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.

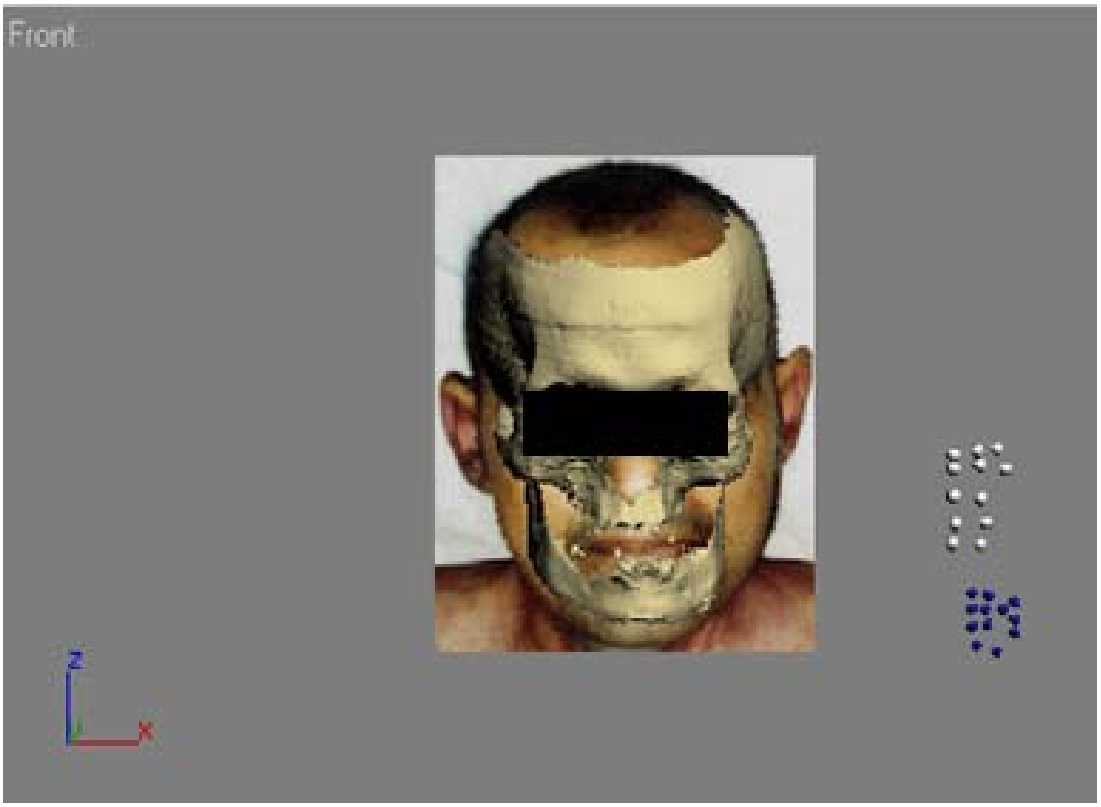

Figure 4.1. The morphological match of a photograph and skull. Note the contours of the skull fit within the face of the photograph, the eyes fit within the orbits, the nose fits over the nasal aperture and the contour of the mandible follows that of the jaw line in the photograph.

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).

