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The computer-aided facial reconstruction system

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Abstract

A computer imaging system was introduced into the facial reconstruction process. The system, which consists of the image processing unit for skull morphometry and the image editing unit for compositing facial components on the skull images, was an original construction. The image processor generates the framework for building a face onto the digitized skull image. For reconstructing a facial image on the framework, several possible data sets of facial components suitable for the skull morphology are selected from the database by operating our original application software. The most suitable cutout samples of facial components are pasted up over the framework in accordance with the anatomical criteria. The database of facial components consists of 24 contours, 18 eyes, 9 eyebrows, 27 noses, 9 lips and 16 hairstyles. After provisional reconstruction, the facial image is retouched by correcting skin colors and shades with an 'electronic painting device'. The resulting image is a great improvement on images made by the conventional clay and drawing method, both in the operational aspect and in the flexibility of creating multiple versions. The present system facilitates a rather objective and rapid approach and allows us easily to generate a range of possible faces. The computer-aided facial reconstruction will lead to an increase in chances of positive identification in practical cases.

Keywords: Physical anthropology; Personal identification; Facial reconstruction; Computer imaging equipment

1. Introduction

Forensic facial reconstruction is the scientific art of visualizing a face on the skull for personal identification. This technique may be highly useful when other efforts

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are unsuccessful in establishing the origin of unknown skulls [1,2]. To date, the facial reconstruction has mainly been carried out by using sculpting and drawing techniques, taking into account the anthropological findings, appropriate facial skin thickness and anatomical relation between a skull and facial features [1–5]. In Japan, the two-dimensional anatomical drawing method based on skull photographs is preferred as a practical method instead of the three-dimensional technique in clay.

Facial reconstruction has occasionally been useful for identifying an individual from the skull, nevertheless the validity of this technique as a guide to personal recognition has been questioned due to its high subjectivity, its requirement for artistic talent and so on [6,7]. In order to solve the methodological problems, in recent times electronic imaging equipment has widely been applied to facilitating the technical procedure of facial reconstruction [6,8,9].

The present study was designed to establish the operation system and the database for adding a computer system into the facial reconstruction technique.

2. Methods

2.1 Equipment and operation program

The present computer system consists of two main computer units, namely the image processing unit for skull morphometry and the image editing unit for compositing facial components on the skull image.

The following equipment and operation program are included:

(a) Image processing unit: The unit consists of our original application software and associated hardware, consisting of a DPAX2.5 image processor (Nexus Inc., Japan) connected to an NEC PC9801-DA host computer, a CCD-camera (HC-240, Ikegami Japan), and a 650 Mb 5-in. MO disk drive (SMO-S501, Sony, Japan) as a memory unit. The MO disk can store ~600 full size pictures per cartridge.

(b) Image editing unit: The main hardware is a graphic editor 'PAINTBOX V-series' (Quantel Ltd., UK), featuring computer graphics for compositing, painting and editing image data. As peripheral equipment, a 21-in. high-resolution color TV monitor (CM201N, ShibaSoku, Japan), a memory unit with a SCSI 1.2-Gb hard disk drive and a film recorder (FR-2000, Nippon Avionics, Japan) are attached to this unit. The hard disk drive can store ~1200 full size pictures or an equivalent number of full size cut-outs for the database of facial components.

(c) Operation program: The computer-aided facial reconstruction described here is performed in the same fashion as the two-dimensional drawing method. The present computer system can be operated by using our original application software.

