Chai Dong-Sheng,[1] *M.D.; Lan Yu-Wen,*[1] *M.D.; Tao Cheng*[1]*;*
Gui Run-Ji[1]*; Mu Yong-Chuan*[1]*; Feng Jian-Hai*[1]*;*
Wang Wei-Dong[1]*; and Zhu Jiang*[1]

A Study on the Standard for Forensic Anthropologic Identification of Skull-Image Superimposition

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ABSTRACT: By means of X-ray photography tests were made of 224 (100 males and 124 females) volunteer Chinese adults of Han nationality to study the related regular patterns of superimposed projection of face landmarks onto the skull. On the basis of these tests, the present article reveals from a forensic anthropology angle the related regular patterns of plane projection of the human face with its skull. Study shows that there exist a strict individual identity and exclusiveness in relation between the human face and skull. The related regularity of displacement of face landmarks appears in projection of the skull with the human head at different photographic positions and angles. On the basis of this discovery, 52 indexes in 4 groups were established as a standard for judging the identification of a skull's body origin by means of skull-image superimposition. Based on forensic anthropology, the technique has raised to a great extent the credibility of unknown skull identification. In the past 8 years, 89 unknown skulls have been identified with their body origins which provided important and accurate evidence for the solution of murders with dismembered bodies, skeletonized bodies, and unidentified dead bodies.

KEYWORDS: physical anthropology, human identification, superimposition, photography

Identification of skull body origin with skull-image superimposition is a means of identifying a skull with a picture of a missing person (the suspect) through photographic superimposition. This method has aroused attention from legal medical experts of various countries, and studies and modifications have been made in identification standards and superimposition [*1–3*] since 1935 when British legal medical expert J. Glaister and Professor J. C. Brach successfully identified the body origin in the Ruxton Case [*4*]. But under circumstances in which there is lack of an anthropologic relationship between face and skull projections, it is hard to judge scientifically and exactly the results of an identification done with skull-image superimposition because of the variation in projection caused by human image photographing and the interference of skull similarity. From the study on the 224 test subjects by means of X-ray photography, it was discovered that there exists a strict individual identity and exclusiveness in face landmarks with corre-

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[1]Director and forensic doctor, senior engineer, engineer, chief inspecting forensic doctor, and assistant engineers, respectively, Tieling 213 Research Institute, Tieling, Liaoning Province, China.

sponding parts on the skull. For judging the identity of a skull with a human photo, 52 indexes [5,6] in 4 groups were established as an identification standard. This provides an important forensic anthropologic base for identifying the skull's body origin with the method of skull-image superimposition.

Procedures of Study

Objects of Study

Of Han nationality, 224 healthy Chinese adults (100 males and 124 females) aging from 18 to 55 were selected from voluntary test subjects.

Landmarks and Marking Lines on Face and Skull

Thirty-four landmarks were selected (see Fig. 1).

Selection of Marking Lines—A marking line is formed by the connection of landmarks. The cross lines are horizontally parallel while longitudinal lines are vertical to the cross lines. In this study the line between the two ectocanthions was used as a horizontal baseline and the front central line was vertical to the bi-ectocanthion line while other marking lines, all running through respective landmarks, were parallel with or vertical to the bi-ectocanthion line. Eight marking lines were selected. In Fig. 2, the line between the two ectocanthions was fixed first and in Fig. 3 the line between the two ectoconchions was selected first.

Practical Procedures of Study

Anthropologic measurement was first made with face landmarks of test subjects.

An X-ray head photo of the superimposed projection of face landmarks and skull was taken.

