Rynn, C and Wilkinson, CM

**Appraisal of traditional and recently proposed relationships between the hard and soft dimensions of the nose in profile**



**Article**

**Citation** (please note it is advisable to refer to the publisher's version if you intend to cite from this work)

**Rynn, C and Wilkinson, CM (2006) Appraisal of traditional and recently proposed relationships between the hard and soft dimensions of the nose in profile. Amercian Journal of Physical Anthropology, 130 (3). pp. 364-373. ISSN 0002-9483**

# Appraisal of Traditional and Recently Proposed Relationships Between the Hard and Soft Dimensions of the Nose in Profile

Christopher Rynn* and Caroline M. Wilkinson

*University of Manchester, Manchester, UK*

*KEY WORDS* facial reconstruction; nasal profile; forensic science

*ABSTRACT* This paper tests six methods of predicting external nasal profile proportions, using the form and dimensions of the bony nasal (piriform) aperture. A sample of 122 lateral cephalograms was measured and traced before each method was attempted, under blind conditions where appropriate. Error was assessed by comparing predicted to actual proportions. Methods used by the following authors were tested: Krogman and Iscan ([1986] The Human Skeleton in Forensic Medicine, Springfield: C.C. Thomas), Gerasimov ([1955] The Reconstruction of the Face on the Skull), Prokopec and Ubelaker ([2002] Forensic Sci. Commun. 4:1–4), Macho ([1986] J. Forensic Sci. 31:1391–1403), George ([1987] J. Forensic Sci. 32:1305–1330), and Stephan et al. ([2003] Am J. Phys. Anthropol. 122:240–250). The two-tangent method by Gerasimov ([1955] The Reconstruction of the Face on the Skull) was found to perform best at predicting a point on the nasal tip on male and female preoperative subjects. The method of Krogman and Iscan ([1986] The Human Skeleton in Forensic Medicine, Springfield: C.C. Thomas) performed poorly, as did the nasal profile determination method (Prokopec and Ubelaker [2002] Forensic Sci. Commun. 4:1–4). The other methods, all derived by a process of regression calculations, were shown to perform with variable accuracy on this sample, despite the age range and ethnicity of this sample closely resembling that of the samples from which these methods were derived.

Facial reconstruction or approximation is the procedure of rebuilding a face onto an anonymous skull to aid identification in forensic and archaeological or paleobiological cases (Gerasimov, 1971; Gatliff, 1984; Krogman and Iscan, 1986; Prag and Neave, 1997; Taylor, 2001). The tech- niques employed can be categorized into two-dimensional (2D), three-dimensional (3D), and autonomous computer- generated methods. The 3D method can be further divided into the Russian method, originating from Gerasimov (1955), which requires substantial knowledge of facial anatomy to predict individual muscle morphology, and the North American method, mainly from Krogman and Iscan (1986), which relies mainly on mean tissue depth meas- urements at numerous bony landmarks on the skull. These two approaches can be merged to form combination methods that rely more equally on anatomical reconstruc- tion to dictate the shape of the face, and tissue-depth data to guide the practitioner. For descriptive purposes, the tis- sue-depth method shall be referred to as facial approxima- tion, while the methods which use the gradual rebuilding of underlying anatomy, including combination methods, shall be referred to as facial reconstruction. The purpose of facial reconstruction/approximation is to recreate a face from the skull that resembles the individual in life enough to promote recognition.

Any method of facial reconstruction/approximation is based on the identification of interrelationships between the hard and soft tissues of the face. The Roman physician Galen (ca. AD 129–199) is often quoted as saying, "As poles are to tents and walls to houses, so are bones to all living creatures, for other features naturally take their form from them and change with them." This analogy serves to illustrate the notion of predictability of soft-tis- sue contours from hard-tissue form. However, the impression that bone is a rigid scaffold onto which the soft tis- sues are anchored is a misconception, since the hard and soft tissues develop together and directly affect each other through life. In addition, the process of evolution, which is driven by functionality, has shaped the facial pattern. Consequently, skull shape is created by in vivo internal and external forces exerted upon it by the soft tissue, and by evolutionary soft-tissue development. Therefore, the soft/hard tissue relationship is partially reciprocal, rather than facial form simply being dictated by the skull (Enlow and Hans, 1996; Larsen, 2001). These complex processes, and their functional relationships, must be understood in order to propose causal relationships between bone and soft anatomy. Gerasimov (1955) believed that the size of the markings on the skull left by muscle attachments was directly related to the size and shape of the muscles. He also claimed that it was wrong to treat the features and details of the face as separate elements, and suggested a holistic approach to the composition of the face.

