A WEB-ORIENTED APPLICATION FOR 3D CRANIOFACIAL RECONSTRUCTION IN FORENSIC MEDICINE

Leticia Carnero Pascual[1]
Carmen Lastres Redondo[1]
Belén Ríos Sánchez[1]
David Garrido Garrido[1]
Asunción Santamaría Galdón[1]
[1]CeDInt-UPM. Universidad Politécnica de Madrid
Edif. CeDInt-UPM. Campus de Montegancedo. 28223Pozuelo de Alarcón. Spain

José Antonio Sánchez Martínez[2]
[2]T-Systems Iberia
CRV.C/ Sant Joan de La Salle, 42. 08022 Barcelona, Spain

ABSTRACT

Human identification from a skull is a critical process in legal and forensic medicine, especially when no other means are available. Traditional clay-based methods attempt to generate the human face, in order to identify the corresponding person. However, these reconstructions lack of objectivity and consistence, since they depend on the practitioner. Moreover, the results of the reconstruction cannot be easily distributed and consulted from everywhere. This paper presents a completely objective 3D craniofacial reconstruction automatic system that provides access to the reconstructions through the Web. The software tool is able to generate an individual facial reconstruction from the 3D image of the skull and three parameters: age, gender and Body Mass Index (BMI) of the individual. Afterwards, the reconstruction can be manually modified by changing any tissue depth value. Both entry data and the reconstructions generated by the tool will be stored in a database, so they are accessible from the Internet.
Conclusions of this paper yield promising results: on the one hand, the scientific and technical feasibility of the presented craniofacial reconstruction technique is proved, and also its preference against traditional craniofacial reconstruction methods. On the other hand, this procedure means a remarkable advantage from the point of view of access, visualization and sharing of information, and also in terms of security, since it includes an authentication protocol.

KEYWORDS

3D Craniofacial reconstruction, 3D modeling, mesh, landmark, web visualization, web access.

1. INTRODUCTION

The purpose of forensic craniofacial reconstruction is the identification of human and osseous remains. It aims to produce an image from a skull, providing sufficient likeness of the individual it belonged to, when there is no other mean available (Krogman 1986). So far, this task has been performed by traditional 'plastic' methods, using clay. The process is carried out by an artist, who models soft tissues knowing tissue depth in some landmark points on the skull. Depths elsewhere are interpolated between these points by intuition. In that process, replicas of real skulls are used, to avoid damaging them (Iscan and Helmer 1993). This procedure has clear disadvantages: on the one hand, it is an artistic method, which implies subjectivity. In fact, the results obtained always differ between practitioners, and also between reconstructions (the process is non-repeatable). On the other hand, the technique is slow, as it usually takes one or two days, even for skilled practitioners. Due to the materials employed, the method is dirty and expensive. Finally, the generated reconstructions are not easily transportable, which makes difficult their distribution or sharing.

All these disadvantages result in an increasing importance of the computer-aided facial reconstruction idea (de Greef et al. 2005). Based on this fact, several works and proposals have been developed recently (Miyasaka et al. 1995, Shahrom et al. 1996, Tyrell et al. 1997, Recheis et al. 1999, Claes et al. 2006, Vandermeulen et al. 2006). They all suggest the different advantages of computerized 3D craniofacial reconstruction, which manage to solve the disadvantages of traditional methods.