Lead drops 2.0 mm in size were stuck to the 34 landmarks selected for the test subject's face, with two ectocanthions as object points. The object point was 45 mm away from

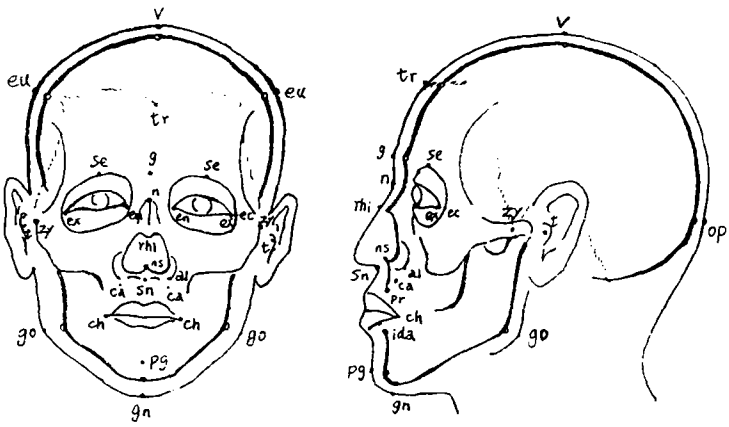


FIG. 1—*Landmarks often used on face and skull:* g: *glabella*, tr: *trichion*, v: *vertex*, op: *opisthocranion*, n: *nasion*, sn: *subnasal*, gn: *gnathion*, p: *pogonion*, rhi: *rhinion*, ns: *nasospinal*, pr: *prosthion*, ina: *infradentale anterius*, t^{λ}: *tragion*, eu^{λ}: *euryon*, al^{λ}: *alare*, ch^{λ}: *cheilion*, en^{λ}: *entocanthion*, ex^{λ}: *ectocanthion*, zy^{λ}: *zygion*, go^{λ}: *gonion*, ca^{λ}: *caninion*, se^{λ}: *superciliary, and* ec^{λ}: *ectoconchion.* $^{\lambda}$*denotes two-side marks.*

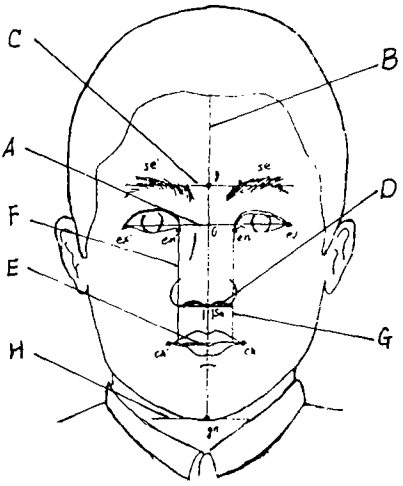


FIG. 2—*Marking lines on face:* A: *line ex' – ex,* B: *front central line g – gn,* C: *line se' – se,* D: *line – sn,* E: *line ch' – ch,* F: *vertical line en' – eh',* G: *vertical line en – eh and* H: *line – gn –.*

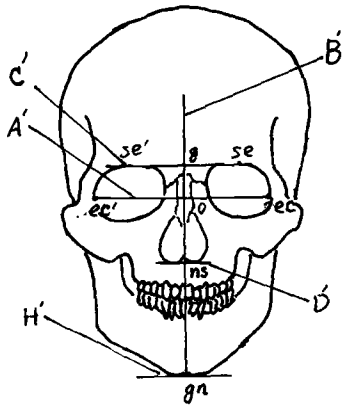


FIG. 3—*Marking lines on skull:* A': *line ec' – ec,* B': *front central line g – gn,* C': *line se' – se,* D': *line – ns –, and* H': *line – gn –.*

the X-ray film that was 2.0 m away from the X-ray tube ball. An X-ray head photo in pitch position was taken at every 5° and one in horizontal deflection was taken at every 10° (see Fig. 4). Marking relationships of the face with the skull were measured and computed respectively on the X-ray head photo taken. Data thus obtained, which was corrected for its enlargement and lack of fidelity caused by X-ray photography, were made to conform with the actual projection data. The correction formula is:

$$R = (D - d)\frac{I}{D}$$

where R is corrected data, D is the distance between target and film, d is the distance between object and film, and I is data of the X-ray picture actually measured.

