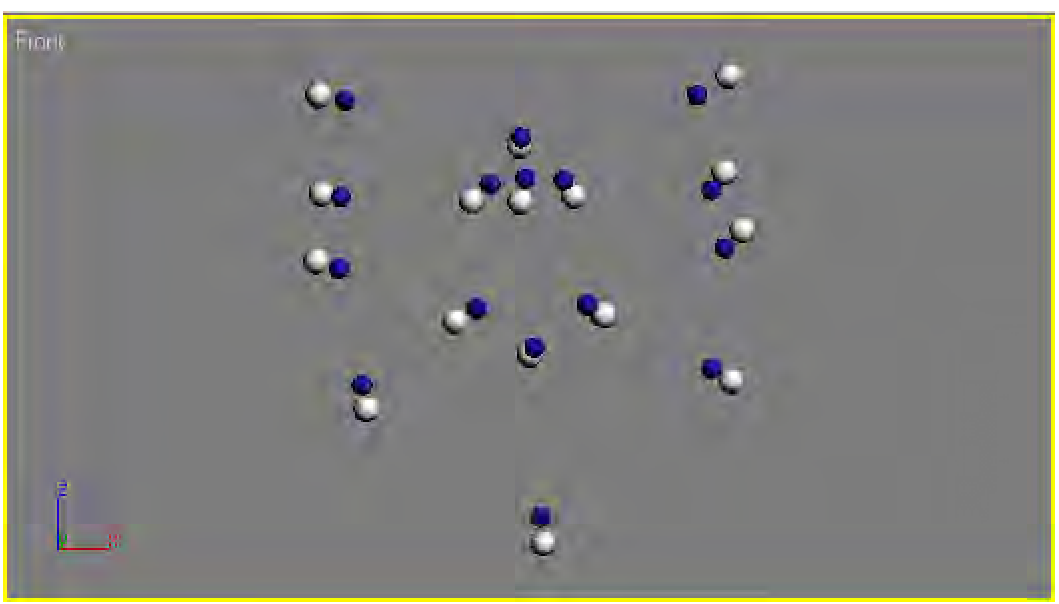


<u>6325 skull i dot match</u>

The correct skull was matched to the photograph.

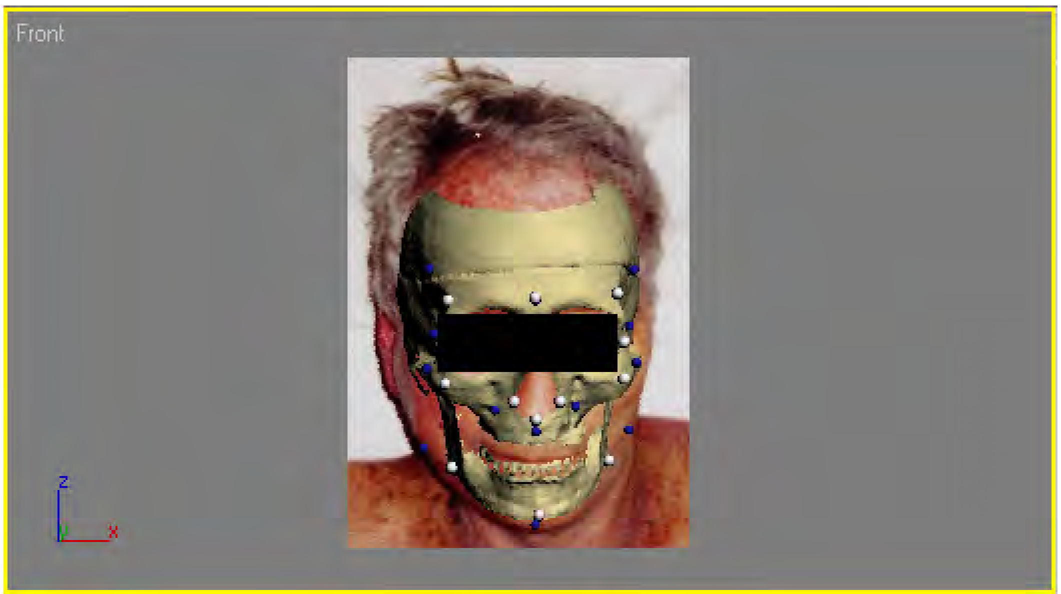


<u>6314 skull e match</u>

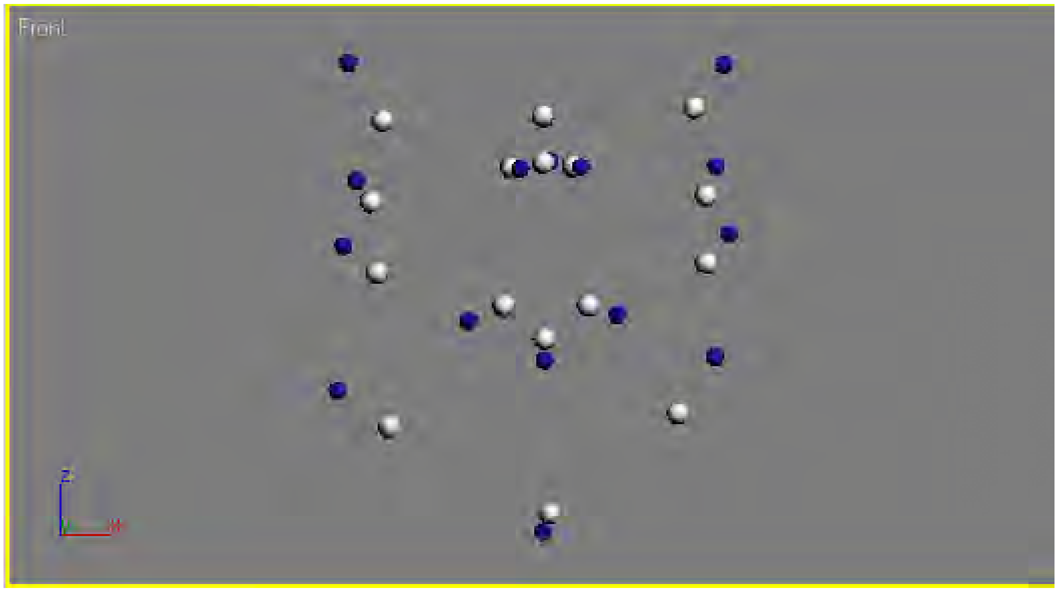


<u>6314 skull e dot match</u>

The correct skull was matched to the photograph.

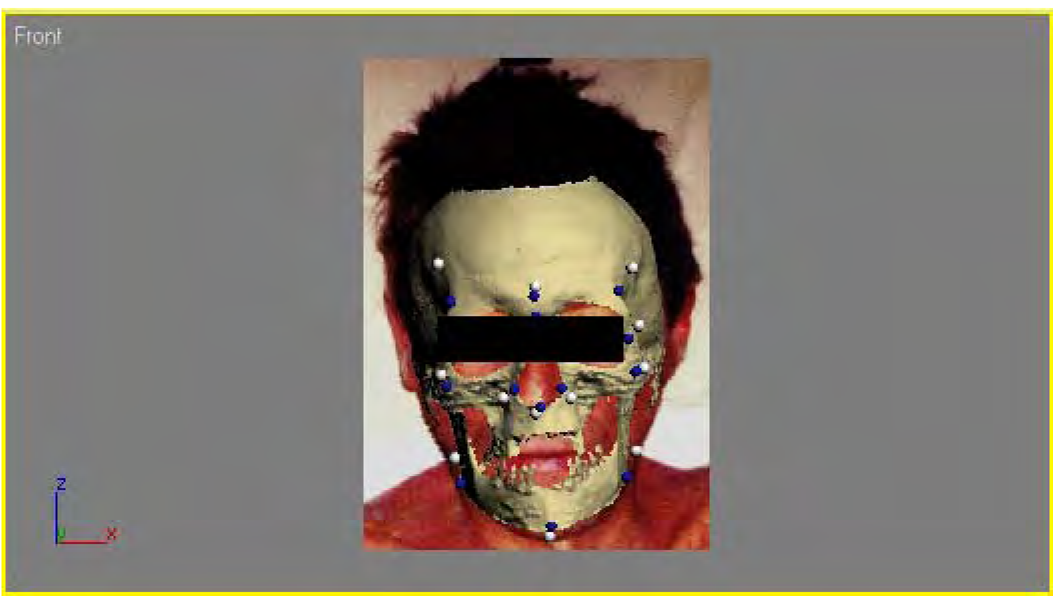


6367 skull j match



<u>6367 skull j dot match</u>

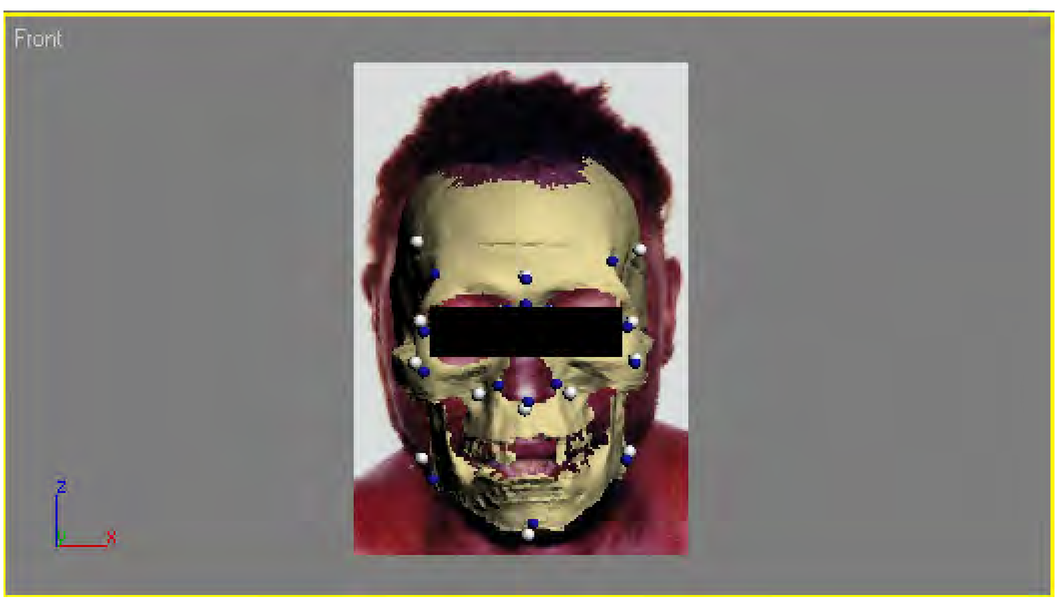
The correct skull was not matched to the photograph.



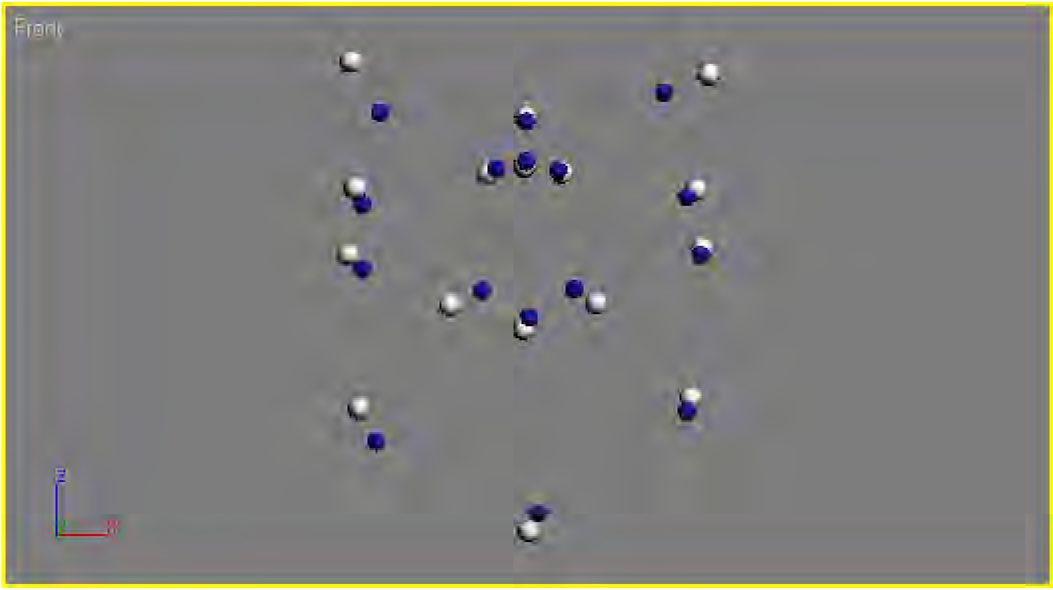
<u>6374 skull j match</u>

6374 skull j dot match

The correct skull was not matched to the photograph.

