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A Test of the Accuracy of Facial Tissue Thickness Measurements Taken from Computed Tomography

Amy L. Schilling
University of Tennessee, Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Amy L. Schilling entitled "A Test of the Accuracy of Facial Tissue Thickness Measurements Taken from Computed Tomography." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

William M. Bass, Major Professor

We have read this thesis and recommend its acceptance:

Richard Jantz, Murray K. Marks

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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A TEST OF THE ACCURACY OF FACIAL TISSUE THICKNESS MEASUREMENTS TAKEN FROM COMPUTED TOMOGRAPHY

A Thesis Presented for the
Master of Arts Degree
The University of Tennessee, Knoxville

Amy L. Schilling
May 1997

DEDICATION

To

J. A. S. and S. R. S.

for their faith and support.

ACKNOWLEDGMENTS

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ABSTRACT

Computed Tomography (CT) as a source from which to gather measurements of facial tissue depth is investigated. Measurements made from the surface of the bone to the outer skin surface were taken at the landmarks used by Rhine and Campbell (1980). These distances were measured on the axial slices of the Visible Human Male anatomical data and compared to measurements taken at the same landmarks on the Visible Human Male CT taken on the frozen specimen.

While two of the measurements varied by several millimeters, no statistically significant differences were found. Locating the correct landmark on an axial image is sometimes difficult. However, it is worth the extra time as CTs offer many advantages over more traditional methods.

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I. INTRODUCTION

FACIAL REPRODUCTION

The identification of human remains is an important aspect of forensic science. Positive identification is necessary to aid in solving a death investigation, bringing a criminal to justice, and to help the victim's family come to terms with the death of a loved one. Many subdisciplines within the forensic sciences assist in death investigations including questioned documents, ballistics, serology, chemistry, fingerprints, criminalistics, odontology, pathology, and anthropology. Each specialty provides one piece of the human identification puzzle and adds it to those provided by other law enforcement agencies.

Not every specialty area is useful in every case requiring an identification. The evidence collected and the questions posed dictate which specialists are involved in an investigation. When the identification of skeletalized or partially skeletalized remains are found, a forensic anthropologist is often called in for assistance. Forensic anthropology is concerned with the identification of human remains from the skeleton and decomposing remains. After determining that the remains are human, an analysis of the bones is conducted during which the investigator develops an opinion as to how many individuals are represented and on the sex, age, ancestry, and stature of all the remains (Stewart, 1979).

In situations where human remains have been found but cannot be identified, a reproduction of the face from the skull may be performed by a forensic anthropologist. This is not used as a means of positive identification but as an aid in gaining leads or confirming suspected identity. Facial reproductions rely upon the validity of facial soft tissue thickness measurements for their accuracy in reproducing the face of the deceased. This study investigates the use of computed tomography (CT) images as a source for the collection of soft tissue thickness data.

LITERATURE REVIEW

Facial reproduction is an attempt to create a visual representation of how the deceased appeared in life and can be divided into four distinct categories: the reconstruction of facial soft tissues that have been mangled or otherwise damaged but are still present with the body; photographic superimposition and comparison; two-dimensional artist drawings; and three-dimensional reproduction through the application of clay or plasticine to the skull or digitally, using a computer.

Facial Reconstruction

In situations where the facial soft tissue has been mutilated but is still available, it can be replaced on the skull in an attempt to reconstruct identifying facial features. This method is termed "reconstruction" rather than "reproduction" (Rhine, 1990) because it

is a reconstruction or piecing together of the actual facial tissue rather than a reproduction of how it may have looked. To adequately perform this procedure requires knowledge of anatomy along with artistic ability, special equipment and supplies (Drake and Lukash, 1978). However, it does not depend on facial tissue thickness data as do the three facial reproduction techniques. Facial reconstruction has proved successful and offered valuable help in the identification of intentionally or accidentally mutilated individuals (Drake and Lukash, 1978; Spitz et al., 1970).

Photographic Superimposition

In situations where the remains are skeletalized or there is not enough soft tissue remaining on which to perform a reconstruction, the investigator has three options for facial reproduction: 1) photographic superimposition 2) two-dimensional artist drawings, or 3) three-dimensional reproduction using clay or computer. Photographic superimposition or comparison is a technique that has been used for many years, beginning with the reproduction of the faces of historical figures such as Schiller, Raphael and Kant (Welker, 1883, 1884, 1888), Sir Thomas Browne (Tildesley, 1923), Robert the Bruce, George Buchanan and Jeremy Bentham, Lord Darnley (Pearson, 1924, 1926, 1928) and Oliver Cromwell (Pearson and Morant, 1934). These have all been reproduced using the photographic/portrait superimposition or comparison method.

Unlike the reconstruction of mutilated facial tissue which requires soft tissue, photographic superimposition requires that the

remains be at least partially clear of soft tissue so that the underlying bony structures can be readily examined. Many cases (Helmer, 1987; Reddy, 1973) and methods have been published (Bastiaan, et al., 1986; Brocklebank and Holmgren, 1989; Chai, et al., 1989; Dorion, 1983; Iten, 1987; Klonaris and Furue, 1980; McKenna, 1988; McKenna, et al., 1984), but the first well known case to which it was applied was that of Dr. Buck Ruxton who was eventually convicted of killing and dismembering his wife and nursemaid (Glaister and Brash, 1937). In the case, partial remains of two bodies were found wrapped in newspaper and scattered throughout a stream in rural Scotland in 1935. Since there was not enough soft tissue on the skulls for identification, a forensic analysis determined that the bodies were both female and that one was young (twenties) and one in her thirties. Two women were reported missing shortly after the discovery of the bodies and their photographs were published in the local papers. One investigator in the case, seeing the photos, noticed a similarity between the shape of the faces and the shape of the skulls in the stream. Thus the investigation began to focus on the two women; photographs were collected from the families and the investigators performed a photographic superimposition of the photographs and the skulls.

The process began with enlargement to natural size of two photographs of each woman. To do this, objects within the photographs were used as guides for the size of the photo. The photographer reconstructed the photograph of Mrs. Ruxton using the tiara and dress she wore in one of the photographs. By comparing

the original photograph to the reconstructed life-size photograph he was able to determine the amount of enlargement necessary to bring the original to natural size. A similar procedure was carried out in the enlargement of the remaining photograph of Mrs. Ruxton and the two of Mary Rogerson.

Life-size photographs of each skull were then taken in four positions as close to the head positioning in the pictures as possible. Outlines of each skull in every position were made and compared to outlines of the photographs to judge the accuracy of the positioning. This done, the skulls were oriented to the approximate positions of the pictures. The "salient" features of the heads in each picture and of the skulls themselves were outlined on tracing paper and nasion and prosthion were marked. The tracings of the photographs were superimposed on the outlines of the skulls. This immediately indicated that skull number 2 most closely fit the portrait of Mrs. Ruxton and skull number 1 fit that of Mary Rogerson. The actual superimposition took place with the combining of a negative of the skull with a positive of the photograph. The outlines were pinned together at the registration points and photographed using X-ray film. This created a combination of the skull and portrait allowing investigators a clear look at the fit of each skull to each photograph.

When the photographic superimposition evidence was presented in the trial of Dr. Ruxton, some objections were raised by the defense as to whether the photographs could truly be enlarged exactly to life-size. While this is a concern, every precaution was taken to make the enlargement as life-size as possible through the

reproduction of the photograph using the original tiara and dress and other measurable landmarks in the original photos. Additionally, the investigators were not trying to prove conclusively that skull number 1 was, beyond a doubt, that of Mary Rogerson or that skull number 2 was guaranteed to be that of Mrs. Ruxton. The superimpositions did demonstrate the individuality of the skulls and suggested that skull number 1 might be that of Mary Rogerson and number 2 that of Mrs. Ruxton. The photographic evidence was accepted and, along with the other medical and legal evidence, aided in the conviction of Dr. Ruxton (Glaister and Brash, 1937).