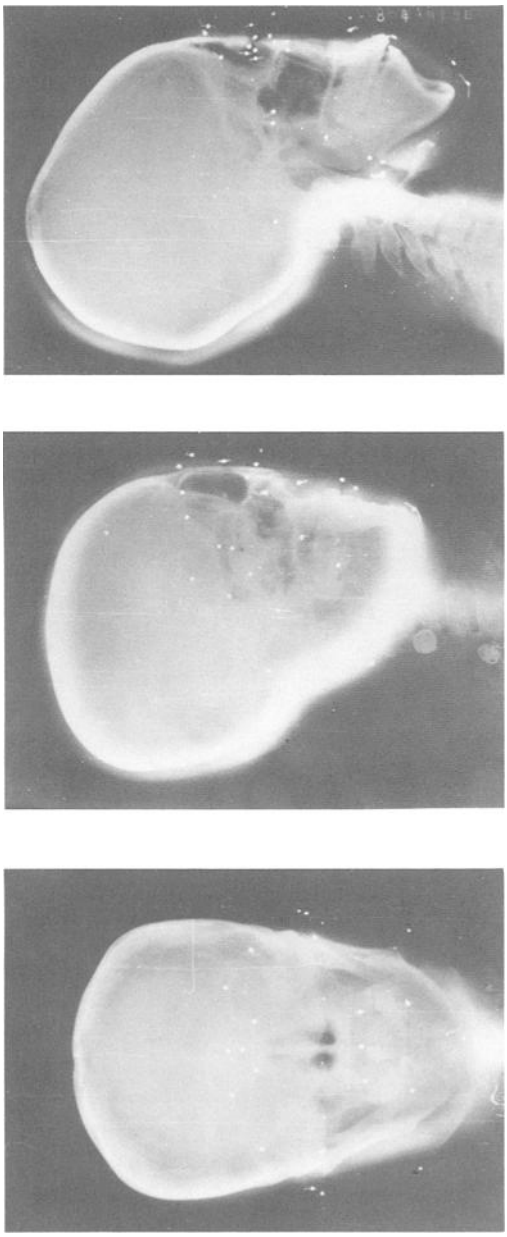


FIG. 4—*Relationships of face landmarks with skull with left deflection of image at horizontal position.* (left) *Relationship of X-ray head photo's landmarks with skull taken at 0° azimuth.* (middle) *Relationship of X-ray head photo's landmarks with skull taken at 90° azimuth.* (right) *Relationship of X-ray head photo's landmarks with skull taken at 45° azimuth.*

Analysis and Result

Establishment of Superimposing Angles and Their Related Indexes

Through anthropologic measurement of the test subjects' face landmarks and study of the X-ray head photos, it was discovered that the relationship reflected on the X-ray head photo of the face landmarks and skull changed in a different way and in a regular pattern from the X-ray head photos taken with a human image at different angles. The changes could be observed directly and measured, but some of the changes could not be measured directly but could only be reflected through related indexes.

The photographing angle for the human image and the skull photo was determined by means of a deflection index and a pitch index.

It was discovered in study that the deflection and pitch angles could be measured and computed by means of changes in line sections of the line between two ectocanthions and the front central line (see Fig. 2).

$$\text{Image deflection index } X = \frac{(0 - \text{ex}) \text{ length}}{(0 - \text{ex}') \text{ length}}$$

From deflection index X, the deflection angle $Y°$ can be calculated: $Y° = 91.33 \sim 89.0 X$. $S_{ya} = 1.83°$.

$$\text{Image pitch index } X° = \frac{(\text{g} - \text{Sn}) \text{ length}}{(\text{Sn} - \text{gn}) \text{ length}}$$

From pitch index X, the pitch angle $Y°$ can be calculated: $Y° = 94.54 - 98.70X°$. $S_{ya} = 1.38$.

