TECHNICAL NOTE

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The Relationship between the Soft Tissues and the Skeletal Detail of the Mouth

ABSTRACT: The estimation of mouth width and lip thickness from the skull for facial reconstruction has traditionally relied upon scant scientific research and "rules of thumb" laid down by subjective interpretation and experience. This study tested these assumptions by taking caliper and photographic measurements of mouth width and interpupillary and interlimbus distances of 96 subjects and lip thickness and teeth height measurements of 95 subjects. The most reliable indicator of mouth width was found to be the interlimbus distance, and lip thickness was positively related to the height of the teeth. There were no differences in these relationships between men and women. Standards for predicting the lip thickness from the teeth height were suggested for White Europeans and Asians from the Indian subcontinent.

KEYWORDS: forensic science, facial reconstruction, anthropometry, mouth

Facial reconstruction is the building of the face of an individual onto the skull (1,2) and has been used primarily in the forensic field for the identification of skeletal remains (3,4). The supporting principal behind forensic facial reconstruction is that the proportions of the bone beneath define facial form. This was suggested by Krogman and Iscan (5), who stated that "the skull is the matrix of the living head; it is the bony core of the fleshy head and face in life." Many forensic investigations worldwide have used facial reconstruction to produce recognition and identification. The American method, as practiced by Gatliff (1), claims a 65% success rate, and the British method, as used by Wilkinson and Neave (4), claims a 75% success rate.

Some researchers have suggested that facial reconstruction is not a reliable investigative tool. In 1922, Stadmuller (6) produced several accuracy studies and concluded that facial reconstruction provided only an approximation of a basic head type. Hagland and Reay (7) evaluated two- and three-dimensional facial reconstruction techniques in the Green River serial murder investigation and concluded that "although resemblance to the deceased is desired, this goal is rarely achieved . . . and unrealistic expectations among both the public and the investigators have been created." More recently, Stephan and Henneberg (8) carried out an evaluation of several methods of facial reconstruction, and their results also suggested that facial reconstruction does not produce a good likeness of an individual and would be detrimental to any forensic identification case.

Other researchers disagree with these studies. Wilder (9) was a great proponent of the facial reconstruction procedure and believed that the method was so simple that, if directions were followed, the first attempt would inevitably be at least moderately successful.

However, he did warn that any weakness lay in the subjective interpretation of the investigator at such features as the lips, the soft parts of the nose, and the set of the eyes. In 1970, Snow and his colleagues carried out an assessment of facial reconstruction and expressed guarded optimism that a reconstruction may produce a face bearing a fundamental resemblance to the individual. Gerasimov (10) believed that any errors in facial reconstruction were produced by carelessness of the sculptor and lack of attention to the soft and hard tissue relationships. In 1940, he carried out a blind mass control experiment using twelve cadavers from Moscow Medical Institute and claimed that all twelve heads established a similarity with police photographs of the deceased. Neave (3) used a skull copied from the CT data of a live volunteer to carry out an appraisal of his reconstruction technique. The reconstruction was sufficiently similar to the individual for Neave to recognize him in a room full of people. Wilkinson and Whittaker (11) produced a detailed evaluation of facial reconstruction using five juvenile cases. All five reconstructions were correctly identified by face pool assessment, and further resemblance rating assessments suggested that all the reconstructions were a close likeness to the identified individuals.

There has been substantial research quantifying the relationship between the skeletal structure of the skull and the overlying soft tissues of the face with the express purpose of facilitating facial reconstruction. Gerasimov (10) stated that there was a clear correlation between the form of the skull and the surface of the soft stratum and claimed that the main mistake made when carrying out a facial reconstruction was to view the separate details of the face as something independent or isolated from the general composition of the face. Broca (see Ref 12) was the first researcher to study the relationship between the structure of the skull and the overlying soft tissues that define appearance. He noted that the features of the face appeared to be based on the individual, but that there was great individual variation in soft tissue thickness. The caricaturist Drucker (see Ref 13) stated, "We all have the same features; it is the spaces

between them, their proportions, and relationships to one another that distinguish one face from another." The majority of research related to facial reconstruction has centered on the relationship between the bony skull and the nose (14,15), and there has been little actual scientific study of many other features of the face.