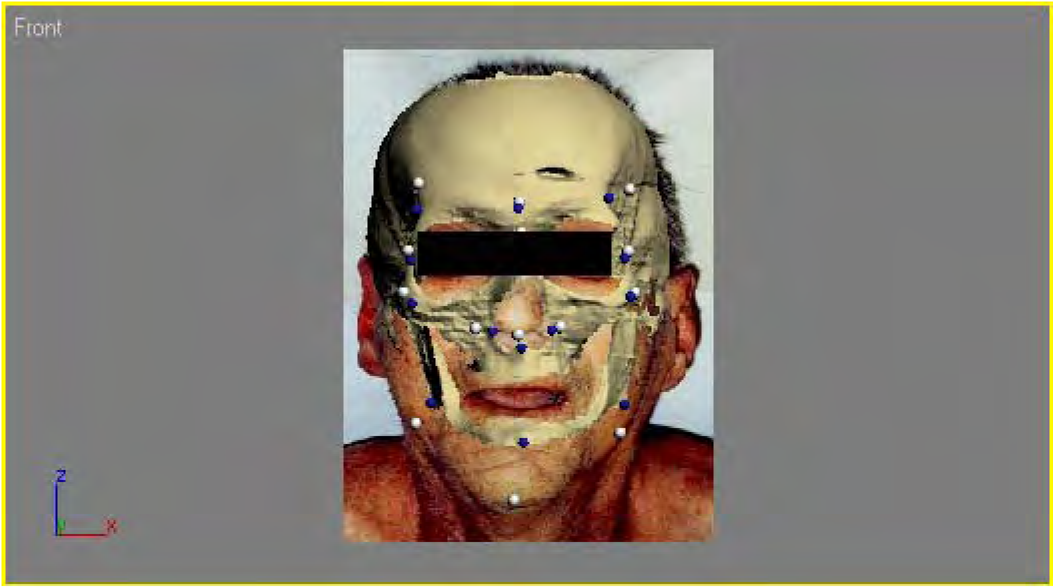


6391 skull j match



6391 skull j dot match

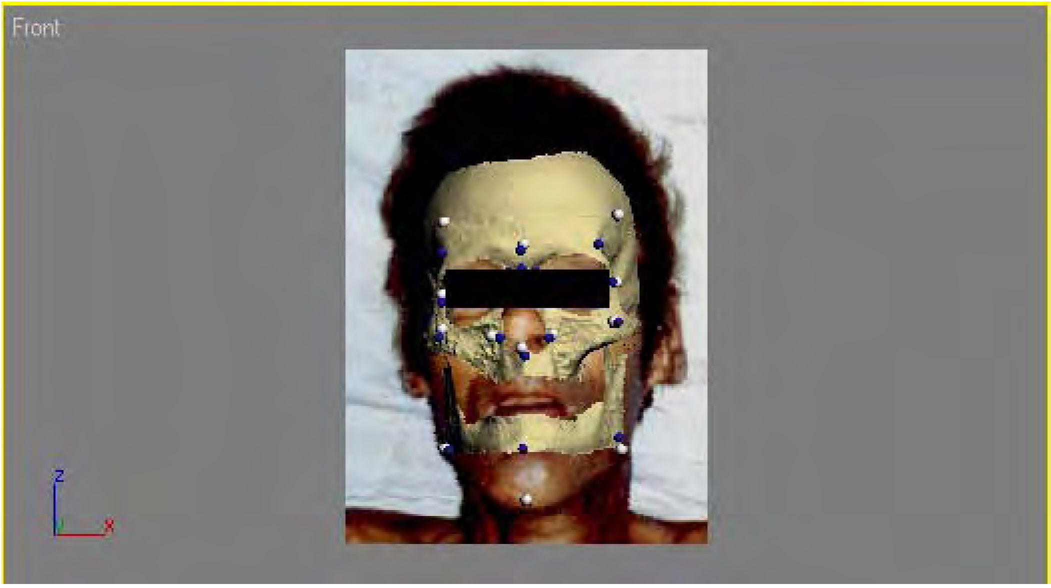
The correct skull was matched to the photograph.



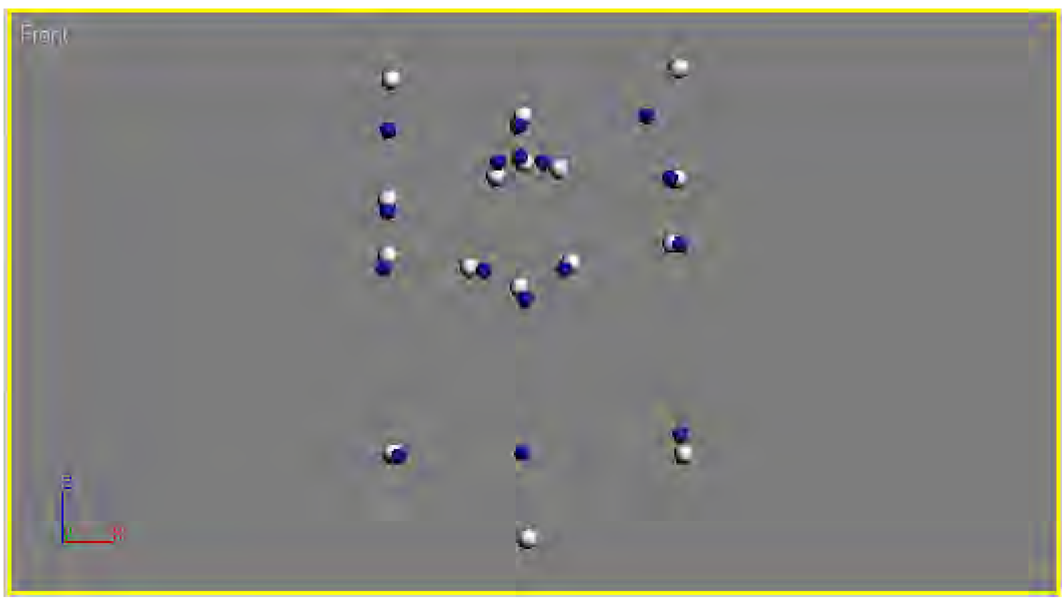
<u>6207 skull a match</u>

<u>6207 skull a dot match</u>

The correct skull was not matched to the photograph.

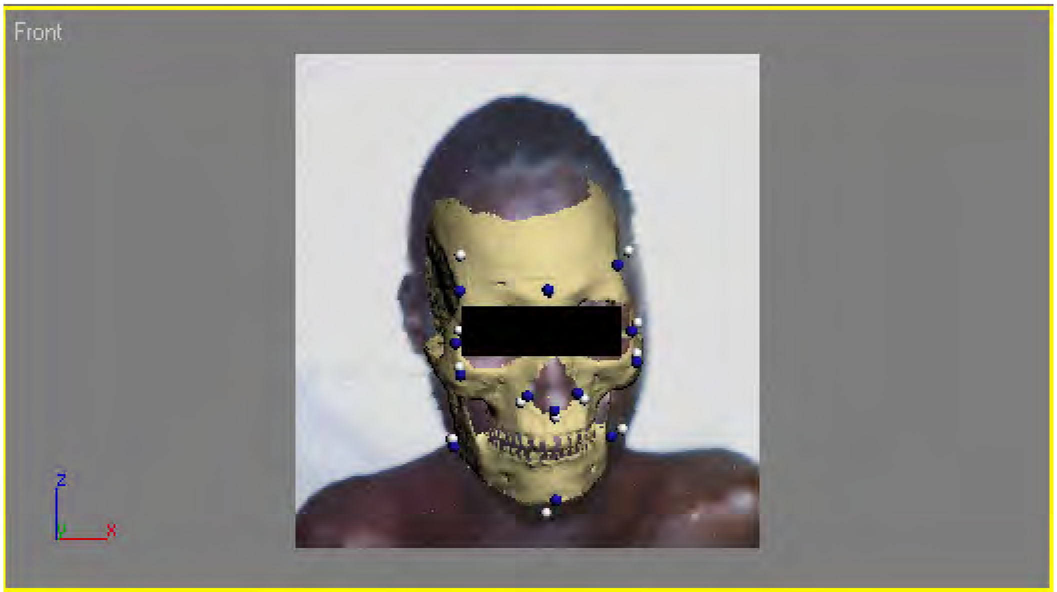


<u>6269 skull a match</u>

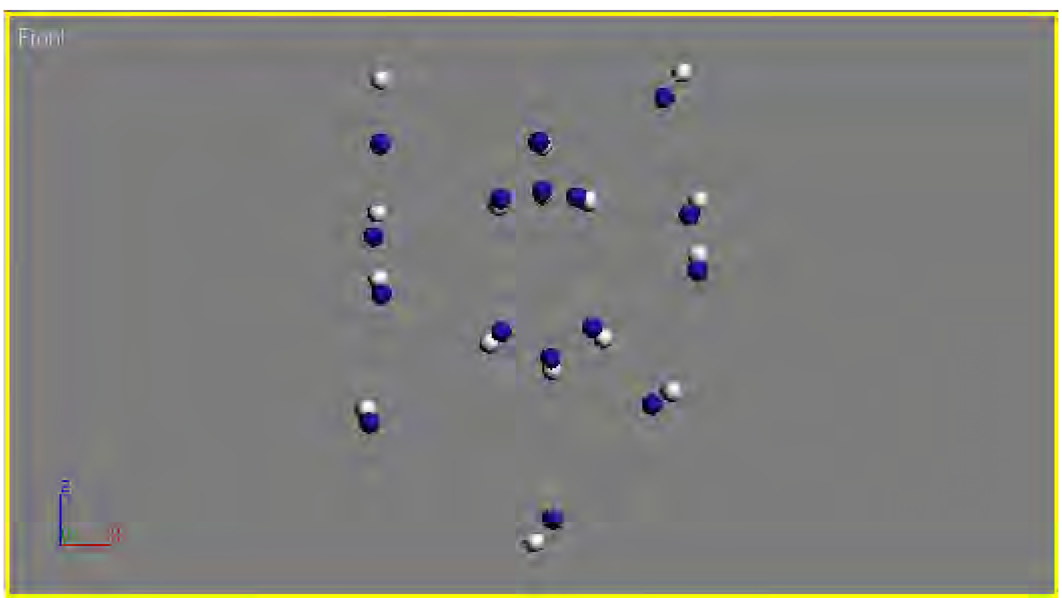


<u>6269 skull a dot match</u>

The correct skull was matched to the photograph.

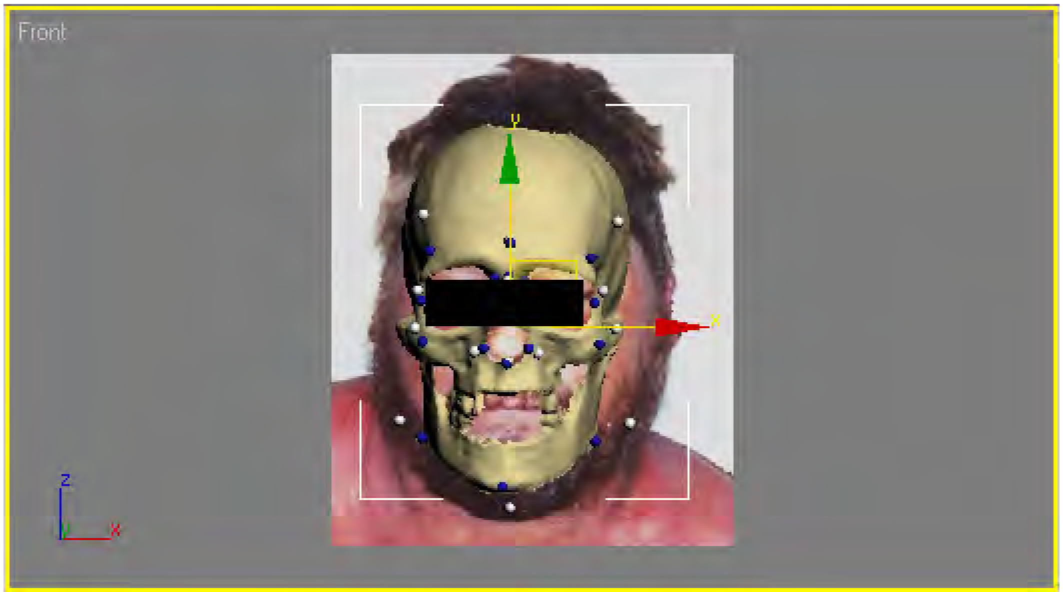


6218 skull g match



6218 skull g dot match

The correct skull was matched to the photograph.