Calculation of the angle for the skull photo is basically the same as above for the human image. The only difference is in the selection of line sections on the skull used for index calculation (see Fig. 3).

$$\text{Skull photo deflection index } X = \frac{(0 - \text{ec}) \text{ length}}{(0 - \text{ec}') \text{ length}}$$

$$\text{Skull photo pitch index } X° = \frac{(\text{g} - \text{ns}) \text{ length}}{(\text{ns} - \text{gn}) \text{ length}}$$

In calculation of pitch angle, its positive value denotes pitch-up angle and its negative value denotes pitch-down angle.

Interrelated Relationship of Face Landmarks with the Skull Expressed by Means of the Interrelated Index

Some of the distance relationships indicated by face landmarks and marking lines on the skull may objectively reflect the position of the landmark, for instance, the distance of the superciliary to the supraorbital. But some of them are not able to reflect the relationship of their positions, such as entocanthion and so forth, especially the relationship between the eye and its orbit as well as their displacement at different positions and angles. But through study, it was discovered that the superimposing relationship of the eye with the orbit could be expressed by means of an interrelated index (see Fig. 5).

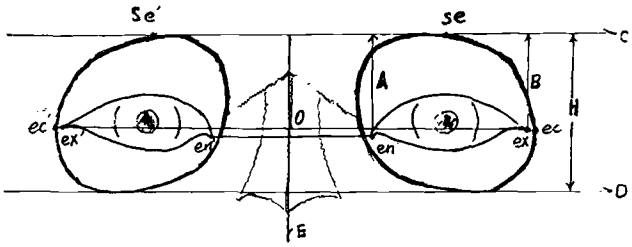


FIG. 5—*Respective marking relationship of eye with orbit:* A: *distance from entocanthion to supraorbital,* B: *distance from ecotocanthion to supraorbital,* C: *supraorbital,* D *orbital,* E: *front central line,* H: *orbital height and* O: *intersection point of front central line with line between two ectocanthions.*

For example,

$$\text{entocanthion index} = \frac{A}{H}$$

$$\text{ectocanthion index} = \frac{B}{H}$$

$$\text{index of distance between two entocanthions} = \frac{\text{en}' - \text{en distance}}{\text{ec}' - \text{ec distance}}$$

and

$$\text{index of distance between two ectocanthions} = \frac{\text{ex}' - \text{ex distance}}{\text{ec}' - \text{ec distance}}$$

and, moreover, the cheilion is determined by the cheilion index. If the ectocanthion in the human picture is not clear, the index or rima palpebrarum length can be used to determine its position.

Interrelated Relationship of Face Landmarks with the Skull and the Regular Patterns of Variation Observed When They Were in Different Angles

From part of the indexes listed in Table 1, it is obvious that only the index of distance between two entocanthions and positions of the entocanthion vertical line and maxillo-teeth are relatively stable, and no change was observed with changes in the angle of image pitch and deflection. All the rest of the indexes of the landmarks change in a regular pattern with change in the image photographing angle. Generally, landmarks are observed to move upward along with the upward pitch of the human image and to move downward with the downward pitch of the human image.

On Soft Tissue Thickness of the Face Landmark and Its Regularity that Appear Along with a Change in the Angle of Image Photography

The thickness of landmark soft tissue can be measured and determined from a corrected X-ray head photo. No change of an increase or decrease along with a change in angle was observed in all of its indexes. All landmarks that could be observed, however, bear a direct relation with the deflection angle. For instance, landmarks on the front central line and on the back of the head, glabella, and opisthocranion could only be observed when the image deflection was close to 90° (see Table 2).