Early automated computer methods used averaged soft- tissue depth data, essentially to create an "average face"

Grant sponsor: Ruby and Will George Trust; Grant sponsor: Ronald Raven Bequest Fund; Grant sponsor: Sir Richard Stapley Trust; Grant sponsor: Newby Trust; Grant sponsor: Miss Marie Taylor.

*Correspondence to: Christopher Rynn, University of Manchester, Manchester, UK. E-mail: chrisrynn@gmail.com

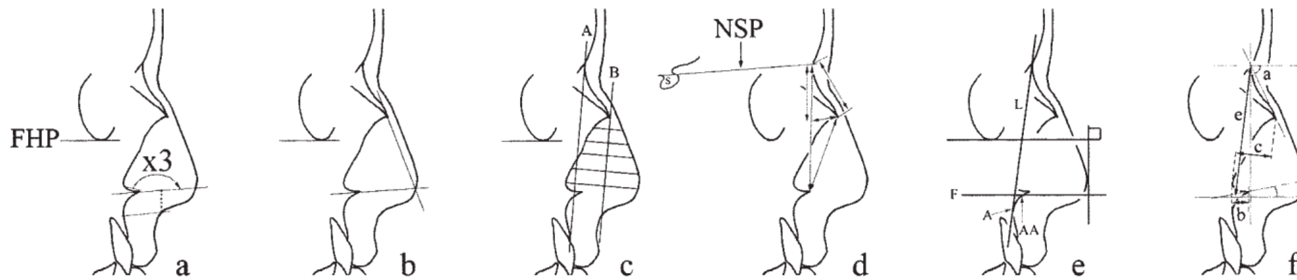


Fig. 1. a: Krogman and Iscan (1986). b: Two-tangent method (Gerasimov, 1955). c: Prokopec and Ubelaker (2002). Line A is nasion-prosthion line, line B is parallel to line A and touches rhinion. d: Macho (1986). Measurements were taken in, or perpendicular to, nasion-sella plane (NSP), and put through relevant regression equation to predict height, length, and depth of nose (defined in text). e: George (1987). Line L runs from nasion to point of most flexion beneath nasal spine, point A. Line F is parallel to FHP, and passes through point AA, halfway along inferior slope of nasal spine. Projection is percentage of line L (measured from nasion to point A) along line F from intersection with line L (60.5% for males, 56% for females). f: Stephan et al. (2003). a, nasal bone angle as measured from nasion to rhinion; b, tip of nasal spine to lateral aperture border at base; c, rhinion to most posterior point of aperture border, measured perpendicular to nasion/prosthion plane (line A in method 3, c); d, nasal spine angle from FHP (positive if above FHP); e, distance of point AA (method 5, in e) from nasion.

of particular age, ethnic group, and sex, and wrapped it around the skull to take into account the skull's basic shape (Vanezis et al., 2000). The methods of Krogman and Iscan (1986) also rely on mean tissue depths, but incorporate the input of the practitioner, who applies various observed and quantified "rules of thumb," along with personal experience and intuition, to interpret the skull and produce the face. These methods of Krogman and Iscan (1986) were shown to generate recognizable likenesses well above chance (Van Rensburg, 1993). Some computerized methods have a tendency to disregard nuances inherent in the skull, partly due to the resolution of clinical imaging, such as CT and MRI scans, and partly as certain details on the actual skull may not be visible but are palpable. Some of these details are important to facial features, such as the malar tubercles, which dictate the attachment of the outer canthi and therefore the angle of the eyes (Gerasimov, 1955; Stewart, 1983; Fedsoyutkin and Nainys, 1993).

Stephan (2003a) noted that the morphological prediction of the majority of facial muscles is difficult due to the delicacy and variability of the muscles of facial expression. Many of these muscles, while originating on the skull, insert into the orbicularis oris sphincter that forms the mouth (Sobotta, 1983; Warwick and Williams, 1973), and Stephan (2003a) found it difficult to see how this sphincter's morphology could accurately be predicted due to the lack of definable skull markings associated with it. However, the origins of muscles that insert into the orbicularis oris leave attachment markings on the skull, and with anthropological knowledge and experience, it should be possible to make justifiable estimations as to the position of such muscles from one attachment mark rather than both, since the areas of insertion into the orbicularis oris are predictable to within an acceptable degree of variation by the use of established anatomical standards (Bron et al., 1997; Gosling et al., 1990). A hypothetical advantage of combination methods is the use of tissue-depth data alongside facial anatomy, so that in areas such as the orbicularis oris, the tissue-depth pegs act to guide the hand of the practitioner, yet subjectivity is reduced by the influence of the contours of the musculature.