The method used in the Ruxton case has since been modified by Gruner and Reinhard (1959). They projected the skull onto a photograph and then photographed that superimposition. Leopold (1978) altered that method by placing a projection screen between the skull and a large-format camera. Computers are now being employed in photographic superimpositions. Yuwen and Dongsheng (1993) use a microcomputer to determine aspects of the superimposition that had before been estimated. The natural size of the photograph is approximated by the microcomputer along with the angle of superimposition and optimum objective length (original photographic length).

Two-Dimensional Reproduction

Two- and three-dimensional facial reproductions are fairly similar procedures. In both methods, facial tissue thickness data is used to determine the amount of tissue to be applied to the skull.

The tissue is then added to complete the reproduction. In two-dimensional reproduction this is done using pencil and paper over a photograph or slide of the skull, while in three-dimensional reproduction the soft tissue and facial features are physically added (using clay or plasticine) to the skull or a cast of the skull. Two-dimensional reproductions have a few advantages over three-dimensional reproductions in that they are produced more quickly, can be easily altered or adjusted with a pencil and eraser, and cost less to create. They still require artistic ability, necessitate a knowledge of lighting and shadows and offer only limited views of the reproduction; usually only frontal or lateral (Caldwell, 1981).

A two-dimensional reproduction begins with photographing the skull in question and enlarging the photos to life size. An outline of the skull is made and the facial soft tissue depth data is applied along with the facial features. Both lateral and frontal views are made and continuously compared. Figure 1 provides an example of a two-dimensional artist reproduction of the face of a 2,500 year old female mummy by Dr. Robert George (a three-dimensional clay reproduction of the same mummy is pictured in Figure 2). Two lateral and frontal views are shown illustrating the steps taken by the artist. This technique has proven quite helpful in identification (Cherry and Angel, 1977).

Another form of the two-dimensional reproduction of faces is called composite drawing. These drawings are often done by police artists. A composite drawing is a likeness or similarity of a person rather than a portrait. Like the other forms of facial reproduction, it

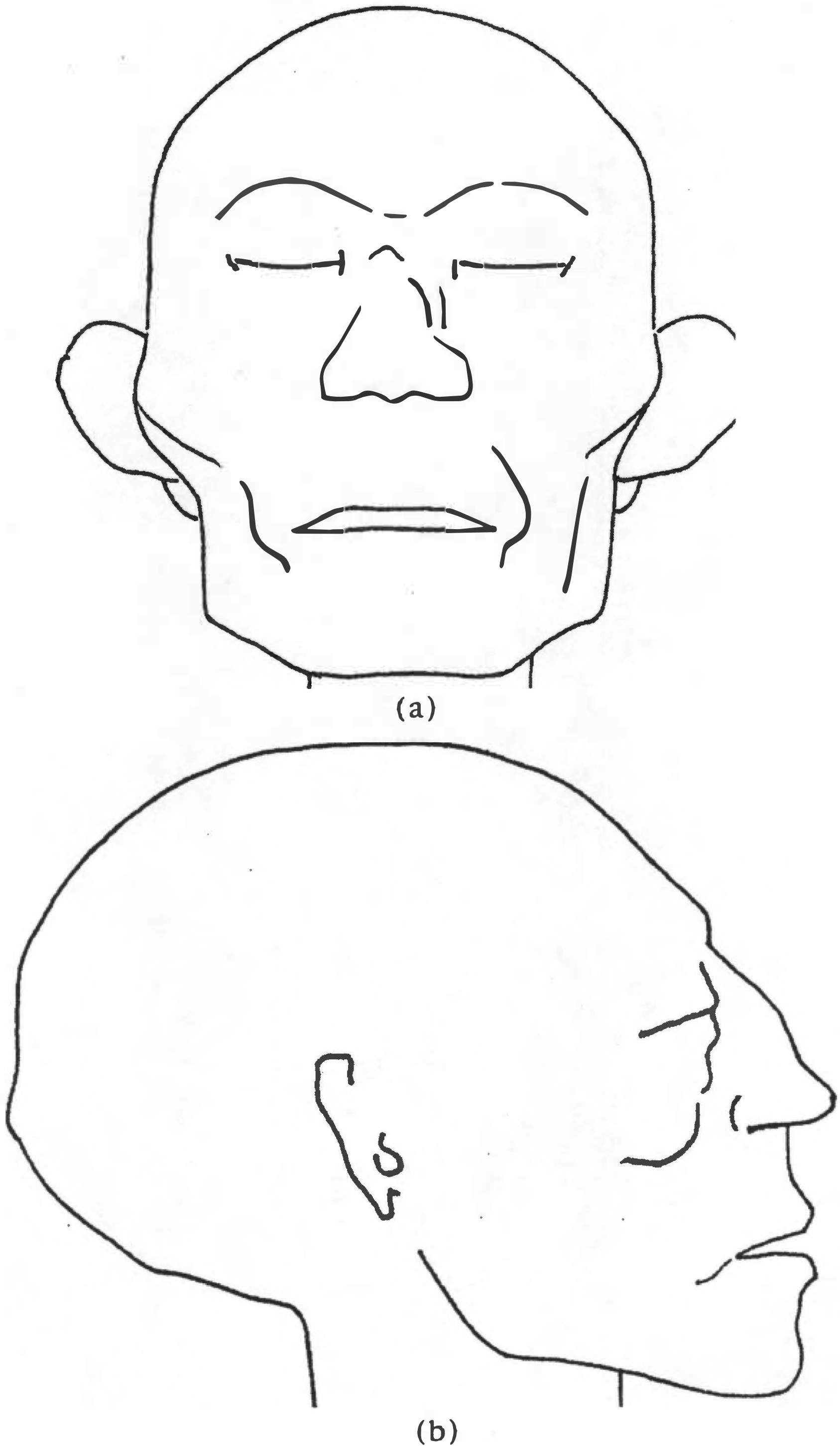

Figure 1. Two-dimensional reproduction of mummy Wenu-hotep. Frontal (a) and lateral (b) views.

Source: Dr. Robert George.

(c)

(d)

Figure 1. (continued)
Frontal (c) and lateral (d) views of completed reproduction.

is considered to be "a tool of identification, elimination and corroboration" (Domingo, 1986). Police artists produce this type of reproduction using descriptions of a suspect given by eye-witnesses which makes the job more of a challenge because the artists must rely on quick glimpses and memories. Composite drawings can be entirely hand drawn reproductions or composed using a kit containing a wide variety of facial features, such as an Identikit.

Three-Dimensional Reproduction

Three-dimensional facial reproductions are similar to two-dimensional reproductions except that they use the skull as a basis for the soft tissue applied as clay or plasticine. They are dependent upon subjective artistic ability and the accuracy of the facial soft tissue depth data available. This method requires that the skull (or cast) of the unidentified individual be present and is achieved by placing markers indicating the average tissue depth measurement for the estimated sex, age group and ancestry of the deceased (as determined by a forensic anthropologist) at predetermined craniofacial landmarks. This is often done by cutting sections of eraser or teflon plugs to the length indicated by the tissue thickness data and affixing them to the skull surface. The next step can be carried out by either connecting the markers with layers of clay or by forming each muscle individually and using the origin and insertion points and general size to determine how and where the clay muscle should be placed. Care must be exercised never to exceed the soft tissue depth markers. Eyes are inserted into the

orbits and the nose, mouth, chin and ears are all fashioned and applied to the best of the artist's ability (Angel, 1986; Gatliff, 1984; Gatliff and Snow, 1979; George, 1993). A three-dimensional reproduction of a mummy is illustrated in Figure 2. This reproduction was done by Raymond Evenhouse using a CT scan of the mummy's head. Each CT slice was traced onto a piece of foam board, cut out and re-assembled into a three-dimensional model of the skull (Figure 2a, b). Tissue depth markers were placed on the skull in the appropriate locations (Figure 2c) and the soft tissue filled in around them (Figure 2d). Finally, color was added to the skin and additional features were added (Figure 2e). The result is a remarkably life-like face.