TABLE 1—*Interrelated relationship of face landmarks with the skull.*

	Front Position 0°: $\bar{x} \pm \delta$	Regular Patterns of Displacement with Change in Position and Angle of Human Image
Distance from superciliary to supraorbital	0.69 ± 1.74 mm	Pitch: $Y = 0.98 + 0.298X$ mm
Ectocanthion index	0.61 ± 0.05	Pitch: $Y = 1/(-1.732 \times 10^{-5} - 1.564 \times 10^{-5}X + 0.027X^2)$
Entocanthion index	0.67 ± 0.47	Pitch: $Y = 0.6586 - 5.714 \times 10^{-3}X$
Index of distance between two ectocanthions	0.94 ± 0.02	Deflection: $Y = (X - 0.94)/(-6.1035 \times 10^{-5} - 100X)$
Index of distance between two entocanthions	0.37 ± 0.02	No change in both pitch and deflection positions
Distance from subnasal to nasospinal line	−3.63 ± 1.77 mm	Pitch $Y = 2.9186 + 0.4696X$
Entocanthion vertical line with position of maxillo-teeth	Positioned 3rd tooth (left right)	In deflection, no change observed in the vertical line opposite to deflection with position of 3rd tooth
Distance from ectocanthion to supraorbital line	2.18 ± 0.457 mm	Deflection side: $Y = (X - 2.41)/5.2165 + 0.0878X)$ Opposite side of deflection: $Y = (X - 5.31)/(1.0314 + 4.603 \times 10^{-2}X)$
Index of cheilion line	1.183 ± 0.235	Little change in both pitch and deflection
Index of distance between mandibular angles	0.799 ± 0.04	Disappeared with deflection over 20°

TABLE 2—*Relationships of landmark soft tissue thicknesses with different deflection angles (mm).*

		0°	15°	30°	45°	60°	90°
Vertex		6.00 ± 0.04	6.12 ± 0.02	6.12 ± 0.96	6.04 ± 0.76	6.10 ± 0.74	6.22 ± 0.94
	Euryon						
	left	7.23 ± 1.28	8.20 ± 1.27				
				. . .	. . .	. . .	. . .
	right	7.27 ± 1.23	7.30 ± 1.14				
	Zygion						
	left	6.95 ± 1.61	8.53 ± 1.79	9.69 ± 1.66			
					. . .	. . .	. . .
	right	6.95 ± 1.61	5.96 ± 1.54	. . .			
	Tragion						
	left	8.34 ± 1.79	8.90 ± 1.79				
				. . .	. . .	. . .	. . .
	right	8.34 ± 1.79	6.11 ± 1.25				
	Gonion						
	left	10.8 ± 2.46	14.5 ± 3.11	15.82 ± 2.70	14.8 ± 2.13		
						. . .	. . .
	right	10.8 ± 2.46	10.1 ± 2.55	. . .			
Gnathion		7.37 ± 1.07	7.61 ± 1.57	7.50 ± 1.42	7.30 ± 1.45	7.25 ± 1.31	7.41 ± 1.31
Zygion		. . .	9.22 ± 1.57	10.3 ± 1.58	10.9 ± 1.57	11.3 ± 1.56	. . .
Opisthocranion		. . .	. . .	. . .	. . .	. . .	6.95 ± 1.38
Trichion		. . .	. . .	. . .	. . .	. . .	5.03 ± 1.64
Glabella		. . .	. . .	. . .	. . .	. . .	5.71 ± 0.94
Rhinon		. . .	. . .	. . .	. . .	. . .	3.13 ± 2.20
Subnasal		. . .	. . .	. . .	. . .	. . .	10.6 ± 2.57
Pogonion		. . .	. . .	. . .	. . .	. . .	11.3 ± 2.48

Relationship of Profile Morphological Curve with Deflection Angle

There exists a very high identity and exclusiveness between the cephalo-facial profile morphological curve and the skull curve. The appearance of the cephalofacial profile morphological curve is directly related to the deflection angle of the human image (see Table 3 and Fig. 6).