There are still areas of the face where multiple standards for reconstruction/approximation exist, and there is still disagreement over which technique, if any, to use (Stephan, 2003a; Stephan et al., 2003; Wilkinson et al., 2003). Research into such areas is important for the progress of this field toward more accurate results.

Nasal form and dimensions in frontal view were shown to be of relatively little significance for recognition (Haig, 1984, 1986; Fraser and Parker, 1986), compared to the shape, dimensions, and position of other features and overall face shape. However, this may not be the case in profile or in three-quarter view (Bruce, 1998), and any improvements made in the prediction of the projection and form of the cartilaginous nasal profile from cephalometrical analysis of the nasal (piriform) aperture would be useful in lateral 2D and 3D reconstruction/approximation of the facial profile. Although frontal images are used primarily when publicizing a 3D approximation/reconstruction in the USA, this is not the case in the UK, where a full rotation of the head is commonly used.

Several methods are currently used to predict the form of the external nose, although there are those who believe that it is impossible to predict accurately the shape of the nose from the piriform (nasal) aperture (Virchow, 1912, 1924; George, 1993), or that there is no correlation whatsoever between the soft and hard nose (Suk, 1935). Still, many believe that the nasal bridge and nasal spine can be used in various ways to predict the tip of the nose (Gerasimov, 1971; Krogman and Iscan, 1986; Prag and Neave, 1997; Wilkinson, 2004).

The pronasale is generally defined as the most anterior point on the nose when the head is aligned in the Frankfurt horizontal plane (FHP), which passes through the porion (superior border of the external auditory meatus) and the infraorbital border.

Krogman developed a method for pronasale prediction, first published in 1962 (Krogman and Iscan, 1986), and this is commonly used in North American facial approximation (Fig. 1a). A line is projected, following the direction of the nasal spine, and the average soft-tissue depth at midphiltrum is transferred to it (Krogman and Iscan, 1986). The length of the nasal spine, from the junction with the vomer to the tip, is tripled and added to the transferred depth. If the junction between the vomer and maxilla is invisible, then the length of the nasal spine can be taken as the distance between the tip and the lateral border of the piriform aperture in profile (Stephan at al., 2003). Stephan et al. (2003) found that this method performed with low accuracy when tested on 59 lateral cephalograms.