As in two-dimensional reproductions, three-dimensional facial reproductions were initially produced in an attempt to reproduce the faces of historical figures such as J. S. Bach and Francisco Pizarro (Gatliff, 1986; His, 1895). Successes in the historical arena led to the use of the three-dimensional method in the study of early and prehistoric humans and archaeological populations, (Gerasimov, 1971; Glassman et al., 1989; Kollman and Buchly, 1898) Egyptian mummies (Wright, 1991) and in forensic cases (Gatliff, 1984; Gatliff and Snow, 1979; Haglund and Reay, 1991). Studies on the resemblance of the sculptures to living photographs of the deceased have shown that some of the reproductions are surprisingly accurate, while others, even by the same artist, do not provide as many similarities to the deceased (Haglund and Reay, 1991; Helmer, et al., 1993; Snow, et al., 1970).

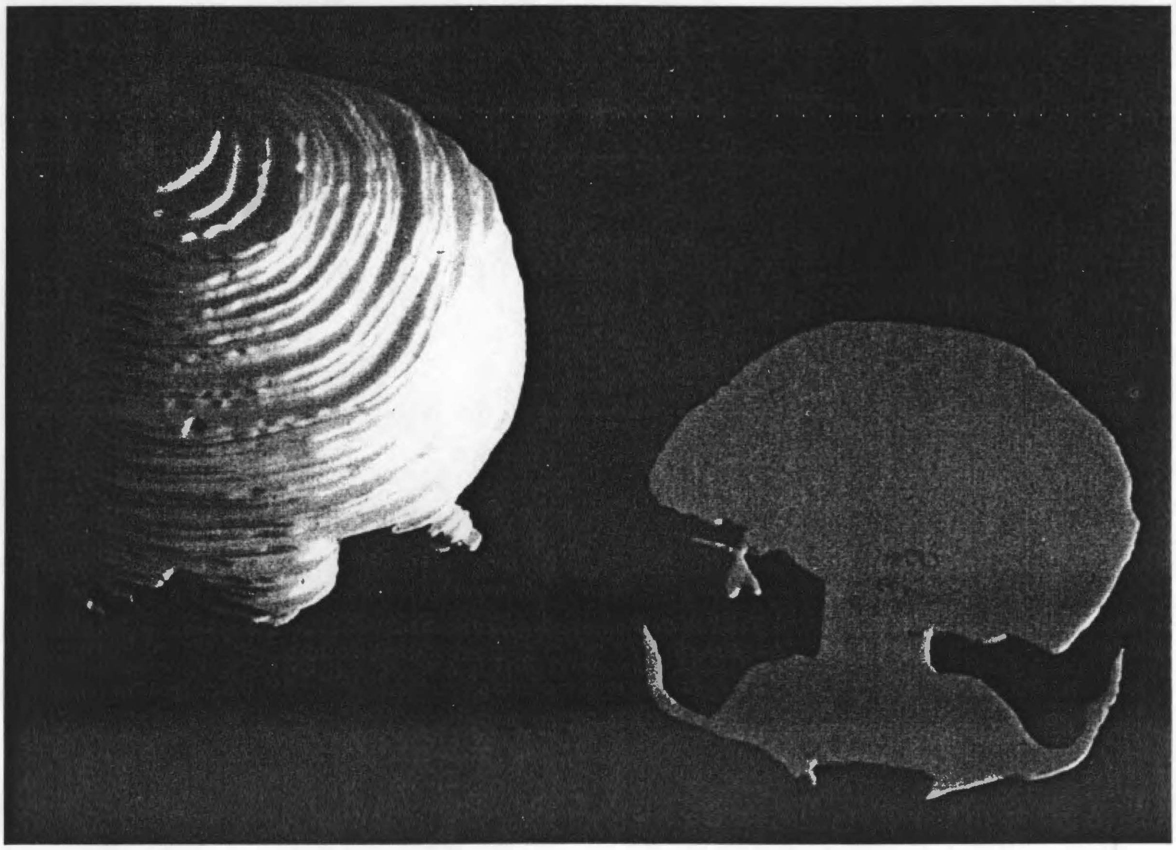

Figure 2. Three-dimensional reproduction of mummy Wenu-hotep.
(a) CT slices traced onto foam core and cut out.

Source: Dr. Raymond Evenhouse.

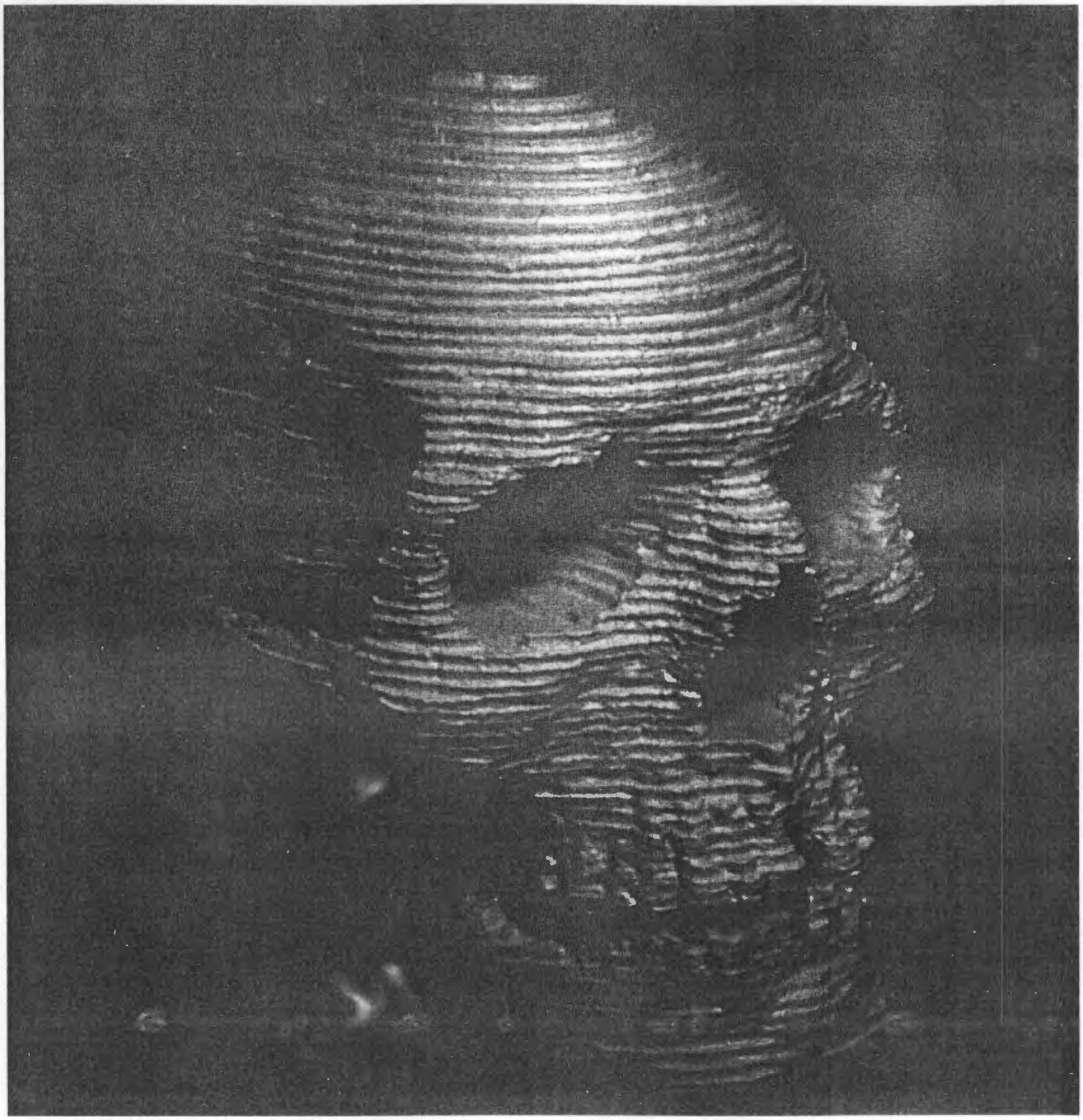

Figure 2. (continued)
(b) CT slices re-assembled to form Wenu-hotep's skull.