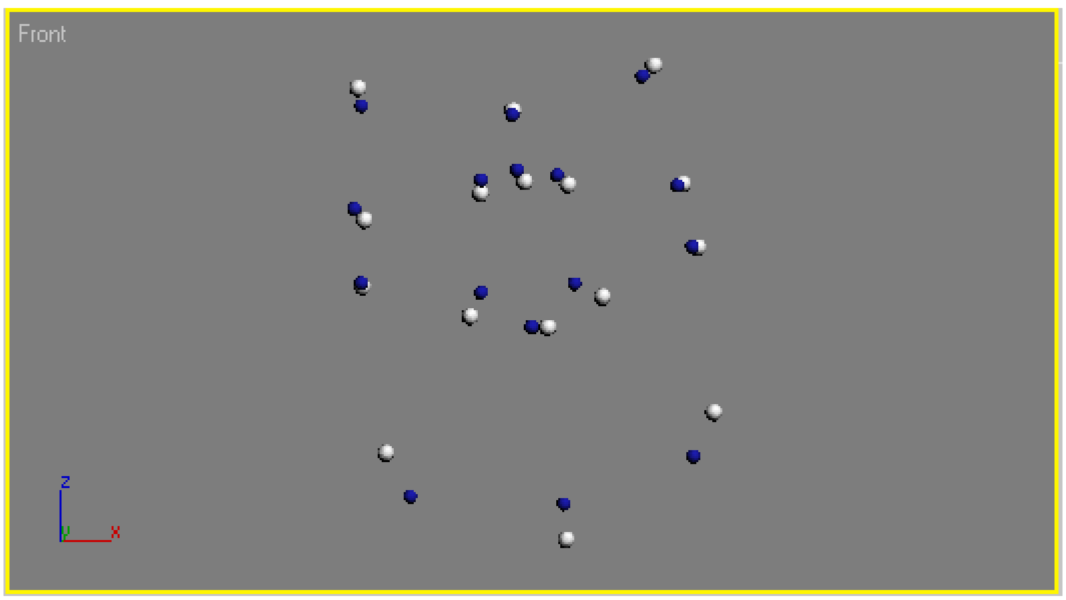


6248 skull c match

6248 skull c dot match

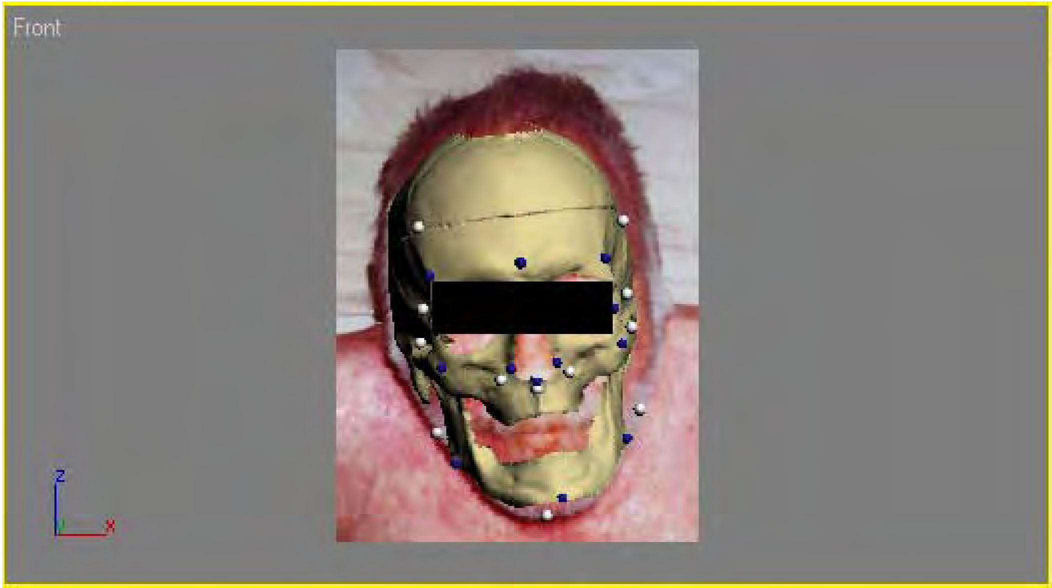
The correct skull was not matched to the photograph.

6317 skull f match



6317 skull f dot match

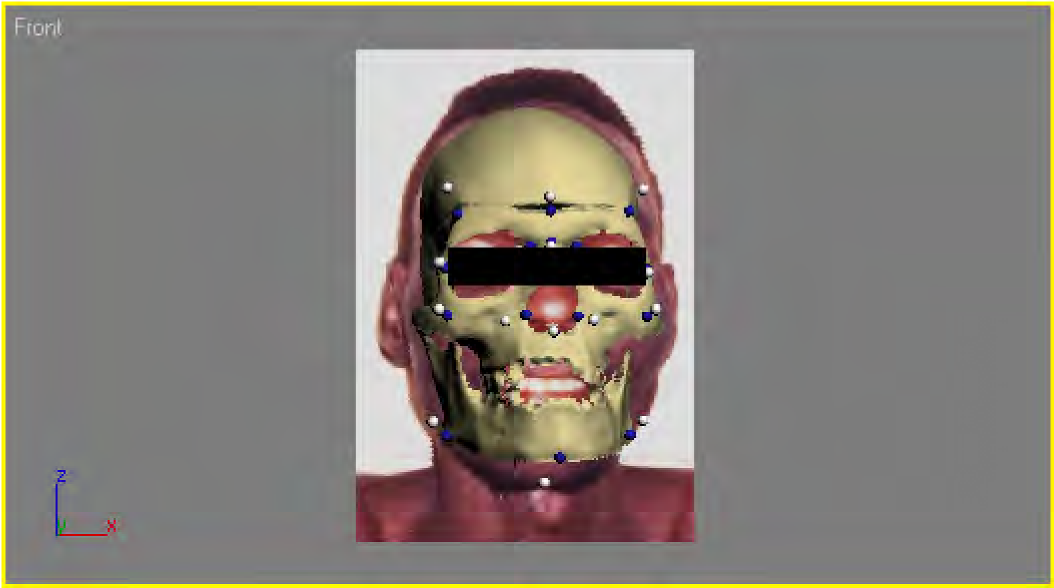
The correct skull was matched to the photograph.



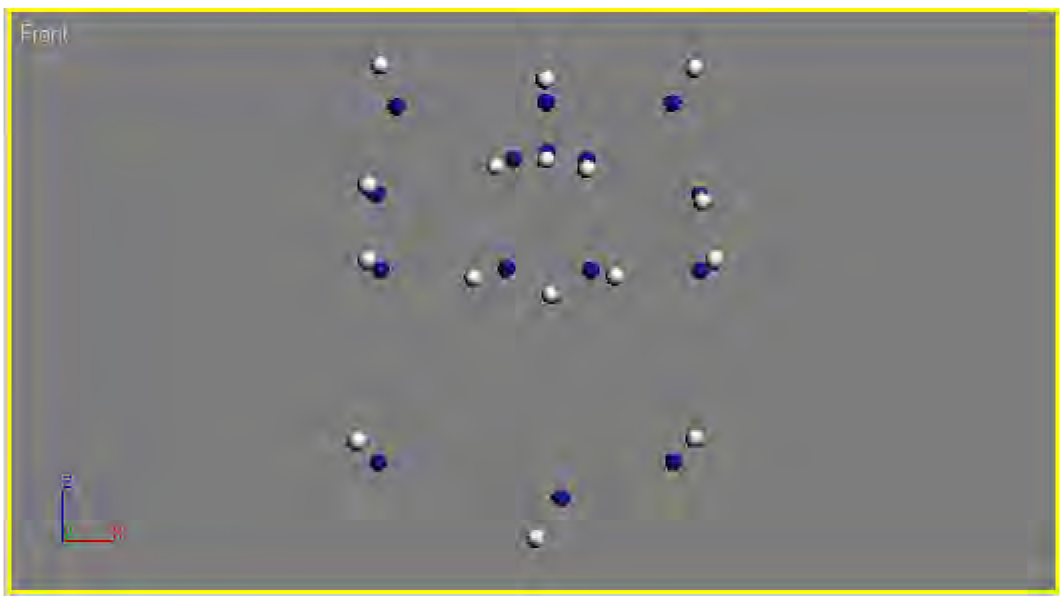
<u>6327 skull c match</u>

<u>6327 skull c dot match</u>

The correct skull was not matched to the photograph.

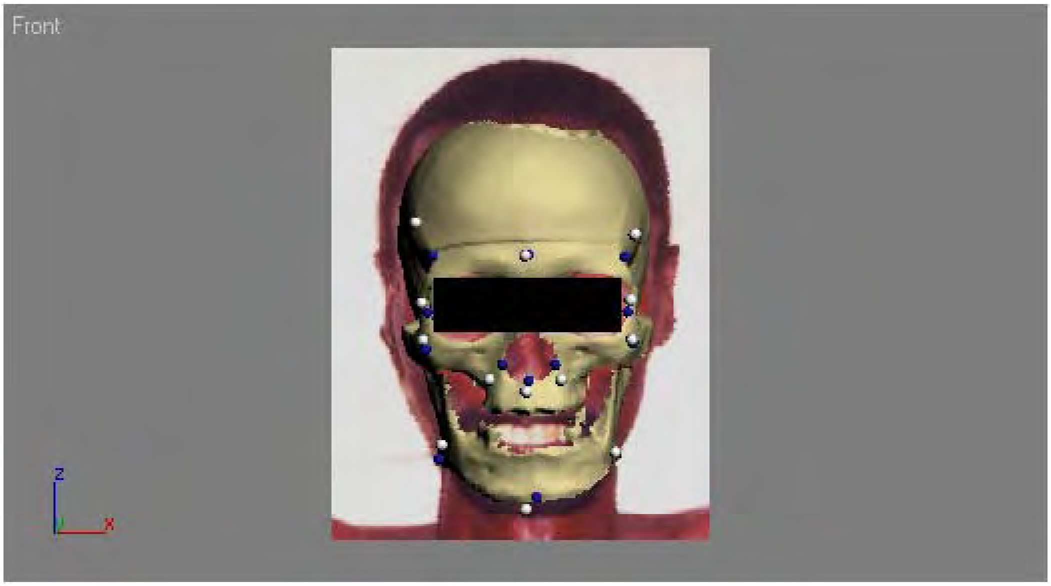


6371 skull b match

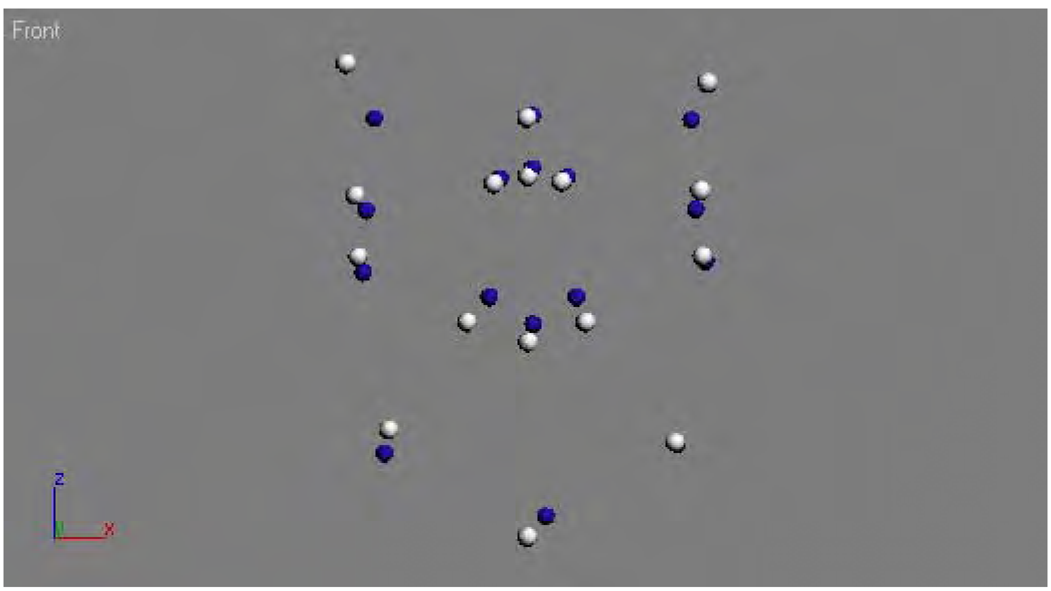


6371 skull b dot match

The correct skull was matched to the photograph.