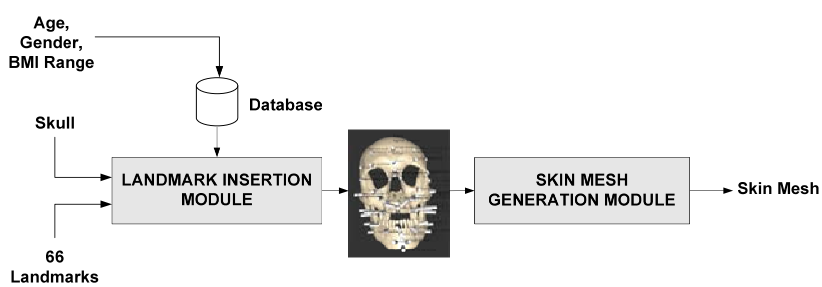
This paper presents the results of a R&D project, which aims to develop a 3D craniofacial reconstruction automatic system, due to the motivation the above mentioned techniques means. Moreover, a web application has been developed, so results can be consulted and modified by authenticated users via web. The whole system consists of a main application able to generate a 3D mesh simulating the skin of a person from the 3D image corresponding to his/her skull. Facial features are not included in the generated mesh, as they cannot be confidently deduced only from skull (Wilkinson 2004). For this purpose, a completely objective method is used. On the other hand, both input data and reconstructions generated by the main application are contained in a database, which can be accessed from the Internet.

2. MAIN APPLICATION DESCRIPTION

The main application scheme comprises the following elements, as shown in Figure 1:

- Input Data: set of three different types of data used by the application to generate the soft tissue mesh:
  - Skull image: a 3D image of the skull needed to obtain its facial reconstruction.
  - 66 landmark points placed on the skull surface: in those reference points, soft tissue depth is known.
  - Age, gender and BMI range of the person the skull belongs to. Age and gender can be deduced from skull morphology, so they will always be known by the user (Wilkinson 2004, Moore-Jansen et al. 1994). However, BMI range will be an unknown parameter, so it will be estimated.
- Landmark insertion module: in charge of placing each landmark point in each position over the skull, and assigning the corresponding soft tissue depth value, according to age, gender and BMI parameters. This functional block will be described in Section 3 of this document.
- Soft tissue generation module: responsible for generating the skin mesh from the set of landmarks, where soft tissue depth is known. This block will be analyzed in Section 4.

Figure 1: Main application scheme



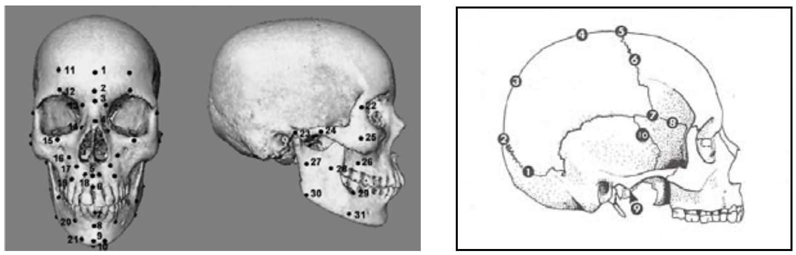
The application database consists of a set of tissue depths in each reference point, varying according to age, gender and BMI attributes. This fact means that the database complexity is very small, compared to those used in other works, consisting of CT images (Vandermeulen et al. 2006). Consequently, the calculation of tissue thickness values in all the landmark points is very fast.

3. LANDMARK INSERTION MODULE

The Landmark Insertion Module (LIM) block is in charge of placing 66 reference points on the skull surface, and assigning them a tissue depth value, based on a set of parameters of the person: age, gender and BMI range (previously introduced by the user in the system via the graphic user interface). The reference points used for this purpose are two sets of points traditionally used in forensic medicine. The first set (Figure

2–Left) results from an anthropological study carried out by the Legal Medicine School of Universidad Complutense de Madrid (EML). They are compulsory points, since they make possible to generate soft tissue in frontal and lateral sides of a skull. A second set of points has been considered to generate soft tissue around the whole skull (see Figure 2-right). That set of points has been selected so most users can recognize them unequivocally. Moreover, the soft tissue depth variations in that zone can be disregarded and their magnitude can be approximated by tissue depth in point 1 (see Figure 2–Left).