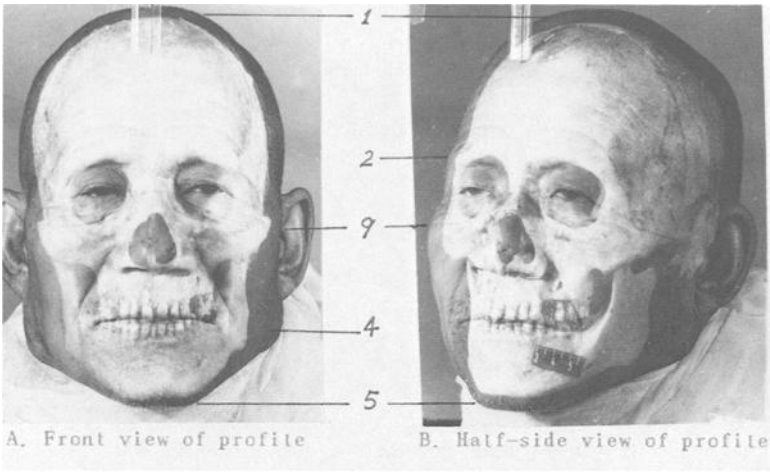
On the Problem of Determining Lines

The eight marking lines on the face are also called determining lines. The superimposition of the marking lines on the human image with those on the skull is in effect the interrelated relationship among the landmarks. The superimposition of the bi-superciliary line with the supraorbital line, for instance, is actually expressed by the distance from the superciliary to the supraorbital line. The relationships of the bi-superciliary with the bi-supraorbital line, the subnasal line with the nasospinal line, the gnathion line on the human image with that on the skull, and the bi-entocanthion line with the caninion on the skull are all measured and determined by means of the interrelated distances between the landmarks. Of all the marking lines, only the bi-ectocanthion line and the front central line are key lines because the bi-ectocanthion line determines the deflection angle of the human image and its length is the index for judging whether the human image has been restored to its original size, while with the front central line, the pitch angle of the human image can be computed. In the front view, the front central line on the human image should completely superimpose with that on the skull. Along with the increase of the deflection angle, the distance between the two lines increases. At 90° of deflection, the parallel distance between the two lines should be the soft tissue thickness of the glabella, approximately 6.0 mm. The standard for judging the superimposition of the two lines, therefore, should be expressed with the distance between the glabella on the human image and that on the skull. Its regular pattern is $Y = 0.067X$, where Y is the distance between the two glabellas and X is the deflection angle.

TABLE 3—*Relationships of landmark soft tissue thicknesses with different deflection angles (mm).*[a]

	Deflection Angle					
Profile Curve	0°	15°	30°	45°	60°	90°
Head vault curve	+	+	+	+	+	+
Arcus superciliary curve						
left	+	+	+	+	+	+
right	+	+	+	+	+	+
Gonion curve						
left	+	+	+	−	−	−
right	+	+	+	+	+	+
Nose curve	+	+	+	+	+	+
Lower jaw curve	+	+	+	+	+	+
Head back curve	−	−	−	−	−	+
Forehead curve	−	−	−	−	−	+
Pogonion curve	−	−	−	−	−	+
Zygomatic curve						
left	+	+	+	−	−	−
right	+	−	−	−	−	−

[a]Note: + denotes appearance and − denotes no appearance in left deflection positions.



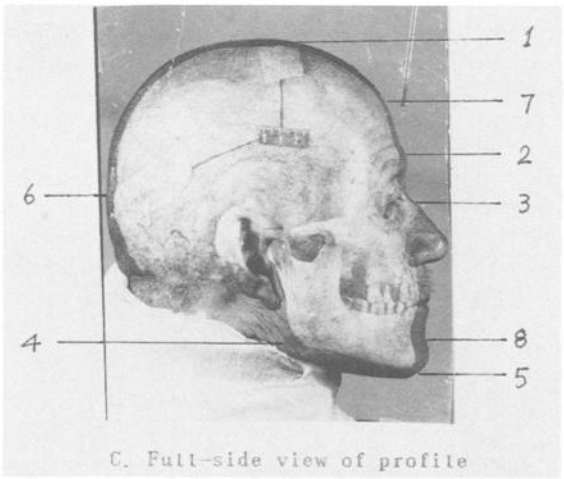


FIG. 6—*Profile morphological curves on all parts* (A: *front view*, B: *half-side view*, C: *full-side view*): 1. *head vault curve*, 2. *arcus superciliaris curve*, 3. *nose curve*, 4. *gonion curve*, 5. *lower jaw curve*, 6. *head back curve*, 7. *forehead curve*, 8. *pogonion curve, and* 9. *zygomatic curve*.