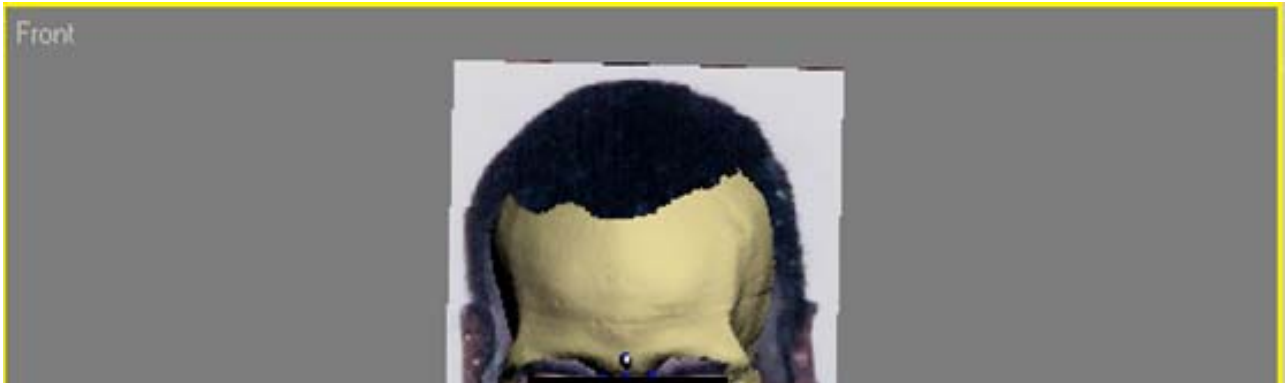

Figure 4.3. Group match. The match between photograph and skull using the landmarks- with the skull and photograph visible. The blue dots are the photograph landmarks and the white dots are the skull landmarks.

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.

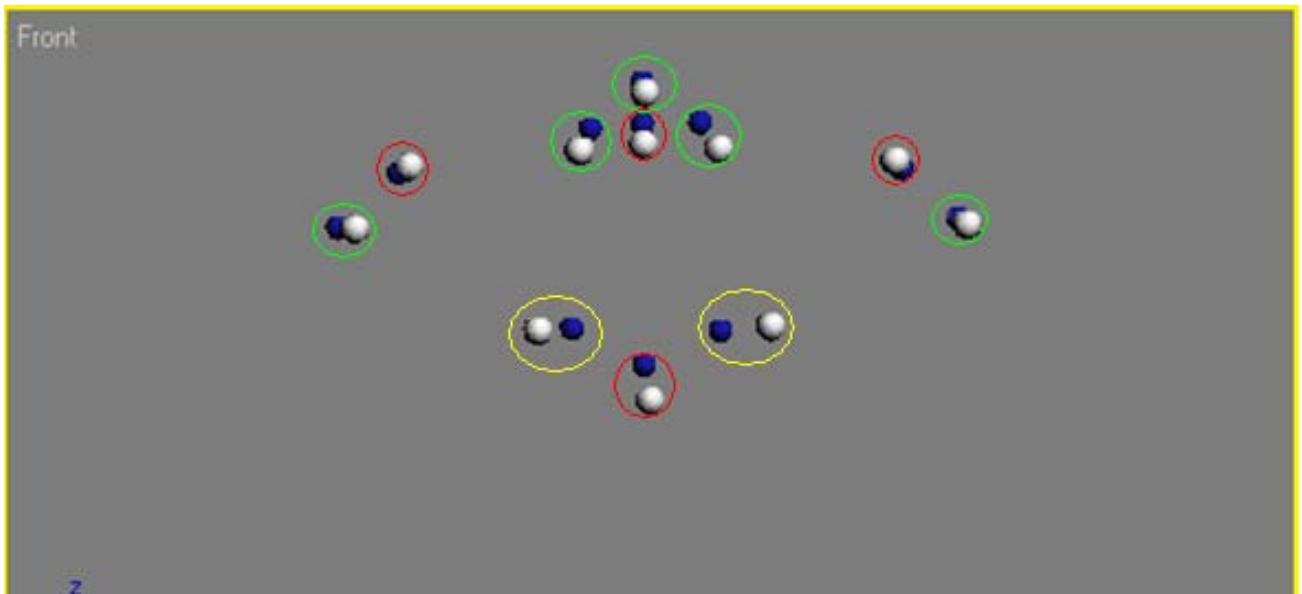

Figure 4.4. Dot match. The match between photograph and skull using the landmarks- with the skull and photograph not visible. The blue dots are the photograph landmarks and the white dots are the skull landmarks. The red circles indicate the orientation landmarks, the green circles indicate the primary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