The software consists of six main programs (Table 1). Among these programs, the 'Registration program' is available for preparing the database of facial components. In the Registration program, there are two main function menus. By operating these program menus, facial images of subjects are taken by the TV camera, and then the facial components of each subject are classified and registered, resulting in the establishment of the image database for facial components. On the other hand, the

Table 1
The original application software for computer-aided facial reconstruction

Registration program	Facial reconstruction program	Retrieval program
Face image input	Item (sex, orientation)	Editor program
Item (sex, age)	Skull image input	Maintenance program
Scale calibration	Shull morphometry	File list
	Anatomical landmark	MO format
Database management	Soft tissue thickness	Exit
Database of contour	Components retrieval	Backup copy
Database of eyes (left, right)	Contour	
Database of eyebrow	Eyes and eyebrows	
Database of nose	Nose	
Database of lips	Lips	
Database of hairstyle	Hairstyle	
	Evaluation	
	Superimposition mode	
	Wipe mode	
	Save	

practical operation for reconstructing faces is performed by using the 'Execution program'. This program enables us to initially put the framework onto the skull image. For reconstructing facial images, relevant facial components are semi-automatically selected from the database by operating the Retrieval menu of the Execution program. The final composite faces are anatomically checked with the corresponding skull by operating the evaluation menu of the program. Furthermore, the software includes several additional programs such as 'Retrieval', 'Editor', 'Maintenance' and so on.

2.2 Database of the facial components

As mentioned above, the database of facial components is constructed by operating the Registration program. For making this database, frontal and lateral standardized facial images from 239 male and 96 female Japanese adults were used in this study. Each person was subjected to the anthroposcopic and somatometric examinations of the face. The items of the anthroposcopic investigation were face type (contour), Mongolian fold (+,–) and sulcus palpebralis superior (+,–) in the eyes, inclination of the eyeslits, shape and inclination in the eyebrows, profile and tip position in the nose, shape of the oral slit, hairstyle and so on. In the somatometric investigation, 20 items of head length, head breadth, head height, bizygomatic breadth, morphologic face height, facial index (by Garson), bientocanthion and biectocanthion breadth, eye length, eye height, eyeslit index (height/length), interpupillary distance, nose breadth, nose height, nasal index, mouth breadth, total lip height, lips index (total lip height/mouth breadth $\times$ 100), upper and lower lip height were set up. All data obtained were subjected to the statistical analysis. The classification items described above were set up with reference to the reports of Asami [10] and Ichikawa [11].

The anatomical criteria of each facial component (contours, eyes, eyebrows and noses) are summarized as follows:

Contours. Two classification items were established on the basis of the Garson's facial index (morphologic face height/bizygomotic breadth × 100, three types: euryprosopic, mesoprosopic, leptoprosopic) and the shape (eight types: elliptic, oval, inverted oval, round, quadrangular, rhomboid, trapeziform, pentagonal) classified by the Pöch's criterion. Therefore, according to the combination of these components, 24 types in total were prepared as the standard cutout samples of the facial contour.

Eyes. Three classification items were established on the basis of the inclination (three types: downward, level, upward), the shape (two types: Mongoloid type, Caucasoid type) and the size (three types: broad, middle, narrow). According to the combination of these components, 18 types of the standard cutout samples of the eyes in total were prepared. In general, it is very difficult to anatomically determine the shape of eyes from a skull alone. The present anthroposcopical studies indicated that the eyes in Japanese population can be divided into two main types, Mongoloid and Caucasoid. The Mongoloid type is characterized by the single upper-eyelid with Mongolian fold. On the other hand, the Caucasoid type is prescribed on the condition showing the double upper-eyelid without Mongolian fold. The frequency of appearance of Mongoloid and Caucasoid types was 35% (male: 36.8%; female: 32.3%) and 37% (male: 34.9%; female: 43.2%), respectively. In Japanese, especially, there is a strong tendency for single-eyelid subjects to have a Mongolian fold and double-eyelid subjects to have no Mongolian fold. This tendency was analyzed by the χ^2-test, and the result was statistically significant at the 0.01 level. The size of eyeslits was classified into three groups on the basis of the statistical value (standard deviation value) of the eyeslit index. The mean value and standard deviation of eyeslit indices within our reference subjects were 31.2 ± 4.7 for male and 35.4 ± 4.7 for female. In addition, the somatometrical findings suggested that eyeslits in single-eyelid subjects tend to be narrower than those in double-eyelid subjects. The mean values of the eyeslit indices in single- and double-eyelid groups were 32.0 (male: 30.1; female: 34.0) and 34.5 (male: 32.4; female: 36.7), respectively. This difference was significant by Student's t-test ($P < 0.05$).