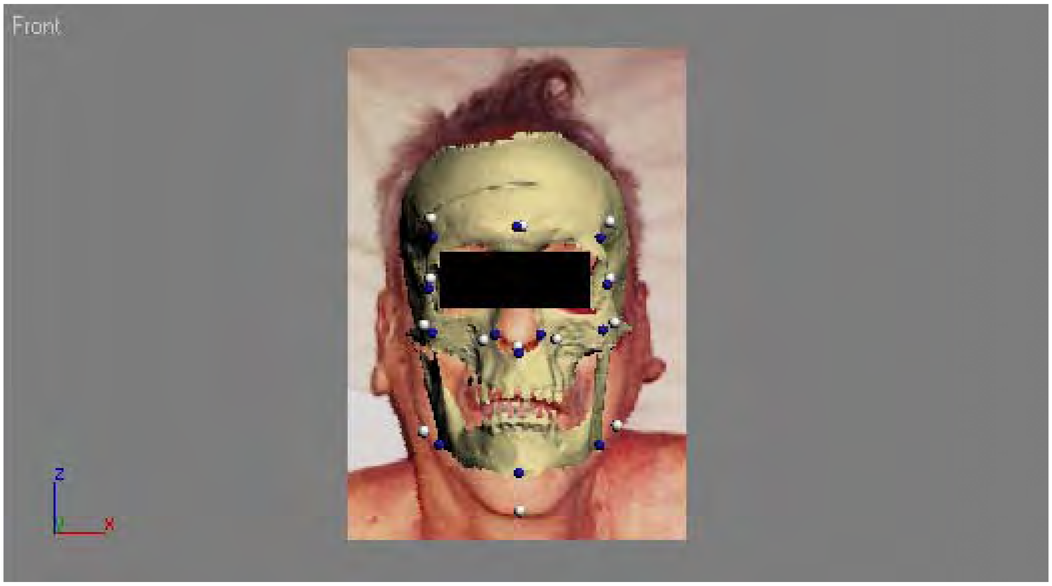


6376 skull g match

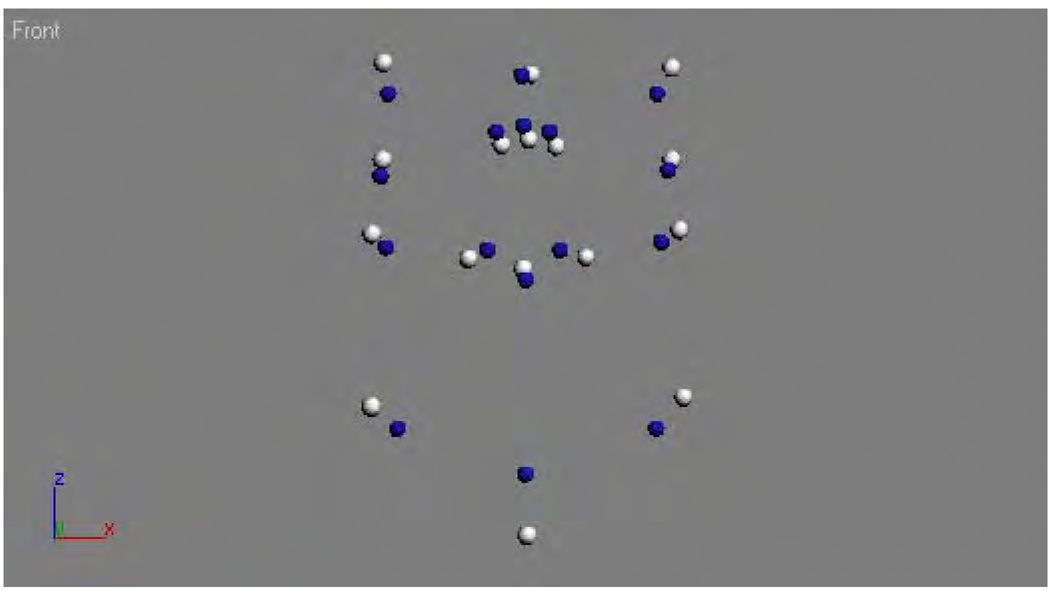


6376 skull g dot match

The correct skull was matched to the photograph

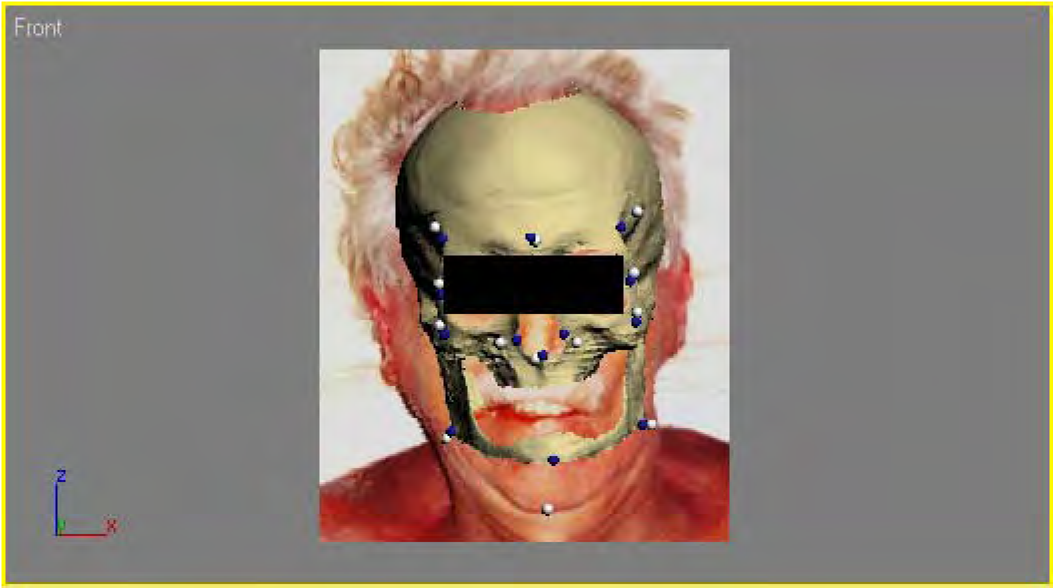


6381 skull d match

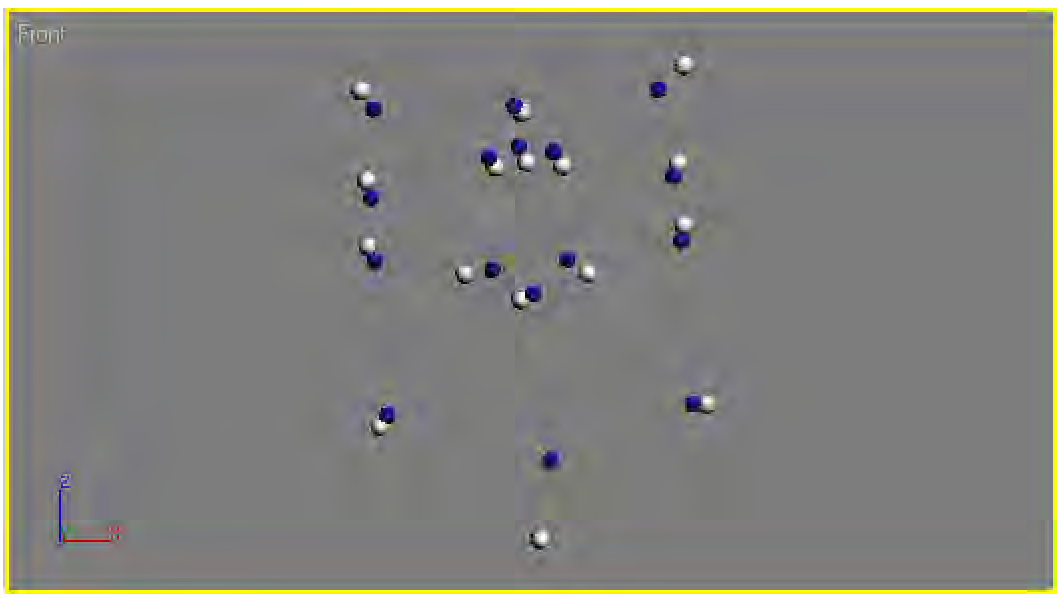


6381 skull d dot match

The correct skull was matched to the photograph.

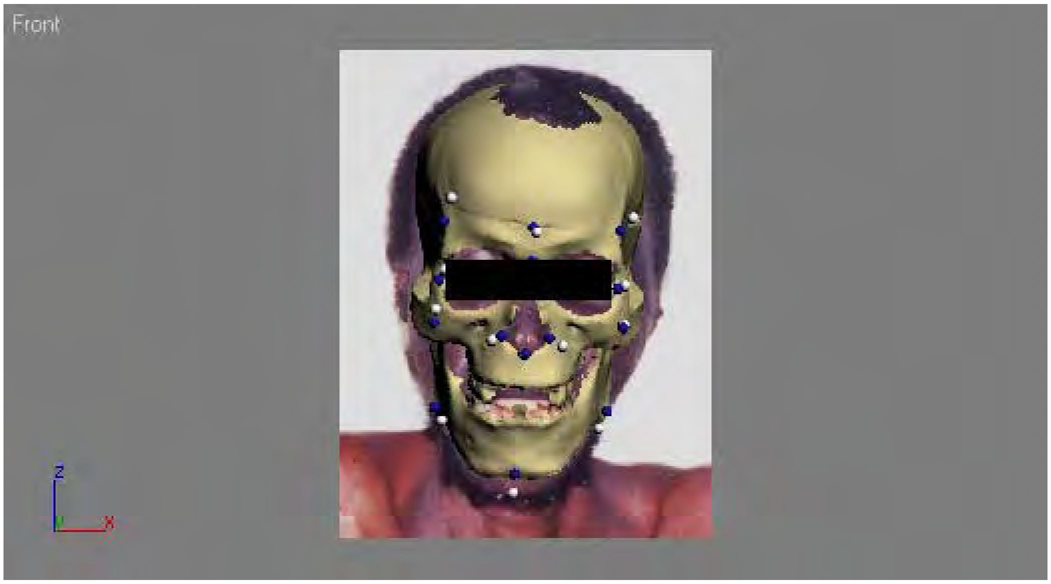


<u>6385 skull f match</u>

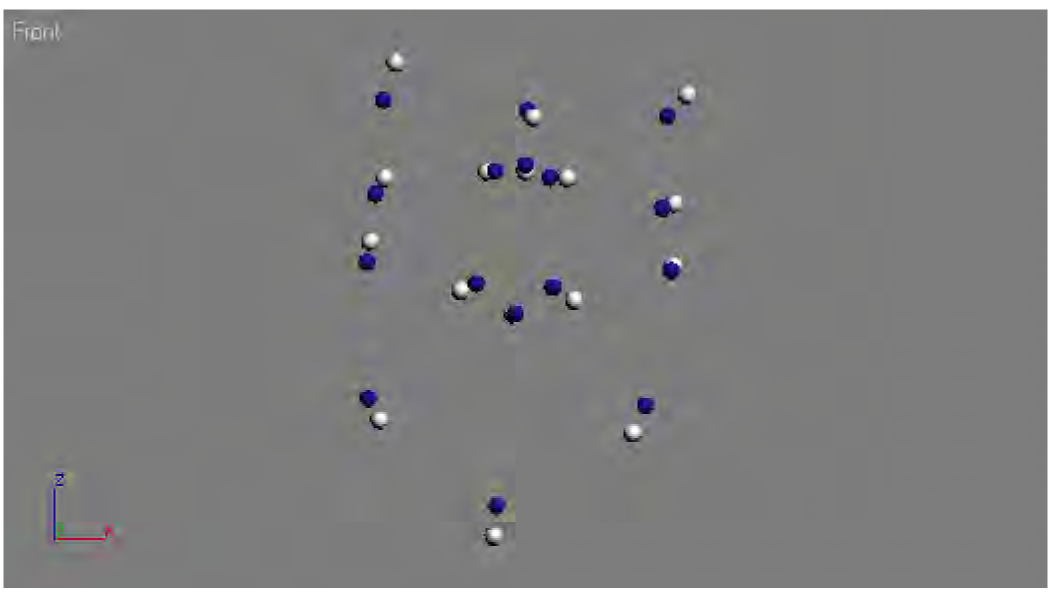


<u>6385 skull f dot match</u>

The correct skull was matched to the photograph.

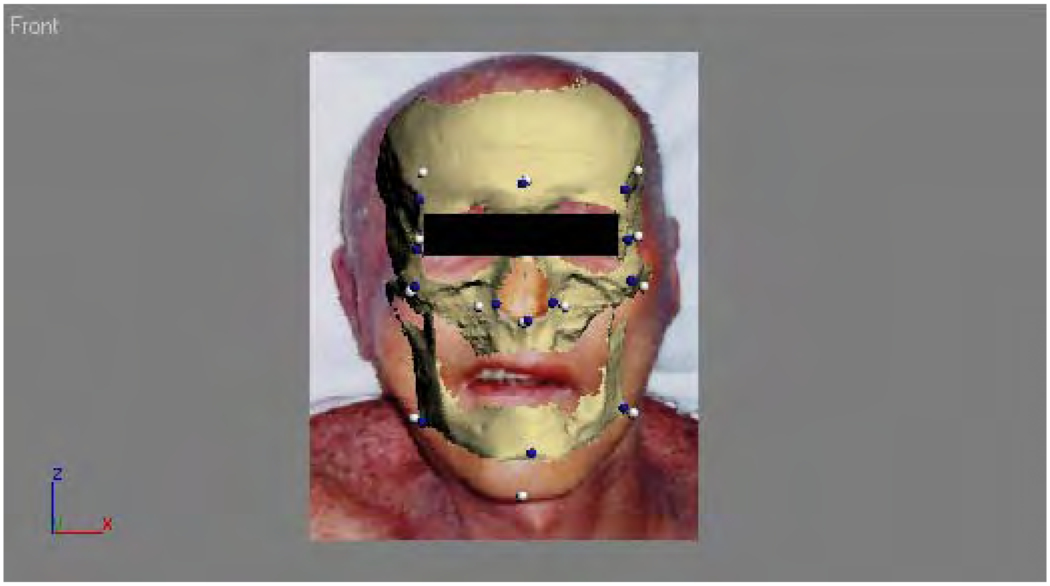


<u>6299 skull a match</u>

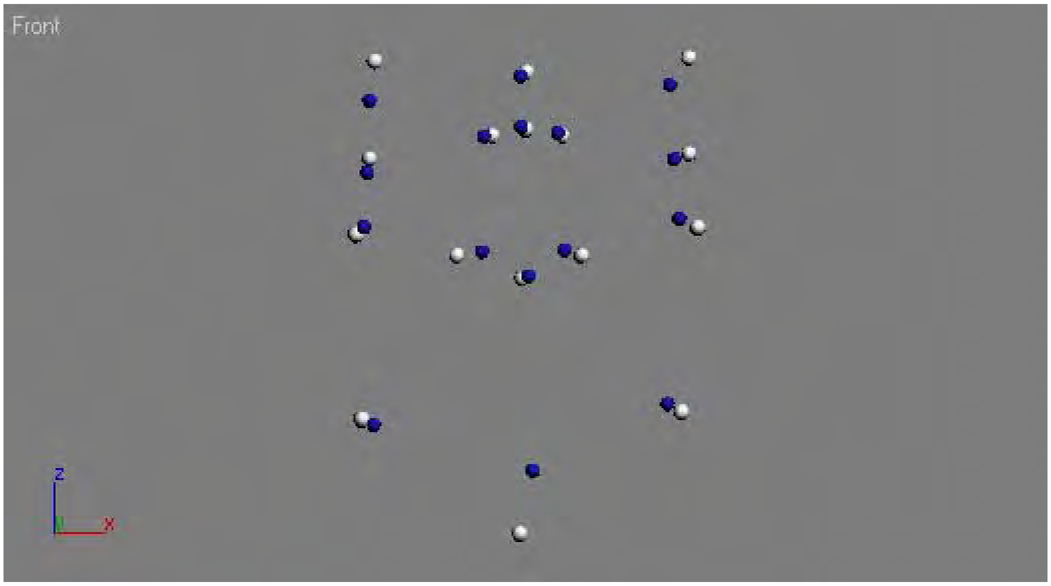


<u>6299 skull a dot match</u>

The correct skull was matched to the photograph.