The mouth is a vital part of the final face, and its position clarifies the correct proportions of the face. A large portion of the research related to the mouth has been carried out within the fields of dentistry and maxillofacial surgery. Farkas et al. (16) carried out a detailed anthropometrical study of North American Whites, which included linear measurements of the lips and mouth. Ferrario et al. (17) studied mouth width and total lip height of adult North Italians using optoelectronic equipment. They found that these measurements were greater in men than women, and similar three-dimensional studies on German, Czech, North American Whites, and North American Latinos showed comparable results (18,19). However, a previous study by Ferrario et al. (20) using photographic measurement had shown no sexual dimorphism. These studies have greatly increased our understanding of the morphology of the mouth in different population groups, but provide no information regarding the relationship between the hard and soft tissues. Some forensic anthropological studies have attempted to predict the position and size of the mouth and lips from the skeletal structure, and there appears to be a great deal of disagreement. Latta (21) found that men had wider mouths than women, and Blacks had wider mouths than Whites. It is well documented that the corners of the mouth can be positioned on a radiating line from the canine-first premolar junction (12,17). However, there are also many suggested standards for the position of the corners of the mouth when the teeth are not present. Broadbent and Mathews (22) stated that the junction of the upper and lower lips is on a line perpendicular to the medial border of the iris, but other researchers place the corners of the mouth by aligning them with the midpupil or the widest point of the chin (5,18). Latta et al. (23) studied the relationship between the width of the mouth, interalar width, bizygomatic width, and interpupillary distance on edentulous patients. They found no correlation between any of the widths, and this remained when the results were divided by sex or ethnic group. Gerasimov (10) stated that the thickness of the lips is based on the prognacy of the teeth—the incisors and alveolar parts of the upper and lower jaws. He claimed that small straight teeth were characteristic of thin lips and orthognathism, and prominent big teeth were characteristic of thick lips and prognathism. He also stated that the height of the enamel of the middle incisor is equal to the thickness of the middle of the pigmented part of the lip, which is in agreement with Gatliff and Snow (24), who determined the vertical thickness of the lips from the gum line to gum line measurement. But Gerasimov warned that the thickness of the lips is not a constant feature—that it changes with age and varies within the same racial group, and Angel (25) stated that lip thickness depends upon the projection of the teeth, racial group, and the strength of incisive and buccinator muscles.

The aims of this research were to study the relationship between the position of the corners of the mouth and the position of the eyes, and the relationship between the thickness of the lips and the height of the tooth enamel, and to evaluate the possible applications of this study for use in forensic facial reconstruction, in comparison to the current methods used.

Method

One hundred and ninety-one volunteers were studied, aged 20 to 60 years, with 88 males and 103 females. The mouth width, inter-

limbus (medial borders of iris), interpupillary (midpupil to midpupil) distances were measured on 96 subjects (41% male and 59% female) using Mitutoyo digital calipers (to the nearest 0.01 millimeter) with the subject exhibiting a relaxed facial expression. Each measurement was repeated three times. Digital photographs of each subject were also taken from a frontal view using a Fujifilm digital camera, one showing a relaxed facial expression and one showing the teeth. Real quantitative measurements were not carried out using the computer method, but proportional measurements of interpupillary and interlimbus distances could be made relative to the mouth width using the line measurement tool in Adobe Photoshop. The statistical package SPSS was used to carry out analysis of the results. The reliability of the measurement techniques was calculated as the mean coefficients of variation for the caliper and photographic methods. Correlation coefficients between mouth width and the interpupillary and interlimbus measurements were calculated using Pearson's correlation tests for both caliper and photographic methods, and the limits of agreement between those measurements were calculated using Bland-Altman plots for caliper measurements. Differences between sexes and ethnic origin groups were studied using one-way analysis of variance.