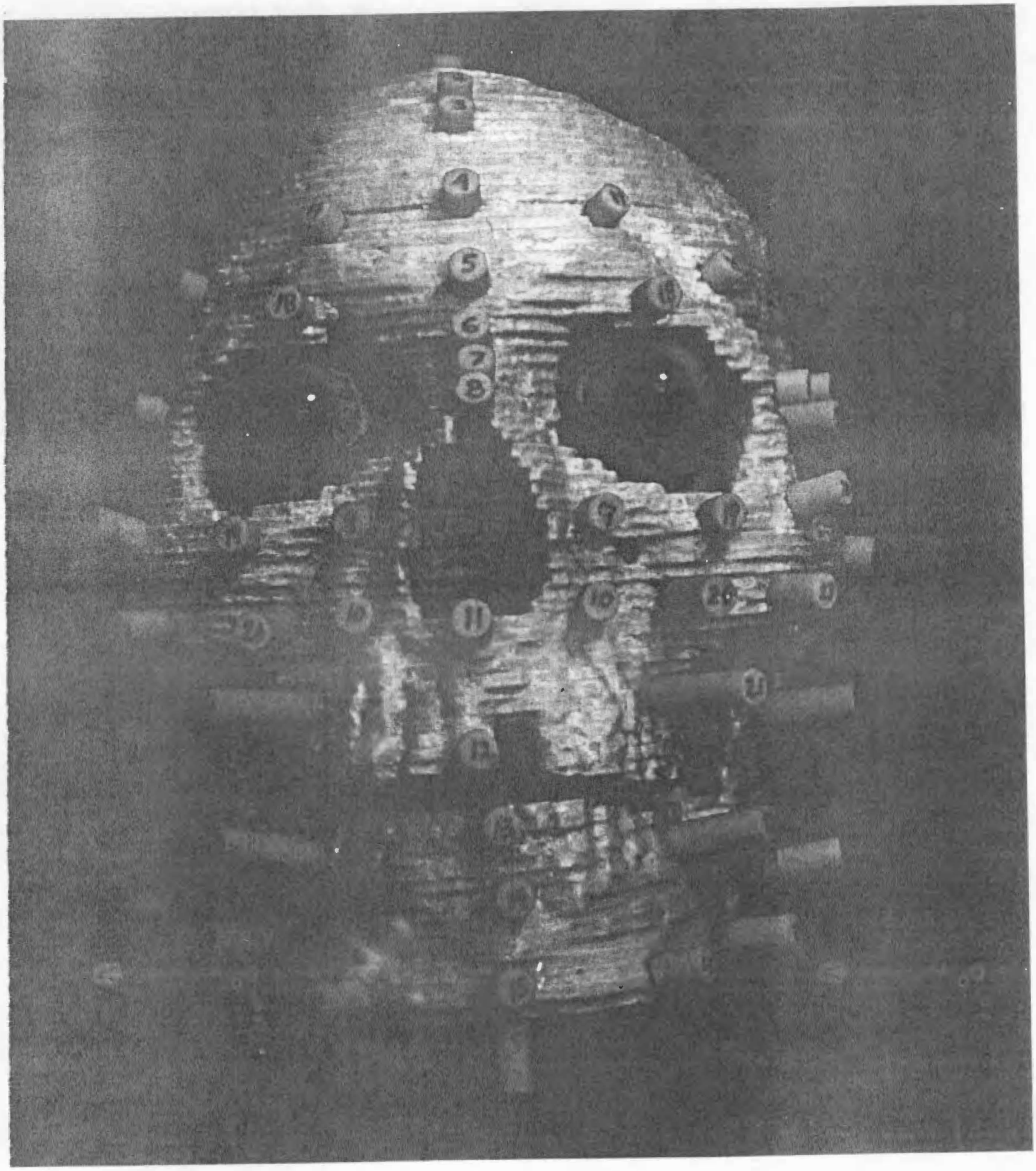

Figure 2. (continued)
(c) Facial tissue thickness markers placed on the skull.

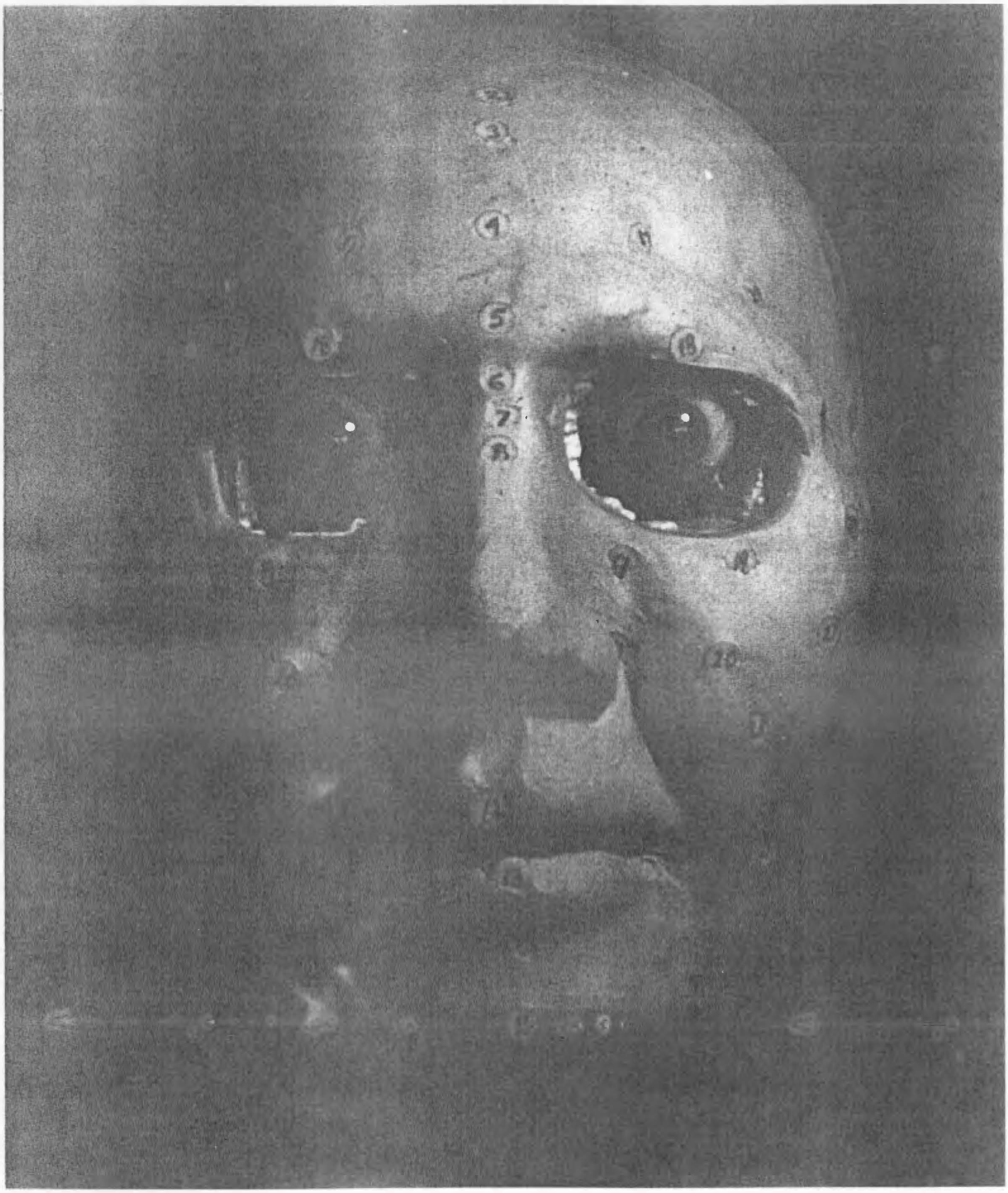

Figure 2. (continued)
(d) Clay filled in around facial tissue thickness markers to form Wenu-hotep's facial tissue.