Figure 2: Landmark definition used for craniofacial reconstruction in this work. (Left) Set of 52 points to generate facial reconstruction in facial zone. Points 22-31 are bilateral (De Greef et al. 2006). (Right) Set of 14 points to generate craniofacial reconstruction in neurocranium. Points 1, 8-10 are bilateral, and 9 is not used (Moore-Jansen et al. 1994).



Therefore, two main processes participate in this module: landmark insertion (described in section 3.1), in charge of identifying the 66 landmark positions on the skull 3D image, and tissue depth load (analyzed in section 3.2), responsible for determining tissue thickness in all those reference points.

3.1 Landmark Insertion

The landmark insertion process places the set of 66 reference points on the skull 3D image. Two different ways to accomplish this task have been implemented: manually and automatically.

In the manual procedure, user inserts all landmarks directly on the skull image. The list of 66 reference points is displayed in the graphic user interface, via a combo-box element. The user only has to select one reference point and click on the skull image on its relevant position. The procedure is order-independent.

In the automatic procedure, all the landmarks will be placed automatically on the image. In order to perform that task, the skull 3D image is projected on the frontal, right and left planes, and landmark positions are calculated into these projection planes, since those positions are invariant in every skull. For this purpose, the skull had to be oriented previously, so that skull is in front position respect to viewer camera, faced towards it. Once all points have been placed on the projected images, an inverse transformation is applied over them to recover the whole 3D image, with all the landmarks placed on it. Likewise, user is allowed to modify any resultant position, if inaccurate.

3.2 Tissue depth load

Once all reference points have been placed on the skull 3D image, tissue thickness is assigned to each one, according to the age, gender and BMI range parameters previously introduced. Soft tissue depth values in reference points are known thanks to the anthropological study to characterize tissue depth information of Spanish population, performed by EML. This study is still in progress, and until this moment, it has been carried out with 160 people, men and woman, aged between 20 and 90 years old, and based on a previous study of Belgian population (De Greef et al. 2006). Tissue thickness values are classified into several groups:

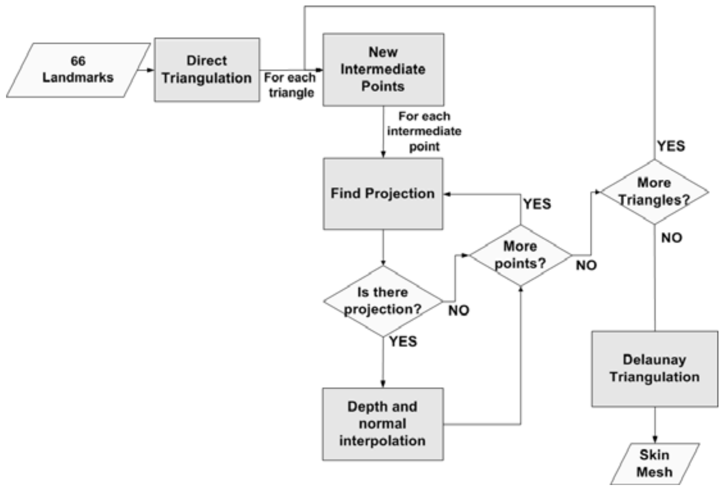
- According to gender: men and women.
- According to age: between 20 and 29 years old, 30 and 39, 40 and 49, 50 and 59, and older than 60.
- According to BMI range, population can be divided into 3 groups: people with BMI lower than 20, people with BMI between 20 and 25, and people with BMI higher than 25.

Considering the previous classification, 30 population groups can be found. For each group, a tissue thickness mean value is available in the database for every landmark. Based on that fact, and depending on the gender, age and BMI range values of the corresponding person, the system will access to the relevant entry in the database (population group and landmark), and will assign its depth value to each landmark.