The maximum upper teeth height, lower teeth height, upper lip thickness, and lower lip thickness were measured on 95 subjects (52% male and 48% female) using Mitutoyo digital calipers, with the subject exhibiting a relaxed facial expression. These measurements were taken at the maximum for both lip thickness and teeth height. The statistical package SPSS was used to carry out analysis of the results. The accuracy of the lip and teeth measurement technique was studied by calculating the reliability coefficients. Correlation coefficients were calculated between the teeth height and lip thickness for upper, lower, and total lip thickness using Pearson's correlation tests, and if the correlation was statistically significant, regression was then carried out to determine whether teeth height could be used to predict lip thickness. Differences between sexes and ethnic origin groups (84% White European and 16% Asians from the Indian subcontinent) were studied using one-way analysis of variance.

Results

The mean coefficients of variation were very small for both the caliper and photographic methods, with none greater than 1%, suggesting that the measurement techniques were reliable (Table 1). There were positive correlations between the interpupillary and interlimbus distances and the mouth width (see Table 1). The most reliable guide to mouth width was shown to be the interlimbus distance where the mean difference was 2.6 mm. The interpupillary distance showed a mean difference of 10.5 mm (see Table 1). The photographic and the caliper methods were compared and Bland-Altman analysis showed no difference between the measurements at the interpupillary and mouth width measurements, but the interlimbus measurement was shown to be larger using the calipers than when using the photographic method (see Table1). Analysis of variance showed that females had significantly smaller mouth width, interlimbus, and interpupillary distances than the males, but that the relationships between the interlimbus and interpupillary distances and the mouth width were not significantly different between males and females (Table 2). There were no differences in these distances or relationships related to ethnic group (see Table 2).

The reliability coefficients for the lip and teeth measurements were all above 90%, suggesting that the measurement technique had high reliability (Table 3). Correlation coefficients showed a

TABLE 1—*Statistical analysis of the caliper and photographic mouth measurements.*

	K-S test	Coeff Variation	Correlation Coeff (R) to ch-ch	p Value	Mean Difference to ch-ch	Mean Ratio to ch-ch
Caliper						
ch-ch	0.766	0.38				
ir-ir	0.778	0.29	0.55	<0.001	2.6	1.05
p-p	0.643	0.23	0.51	<0.001	10.5	1.22
Photographic						
ch-ch	0.246	0.72				
ir-ir	0.455	0.54	0.252	0.007	0	1
p-p	0.567	0.19	0.234	0.011	1.2	1.23
Caliper - photographic						
ir-ir					0.05	
p-p					−0.01	

ch-ch = mouth width, ir-ir = interlimbus distance, p-p = interpupillary distance.

TABLE 2—*Caliper (mm) and photographic (units) measurements of mouth width, interlimbus distance and interpupillary distance.*

(mm/units)	Male (n=39) Mean	SD	Female (n=57) Mean	SD	WE (n=64) Mean	SD	Ind (n=32) Mean	SD	Total (n=96) Mean	SD	t-Tests or Mann Whitney U Tests Bet Sexes	Bet Ethnic Groups
Caliper												
ch-ch	50.3	4.02	47.9	3.39	48.8	3.69	49	4.11	48.9	3.82	0.003	0.771
ir-ir	52.9	4.56	50.6	3.63	51.5	4.34	51.7	4.34	51.5	4.16	0.009	0.807
p-p	60.8	4.2	58.5	3.94	59.5	4.42	59.3	4.42	59.4	4.18	0.009	0.834
ir-ir/ch-ch	1.05	0.08	1.06	0.08	1.06	0.08	1.06	0.08	1.05	0.08	0.723	0.935
p-p/ch-ch	1.21	0.09	1.22	0.09	1.22	0.09	1.21	0.09	1.22	0.09	0.837	0.573
Photographic												
ch-ch	5.4	1.72	5.1	1.11	5.1	1.14	5.4	1.79	5.2	1.39	0.413	0.3
ir-ir	5.3	1.68	5.2	1.09	5.2	1.14	5.4	1.72	5.2	1.35	0.6	0.576
p-p	6.5	2.07	6.4	1.38	6.4	1.42	6.5	2.15	6.4	1.69	0.746	0.726
ir-ir/ch-ch	0.1	0.08	1.02	0.09	1.02	0.09	0.99	0.09	1.01	0.09	0.291	0.19
p-p/ch-ch	1.21	0.1	1.24	0.1	1.25	0.1	1.2	0.1	1.23	0.1	0.131	0.15