Figure 2. (continued)
(e) Completed facial reproduction.

Computerized Reproductions

Computers have begun to play a role in the three-dimensional reproduction of faces. They do the same kind of reproduction as an artist, but there is no physical sculpting involved. Several different methods have been used. In most, the unknown skull is digitized or scanned into the computer. Then, the standard facial soft tissue depth measurements are applied by the computer. Features such as the nose and ears are developed from standards as in the Identikit. A skin patch is also used to simulate the texture of the skin (Voci, 1990). Computer reproductions are also being done without the use of the tissue depth data. This method requires scanning in the skull and facial soft tissue of an individual fitting the age, sex and ancestry of the unknown skull, scanning in the unknown skull and then applying the soft tissue of the known skull to the unidentified skull in the place of the usual soft tissue depth measurements (Addyman, 1994; Evenhouse and Stefanic, 1992; Vanezis, et al., 1989). Evenhouse et al. (1992) have created a computerized reproduction method similar to that of Vanezis et al. (1989) using an "average" face created by digitally combining the faces of five people of the same age, ancestry and weight. This “average” face is stretched over the unknown skull to produce a face on that skull. This method has produced reproductions that bear a close likeness to the deceased. At present, this is only a two-dimensional method, although Evenhouse and colleagues have already begun to modify it into three-dimensions.

Computerized reproductions have some advantages over sculpted reproductions First, the reproductions have the potential to be accurate and easily manipulated or changed. Second, they are not as time consuming to create. Third, while there is still some subjectivity involved, it is reduced from that of the clay sculpture method.

INTRODUCTION TO CURRENT STUDY

Three-dimensional clay and some computerized methods of facial reproduction along with two-dimensional artists' reproductions (those not relying solely on kits such as Identikit), depend heavily on the quality of the soft tissue depth data. Unfortunately, the validity of these measurements is often called into question. Suk (1935) has discussed the difficulties with the cadaver studies commonly used for facial soft tissue thickness data. Most of the data currently used in facial reproductions was collected using a probe, such as a needle, with a piece of rubber lined up even with its tip. This is inserted into the face of a cadaver at different landmarks. When the probe reaches the bone it is pulled out and the displacement of the rubber piece is measured (Gerasimov, 1949; His, 1895; Kollman and Buchly, 1898; Rhine and Campbell, 1980; Rhine and Moore, 1982; Suzuki, 1948). Welker (1883) used a similar technique using soot on the tip of a knife. This type of study is open to criticism for several reasons. First, the measurements are taken from cadavers lying on their backs, allowing gravity to pull the tissue down. Second, the cadavers

have begun to decompose. Third, as the probe is inserted it disrupts the tissue around it which may give an erroneous measurement (Suzuki, 1948). This disruption, in addition to possible distortion of the tissue due to decomposition, drying or embalming (Todd and Lindala, 1928) could greatly impair the validity of the results. Third, the exact location of the bony landmark the investigator is attempting to locate is often missed using palpation (Suzuki, 1948). Fourth, the sample sizes have been small and statistically inadequate (Rhine and Campbell, 1980).

Alternative Collection Methods

Wilder (1912) commented that with the right database of facial tissue thicknesses it would be difficult to produce an *unsuccessful* reproduction. With this in mind, it seems worthwhile to investigate new methods of gathering such data. Several alternative methods are being explored to collect data that is not affected by decomposition, collected on a large number of people with different ancestral backgrounds and representing a variety of body compositions and different age groups. These approaches minimize the problems of locating underlying bony landmarks and tissue distortion. Ultrasound has been investigated as one of these alternative methods (Hodson, et al., 1985; Wade and Rhine, 1985). Using ultrasound satisfies many of the deficiencies of older methods, including increased accessibility, more visual clues to the location of the underlying bony landmarks and the use of living subjects. However, the results from ultrasound studies, while promising, have

produced results differing from other techniques at some landmarks by as much as 3 millimeters (Gurche, 1996, personal communication).

Radiographs have also been examined providing positive results. Dumont (1986) used lateral radiographs taken in routine orthodontic practice to collect measurements on adolescents. The radiographs solve many of the problems associated with the probe method as they provide views of living subjects thereby eliminating distortion of facial soft tissue by probes, embalming or decomposition. They are also readily available on a large number of people not often seen in the cadaver studies and can be easily referred to at a later date if needed.

Another promising source from which to gather data on facial soft tissue depth in a variety of populations is the CT scan. CTs are produced through a combination of radiographs and computer reconstructions. Measurements are made from multiple directions in a plane through the patient. A cross-sectional image is then mathematically reconstructed from these measurements. The result is a gray scale image that presents a clear picture of the bone and soft tissue.

CT offers the researcher unlimited points at which to measure soft tissue depth; the opportunity to collect data from large numbers of individuals. It is non-invasive and non-destructive, can be taken from live subjects and the same measurements can be taken repeatedly to evaluate interobserver error.

This study investigates the validity of facial tissue thickness measurements taken from CTs of the Visible Human Male (VHM).

Measurements taken from the axial CTs are compared to the same measurements taken from the VHM digitized anatomy. Because it is so comprehensive, the Visible Human Male provides the opportunity to investigate many aspects of human anatomy. The CTs were taken on the specimen after freezing, have been aligned with the anatomical data and are easily comparable on a computer.

If CTs are shown to produce viable data for facial soft tissue thickness measurements, more data can be collected on a wide variety of subjects, thus enriching the foundation upon which facial reproductions are made. New data taken from living subjects will also allow for testing of the traditional facial soft tissue thickness measurements through comparison.

II. MATERIALS AND METHODS

Visible Human Data

The VHM data set was developed at the University of Colorado School of Medicine beginning in 1993 under contract for the National Library of Medicine. The 15 gigabyte data set includes digital, anatomic, magnetic resonance (MR) and CT images derived from a 38 year old male cadaver donated to the Texas State Anatomical Board. The cadaver was embalmed with 1% formalin solution before being taken to Colorado. It was received at the Colorado State Anatomical Board eight hours after death and taken to University Hospital at the University of Colorado where MR and initial CT images were gathered. The specimen was frozen and placed in a walk-in freezer maintained at or below -70° Celsius. CT scans were taken again at a higher spatial resolution after freezing.

A cryomacrotome developed at the University of Colorado School of Medicine designed to remove material from a frozen specimen was used to slice the cadaver from head to toe at 1 millimeter intervals. Prior to slicing, the frozen cadaver was cut into four blocks 22 inches high, 21 inches wide, and 14 inches deep in order to fit into the cryomacrotome. Each block was placed in an aluminum mold which was filled with a 3% gelatin solution colored with blue food dye. The gelatin served to stabilize the specimen in the mold and was colored blue so that it could be easily distinguished from the outer layer of skin on the specimen. The mold and specimen were again frozen to -70° Celsius.

Beginning at the top of the head, 1 millimeter cuts were made continuing down through the toes. As each cut was made, the tissue being sliced away was destroyed. After the block passed under the blade for each cut photographs were taken of the remaining specimen by three cameras: a digital camera capturing red, green and blue images; a 35-millimeter camera and a 70-millimeter camera. The digital images were immediately stored on an Apple Macintosh Quadra 840 AV and transferred to a SUN 4/330 computer. These digital images were processed and lined up re-creating the block as it appeared prior to cutting. Comparisons to the frozen CT were made to correctly align the CT and anatomy images. The CT, MR and anatomic slices were given corresponding numbers to increase the ease with which the data set can be used (Spitzer et al., 1996). The result of this project is a complete three-dimensional digital atlas of human anatomy. A Visible Female has been added to the collection of data, broadening the wealth of information available. The Visible Human Project has revolutionized anatomical and surgical research and education.