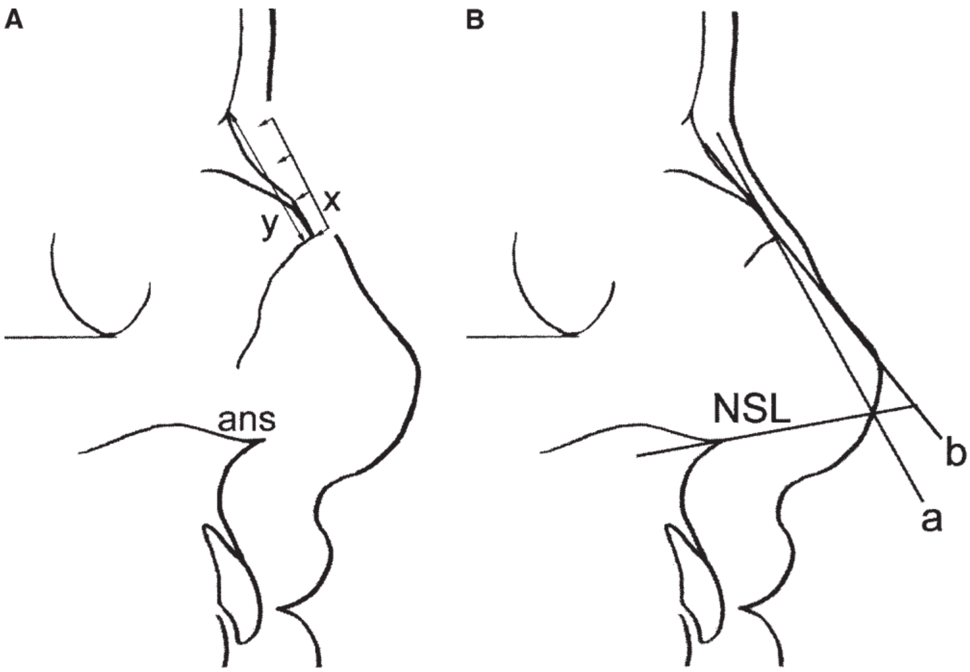


Fig. 2. A: x, length of most distal part of nasal bones, which follows an altered direction; y, length of nasal bones from nasion to rhinion (three times x is shown to be less than y); ANS, anterior nasal spine. B: a, tangent to end of nasal bones (see X in a). b, tangent to last 1/3 of nasal bones; NSL, nasal spine line. Difference between intersections of a and b with NSL show amount of overestimation when line b is used.

The original rule of Krogman and Iscan (1986) was that the soft projection of the nose was equal to three times the length of the nasal spine (Krogman and Iscan, 1986; Taylor, personal communication in 2003). Comparison of three times the nasal spine length to the projection of the soft nose, from soft subnasale to pronasale using the actual soft-tissue depth, may indicate the potential error of using the mean soft-tissue depth at subnasale.

Gerasimov (1955) also developed a method for nasal tip prediction, and this is commonly used in anatomically based methods of facial reconstruction (Fig. 1b). A line is projected following the direction of the nasal spine. A second line, which is a tangent to the most distal portion of the nasal bones, is projected, and the intersection between the two lines should fall on the tip of the nose. Gerasimov (1955) described the relevant distal portion as the last third of the length of the nasal bones, but often the change in direction of the bone is smaller than a third of the length (Fig. 2A). This method was reported (Stephan et al., 2003) to overestimate nasal projection, but this may be due to misplacement of the nasal-bone tangent due to strict adherence to the "last third" definition in cases where the nasal bones change direction downward toward the end (Fig. 2B). Gerasimov (1955, p. 29 in English translation) also stated that the soft part of the nose is a "natural continuation of the bony part." Therefore, it is this "drop-off" at the most distal part of the bone from which the tangent must be drawn.

In addition, Gerasimov (1955) suggested that the shape of the nasal profile could be predicted (Fig. 1c). He took a line between the bony nasion and prosthion (the most anterior part of maxillary alveolar bone), and drew a parallel touching the rhinion (most distal point on the nasal bones). He then mirrored the lateral border of the piriform aperture about this line by way of projected perpendiculars of equal length on either side (Prokopec and Ubelaker, 2002). Gerasimov (1955) claimed that this illustrated the profile of the nasal cartilage, and so added 2 mm to account for the skin depth. Stephan et al. (2003) found this method to be reliable at predicting pronasale projection in the FHP when tested on 59 lateral cephalograms. However, this method does not take into account the asymmetry of the lateral nasal bones, and further study is necessary to establish whether asymmetry could be accommodated. This technique will be referred to as the method of Prokopec and Ubelaker (2002).

An alternative method to predict the dimensions and position of the external nose was suggested by Macho (1986), conceived after the hypothesis of Goldhamer (1926) of multivariate skull cephalometrics (Fig. 1d) correlating with external craniometric measurements. Measurements were taken of the external nose and bony nasal aperture in the nasion-sella plane. The seven craniometric measurements of the nasal aperture in profile described in Macho (1986) (Fig. 1d) were compared to external measurements of the height (from soft nasion to soft subnasale), length (from soft nasion to pronasale), and depth (pronasale to soft subnasale), which form a triangle describing the external nose. Soft-tissue depths from hard to soft nasion, and from hard to soft subnasale, were taken as an aid to placement of the triangle of the nose. The two sets of measurements were used to generate regression equations. Macho (personal communication in 2003) acknowledged that this method is impractical for facial reconstruction, since the soft-tissue measurements are measured from the bony landmark to the soft-tissue landmark, rather than perpendicular to the bone surface. Even though minimum skin thickness over the nasal bones was a third point of placement, the predicted triangle of the nose could be moved several millimeters around this point if the angles of predicted tissue depth over the nasion and nasal spine were altered. However, her results suggest a definite correlation between the bony nose and soft nose.