ch-ch = mouth width, ir-ir = interlimbus distance, p-p = interpupillary distance, WE = White European, Ind = Asian from the Indian sub-continent.

TABLE 3—*Lip and teeth height measurements and statistical analysis of the results.*

HEIGHTS (mm)	TOTAL (n = 95) Mean	SD	Reliability Coeff	K-S Tests	SEX Male (n = 49) Mean	SD	Female (n = 46) Mean	SD	ETHNIC GROUP WE (n =80) Mean	SD	Ind (n =15) Mean	SD	ANOVA Bet Sexes	Bet Ethnic Grps
Upper lip	6.1	1.88	0.97	0.96	6.1	2.16	6.2	1.54	5.8	1.79	7.8	1.42	0.769	<0.001
Lower lip	9.0	2.24	0.96	0.82	9.4	2.26	8.5	2.16	8.7	2.22	10.5	1.72	0.075	0.003
Total lips	15.1	3.8		0.85	15.4	4.17	14.7	3.36	14.5	3	18.3	2.78	0.368	<0.001
Upper teeth	9.3	1.66	0.95	0.99	9.6	1.8	8.9	2.16	9.2	1.63	10.0	1.72	0.042	0.09
Lower teeth	8.1	1.9	0.93	0.62	8.4	2.12	7.7	1.59	7.9	1.94	9.0	1.72	0.115	0.03
Total teeth	17.4	3.2		0.95	18.0	3.57	16.7	2.61	17.1	2.43	19.0	2.64	0.046	0.03

WE = White European, Ind = Asian from the Indian sub-continent.

positive correlation ($p < 0.01$) between the upper lip thickness and maxillary teeth height, lower lip thickness, and mandibular teeth height and the total lip thickness and total teeth height (see Table 3). These correlations also existed in the male and female samples and the White and Asian samples (see Table 3). Analysis of variance showed no significant (at the $p < 0.01$ level) difference between the lip thickness and teeth height measurements between males and females (see Table 3). Subjects with White European ethnic origins recorded significantly thinner upper lips (5.8 mm), lower lips (8.7 mm), and total lips (14.5 mm) than subjects with

Indian subcontinent ethnic origins (7.8, 10.5, and 18.3 mm, respectively) (see Table 3). This suggested that Asian subjects would need a different standard to White subjects when calculating the lip thickness from the teeth height.

For White Europeans, lip thickness can be calculated from teeth height by the following formulae:

- upper lip thickness = 0.4 + 0.6 x (upper teeth height)
- lower lip thickness = 5.5 + 0.4 x (lower teeth height)
- total lip thickness = 3.3 + 0.7 x (total teeth height)

For Asians from the Indian subcontinent, lip thickness can be calculated from teeth height by the following formulae:

- upper lip thickness $= 3.4 + 0.4 x$ (upper teeth height)
- lower lip thickness $= 6 + 0.5 x$ (lower teeth height)
- total lip thickness $= 7.2 + 0.6 x$ (total teeth height)

Discussion

These anthropometry results were comparable with the results of previous studies. The mean mouth widths were similar to some previous studies (18,20,21) and slightly smaller than others (16,17) (Table 4). The mean interpupillary distances were slightly smaller than those of previous studies (16,21) (see Table 4). The differences between the present study and some of these studies may be a reflection of the differences in measurement techniques or of international variation.