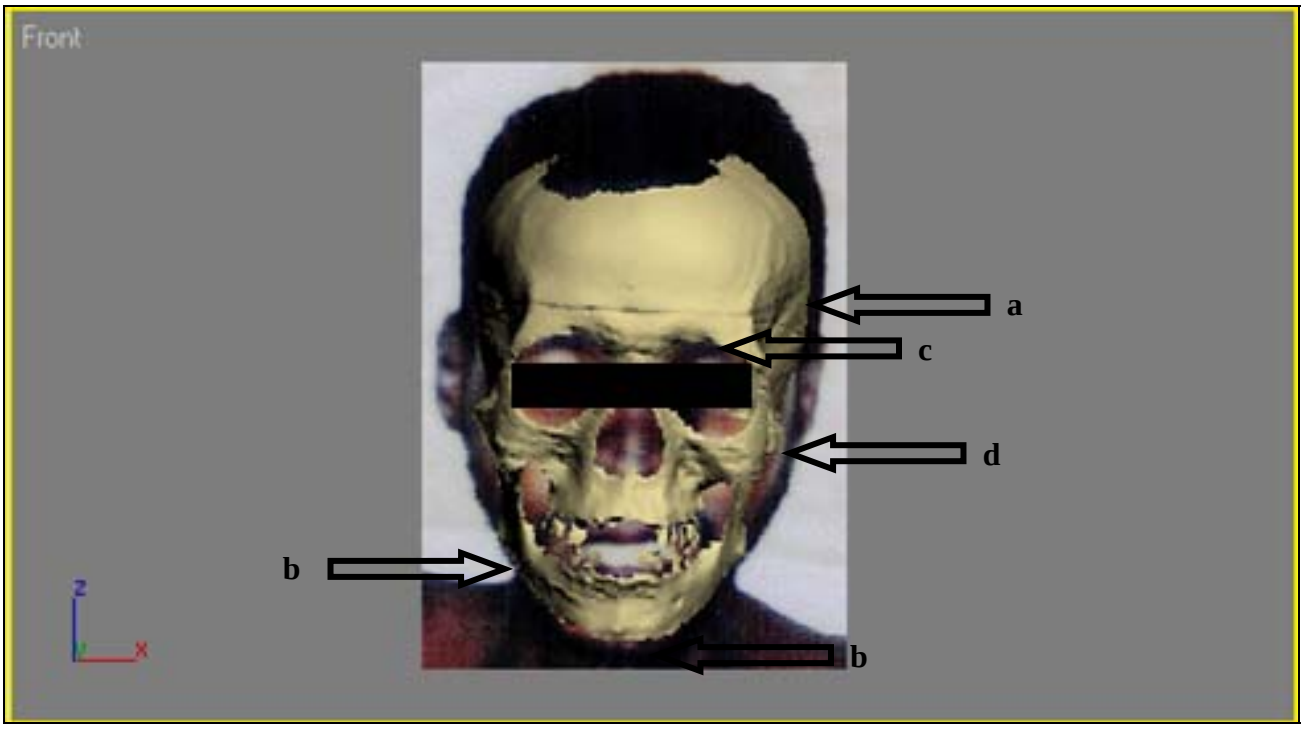

Figure 4.5. 6231 Skull 'g' Morphological matching. This superimposition is an example of a positive match for stage 2 of the study. Arrow (a) indicates the width of the cranium filling the forehead area of the face, (b) indicates that the curve of the mandible is similar to that of the facial jaw, (c) 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.