A method of describing a "balanced" nasal projection used by George (1987), ascertained after observation of 54 cephalograms, and based on "aesthetic" methods of facial surgery according to Goode (Powell and Humphreys, 1984), was also tested by Stephan et al. (2003) and found to be more accurate than the methods of Gerasimov (1955) and Krogman and Iscan (1986). The technique involves drawing and measuring a line (L) from the nasion to the "point of most flexion" under the nasal spine (Fig. 1e), labeled "point A." A line (F) parallel to the FHP is then drawn which passes through point AA, halfway along the inferior slope of the nasal spine. The projection of the external nose should be equal to a proportion of line L, measured along line F from point AA. This proportion is 60.5% in males, and 56% in females (George, 1987).

A study of the reliability of most of these nasal profile prediction methods was carried out on 59 lateral cephalograms by Stephan et al. (2003). A new technique was realized by generating regression equations to quantify links between soft and hard dimensions observed in this sample (Fig. 1f), in a similar way to Macho (1986). However, this study included some postoperative subjects in the sample who had undergone orthodontic surgery, and this may have compromised the results, since nasal soft-tissue displacement is plausible following orthodontic treatment. The authors suggested that these subjects were included as similar individuals might be involved in a forensic investigation. Although this is true, it is also the case that major orthodontic treatment/surgery would probably be evident from the skeletal or dental details to an experienced odontologist.

The aim of this research was to establish which, if any, currently employed methods of reconstructing the soft tissues of the nose are accurate and reliable. The six discussed methods were assessed and compared, with the intention of quantifying errors and the hope of establishing a definitive working method of predicting nasal profile from using the dimensions of the nasal aperture.

## MATERIALS AND METHODS

The sample consisted of 122 anonymous lateral head cephalograms of subjects possessing Caucasoid skulls from the Turner Dental School, University of Manchester. The sex, age, and skeletal type (I, II, or III) of each subject were recorded, along with type of dental occlusal pattern (I, IIi, IIii, or III). The sample was not biased toward those individuals requiring orthodontic treatment, since many subjects required simple dental work. However, 20 scans were of 10 subjects who had been subjected to x-rays before and after maxillofacial surgery or orthodontic treatment, and this variable was considered important enough to separate these postoperative subjects from the sample. Methods to be tested were numbered as follows:

1. Krogman and Iscan (1986);
2. Gerasimov (1955);
3. Prokopec and Ubelaker (2002);
4. Macho (1986);
5. George (1987); and
6. Stephan et al. (2003).

Three tracings were made of each cephalogram, using a 0.5-mm HB retractable pencil on drafting film. Two tracings recorded the soft profile and bony profile together, including the porion (superior border of the external auditory meatus), to obtain the FHP between the porion and the lower border of the eye socket, and the sella turcica, to obtain the nasion-sella plane. The third tracing was identical to the first two, apart from exclusion of the soft-tissue profile. The technical error of repeated tracings was assessed by comparing craniometric measurements of tracings to the same measurements on retracings of 10 subjects. Error was assessed as a coefficient of variation of the error (CVE). This was obtained by adding the squared differences between the two measurements, and dividing by double the number of subjects tested (Table 1). Retracings were also superimposed over original tracings using three crosses, marked on both tracings as reference points, to judge areas of tracing inaccuracy. Areas of greatest inaccuracy were the lateral border of the orbit and the lateral borders of the nasal aperture, approximately halfway between the rhinion and nasal spine. The CVE was low enough to indicate good repeatability of tracing.

*TABLE 1. Technical error of repeatability of tracings shown as coefficient of variance of error (CVE)*

| | CVE |
|---|---|
| Nasion to prosthion | 0.05 |
| Nasion to rhinion | 0.02 |
| Nasion to soft nasion | 0.09 |
| Rhinion to tip of nasal spine | 0.01 |
| Soft nasion to soft subnasale | 0.11 |
| Length of nasal spine | 0.08 |
| Tip of nasal spine to pronasale in FHP | 0.04 |

The tracing showing only the bony profile was used to test methods 1 and 2. A line of projection was drawn to follow the direction of the anterior nasal spine. This line projects from the anterior nasal spine, following the direction of the tapered bone at the end of the spine as if it were an arrow. The area at the tip of the spine is used, distal to any change in contour of the superior and inferior surfaces of the anterior nasal spine. This line is referred to as the nasal spine line (NSL). This technique ensured that the line was identical in methods 1 and 2, and was drawn blind to the actual profile of the nose. Repeatability of drawing the NSL was assessed using 10 tracings of the bony profile, over which NSL was drawn twice, each time on a blank, fixed overlay. The angle between NSL and FHP was measured on each overlay. The mean of the differences between the two angles was 2.42**8**. This was considered low enough to indicate good repeatability of drawing the NSL.