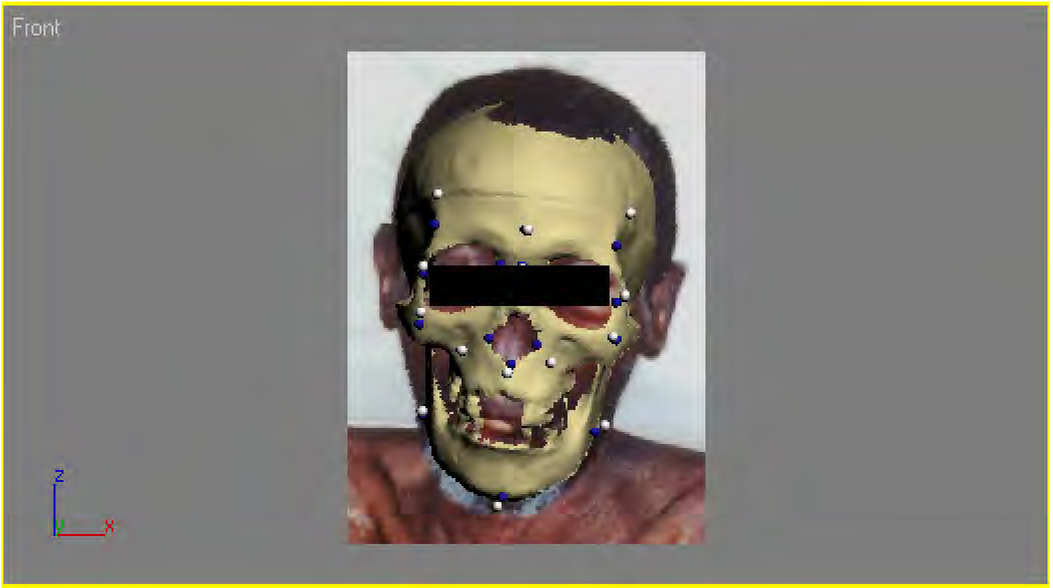


6283 skull a match



6283 skull a dot match

The correct skull was matched to the photograph.

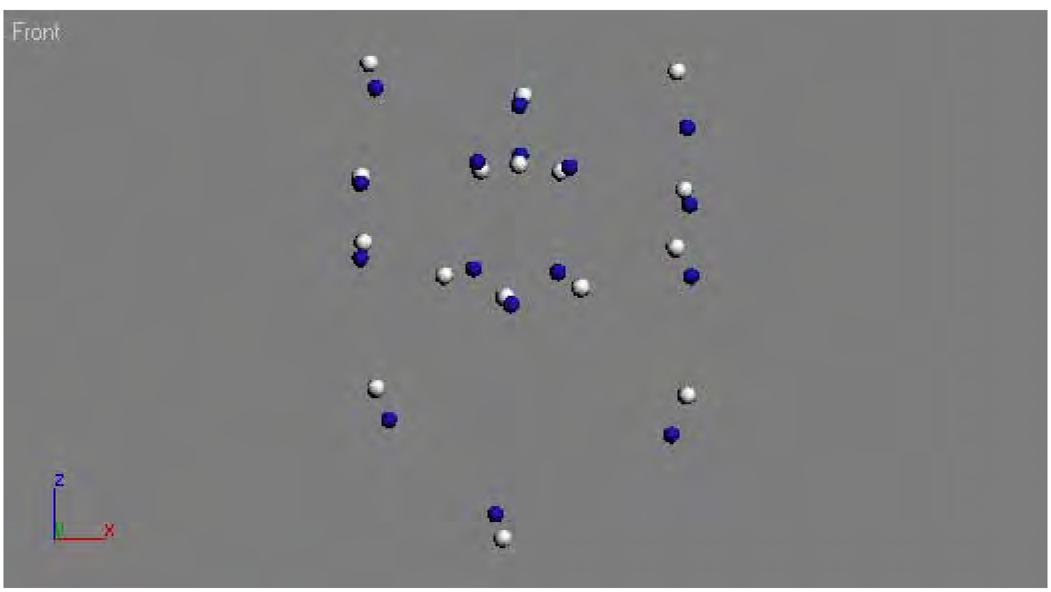


6242 skull g match

6242 skull g dot match

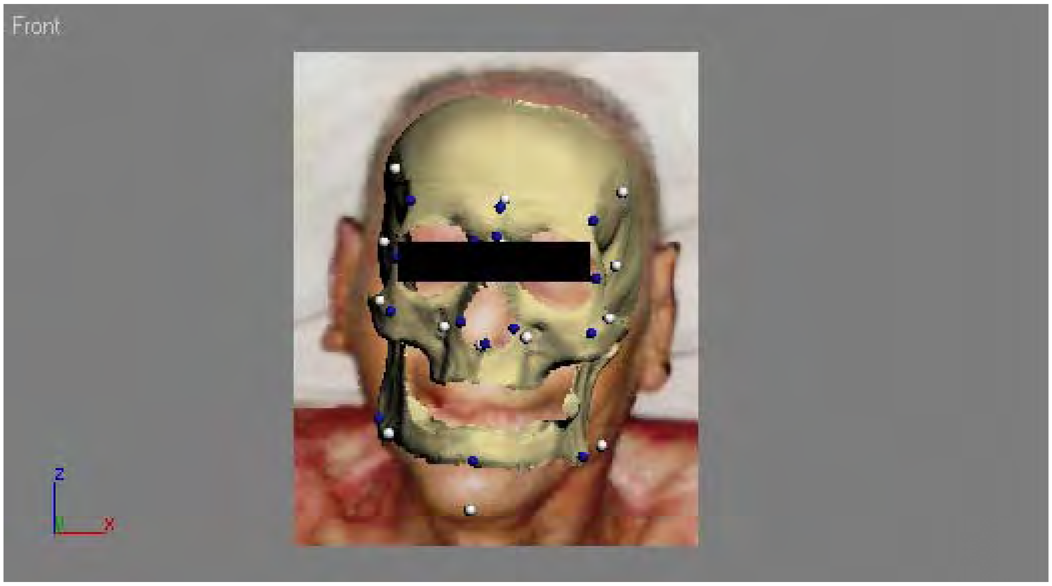
The correct skull was matched to the photograph.

<u>6210 skull i match</u>

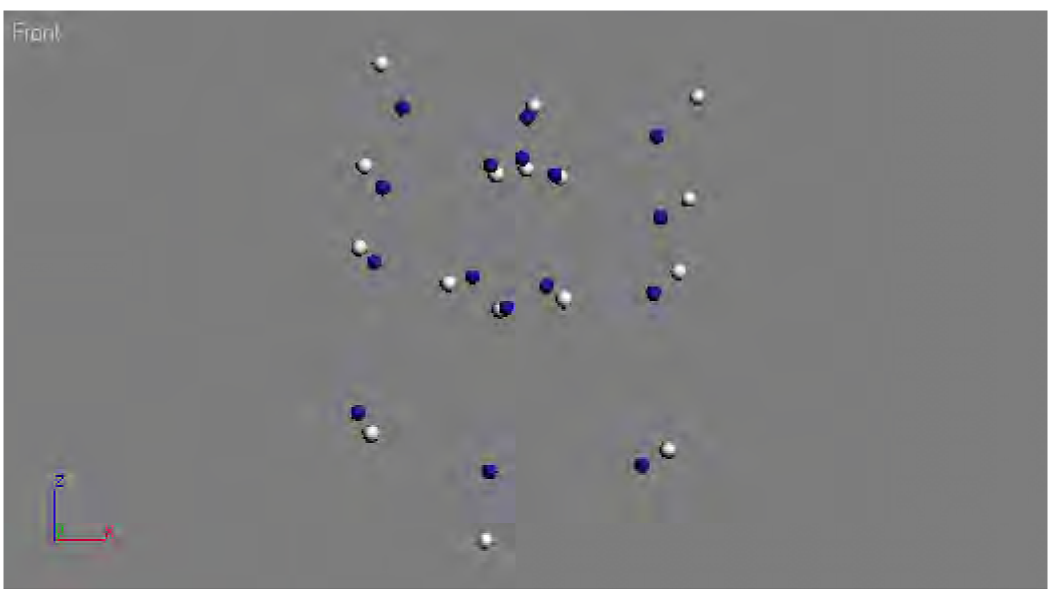


<u>6210 skull i dot match</u>

The correct skull was matched to the photograph.

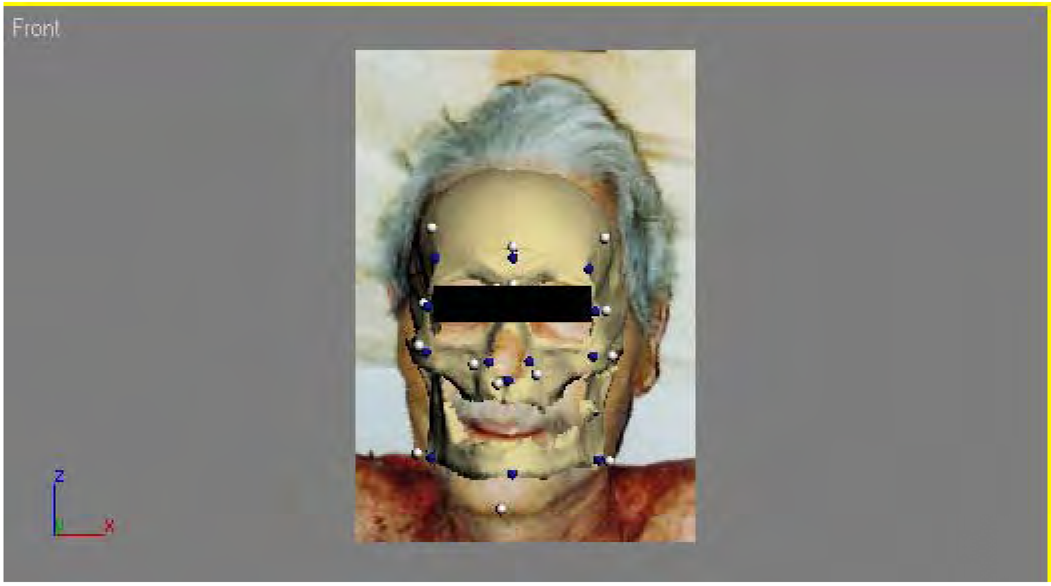


<u>6230 skull g match</u>



<u>6230 skull g dot match</u>

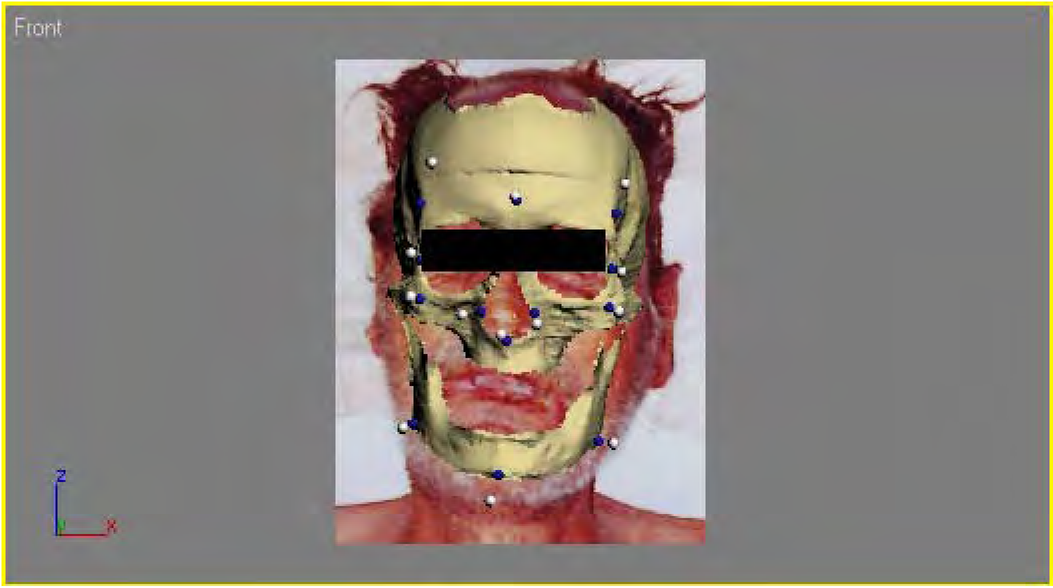
The correct skull was not matched to the photograph.