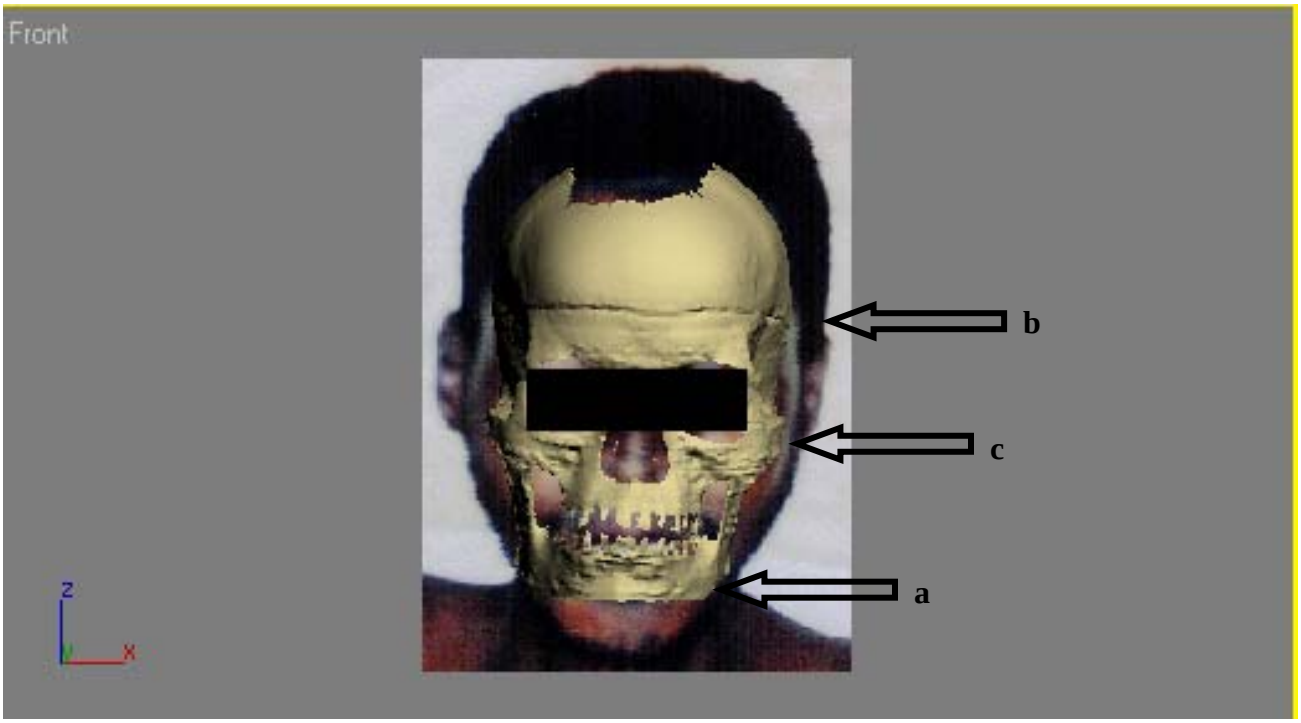

Figure 4.6. 6231 Skull 'h' Morphological. This superimposition is an example of a non-match for stage 2 of the study. Arrow (a) indicates that the angle of the mandible falls outside the contour of the skull (b) indicates that the cranium is too small to fit the contour of the head and scalp areas, and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

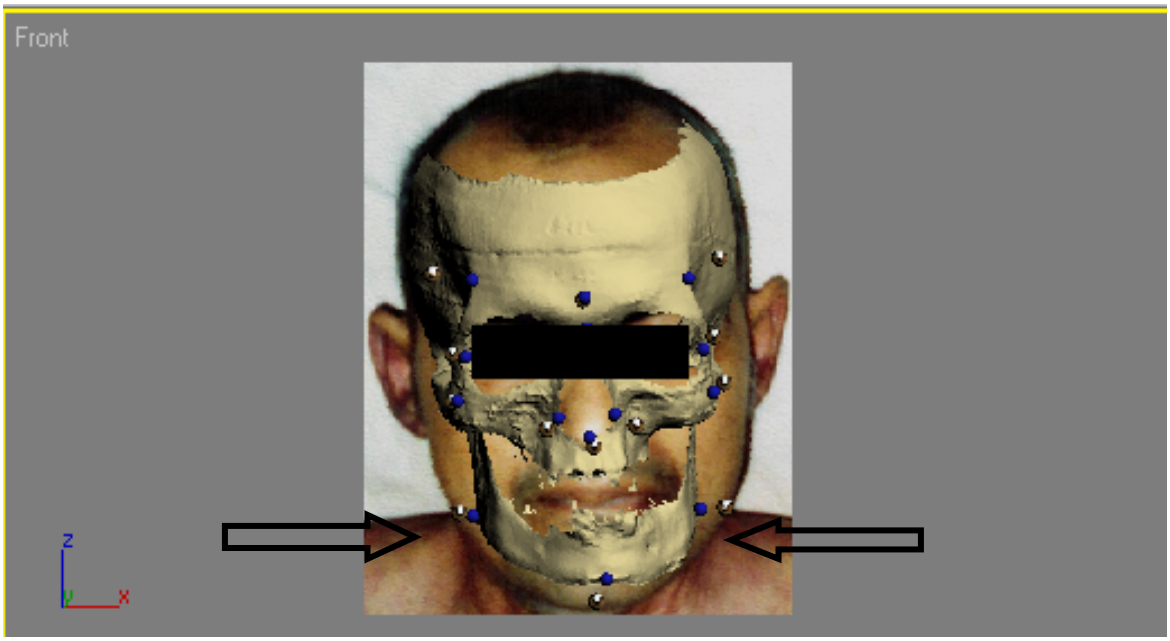

Figure 4.7. Photograph of case 6264, matched to skull 'g'. This superimposition is an example of a positive match. The photograph and skull with their landmarks are all visible in this image- the blue landmarks are from the skull and the white landmarks are from the photograph. The arrows indicate the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