The results of the analyses of the measurements show that the most reliable and accurate guide for mouth width is the interlimbus distance. This is in agreement with Broadbent and Mathews (22), who suggested that the medial borders of the iris are directly above the corners of the mouth. The results of the study by Latta et al. (21) also concur with these results by suggesting that the interpupillary distance is not a reliable indicator of mouth width. However, these results disagree with the "rules of thumb" quoted by Gatliff and Snow (24), Caldwell (26), and Krogman and Iscan (5), who all suggest that the best indicator is the interpupillary distance. The mid-pupil to midpupil distance was shown to be larger than the mouth width by as much as 11.3 mm (see Table 2). This suggests that the accuracy of facial reconstructions produced following the interpupillary standard may be compromised. Clearly the position of the canine teeth will provide the most accurate predictor of the position of the corners of the mouth, but these results suggest that when the teeth are absent, the corners of the mouth may be positioned relative to the medial borders of the iris. The photographic measurement of interlimbus distance was shown to give a larger distance than the caliper method, and this was closer to the mouth width. The photographic method benefited from the ability to work close-up with a fixed eye position and an unflinching subject, so this method was likely to be more accurate than the caliper method.

The mean lip and teeth measurements were also comparable with previous studies (16,20) (see Table 4), and any differences may be a reflection of national variation. The lip and teeth study suggests that White Europeans have thinner lips than Asians from the Indian subcontinent. There are no previous anthropometry studies that included subjects from the Indian subcontinent, but many studies (17,19,27) suggest that there are differences in mouth and lip measurements related to ethnic origin. These results suggested that the canon employed by, among others, Gatliff (1), may be inaccurate and that lip thickness is not the same as gum line to gum line thickness, and the same relationship between the lips and the teeth cannot be assumed for different ethnic origin groups. The wide variation in the lip thickness and tooth height suggested that any relationship must be considered only as a generalization, and that other factors such as prognacy, age, and ethnic origins may play equally determinant roles in lip thickness, as suggested by Gerasimov (10) and Angel (25).

It is clear that further research should be done to confirm these results and to study different ethnic groups. This study has attempted to limit some of the uncertainty surrounding facial reconstruction, using scientific measurements and principles. Any study that increases the knowledge of the facial detail that can be extrapolated from the bony skull will increase the degree of accu-

TABLE 4—Comparison of the results of several anthropometry studies of the mouth.

	Present Study			Farkas et al. (1994)				Latta et al. (1991)				Ferrario et al. (1993)				Nanda et al. (1995)		
n	Male 49	Female 46	Total 95	Diff (M/F)	Male 109	Female 200	Total 309	Diff (M/F)	Male 26	Female 28	Total 54	Diff (M/F)	Male 57	Female 51	Total 108	Diff (M/F)	Male 2525	Female 50	Total (M/F) Diff
ch-ch	50.3	47.9	48.9	yes	54.5	50.2	51.7	yes	55	48	51.4	yes	50.4	47.4	49	yes	50.4	47	48.7 yes
p-p	60.8	58.5	59.4	yes	67	62.6	64.2	yes	63	60	61	yes							
upper lip	6.1	6.2	6.1	NS	8	8.7	8.5	NS											
lower lip	9.4	8.5	9	NS	9.3	9.4	9.4	NS											
total lips	15.5	14.7	15.1	NS	17.3	18.1	17.8	NS					17.9	17.7	17.8	NS			

NS = not significant. All studies include Caucasian subjects.

racy of the facial reconstruction. This is especially valuable in the forensic field, where it will help to improve the success rate of identification using the facial reconstruction technique.

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