Eyebrows. Two classification criteria were established on the basis of the inclination (three types: downward, level, upward) and the shape (three types: straight, arced, triangular). Therefore, nine types were prepared as the standard cutout samples.

Noses. Three classification items were established on the basis of the nasal index (three types: wide, middle, narrow), the lateral shape (three types: convex, straight, concave) and the position of the tip (three types: high, middle, low). According to the combination of these components, 27 types in total were prepared as the standard cutout samples. From the statistical analysis of our somatometrical data on the nose, it was suggested that the correlation between nasal height (nasion-subnasale) and facial height (nasion-gnathion) is relatively high ($r = 0.48$).

Lips. Two classification items were established on the basis of the oral-slit (three types: convex, straight, concave) and the thickness (three types: thin, middle, thick).

Table 2
Standard cutout samples for facial reconstruction. Each standard sample has two image data of frontal and lateral views

Facial component	Classification items	No. of types
1 Contour	Facial index (3), shape (8)	24
2 Eyes	Shape (2), size (3), inclination (3)	18
3 Eyebrows	Shape (3), inclination (3)	9
4 Nose	Nasal index (3), profile (3), tip position (3)	27
5 Lips	Thickness (3), oral slit (3)	9
6 Hairstyle	Shape	16

Therefore, nine types were prepared as the standard samples of the lips. In general, there is no way in which we can be guided effectively as to the precise lip type from a skull alone. For constructing lips, standard samples with a high frequency in the population should be used. The frequencies of appearance of three types in the oral-slit were 15.1% in the convex type, 70.8% in the straight type and 14.1% in the concave type. The thickness of lips was classified into three groups on the basis of the statistical value (standard deviation value) of the lips index. The mean value and standard deviation of lips indices within our reference subjects were 35.1 ± 6.8 for males and 38.7 ± 6.7 for females.

The list of standard cutout samples used in the present facial reconstruction system are summarized in Table 2.

The procedure for making the database of facial components involves initially digitizing faces of the subjects with a CCD-camera interfaced to the image processing unit. The digitized facial images are calibrated in scale, and then electrically cut out. From each subject, five cutout samples such as contour, eyes, eyebrows, nose and lips can be obtained (Fig. 1, left). For registering each cutout sample, an

Fig. 1. Electronic cutout of facial components for making the databases (left) and the instructional message of the registration program (right).

operator selects the appropriate elements from the classification items of sex, age group and anatomical characteristics of each facial component with the menu screen (Fig. 1, right). After complete input, both the item data and the image data are filed and stored in the databank of the computer unit.

3. Results

The present computer system can be operated by using our original computer hardware, operation program and the database of facial components.

3.1 Establishment of the framework

In the first place, by fixing the Frankfurt plane on the horizontal plane, an image of the skull was taken by the TV camera interfaced to the image processing unit. In capturing the skull image, the position of the camera was set up to be horizontal and focused on the nasion of the skull. The distance between the skull and the camera