6253 skull h match

6253 skull h dot match

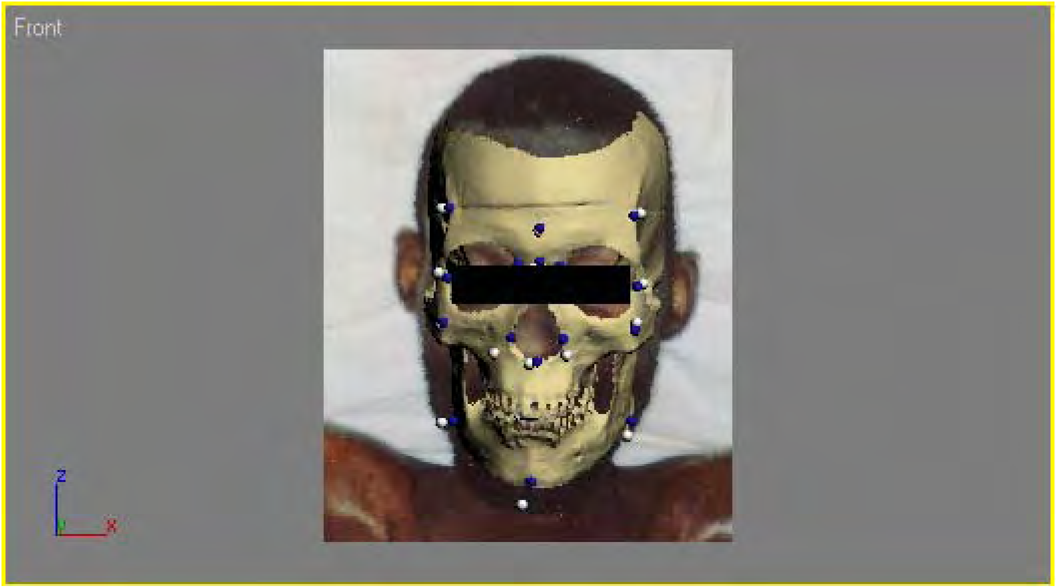
The correct skull was matched to the photograph.



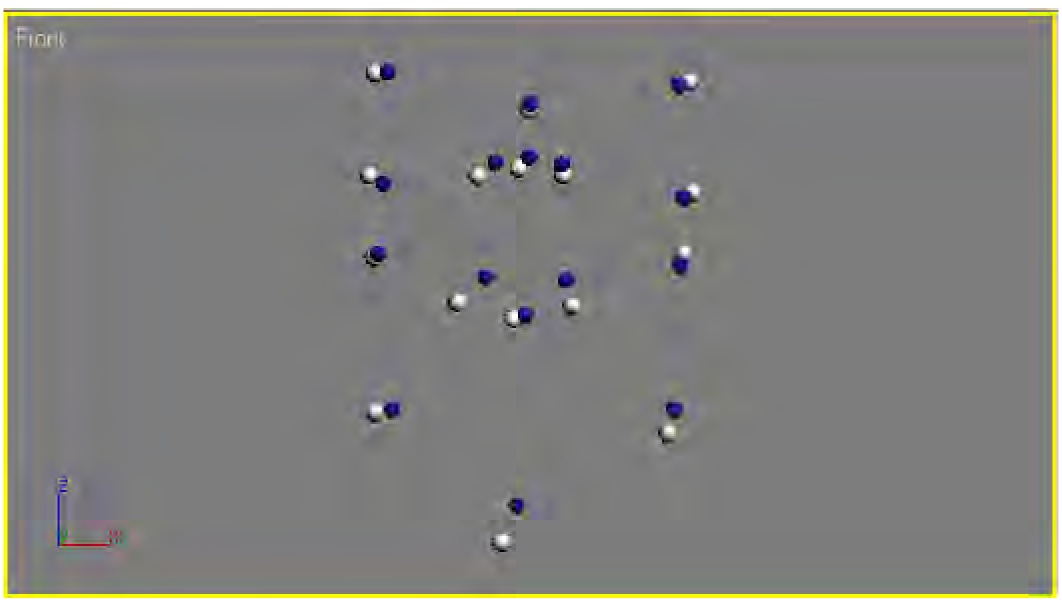
6316 skull c match

6316 skull c dot match

The correct skull was matched to the photograph.



6220 skull e match

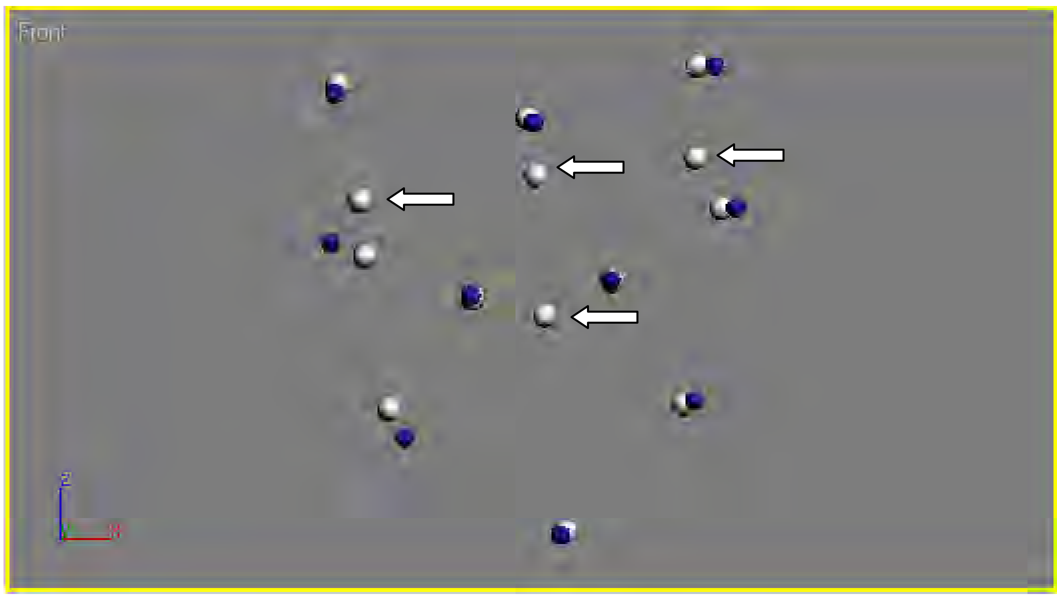


6220 skull e dot match

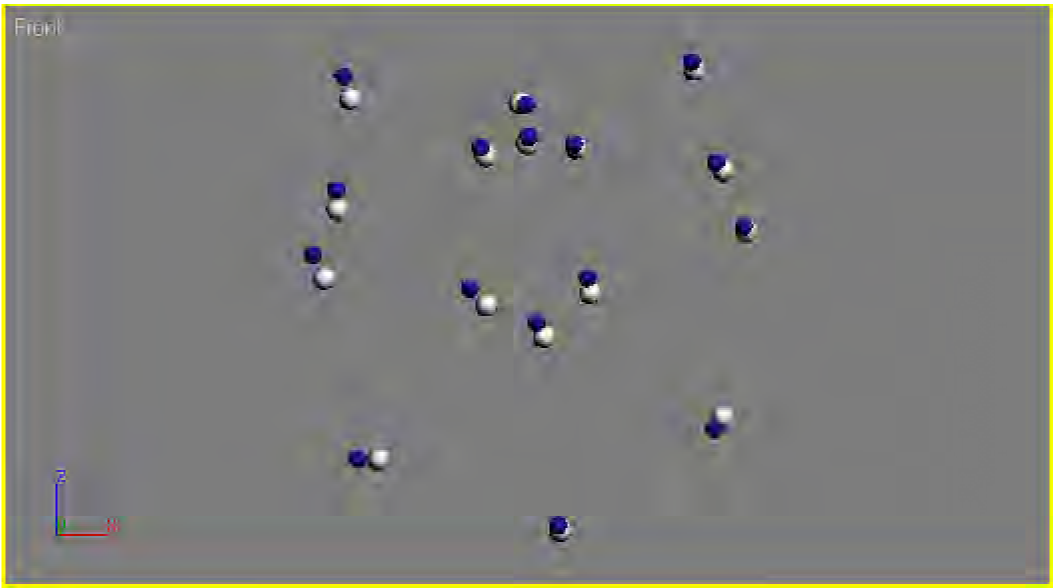
The correct skull was matched to the photograph.

Appendix C: Repeatability Study Results

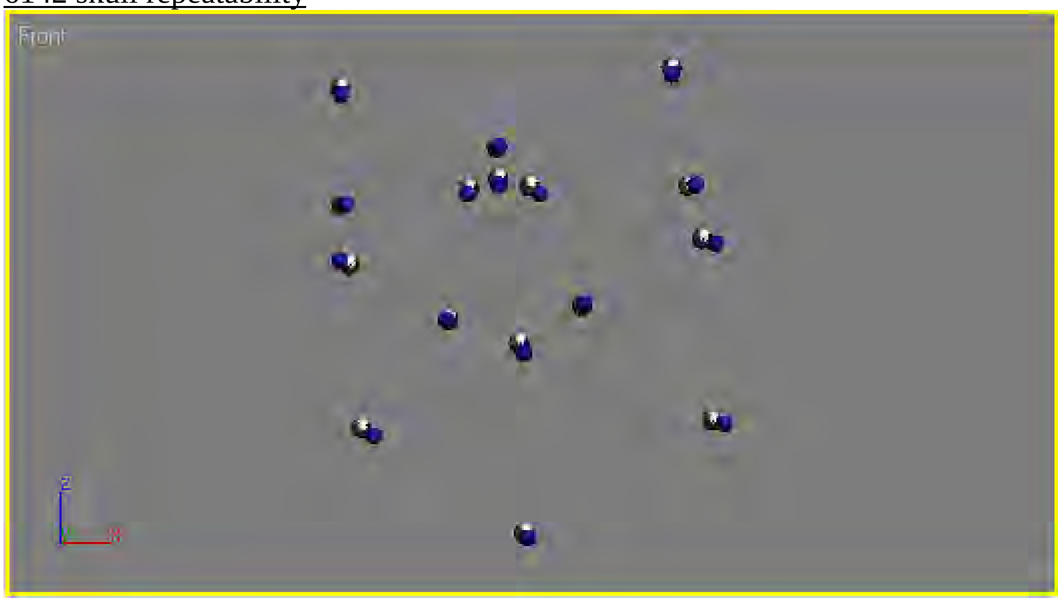
The blue dots indicate the initial landmarks and the white dots indicate the repeated landmarks and this therefore shows the repeatability of placing the landmarks with some time having passed between the initially and repeated landmarks.



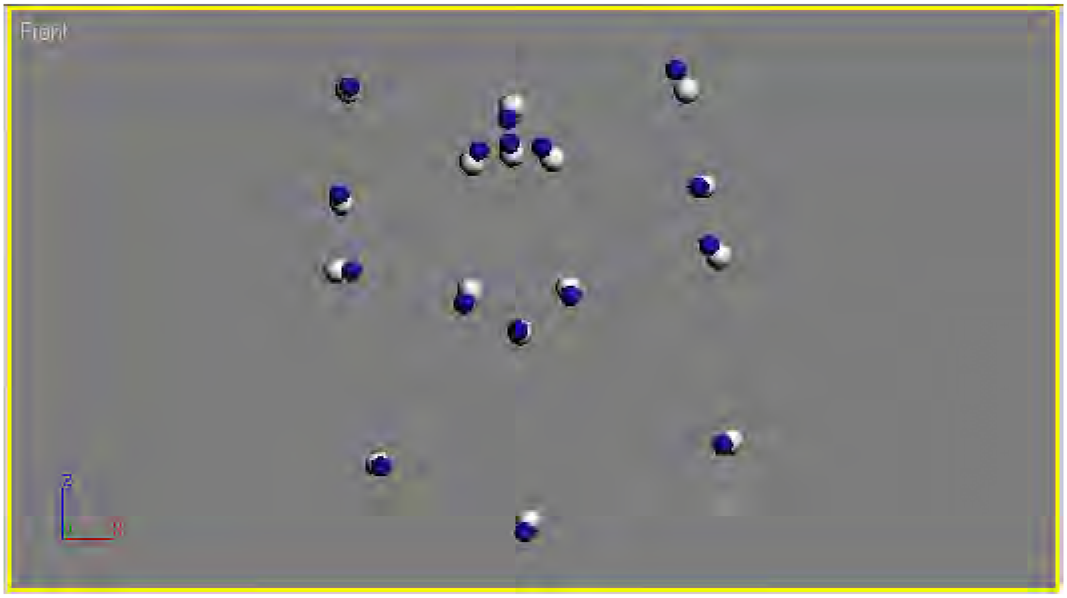
6142 photograph repeatability
These arrows above show where the landmarks have completely overlapped, therefore, only one is visible.