4. SKIN MESH GENERATION MODULE

The Skin Mesh Generation Module (SMGM) block represents the main functional module in the application here presented. From output data generated in LIM, it manages to construct a full 3D mesh representing soft tissue (skin) belonging to the skull. In Figure 3 the block diagram of the present module is illustrated:

Figure 3: SMGM Block diagram



The general aim of this module is to generate a set of intermediate points on the skull surface, whose depth values can be interpolated from thickness values in reference points. The whole set of points (landmarks and intermediate points) will integrate the final skin mesh. For this purpose, the module receives the set of 66 reference points (their positions and depths), and determines new tissue thickness values in each intermediate point, attending to its location (closeness to the rest of landmarks). In the subsequent subsections, main functions participating in the whole process will be described.

4.1 Intermediate point generation

First step in skin mesh generation process is the creation of a set of new intermediate points, which will integrate the resultant final mesh. Those new intermediate points are created by using a new triangulation (transparent to the user). In a further process, those new generated points will be projected towards the skull geometry, so that new tissue depth can be obtained on them.

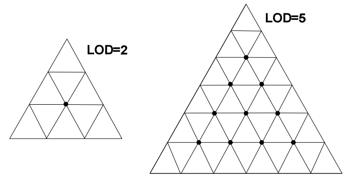
Therefore, the whole process of intermediate point generation concerns two main tasks: the construction of the reference triangle network, and the creation of the new intermediate points in those reference triangles. In relation to the first task, it is carried out from the 66 landmarks positions. A manual triangulation is performed, to optimize the amount of resultant triangles, and its shape and distribution.

Regarding the second task – creation of new intermediate points – for each resultant triangle, several intermediate positions are calculated, both inside the triangle and in its three edges. Creation of intermediate points in each edge consists in dividing that edge in equally-sized segments. Generation of intermediate points inside each triangle attends to a triangle subdivision, presented by Vlachos et al. (2001). A regular inner triangle subdivision is performed, according to the *level of detail* LOD, defined as the number of evaluation points on one edge minus two. The number n of intermediate points generated inside a triangle can be obtained from LOD as: $n = \sum i$, with i=[1,LOD-2] (see example in Figure 4).

To generate all the intermediate points inside the reference triangles, different LOD have been used, attending to the different size of each triangle (for greater triangles, higher LOD values have been applied).

Following this procedure, from a set of 120 reference triangles, a set of more than 11000 intermediate points are generated. Next step is to project all those points towards the skull geometry, to add the relevant interpolated tissue depth value.

Figure 4: Examples of inner triangle subdivision, with LOD=2 and LOD=5. Intermediate points are highlighted.



.

4.2 Intermediate point projection

Once a set of numerous intermediate points have been generated, next objective is to project all those points on the skull surface, in order to obtain a set of intermediate points where soft tissue depth can be added. Projection process is different depending on the location of the intermediate point needed to be projected. Based on this fact, two types of projections are performed: projection of points inside a reference triangle, and projection of points in a triangle edge.

Projection of intermediate points located inside a reference triangle is performed using the normal vector of that triangle. Projection of intermediate points located on an edge will be carried out using the vector $p=n_1+n_2$, where n_1 and n_2 are the normal vector of the triangles sharing that edge.

In both cases, projection will only be performed if the condition $d \leq d_{max}$ is satisfied, where d is the distance between the original intermediate point and the point projected on the skull mesh, and d_{max} is a threshold value. This condition avoids an intermediate point to be projected too far from the 3 nearest landmarks, which constitute the reference triangle (as it would happen, for example, inside eye sockets). The importance of this lies in the fact that the tissue depth associated to the new intermediate points on the skull mesh will be obtained from tissue depth values on those landmarks.