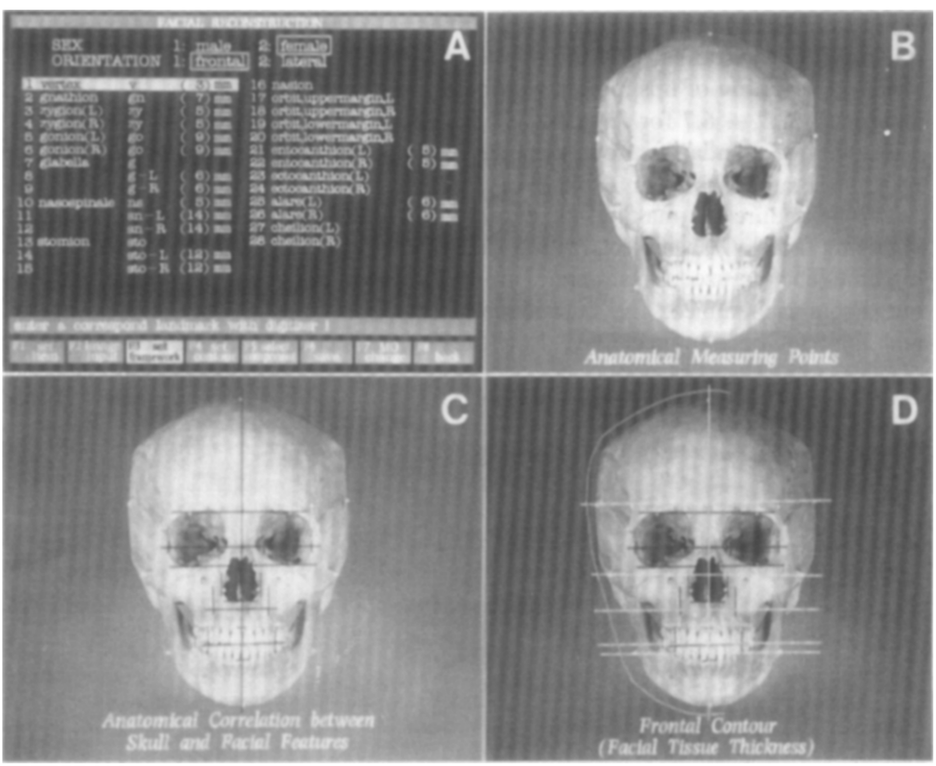

Fig. 2. Establishment of frontal framework for the facial reconstruction. The serial operations can be performed by using the program menu with 28 items for the skull morphometry (A). On the basis of the positions of anatomical landmarks (B), anatomical coordinates for arranging facial components (C) and a standardized facial contour (D) are sequentially determined.

was fixed at 2 m for the purpose of reducing perspective distortion of the image. The digitized skull image data are calibrated in scale, and then X-Y axes for the craniometry are set up. The scaling of the skull was performed automatically by converting the actual measurement between landmarks (zygion-zygion) into the number of pixels on the monitor. In the next place, the image processor generates a framework onto the digitized skull image. These serial operations can be performed by using the 'Skull morphometry' menu of the execution program. In the program menu, there are 28 items for skull morphometry (Fig. 2A). According to the instructional message on the menu screen, an operator indicates all of the 28 measuring points on the skull image with the digitizer (a graphic tablet and stylus), and the image processor semi-automatically establishes the relevant framework immediately. Average data in soft tissue thickness for constructing a facial contour are also indicated on the menu screen even by previously selecting the corresponding sex and orientation of the skull (Fig. 2A). The numerical value of the skin thickness is changeable as required. All of inputting is carried out with the digitizer and keyboard interfaced to the computer unit.

The practical procedure on the image monitor was shown in Fig. 2B–D. Anatomical coordinates for arranging facial components (Fig. 2C) and a standardized facial contour (Fig. 2D) are sequentially determined based of the position of anatomical landmarks inputted (Fig. 2B). At the same time, the measurements of the skull are performed for calculating the facial index, the nasal index and so on. Finally, the framework for the facial reconstruction can be established. The image data of the framework are subsequently translated to the image editing unit.