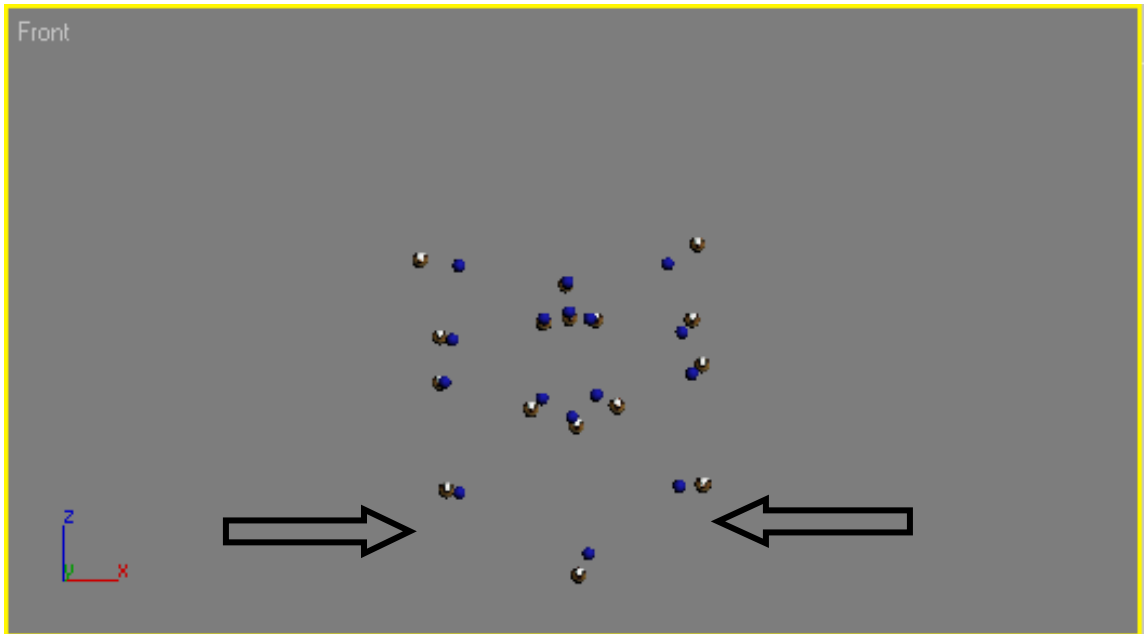

Figure 4.8. Dot match of case 6264 and skull g. This figure shows the superimposition with the skull and photograph removed so that an assessment of the landmarks or 'dots' could be made. This image is an example of matching landmarks. The arrows indicate the landmarks where differences were noted.

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.