Discussion of an Identification Standard by Skull-Image Superimposition and Its Credibility

Based on this study, 52 indexes in 4 groups were established as a determining standard for identifying the skull's body origin by means of skull-image superimposition. In the first group, there are 8 determining lines; in the second group, there are 22 indexes of interrelated relationships; in the third group, there are 13 indexes for soft tissue thickness, and in the fourth group there are 9 indexes for profile morphological curves. Note that not all the indexes above appeared in each case of identification. The index that appears at different deflection angles of the human image may be called the observable index. In determination, if two of the observable indexes are found not to be in line with the data mentioned above (going beyond the scope), then the identity of the human image with the skull can be overruled. If one of the observable indexes is found to be not in

line with the data, then a conclusion of suspicious identity may be drawn. A conclusion of identity of the image with the skull can be drawn only when all the observable indexes completely superimpose.

With the above standard, tests were made for skull-image superimposition of 166 cases (100 males and 66 females) of skulls and images whose body origins had been known. As a result, all the observable indexes fell in scopes of the specified mean values and standard errors.

To evaluate the credibility and exclusiveness of the identification standard, a test of superimposition probability was conducted 10 000 times with 1000 human photos sampled and 10 skulls, none of which were identical with the 1000 pictures. For determination, only 8 determining lines and profile curves were used as judging indexes for superimposition. The image and skull were adjusted to the same angle for each test and the bi-ectocanthion line and front central line were used as baselines for superimposition.

Results obtained are listed as follows. The rate of superimposition of the two baselines plus one marking line with three lines on the skull is 100%. The rate of superimposition of the two baselines plus two marking lines with four lines on the skull is 55.48%. The rate of superimposition of the two baselines plus three marking lines with five lines on the skull is 13.10%. The rate of superimposition of the two baselines plus four marking lines with six lines on the skull is 2.75%. The rate of superimposition of the two baselines plus five marking lines with seven lines on the skull is 0.45%. The rate of superimposition of the two baselines plus six marking lines with eight lines on skull is 0.05%. No complete superimposition of the eight marking lines plus profile curves with the skull was observed. In addition, false superimposition was respectively observed in this study for each marking line, for example, the probability of false superimposition arising in 10 000 times of the test with each marking line is listed in Table 4.

The above test reveals a high individual identity of the identification standard which is of great practical value in getting rid of interference caused by the similarity of the human face and skull and preventing results of false superimposition.

Since 1980, 89 cases of unknown skulls have been identified with this method. Among them, 47 cases were male and 42 cases were female. Cases of skeletonized bodies were 25, cases of high putrefaction in which it was hard to determine body origin were 56, and cases of dismembered bodies were 8. Among the 89 cases 80 were identified as identical. Five cases were rejected as not identical. Four cases body origins were not identified. Cases of missing persons or persons suspected of missing for less than 1 year were 59. Cases of persons suspected of missing for 2 to 5 years were 30. Results of this identification provided scientific and reliable evidence to the judicial department for solving the cases.