3.2 Facial reconstruction

The image editing unit consists of the graphic editor and memory units of the

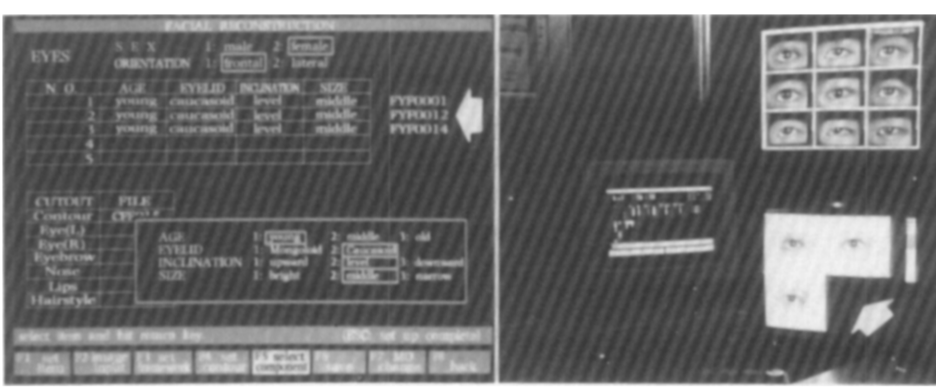

Fig. 3. The contents of the retrieval menu for the eye cutout samples. An operator inputs the relevant elements from the classification items (age, eyelid, inclination, size), and the computer immediately automatically selects the corresponding cutout samples from the eye database. In this case, three files were detected (left: arrow). At the same time, the images of corresponding cutout samples are also displayed on the monitor (right: arrow).