4.3 Intermediate depth and normal interpolation

In the previous step, a set of intermediate points on the skull surface where determined. Next task is to calculate their tissue depth values, to obtain the final set of points which will integrate the skin mesh. In all cases, an intermediate skin position can be obtained as $p_i+n_il_i$, where n_i is the normal vector in the skull intermediate point (projected point), and l_i the thickness associated to it. The way to determine l_i and n_i will differ, depending on the location of the original intermediate points in the reference triangles:

– For skull intermediate points coming from projection of points located inside a reference triangle (p'), n_i and l_i are interpolated from l_1, l_2, l_3, and n_1, n_2, n_3, the depth and normal values associated to the three landmarks integrating the reference triangle (influence landmarks). The subsequent equations are used (Bullock, 1999):
  $l_i = ul_1 + vl_2 + wl_3$, $\quad n_i = un_1 + vn_2 + wn_3$.
  Being $u = \dfrac{area(p', p_2, p_3)}{area(p_1, p_2, p_3)}$, $v = \dfrac{area(p_1, p', p_3)}{area(p_1, p_2, p_3)}$, $w = \dfrac{area(p_1, p_2, p')}{area(p_1, p_2, p_3)}$.
– For skull intermediate points coming from projection of points located in a triangle edge (p'), n_i and l_i are interpolated from l_1, l_2 and n_1, n_2, those depth and normal values associated to the two landmarks integrating that edge (influence landmarks). The following equations are used:
  $l_i = ul_1 + vl_2$ $\quad n_i = un_1 + vn_2$.
  Being $u = \dfrac{dist(p', p_2)}{dist(p_1, p_2)}$, $v = \dfrac{dist(p', p_1)}{dist(p_1, p_2)}$.

4.4 Mesh generation

Once the set of intermediate tissue points from the 66 landmark set has been generated, the next step is to build a 3D mesh from both sets of points. Regarding the fact that the final number of points is greater than

11000, an automatic triangulation algorithm is required. For this purpose, a Delaunay triangulation has been implemented. In Figure 5 a skull with its point sets (landmarks and intermediate points) are shown. In Figure 6, two reconstructions from two different skulls are presented:

Figure 5: Set of landmarks (white cylinders) and skin intermediate points generated (green spheres)

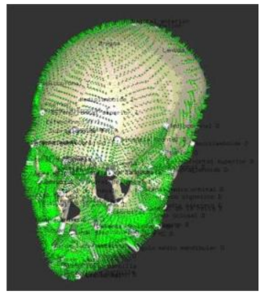
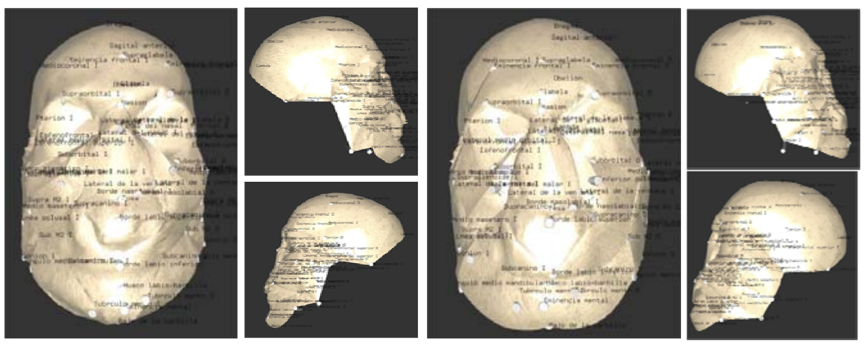


Figure 6: Examples of reconstructions using different skulls. (Left): 53-year-old man with BMI>25, front and lateral views. (Right): 34-year-old man with 20<BMI<25, front and lateral views



In the previous image, the achievements and limitations of this craniofacial reconstruction method can be detected. Regarding the achievements, zones where skull geometry shows soft variations are well reconstructed; this is the case of the forehead, the chin, the upper part and lateral faces of the nose. However, limitations can be found in zones where skull varies; it happens in zygomatic arch zones and near eyes and mouth, especially. In those zones, a greater number of landmarks would be needed.