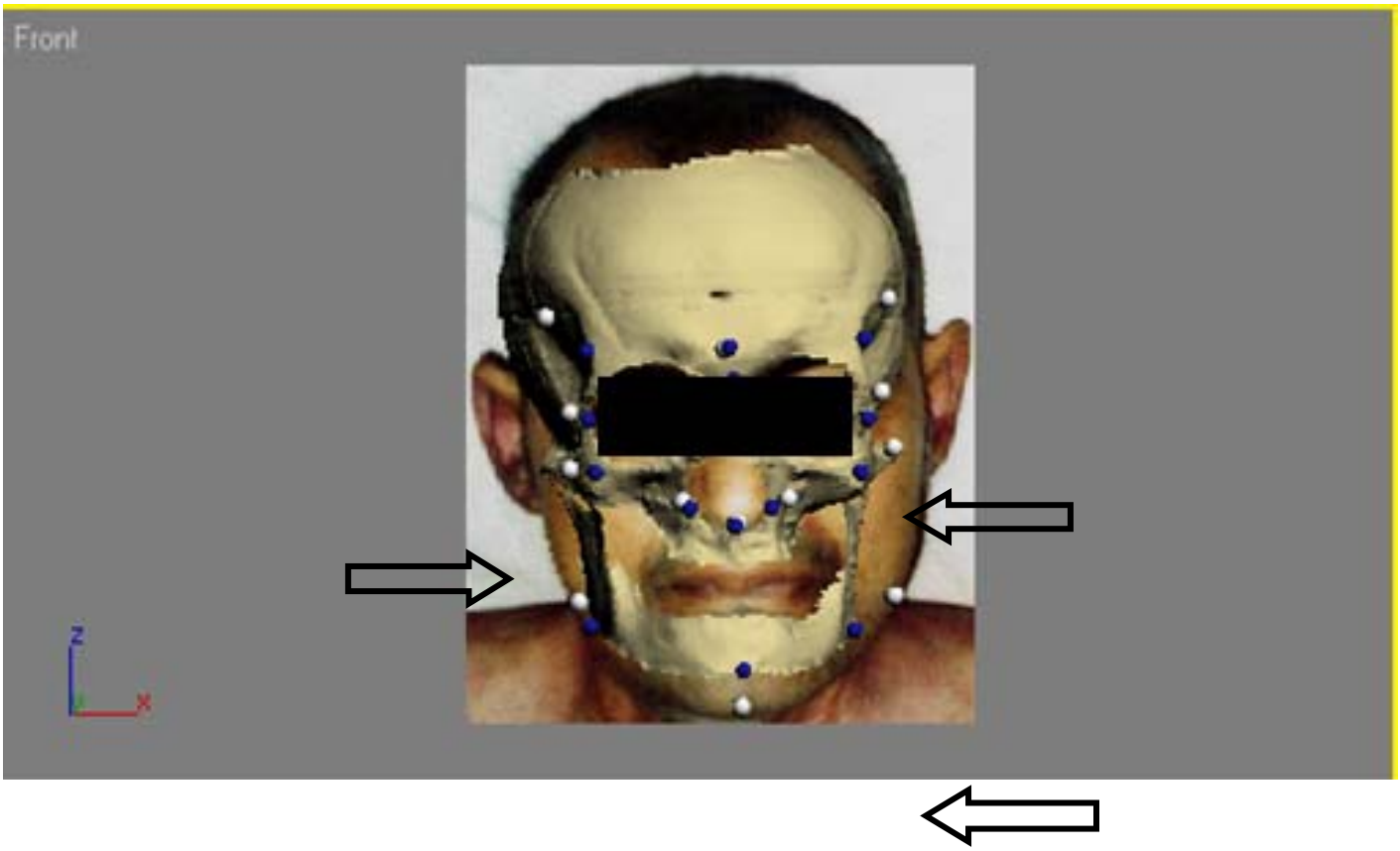

Figure 4.9. Photograph of case 6264, matched to skull 'a'. This superimposition is an example of a non-match for stage 3 of the study as indicated by the differences in the landmarks shown by the arrows above. The photograph (white dots) and skull (blue dots) with their landmarks are all visible in this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