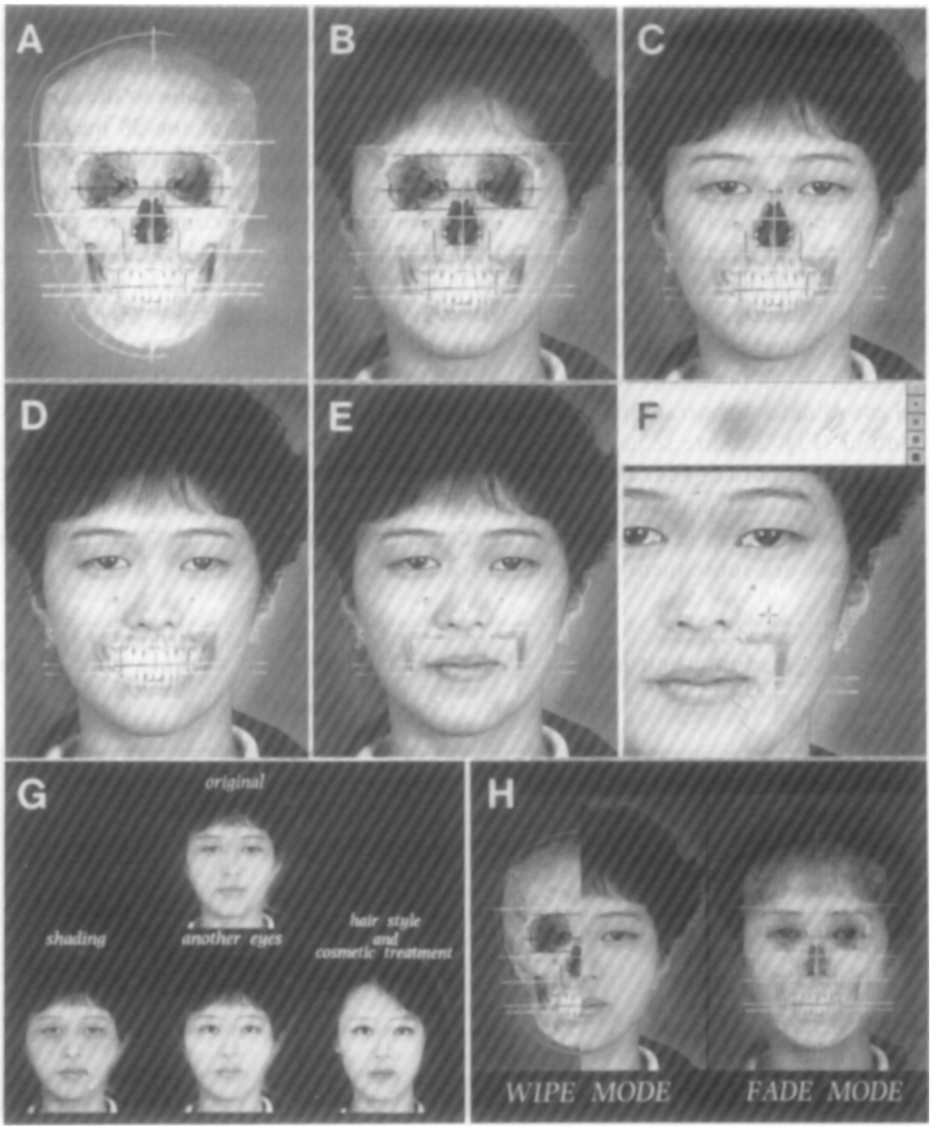

Fig. 4. The process of the facial reconstruction. The relevant cutout samples were pasted up over the framework in the order of contour, eyes and eyebrows, nose and lips (4A–4E). Furthermore, retouch (4F) and modification (4G) of the facial image can be performed, and finally anatomical relations between the skull and the face are checked by using the evaluation program (4H).

database. In this stage, facial components suitable for the skull morphology are selected and added to the framework in accordance with the anatomical and anthropometrical criteria (Fig. 3). The selection of facial components can be objectively performed by retrieving the database of cutout samples. The database of facial components was constructed from existing colored facial images, consisting of 24 contours, 18 eyes, 9 eyebrows, 27 noses, 9 lips and 16 hairstyles. All of the cutout samples are transparencies that can be assembled into individual faces. According to the instructional message of the 'Retrieval menu', an operator inputs the relevant elements from the classification items in each facial component, and then the computer automatically searches the database and immediately indicates the several file names of corresponding cutout samples (Fig. 3, left). On the monitor, the several images of the corresponding cutout samples are also displayed (Fig. 3, right). However, there are the limitations of computer ability in retrieval. Therefore, the most suitable sample must carefully be selected from the corresponding samples by an examiner taking anatomical and anthropometrical findings of the skull into account. Finally, the most suitable cutout sample is adjusted in both size and orientation, and pasted up precisely over the framework. These operations are repeatedly performed in the order of contour, eyes and eyebrows, nose and lips (Fig. 4A–E).

With regard to the positional correlation between eye and orbit, the eyeslits are generally distributed on a lower third of the orbital height [12]. In particular, the position of 'malar tubercle', which is the point of attachment of the lateral palpebral ligament, affects both the position of the outer canthus and the inclination of the eyeslit. Our investigation of the past 50 actual cases positively identified by the superimposition suggested that the frequency of appearance of the upward-eyeslit type was significantly high in the case where the malar tubercle was clearly located in a high position. In the horizontal placement, the entokanthion (en) lies >3 mm inside the medial orbital margin and the ektokanthion (ex) lies on the lateral margin of the orbit. In addition, from our experience in working with superimposition techniques, the skull with high orbits tends to have the eyes of the Caucasoid type. In positioning the eyebrow, it is generally accepted that the midline of the eyebrow lies on the supraorbital margin or slightly inferior to it [12]. The distributions of root, base and wings in the external nose can be suggested by the structure of the nasal aperture and nasal bones. The average distance from the lateral margin of the nasal aperture to the ala (al) of a flesh nose is ~ 6 mm in Japanese people, and subnasale (sn) lies 5 mm below the lower margin of the aperture [12]. In regard to the positional relation between lips and teeth, as a general rule, mouth width corresponds to the distance between the outer margin of the upper first premolar teeth, and the stomion (sto) lies 1 or 2 mm higher than the upper incisal edge [12].