The measurements for method 1 were taken first. Marking the tracing was not necessary, so method 2 could be carried out blind, without any influence from method 1. To test method 2, a line was drawn at a tangent to the most distal portion of the nasal bones, to follow the altered direction of the bone (Fig. 2b).

A tracing showing both the hard and soft profile was then overlaid and aligned using the hard nasion, sella turcica, and prosthion, which were used as reference points due to their high repeatability in tracings. The point of intersection of the two tangents was then compared to pronasale in the FHP, to test method 2. A Cartesian axis was constructed about the FHP and the positions of pronasale, and the point of intersection of the two tangents was defined in x and y dimensions, using nasion as a point of reference. The differences between the point of intersection and pronasale were measured in terms of x and y.

Method 1 was then tested on the same pair of overlaid tracings, since NSL had been drawn blind to the soft profile, and comparison between actual measurements and predicted measurements was necessary. The maxillo-vomer junction was invisible on many of the cephalograms. In these cases, the lateral border of the piriform aperture was used to determine the length of the nasal spine (Stephan et al., 2003). Accuracy was tested by measuring the predicted length of the nose along the nasal spine line, i.e., three times the length of the nasal spine, plus the transferred mean soft-tissue depth. This was then compared to the projection of the nose in the same plane, since this is how the method would be used in practice.

The following lines were drawn on a blank overlay: FHP, NSL, and a line following the line of the bottom of the nasal profile, which will be referred to as the nasal angle (NA). The angle between NA and NSL, and the angle between NA and FHP, were measured to test which plane was more consistent with the angle of the NA. This would show whether it would seem justifiable to define the tip of the nose as the farthest point from the face along the NSL, if this plane took into account the up/down direction of projection of the nose more than the FHP.

Krogman and Iscan (1986) originally found the soft projection of the nose, from soft subnasale to pronasale, to be three times the length of the anterior nasal spine (3[ANS]). The availability of the position of the actual soft subnasale made testing this original supposition possible, despite its lack of practical application. Comparing the magnitude of error when the mean soft-tissue depth was used to the error when the actual soft-tissue depth was used would show to what extent error was compounded by the use of mean soft-tissue depth usage (Table 1).

Method 3 could have been tested blindly, as in Stephan et al. (2003), using separate tracings of the bony profile and soft profile, but the use of a single tracing containing both the bony and soft profiles was preferred, since a direct measurement comparison was carried out rather than a prediction of nasal profile. A blind test was considered unnecessary, and may have increased measurement error.

The cephalometric measurements of the skull used in method 4 were measured on the other tracing containing both bony and soft profiles, and put through the appropriate series of regression equations specified by Macho (1986). The predicted nasal height, length and depth were to be compared to the actual height, length and depth of the soft nose. A blind test was also considered unnecessary here, as this method relies upon a fairly complex series of equations, which eliminates bias.

Method 5 was tested on the same tracing containing both the hard and soft profiles, since comparison to actual dimensions was necessary. Line L was measured, and line F was drawn for each subject. A Cartesian axis was constructed about the FHP, and the distance between the farthest projection of the nose in the FHP and line L was measured along line F (Fig. 1e). This distance was then compared to the appropriate proportion of line L: 60.5% for males, and 56% for females.

The measurements necessary to carry out method 6 were taken from the same tracing containing both the hard and soft profiles, using a $mm^2$ grid on an overlay to set the horizontal and vertical planes so that angles and dimensions could be measured using protractors and digital calipers (the FHP and the plane of line L (nasion to prosthion) of method 5), because drawing lines directly onto the tracing would disrupt the integrity of the profile lines. Measurements were inserted into appropriate regression equations (Stephan et al., 2003) and compared to actual nasal projections.