For example, a male citizen was missing as of 31 Aug. 1983 and five days later a male

TABLE 4—*Superimposition of each determining line.*

Determining Line	Number of Superimpositions	Probability of Superimposition, %
Front central line	10 000	100
Ectocanthion line	10 000	100
Superciliary line	2 400	24
Subnasal line	3 311	33.11
Cheilion line	3 675	33.11
Gnathion line	2 980	29.80
Entocanthion left	2 081	20.81
Vertical line right	1 446	14.46
Profile curves	832	8.32

body of large features caused by putrefaction was found in a river nearby. It was hard to identify the body from its features and dress, but through examination by means of skull-image superimposition with the skull and a photo of the missing man taken when he was alive, it was determined that the skull was identical with the picture of the missing man (see Fig. 7). In another example, a female head was found under a bridge on 26 Sept. 1985 and the head was in a state of adipocere. Homicide was determined by a forensic science expert and reports of missing persons were researched by the local public security department.

A female worker in a factory was suspected of being murdered after she was reported missing on 6 Nov. 1984. The skull and a photo of the missing woman taken before her disappearance were sent to us and an identification by skull-image superimposition was made. As a result, they were identified as the same person. Based on the evidence, the case was solved in a very short time (see Fig. 8).

In the identification of the skull's body origin, a Model TLGA-1 Skull Origin Identification Unit was used. Equipped with a microcomputer system for determining the identification of the skull origin with skull-image superimposition, the device, easy to use, is able to adjust determining lines by itself and to take a superimposed photo.

Among legal medical experts of various countries there is controversy on the credibility of identification of skull origin by means of skull-image superimposition. The Japanese legal medical expert Weino Masayausi argues that "even though there is complete superimposition, it is still unable to identify as the same person" [7]. The Soviet scholar, Professor S. A. Gaspalian, thinks that superimposition of one skull with pictures of several persons might turn up as a result of lack of an objective standard for evaluating the result of identification by skull-image superimposition [8]. Through study on the interrelated relationship of human face landmarks with the skull, we maintain that the skull is the parent that determines the human face and there exists a close relationship of identity and exclusiveness between the skull and the face. The accuracy of identification is raised to a great extent by using the interrelated indexes between them as an identifying standard.

The test mentioned above and the authors' practice in solving cases in the past decade show that a skull can only completely superimpose with an image of its origin and cannot

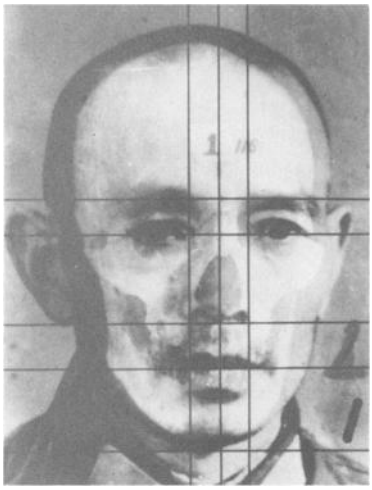


FIG. 7—*A skull of a putrefied male body found in a river on 31 Aug. 1983 and a photo of a male citizen reported missing five days before that were identified by skull-image superimposition as the same person.*

FIG. 8—*A female skull found under a bridge on 26 Sept. 1985 and a photo of a woman worker in a factory reported missing on 6 Nov. 1984 were identified by skull-image superimposition as the same person.*

superimpose with the image of some other person. Requirement for this identification technique is, of course, very strict. Otherwise errors might turn up.

Conclusion

In conclusion, the skull is the parent of the face and there exists a close relationship of identity and exclusiveness between the face and the skull. This is based on study of the interrelated relationship of face landmarks with the skull and the regular patterns of their displacement by means of X-ray photography. This provides a forensic anthropologic base for identification of the skull's body origin by means of skull-image superimposition. Fifty-two indexes in four groups were established that have raised to a great extent the credibility of identification of an unknown skull's origin. But viewed from an anthropologic angle, this method is not perfect in itself. There is still the need to solve the problems of differences in nationality, region, and age. Only when the problems are solved can the technique of skull-image superimposition be more accurate in practice and used more widely.

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Address requests for reprints or additional information to
Lan Yu-Wen
Director of Tieling 213 Research Institute
Hongqi St., Yinzhou District
Tieling, Liaoning Province
P.R. China