4.5 Tests

In this section, the different tests performed to evaluate and validate the proposed method are presented. The main aim is to prove that the craniofacial reconstruction method here described verifies these statements:

1. Craniofacial reconstructions are different for different skulls.
2. Craniofacial reconstructions are different for a certain skull, using different BMI ranges.
3. Craniofacial reconstructions depend on the skull geometry, existing correspondence between skull morphology and skin mesh.
4. The procedure is not subjective, as long as craniofacial reconstructions only depend on tissue thickness values in the 66 landmarks and skull geometry.

To perform the test, 127 3D-scanned skulls (64 women and 66 men) have been used: 3 people aged between 20 and 29, 9 people between 30-39, 8 people between 40-49, 15 people between 50-59, and 96 people older than 60 years old.

Using these skulls, tests consisted on performing reconstructions varying BMI range values in each skull, and comparing results. In order to contrast objectively all existing changes, two representative measures have been taken in both skulls and generated reconstructions: distance between landmarks 1 and 10 (facial length) and between landmarks 23 - left and right (see Figure 2). In Table 1 shows the measures associated to different reconstructions stemming from 7 different skulls:

Table 1: List of measures (in cm.) taken in 7 sample skulls and reconstructions. Missing values are due to missing tissue depth values in those population groups

	Distance 1-10 (facial length)				Distance 23 left-right (bizigomatic breadth)			
	Skull	BMI<20	20<BMI<25	BMI>25	Skull	BMI<20	20<BMI<25	BMI>25
Individual 1 (25-year-old man)	15.19	15.8	15.85	15.9	10.99	12.73	13.65	14.06
Individual 2 (34-year-old man)	16.18	-	17.17	17.26	11.64	-	13.24	13.86
Individual 3 (39-year-old man)	15.29	-	16.27	16.39	12.21	-	13.85	14.67
Individual 4 (45-year-old woman)	14.09	-	15.06	15.15	11.22	-	13.21	13.57
Individual 5 (53-year-old man)	15.42	-	-	16.9	12.2	-	-	14.59
Individual 6 (73-year-old woman)	14.18	-	15.37	15.45	11.9	-	13.65	13.87
Individual 7 (75-year-old woman)	14.51	-	16.62	16.7	11.15	-	12.96	13.24

According to previous results, differences between reconstructions belonging to the same skull using different BMI values have been proved, and also differences between reconstructions from different skulls. Based on this fact, the objectivity of the present craniofacial reconstruction method can be ensured.

5. APPLICATION TO WEB

In this section, the implementation on a Web environment of the 3D reconstruction application is presented. The purpose is to allow different users the visualization from the Internet of both the input data and the generated reconstructions obtained by the main application (described in the previous sections).

Figure 7: Interaction between main application and web users

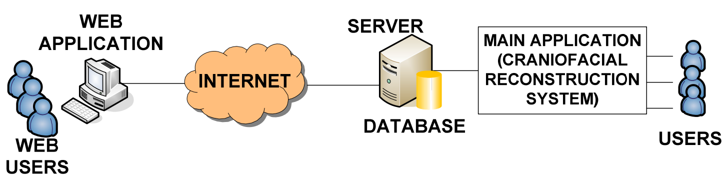


Figure 7 illustrates how web users interact with the main application. It comprises the following elements:

- Web application: web users can access and modify any information used by the main application and stored in the database. It is hosted in the web server and access to the database information by SQL queries. Authentication is required for web users, by means of a login and a password.
- Server: machine connected to the Internet. The database where all the information is stored is contained in this machine.
- Main application: the application described in the previous sections, in charge of generating craniofacial reconstructions objectively from skulls. The machine where the application is installed must belong to the same network than the server.

Thus, user can consult from the Internet any information contained in the application database (skull information and generated reconstructions). Besides, user can modify any information, and update it into the database. In this way, the results of a process that previously was complicated, non digitalized and difficult to share, it is currently available through the Web.

6. CONCLUSIONS

In this paper, a 3D craniofacial reconstruction system has been presented. This system enables to generate objectively the soft tissue of any individual only from his/her skull. Besides, the results can be consulted via web, and also all the information contained in the application database (skulls, their parameters and associated reconstructions).