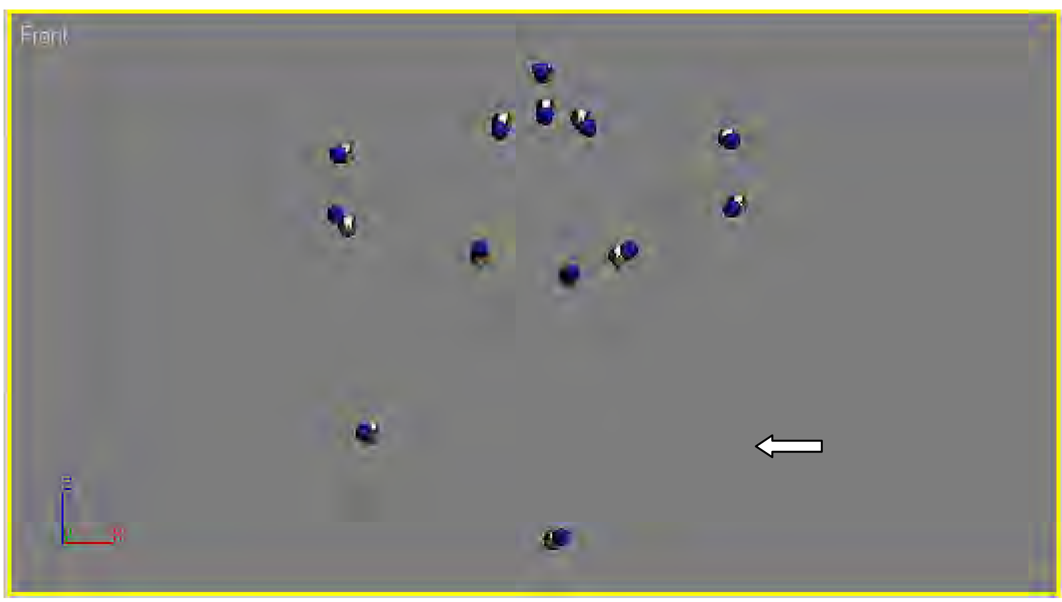
6142 skull repeatability



6219 photograph repeatability

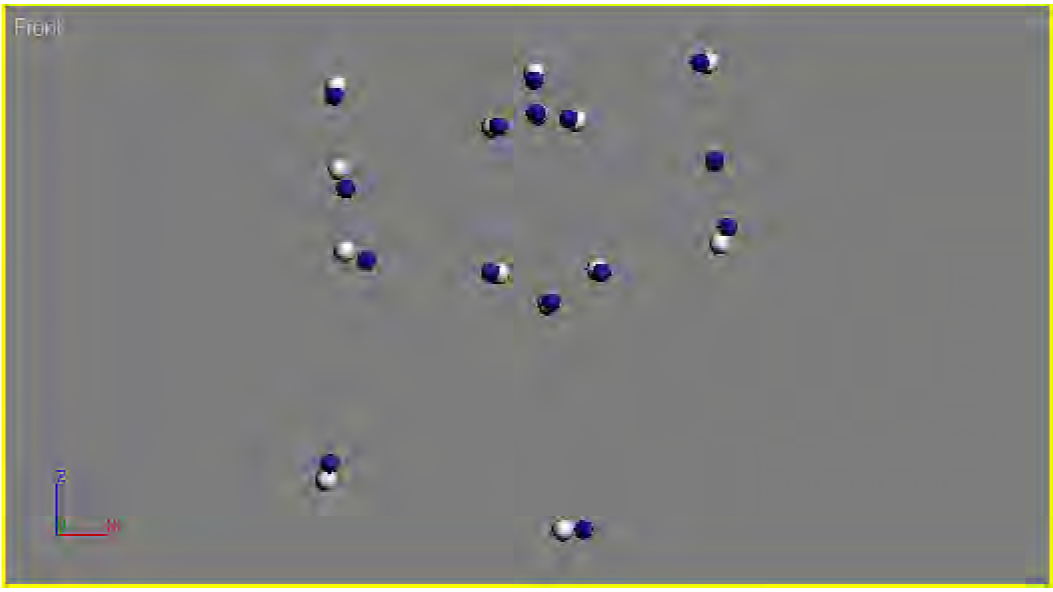


6219 skull repeatability

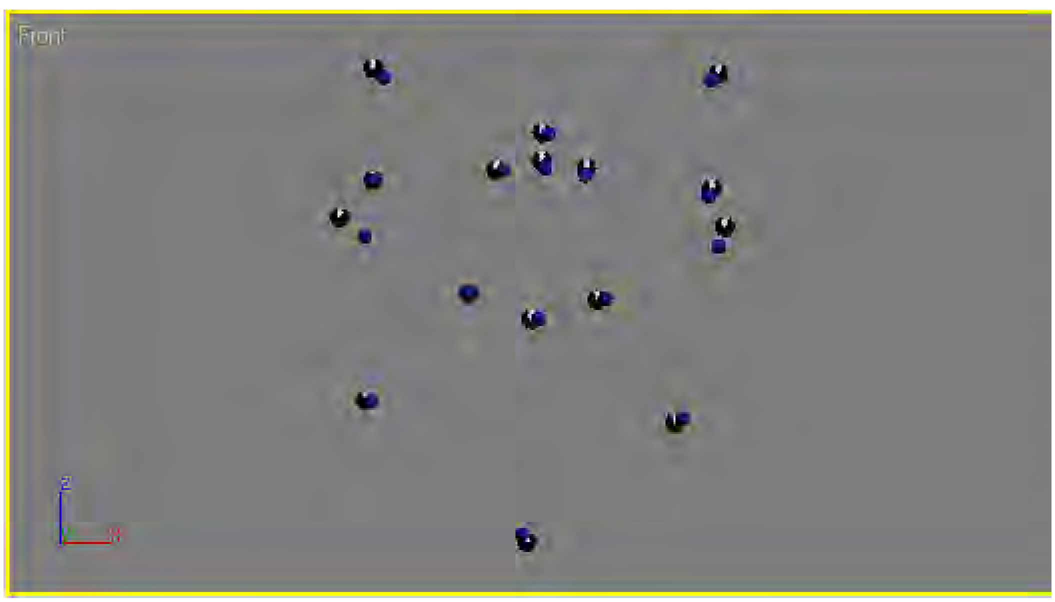


6228 photograph repeatability

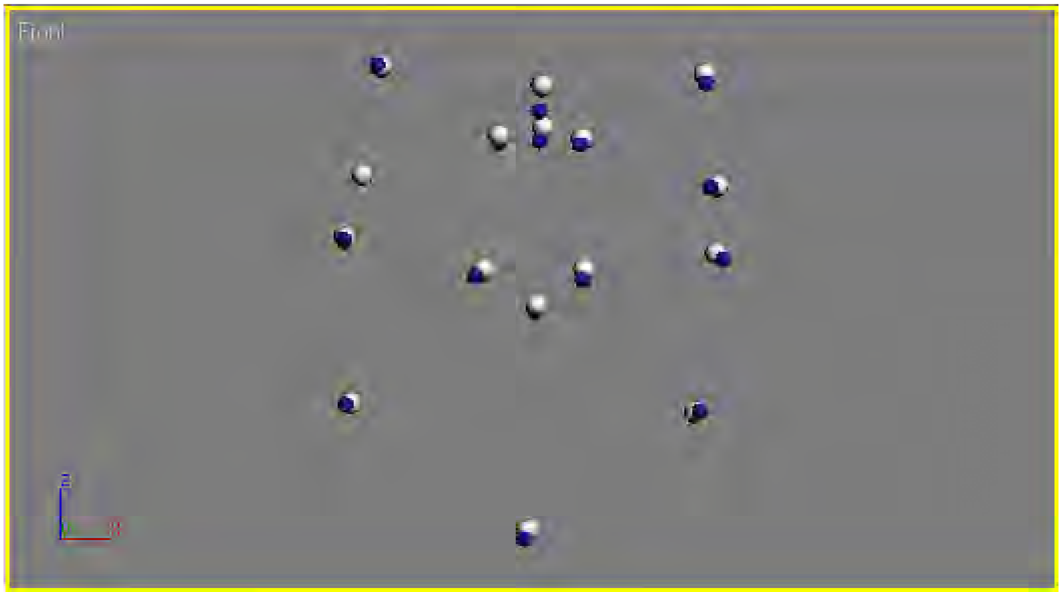
The arrow above illustrates where a landmark was not used due to the angle of the face in the photograph. This landmark could not be viewed and was therefore not included to establish a match.