Data Collection

Measurements for the current study were manually obtained from the axial slices of the digital anatomy using a PIXAR-Sun 3/370 system. The system is equipped with software to provide coordinates of any given point in an image. The x and y coordinates for each landmark (developed by Rhine and Campbell (1980) and shown in Figure 3) were taken at the bone surface and at the surface

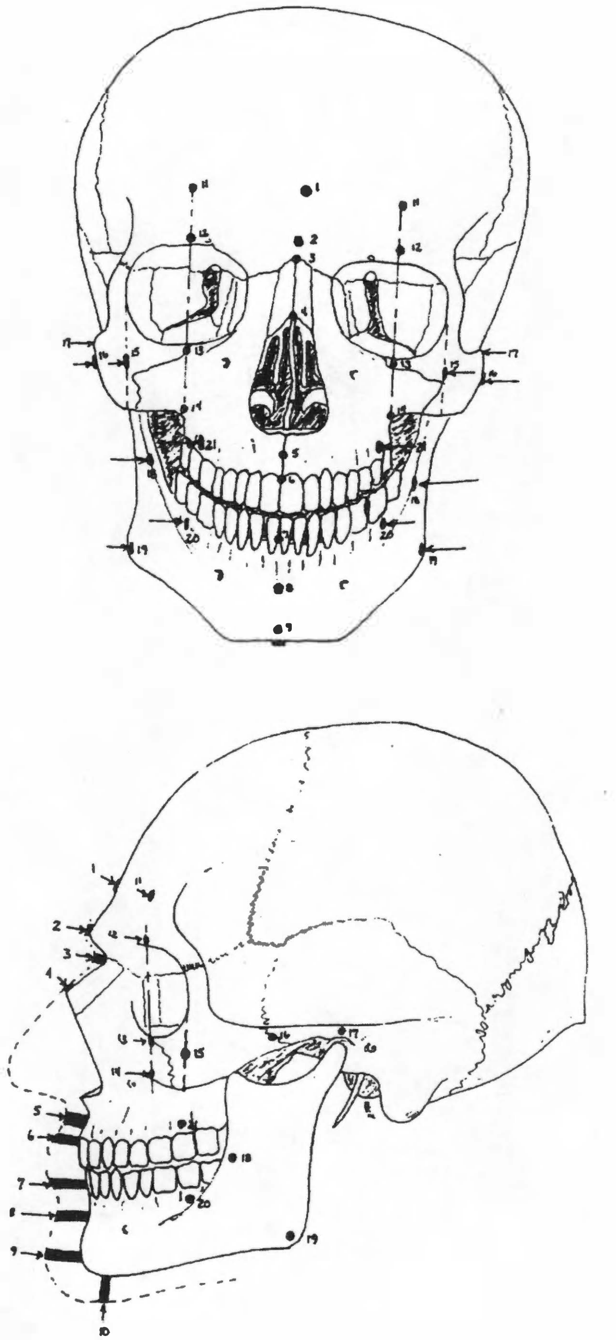

Figure 3. Landmarks for facial tissue measurements.

Source: Rhine, J. S. and H. R. Campbell, "Thickness of Facial Tissues in American Blacks," Journal of Forensic Sciences 25:847-858.

of the skin, as perpendicular to the bone as could be determined visually (Figure 4). The distance from the landmark to the skin was calculated and the process repeated on the axial CT data (Figure 5). These two sets of measurements—those from the anatomy and the CT—were compared to determine the degree of similarity between them.

In spite of the problems with taking measurements from a cadaver mentioned above, this study does involve the use of a cadaver. However, the comparison of measurements is being made between the frozen cadaver anatomy and the CT taken of that frozen cadaver. This is not a test of tissue depth thickness, but a test of the validity of measurements taken from a CT when compared to the actual anatomy.

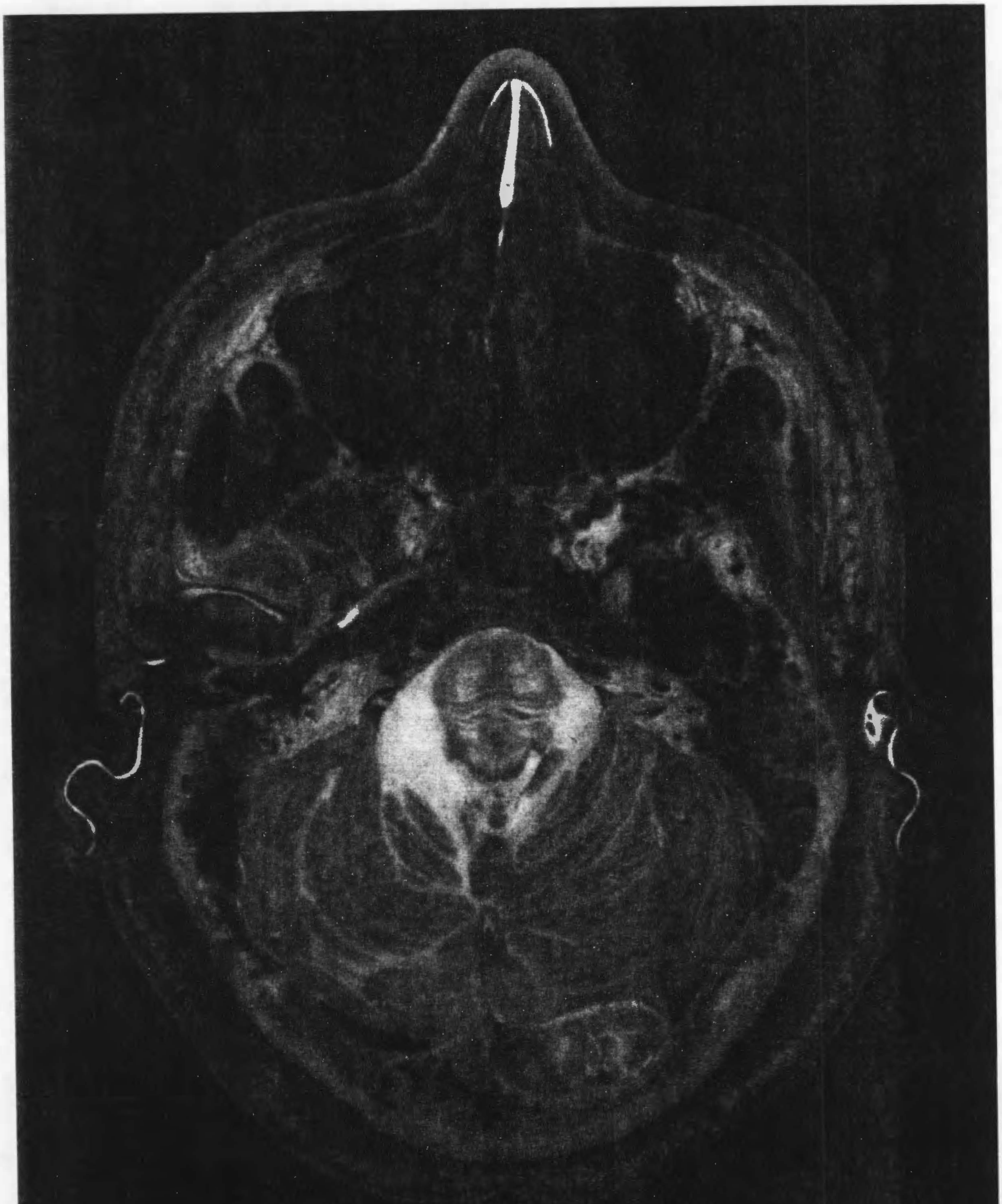

Figure 4. Axial image from the Visible Human Male anatomy.