The sample sizes vary between methods for various reasons. Method 1 (m28; f41), method 3 (m23; f36), and method 6 (m25; f38) required the lateral border of the nasal aperture to be clearly defined, which was invisible on some cephalograms, possibly due to the thin, tapered nature of the bone, or the quality of the x-ray. There were

*TABLE 2. Paired* t*-test to compare predicted to actual projection using method 1 (Krogman and Iscan, 1986) on preoperative subjects*

| | Original supposition | Practical method |
|---|---|---|
| Males (n ¼ 28) | | |
| Mean difference (mm) | -10.90 | -9.30 |
| *P*-values (two-tailed) | 0.00 | 0.00 |
| SD of difference | 8.42 | 9.30 |
| Correlation with 3[ANS] | 0.12 | -0.14 |
| Correlation *P*-values | 0.55 | 0.48 |
| Females (n ¼ 41) | | |
| Mean difference (mm) | -9.00 | -8.90 |
| *P*-values (two-tailed) | 0.00 | 0.00 |
| SD of difference | 8.33 | 8.73 |
| Correlation with 3[ANS] | -0.11 | -0.05 |
| Correlation *P*-values | 0.49 | 0.75 |

[1]Indicates no significant difference between means of predicted and actual values.
[2]Indicates significant positive correlation between predicted and actual values.

*TABLE 3a. Comparison of nasal angle with Frankfurt plane and nasal spine*

| n ¼ 36 | Angle between FHP and NA | Angle between NSL and NA |
|---|---|---|
| Mean | 13.63 | 10.54 |
| Minimum | -14.00 | -1.00 |
| Maximum | 38.00 | 24.00 |
| Range | 52.00 | 25.00 |
| Standard deviation | 11.81 | 5.99 |
| Variance | 139.56 | 35.92 |

cases where both left and right lateral borders of the nasal aperture were visible due to facial asymmetry. The head is aligned for x-rays using fixtures fitted into subjects' ears, which appear on the film with their centers directly over each other. Thus the double shadows around the piriform aperture must be from asymmetry of the facial bones, relative to the external auditory meati. In these cases, an average line was constructed between the two lateral borders, maintaining the contour, using the Broadbent-Bolton technique (Enlow and Hans, 1996). Data were analyzed on SPSS 11.5, using appropriate *t*-tests, tests for correlation, and variance analysis.

## RESULTS

Table 2 shows the results for method 1. Postoperative subjects were excluded because the postoperative sample was not large enough to present statistically valid conclusions. In practice, the method of Krogman and Iscan (1986) seemed to underestimate nasal projection by an average of 9.3 mm in males and 8.9 mm in females. Also, there was no significant positive correlation between three times the nasal spine and the actual depth of the soft nose, suggesting that the length of the nasal spine (measured from the lateral border of the nasal aperture) is not related to the soft projection of the nose.

Table 3a shows the angles between the NA, which is a tangent to the inferior border of the soft nose in profile, and both the FHP and the line projected in the direction of the nasal spine (NSL). There was a difference of approximately 5.8 mm between the standard deviations of the samples, making the standard deviation of the angle between FHP and NA almost twice that of the angle

*TABLE 3b. One-sample* t*-test to compare predicted to actual projection using method 2 (Gerasimov, 1955) on preoperative subjects*

| | Tip defined in NSL | Tip defined in FHP | |
|---|---|---|---|
| | x-axis error (mm) | x-axis error (mm) | y-axis error (mm) |
| Males (n ¼ 44) | | | |
| Mean difference | -0.16[1] | -0.91 | -3.61 |
| *P*-values (two-tailed) | 0.80 | 0.02 | 0.00 |
| SD of difference | 1.56 | 1.92 | 2.25 |
| Standard error of mean | 0.27 | 0.34 | 0.34 |
| Correlation | 0.95[2] | 0.96[2] | 0.91[2] |
| Correlation *P*-values | 0.00 | 0.00 | 0.00 |
| Females (n ¼ 67) | | | |
| Mean difference | -0.34[1] | -0.90 | -3.54 |
| *P*-values (two-tailed) | 0.11 | 0.00 | 0.00 |
| SD of difference | 1.89 | 1.69 | 1.85 |
| Standard error of mean | 0.23 | 0.21 | 0.23 |
| Correlation | 0.90[2] | 0.95[2] | 0.94[2] |
| Correlation *P*-values | 0.00 | 0.00 | 0.00 |

[1] Indicates no significant difference between means of predicted and actual values.
[2] Indicates significant positive correlation between predicted and actual values.