The method used to generate craniofacial reconstructions is based on an interpolating tissue depth algorithm from a set of landmark points, where tissue depth is known. The method can be ensured to be objective, since it only considers skull geometry and individual parameters (age, gender and BMI range). On the other hand, scientific and technical feasibility of the procedure has been proved, and also its preference against traditional clay-based methods. However, the method presents some limitations: it tends to replicate the skull geometry. It provides good results in some facial areas (forehead and chin, for example), but also needs to be improved in others (places where skull geometry is variant), where more landmarks would be needed. In order to validate this method, tests with 127 skulls have been performed, comparing and contrasting generated reconstructions. Future work could proceed in the direction of improving the validation process, comparing any reconstruction to its relevant real skin mesh.

Another advantage of the presented system regards its ability to provide access to its information via web. That means both skulls and their reconstructions can be consulted from everywhere, and also be shared by several forensic communities. This fact was unimaginable with traditional craniofacial reconstruction methods, due the fact that real skulls and reconstructions needed to be protected from any physical damage. On the other hand, security in the access to the data is ensured, since the web application includes authentication procedures (login and password access). Security issue could be improved for future works, by using some security protocol (for example, SSL).

ACKNOWLEDGEMENT

Authors would like to thank the Spanish Ministry of Industry, Tourism and Commerce, for the support provided through the R&D project DEX-560610-2008-39, and the Legal Medicine School of Universidad Complutense de Madrid, which has contributed with the knowledge on forensic anthropology.

REFERENCES

Bullock, D. W. 1999. *Computer Assisted 3D Craniofacial Reconstruction*. Ph.D. thesis, University of British Columbia.

Claes, P. et al. 2006. Craniofacial reconstruction using a combined statistical model of face shape and shoft tissue depths: methodology and validation. *Forensic Science International*, Suppl 1:S147-S158.

De Greef, S. and Willems, G., 2005. Three-dimensional cranio-facial reconstruction in forensic identification: latest progress and new tendencies in the 21st century. *Forensic Science International, 50(1):12-17.*

De Greef, S. et al, 2006. Large-scale in-vivo Caucasian facial soft tissue thickness database for craniofacial reconstruction. *Forensic Science International*, 154 Suppl 1:S126-S146.

Iscan, Y.I. and Helmer, R.P., 1993. *Forensic Analysis of the Skull*. Wiley-Liss, New York, USA.

Krogman, W.M. and Iscan, M. Y., 1986. *The Human Skeleton in Forensic Medicine*, Charles C. Thomas, Springfield, USA.

Miyasaka, S. et al, 1995. The computer-aided facial reconstruction system. *Forensic Science International*, 1-2(74):155-165.

Moore-Jansen, P.M. et al, 1994. *Data Collection Procedures for Forensic Skeletal Material*, University of Tennessee: Forensic Antrhopology Center, Department of Anthorpology, Knoxville, USA.

Recheis, W. et al, 1999. New methods and techniques in anthropology. *Collegium-Anthropologicum*, 2(23): 495-509.

Shahrom, A.W. et al, 1996. Techniques in facial identification: computer-aided facial reconstruction using a laser scanner and video superposition. *International Journal of Legal Medicine*, 4(108):194-200.

Tyrrell, A.J. et al, 1997. Forensic three-dimensional facial reconstruction: historical review and contemporary developments. *Journal of Forensic Sciences*, 4(42):653-661.

Vandermeulen, D. et al, 2006. Computerized craiofacial reconstruction using CT-derived implicit surface representations. *Forensic Science International*, 159 Suppl 1:S164-S174.

Vlachos, A. et al, 2001. Curved PN Triangles. *Proceedings of the 2001 symposiuim on Interactive 3D Graphics.* New York, USA, 159-166.

Wilkinson, C. 2004. *Forensic Facial Reconstruction*. Cambridge University Press, New York, USA.