Figure 5. Axial CT image from the Visble Human Male.

III. RESULTS

The results from this study are presented in Table 1 and Figure 6. Most of the anatomy and CT measurements are similar, varying between 0.03 millimeters to 5.57 millimeters. Most of the coordinates have a difference less than 2.45 millimeters. However, the left and right suborbital measurements show an unusually large difference—3.19 millimeters and 5.57 millimeters respectively. These large differences may not be due entirely to a difference between the two data sets. Rather, some of the difficulties in taking measurements from axial views of the head may have increased the differences between the two numbers.

The initial step in the process followed for the collection of the data in this study was to identify the specific location of the point on the skull where the measurement was to be taken. While several of the points correspond to sutures, edges of the bone or specific teeth (locations 3, 4, 6, 7, 12, 16, 19, 20, 21), many rest upon the widest point on a bone, or are lined up with other points superior or inferior to them (1, 2, 5, 8, 9, 10, 11, 13, 14, 15, 17, 18). This second type of location is much more difficult to identify than the first. It is necessary when locating any point on the skull to scroll back and forth through the slices, sometimes measuring the width of a bone on each slice until the desired point is found. This process can be lengthy and is particularly frustrating if the investigator cannot visualize the face and skull in three-dimensions.

Table 1. Collected data and difference between the CT and anatomy in millimeters

LOCATION	ANATOMY (mm)	CT (mm)	DIFFERENCE CT-ANATOMY (mm)
Midline			
1 Supraglabella	7.51	8.96	1.45
2 Glabella	6.57	6.32	-0.25
3 Nasion	8.76	10.01	1.25
4 End of Nasal	3.76	3.69	-0.07
5 Mid-Philtrum	16.93	17.46	0.53
6 Upper Lip Margin	15.18	15.29	0.11
7 Lower Lip margin	18.15	17.92	-0.24
8 Chin-Lip Fold	15.97	16.86	0.90
9 Mental Eminence	13.46	14.77	1.30
10 Beneath Chin	13.15	13.18	0.03
Lateral			
11 Frontal Eminence, Left	6.26	7.38	1.12
11 Frontal Eminence, Right	7.20	7.38	0.18
12 Supraorbital, Left	10.33	10.54	0.21
12 Supraorbital, Right	10.02	11.07	1.05
13 Suborbital, Left	12.68	9.49	-3.19
13 Suborbital, Right	13.47	7.91	-5.57
14 Inferior Malar, Left	23.79	25.82	2.04
14 Inferior Malar, Right	22.85	25.30	2.45
15 Lateral Orbits, Left	12.21	12.65	0.44
15 Lateral Orbits, Right	13.15	12.12	-1.03
16 Zygomatic Arch, Left	12.21	12.65	0.44
16 Zygomatic Arch, Right	12.21	12.12	-0.09
17 Supraglenoid, Left	18.15	17.39	-0.76
17 Supraglenoid, Right	17.53	15.28	-2.25
18 Occlusal Line, Left	31.61	32.67	1.06
18 Occlusal Line, Right	30.36	32.15	1.79
19 Gonion, Left	28.80	28.99	0.19
19 Gonion, Right	25.04	25.30	0.26
20 Sub-M_2, Left	33.80	33.20	-0.60
20 Sub-M_2, Right	30.05	30.57	0.52
21 Supra-M^2, Left	40.06	38.47	-1.59
21 Supra-M^2, Right	39.75	39.53	-0.23

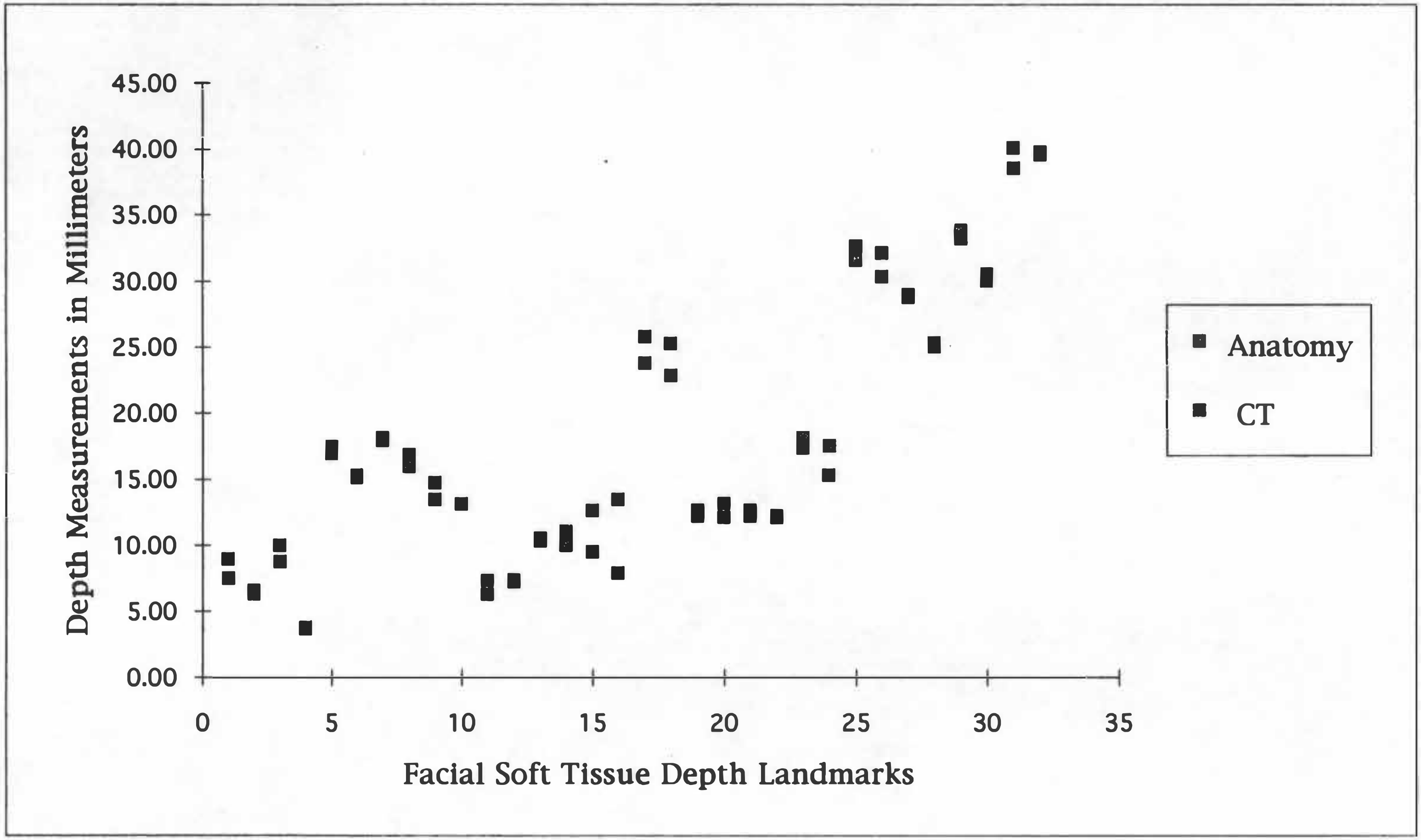

Figure 6. Graphic Description of Data

Additionally, it is difficult to determine whether the exact location of a point has actually been found. This is especially challenging when dealing with some of the locations dependent upon identifying the widest point or upon the positioning of surrounding points.

Another difficulty in data collection was making certain that the location selected on the anatomy corresponded to the same spot on the CT. To do this, the point was located first on the anatomy and then on the CT slice when the corresponding axial slice was opened and the location of the point determined using the same criteria as on the anatomy. The anatomy and CT slices could not be compared on the screen at the same time but were viewed one after the other so the location of the point relied on the memory and accuracy of the investigator.