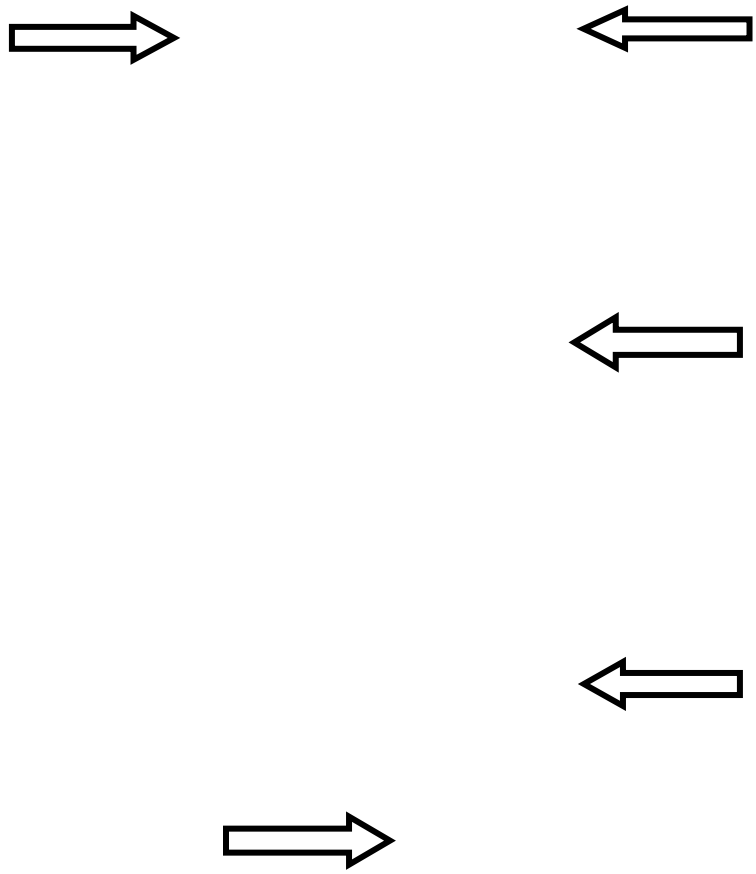

Figure 4.10. Dot match of case 6264 and skull ‘a’. This figure shows the superimposition with the skull and photograph removed so that an assessment of the landmarks or ‘dots’ could be made by the investigator. This image is an example of a non-match between the landmarks of the skull and photograph 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.