6228 skull repeatability

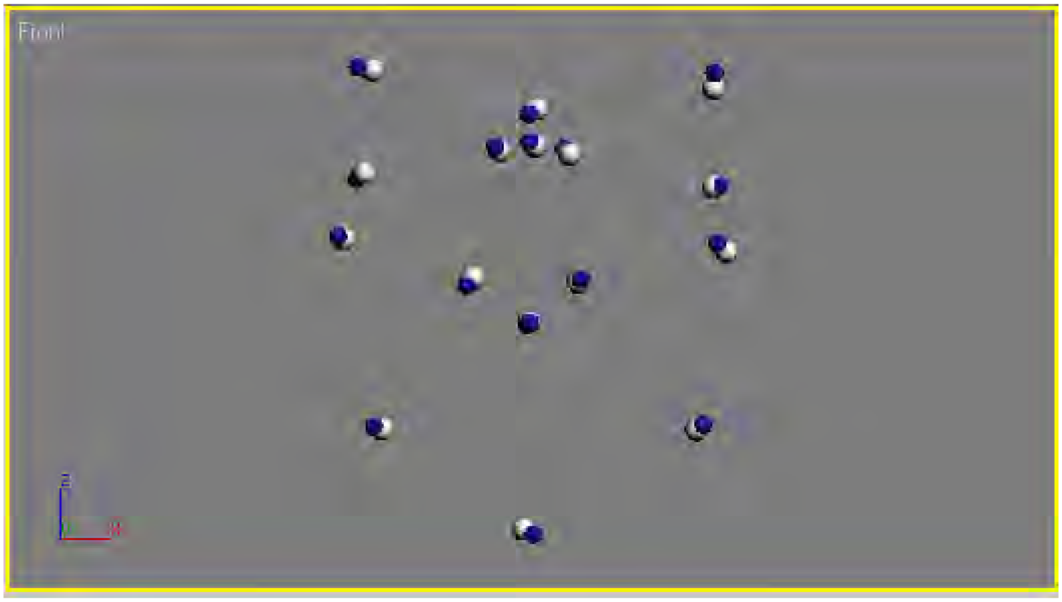


6231 photograph repeatability



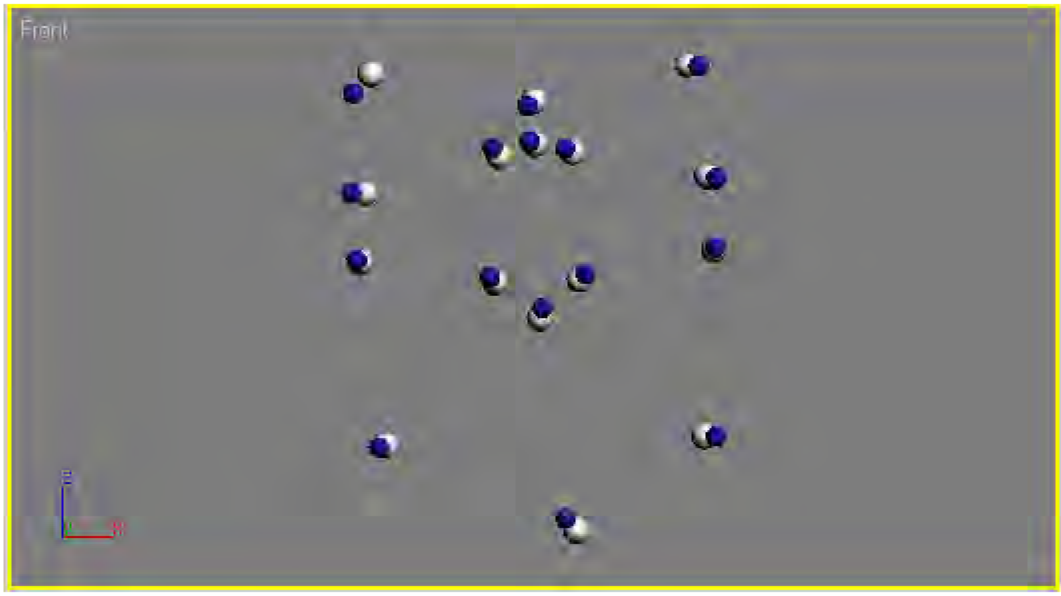
6231 skull repeatability

6235 photograph repeatability

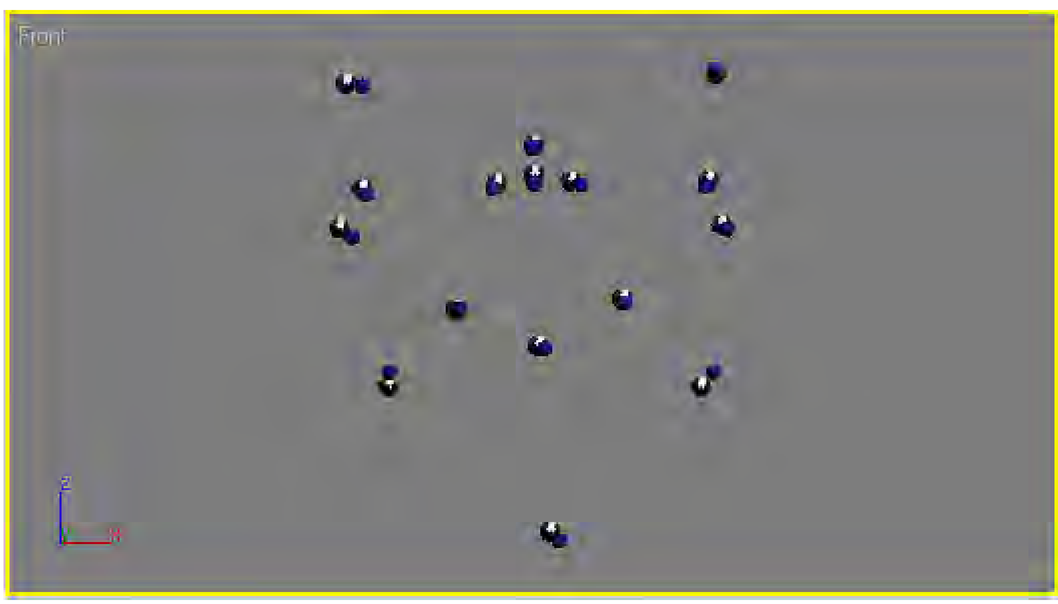


6235 skull repeatability

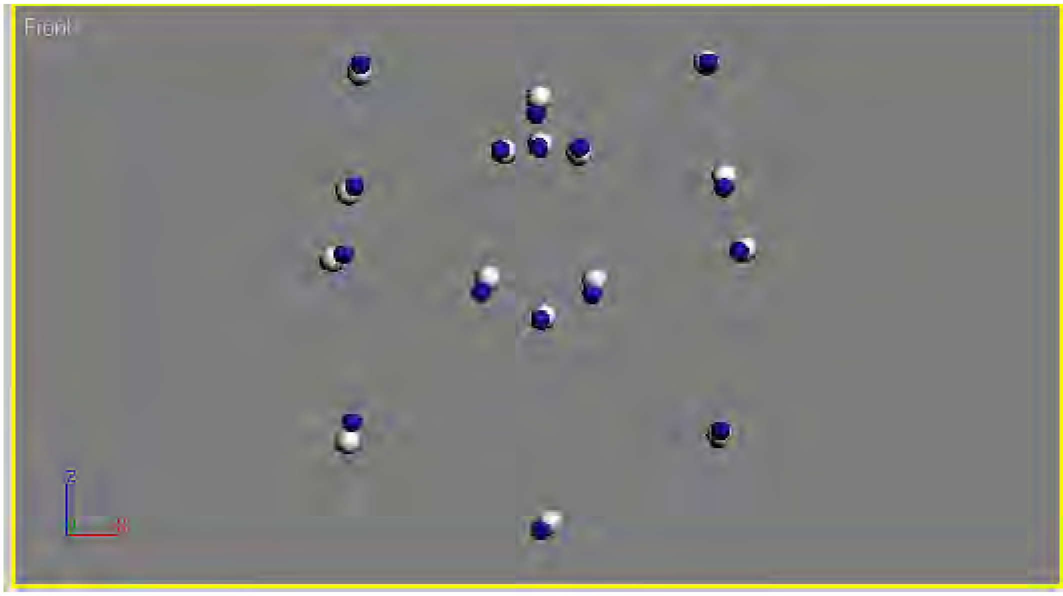
6264 photograph repeatability



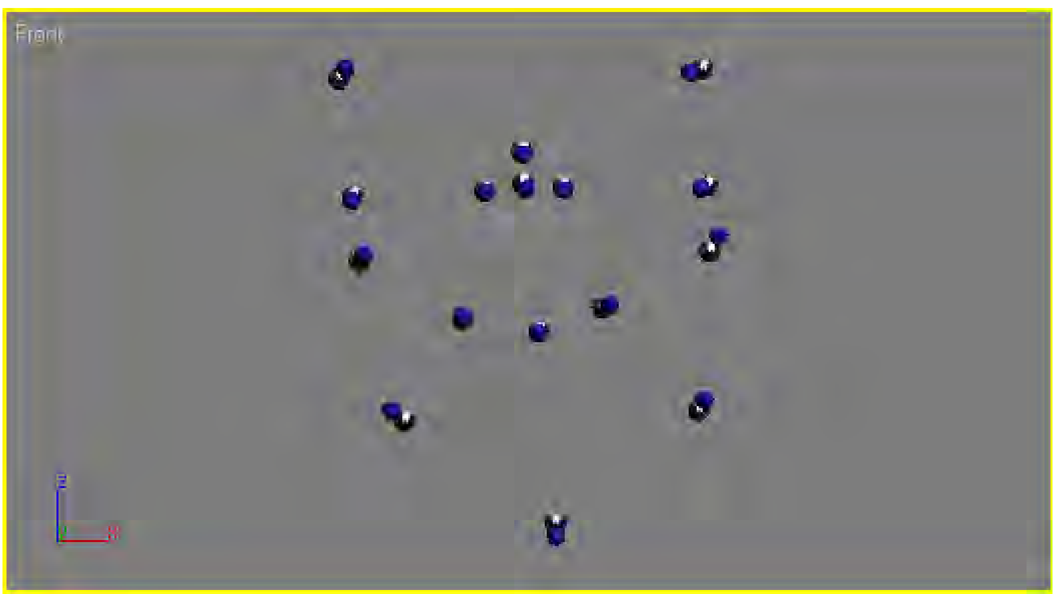
6264 skull repeatability



6280 photograph repeatability

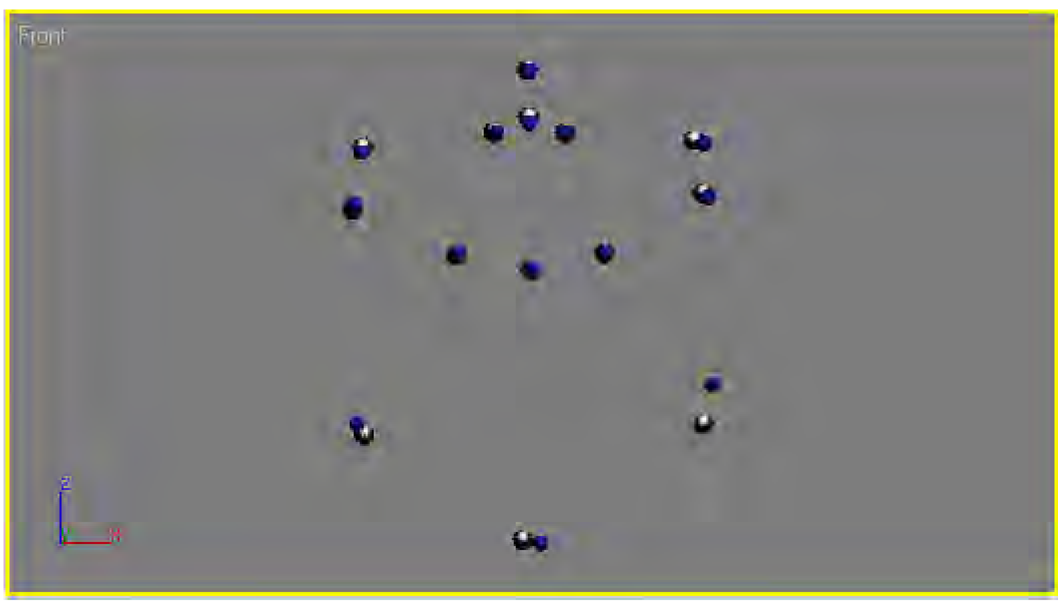


6280 skull repeatability

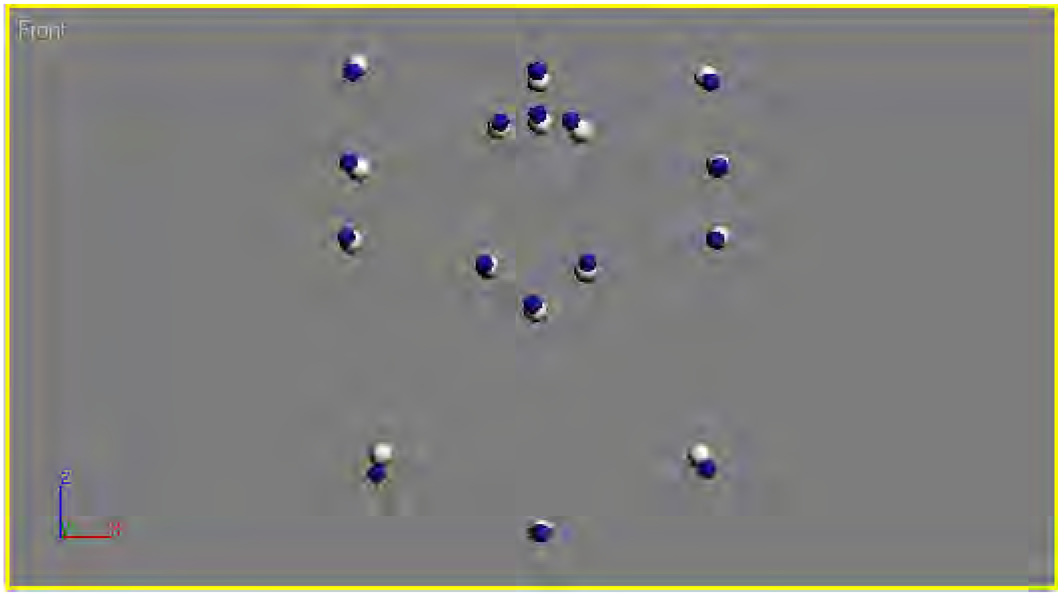


6281 photograph repeatability

6281 skull repeatability

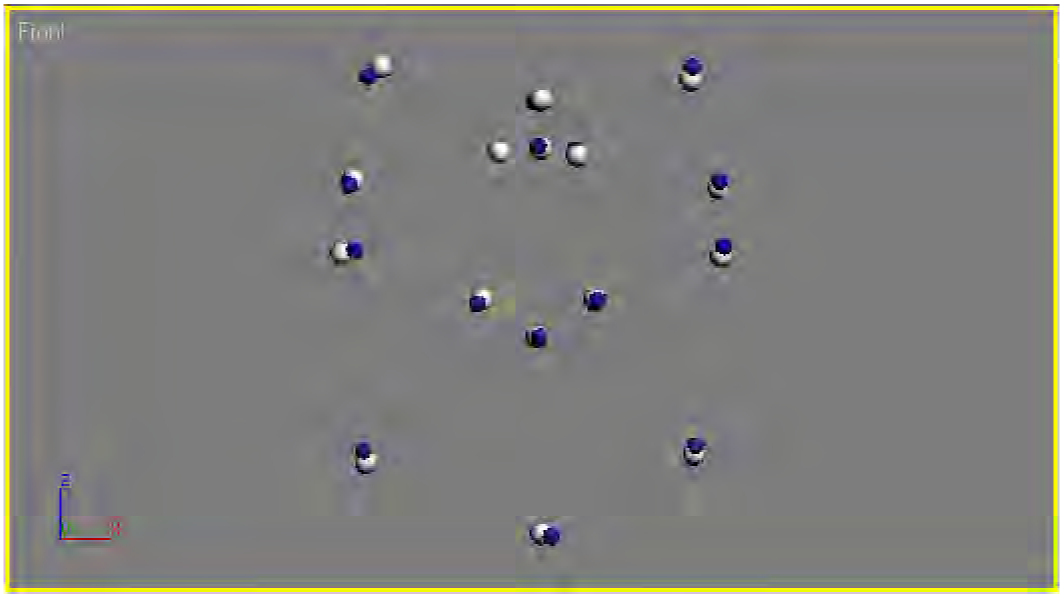


6306 photograph repeatability



6306 skull repeatability

6307 photograph repeatability



6307 skull repeatability