In the current study it was difficult to determine the exact perpendicular for some of the points. Studies done on cadavers cannot produce a definite perpendicular, but it would be a beneficial additional factor when considering how the data will be used. When an artist constructs a three-dimensional reproduction on the surface of the skull or a cast of the skull, the facial soft tissue depth markers are placed directly onto the surface of the skull, making them perpendicular to the bone. The clay forming the soft tissue is applied up to the top of the marker making its outer surface also perpendicular to the skull surface (Figure 2 c, d). It seems reasonable that the facial soft tissue depth measurements taken for use in these three-dimensional reconstructions should be collected with their ultimate application in mind.

In spite of the apparently large differences displayed between two sets of coordinates, the data sets are not different enough to rule out this technique from the possible collection methods. Using Microsoft Excel a paired t-test was performed on the two data sets (Table 2). It produced a t value of -0.17. This indicates that the two groups of data have no statistically significant differences. A Pearson Correlation (Table 3) for the data sets is 0.99. This is quite high and suggests that the two sets have little error variation.

Table 2. T-Test: Paired Two-Sample for Means

	Anatomy	*CT*
Mean	17.84	17.89
Variance	98.45	101.36
Observations	32.00	32.00

Table 3. Correlation Results.

Pearson Correlation	0.99	
Pooled Variance	98.69	
Hypothesized Mean Difference	0.00	
df	31.00	
t	-0.17	
P(T<=t) two-tail	0.87	
t Critical two-tail	2.04	

IV. DISCUSSION

In general, the results of the measurements from the anatomy and CT were consistent. However, a difference of as much as 2.45 millimeters is disconcerting when working with measurements that may measure only a few millimeters themselves. Several problems associated with this collection method may be partially responsible for the discrepancies. Hildebolt et al. (1990) found similar difficulties in their validation study on measurements taken from both CT slices and three-dimensional reconstructions of CT data. In comparing measurements taken at craniometric landmarks on the skull itself with those taken on the individual CT slices and on the three-dimensional reconstructions of the CTs, they found that the measurements taken from the CT slices were not as close to those taken from the original skull or even to the results from tests on the three-dimensional reconstructions. The largest mean difference they had between the caliper/skull measurements and the CT slice measurements was 5.6 millimeters. Comparison between the three-dimensional CT reconstruction and the caliper/skull measurements yielded a 3.4 millimeter maximum mean difference. The authors conclude that the three-dimensional reconstructions of the CT data provided a better, more reliable and more accurate medium for acquiring their measurements as compared to the CT slices.

However, they do maintain that CT data is still a viable place to look for this type of data collection.

Hildebolt et al (1990) highlight most of the same problems with data collection from CT slices as were discovered in this study. A difficulty in locating the proper point coordinates on the slice is chief among them. As they suggest, a three-dimensional reconstruction of the CT data may offer a better alternative medium from which to collect measurements than the individual slices themselves.

The problem of identifying coordinates that are perpendicular from the surface of the bone to the surface of the skin is not an easy one. However, a program could be written that would locate a surface perpendicular to the surface of the bone.

It has been mentioned that due to the frozen state of the specimen in this study comparison of the data gathered to that of other studies using other collection techniques would be fruitless. However, a brief comment on similarities to the radiograph study by Dumont (1986) may be enlightening. The results from this study, albeit from a frozen specimen, are similar to those found by Dumont (Table 4). In her study she found that facial tissue depth measurements taken from radiographs produced results larger in size than those in the cadaver study by Rhine and Moore (1982). There are a few possible explanations for the differences. First, the radiograph study is done using living subjects. This eliminates the drying, embalming and decomposition that tends to affect cadaver studies. Second, identifying bony landmarks is much more easily

done using the radiographs than it is on a cadaver. Third, the tissue is not being distorted by the force of a probe. These explanations can be extended to the data in this study which also produced results greater than those of Rhine and Moore's 1982 study (Table 4).

Table 4. Facial tissue depths of adult Caucasian males in millimeters.

LOCATION	This Study CT	Rhine and Moore (1982)	Dumont (1986)
Midline			
1 Supraglabella	8.96	4.25	
2 Glabella	6.32	5.25	6.60
3 Nasion	10.01	6.50	7.30
4 End of Nasal	3.69	3.00	3.30
5 Mid-Philtrum	17.46	10.00	
6 Upper Lip Margin	15.29	9.75	14.40
7 Lower Lip margin	17.92	11.00	
8 Chin-Lip Fold	16.86	10.75	15.30
9 Mental Eminence	14.77	11.25	9.40
10 Beneath Chin	13.18	7.25	10.10
Lateral			
11 Frontal Eminence	7.38	4.25	
12 Supraorbital	10.81	8.25	
13 Suborbital	8.70	5.75	
14 Inferior Malar	25.56	13.50	
15 Lateral Orbits	12.39	9.75	
16 Zygomatic Arch	12.39	7.00	
17 Supraglenoid	16.34	8.25	
18 Occlusal Line	32.41	17.75	
19 Gonion	27.15	11.00	
20 Sub-M_2	31.89	15.25	
21 Supra-M^2	38.90	18.50	

Even though this study was performed on a frozen cadaver, the CT was taken of the specimen while in the frozen state. This eliminates differences in the two due to the freezing process. The effects of freezing on the tissues of the specimen have not been

thoroughly investigated but it has been determined that the tissues expand slightly after freezing. This may provide one explanation for the larger numbers. Assuming that the expansion is only slight, the numbers are still considerably larger than those of the cadaver study. This may result from the lack of tissue distortion commonly found with the use of a probe. Also, this specimen was processed close to the time of death, reducing the amount of decomposition and desiccation, and a light embalming may have filled out any changes that had already begun.

While there are difficulties with this method, an argument can still be made for its usefulness in the collection of facial soft tissue thickness measurements. The four most damaging aspects of the use of cadavers and probes in studies of this sort are: 1) the decomposition and desiccation of the cadavers, 2) disruption of the tissue as the probe is inserted and removed, 3) the improbability of locating the specific bony landmarks, and 4) small sample size. The collection method described in this study addresses all four of these areas. First, it uses data collected from living subjects, thus eliminating any effect caused by decomposition or desiccation. Second, because a probe is not used, there is no disruption of the tissue of the face. Third, locating the bony landmarks is made easier and more reliable, although still somewhat difficult. Fourth, sample size is limited only to the investigator's access to CT data and with the increased availability of CT equipment, locating it is not challenging. Additionally, CT offers the investigator the opportunity to take measurements at any location on the face included in the

field of view. If utilized, this will increase the information upon which a reproduction is based.

CT slices have the potential to be a valuable source for the collection of soft tissue thickness measurements. Once the major difficulty of detecting the exact location of any bony landmark on the skull is addressed, this method should present few problems or inaccuracies. If interest in CT data persists, it is likely that the issue of landmark location will be mastered. At that time, CT slice data can be used to increase the data base from which facial reproductions are made. One of the key factors in creating a facial reproduction that resembles the face of the person in life is having a large facial soft tissue thickness database from which to draw. The more measurements available, the better the results will be. Along with the improvement of the data base will come advances in computer technology. These two together should be able to produce substantially better digital reproductions than are currently available.

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VITA

Amy Schilling was born in Denver, Colorado on November 12, 1970. She attended Jefferson County Public Schools in Lakewood, Colorado from 1975 until graduation from Alameda Senior High School in May of 1989. She spent fall semester 1989 at Arizona State University before transferring to the University of Colorado Denver campus where she completed a Bachelor of Arts degree in Anthropology and English in May, 1993. Fall semester of 1993 she entered into the graduate program at the University of Tennessee in Knoxville. After completing her course work in Anthropology in 1995, she returned to Denver, Colorado to pursue an internship at the Colorado Bureau of Investigation. While engaged in the internship, she was offered a position on the staff of the Visible Human Project, where she is currently employed. She was awarded a Master of Arts degree from the University of Tennessee in May of 1997.