On the facial image in the process of reconstruction, there are some poor spots such as naked bony surface and uneven skin color between cutout samples. In order to humanize the facial image, unattractive parts are retouched by using the electronic painting device (Fig. 4F). The retouching steps, firstly filling skin color in blanks, secondly matching of the skin color between cutout samples and finally shading skin surface corresponding to undulation of the skull structure, are carefully performed. The resulting images are of objective validity and reality, which is preferred to produced using conventional clay and drawing methods. Furthermore, by using the present computer system we can easily prepare several possible composite images for only one skull sample. As an example, shading around the eyeslit, substitution of single-eyelid for double-eyelid, and as a practical operation, an exchange of hairstyle and makeup are also available (Fig. 4G). After complete reconstruction, anatomical correlation between the skull and the facial image can be checked in the same manner as for the superimposition method (Fig. 4H). The final image is output in full color with the film recorder.

4. Discussion

The forensic facial reconstruction has been performed according to fairly scientific criteria based on anatomy and anthropometry, and has successfully been used for determining a particular person from a questioned skull [13]. However, the validity of facial reconstructions in the personal identification has occasionally been questioned [7]. Also in textbooks on forensic anthropology, Krogman and İşcan [3] and Stewart [4] have presented a review of the facial reconstruction techniques, stating the methodological limitations of current facial reconstructions. It is presumed that the current methods have several fundamental shortcomings such as being highly subjective, requiring artistic talent and being time-consuming.

In recent years, in order to solve the methodological problems, electronic imaging equipment has widely been introduced into facial reconstruction. The greatest advantages of introducing a computer system are the reduction of subjectivity and the shortening of the length of experience required for facial reconstruction. The possibility and validity of computer-aided facial reconstruction have been also investigated in several scientific reports [6,8,9]. In 1988, Perper, Patterson and Backner [6] introduced facial imaging reconstructive morphography (FIRM) as a new method for physiognomical reconstruction. The FIRM system permitted the construction of objective composites of facial features based on precise cephalometric measurements of radiographic films of the skull. In the FIRM system, as a database of facial components, the Smith and Wesson Model II Identi-kit was used. On the other hand, Ubelaker and O'Donnell [8] applied the equipment that had been originally developed to illustrate the aging of missing persons to facial reproduction. Furthermore, a method using three-dimensional computer graphics system was reported by Vanezis, Blowes, Linney, Tan, Richards and Neave [9]. However, they suggested that facial thickness measurements need to be taken from a greater number of anatomical points for the three-dimensional facial reconstruction.

On the other hand, the present computer-aided facial reconstruction is performed in the same methodological fashion as the two-dimensional drawing method. The primary purpose of this study was to establish the operating system and the database of facial components suitable for Japanese facial reconstruction. Our system consists of the image processor for skull morphometry and the graphic editor for compositing facial components onto the skull framework, which can be operated by using our original application software. The databases of facial components were prepared from existing facial images taking account of anatomical characteristics and anthropometrical findings of Japanese facial features. According to the combination of facial components in the database of each sex group, it is possible to composite facial images of ~ 1 million different types. In a future study taking account of the sex (male, female) and age-class (young, middle, old), six different versions of databases will be added to this computer-aided facial reconstruction system.

The current tendency in the forensic facial reconstruction may be computerization of the methodology. However, in view of the present situation of advancing computer technology, it is too early to nominate the best approach and to discuss the present method in comparison with other computer methods. Furthermore, as mentioned by Vanezis, Blowes, Linney, Tan, Richards and Neave [9], there were a number of difficulties, other than those related to the computer hardware and software, which have to be overcome. On the occasion of introducing the computer system into the facial reconstruction method, the most important matter may be to establish supplements of anatomical and anthropometrical criteria and reliable standard databases of facial components. When these tasks are fulfilled, computer-aided facial reconstruction will become a useful tool for the forensic anthropologist and lead to the increase in chances of positive identification from unknown skulls. In addition, the more detailed examinations of physical evidence and additional information for estimating a victim's personality and life-style may heighten the possibility of producing reasonable facial images of the victim.

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