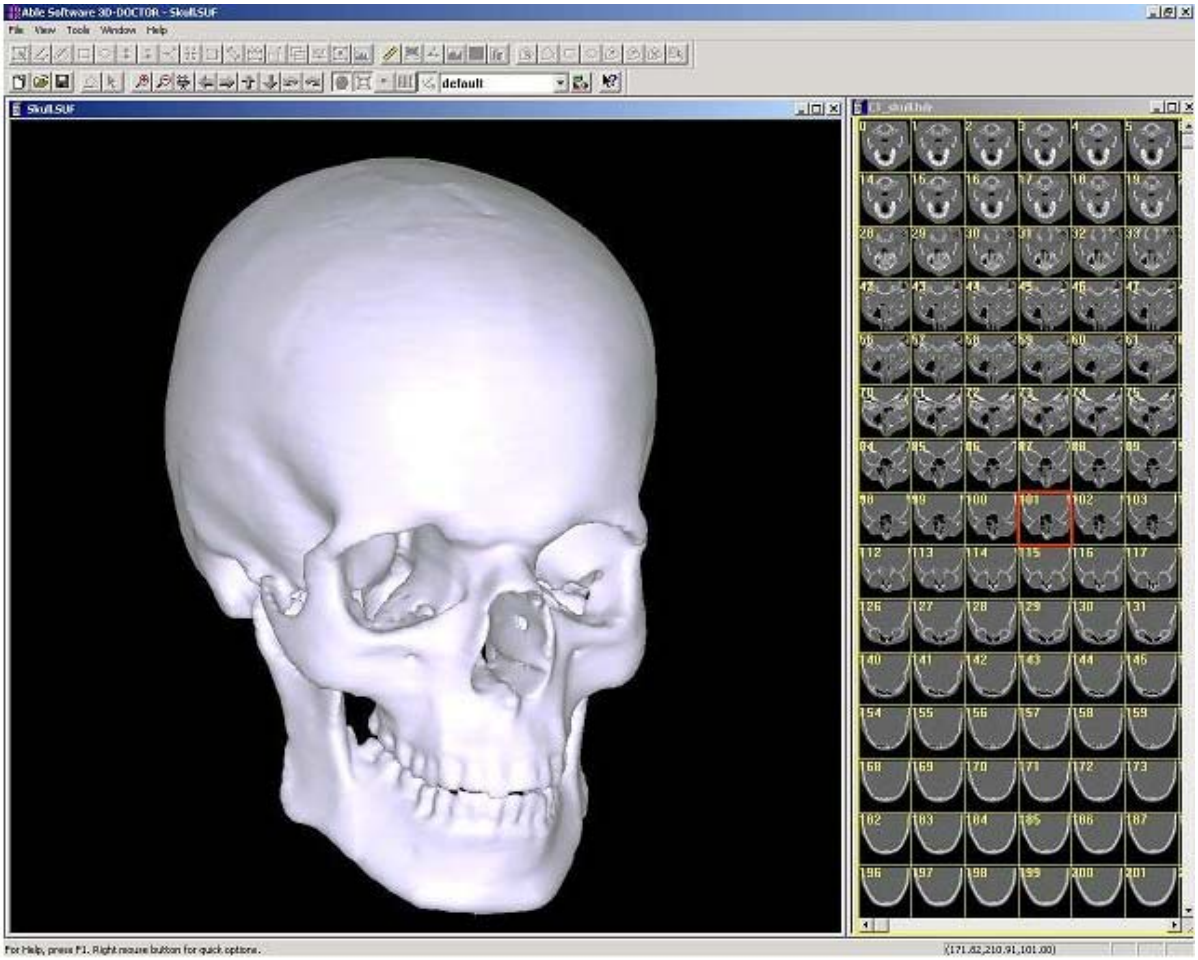

Figure 5.1. 3-dimensional image of a CT scanned skull which has been rendered a 3-dimensional image in 3D Doctor.

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.

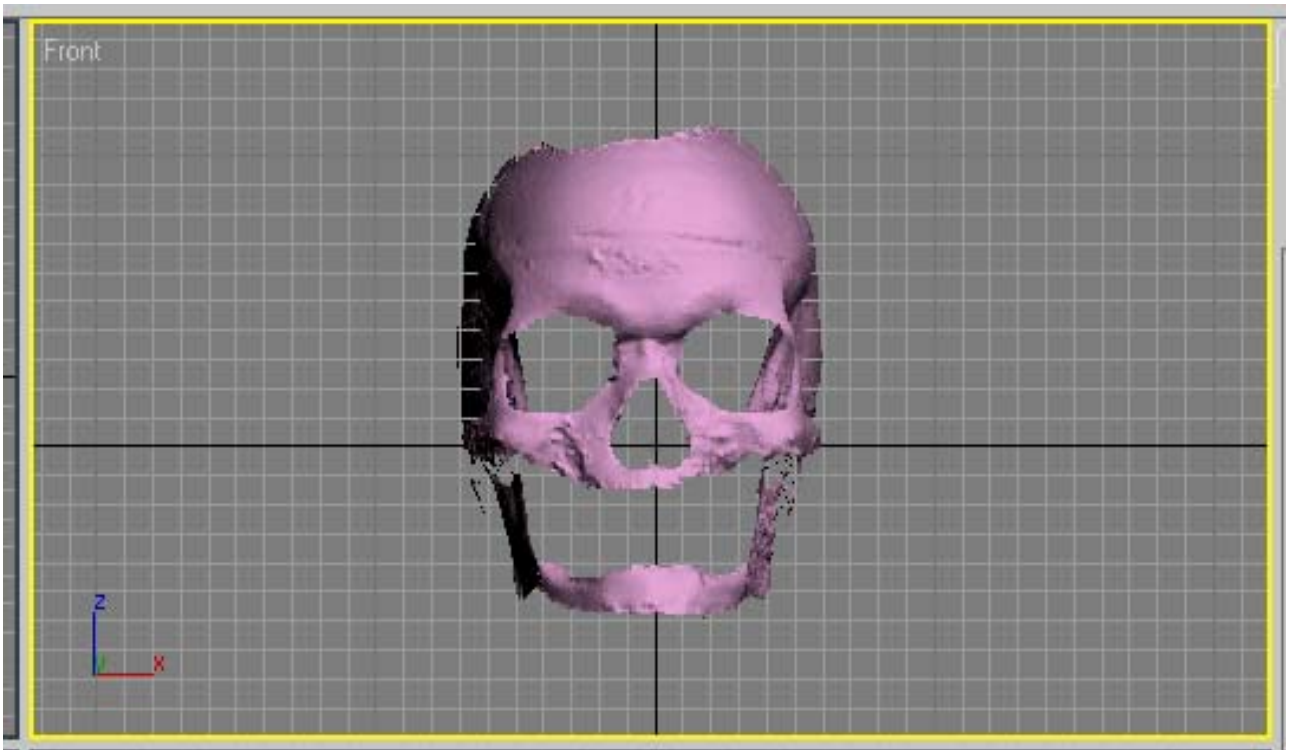

Figure 5.2. 3-dimensional image rendered from a 3D scan at Ergotech viewed in 3D Studio Max.

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