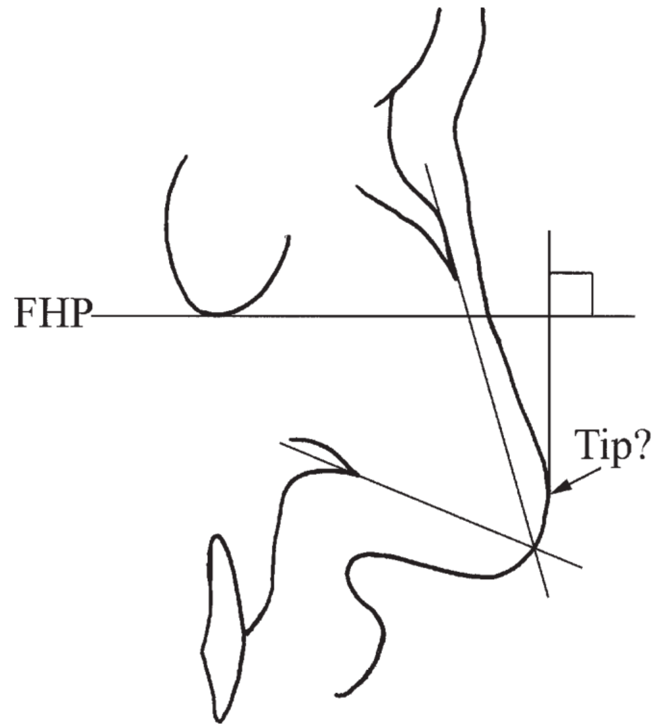


Fig. 3. Difference between tangent intersection (drawn blind to soft profile) and pronasale defined as most anterior point on nose, with skull aligned in Frankfurt horizontal plane (FHP).

between NSL and NA. Also, the range of angles between FHP-NA was more than double the range of angles between NSL-NA. An independent-samples *t*-test was carried out on the samples, and the results of Levene's test showed a *P*-value of 0.001, meaning that the variances of the samples were significantly different. These results showed that the NSL followed the NA much more closely than the FHP.

It became apparent while testing method 2 that the tangents often intersected very close to the surface of the skin on the tip of the nose, while pronasale (as defined in the FHP) appeared as a point, sometimes millimeters away on the tip of the nose. The most extreme example is shown in Figure 3. The results of Table 3a, in combination with the fact that Gerasimov (1955) did not specifically define the nasal tip in the FHP, suggest that this definition of pronasale did not take into account the direction of projection of the soft nose, i.e., whether the nose was upturned, straight, or downturned. This may explain why previous research (Stephan et al., 2003) found this method to be inaccurate. Table 3b shows that the NSL crossed the skin surface, on average, 3.61 mm from pronasale in the FHP (mean difference in y). In addition, the NSL crossed the soft profile surface in the area of the tip of the nose, as it would be defined in lay terms, on every single subject. These observations suggest that the NSL should be employed as a plane of measurement in which to test error, by defining the tip of the nose. This plane of measurement would only measure error in one dimension, but the angle of the NSL followed the line of the columella (nasal angle) much more closely than the FHP, and showed good repeatability.

Table 3b shows that the two-tangent method of Gerasimov (1955) predicted a point on the nasal tip accurately on preoperative subjects, with the nasal tip defined in the NSL, but that the method actually underestimated nasal projection in the FHP by, on average, 0.9 mm in both males and females. This does not seem to be much in practice, despite being statistically significant, until we take into account the size of the error in the vertical plane, y, which was on average 3.6 mm in males, and 3.5 mm in females.

Figure 4 shows the results for method 2, with the tip defined in the nasal spine plane (NSL), of the 10 subjects for whom preoperative and postoperative cephalograms were available. All values were shown as positive numbers in Figure 4 to help visualize the increase in error between pre- and postoperative subjects. The subjects for whom the error was an underestimation of the predicted dimension are marked with an asterisk. In these cases, the predicted dimension was a larger underestimation postsurgery. Subjects 3 and 4 were the same patient, before and after a brace (subject 3), and before and after a subsequent mandibular osteotemie (subject 4). Although there were too few subjects from whom to draw valid statistical conclusions, this test showed that further research is necessary to investigate whether maxillofacial surgery significantly affects the accuracy of nasal prediction methods. This may be the case if these 10 subjects are indicative of the norm.

Subjects 1–3 showed the effects of a fixed brace on nasal tip estimation. Subjects 4–6 underwent mandibular osteotemies, while subject 7 showed the effect of a maxillary osteotemy (which was, surprisingly, relatively small). Subjects 8–10 had corrective surgery for a cleft lip and palate. Although the sample was too small to draw statistically significant conclusions, Figure 4 shows that the prediction of the nasal tip using method 2 was affected by between 1.46 mm (subject 2; brace) and 19.52 mm (subject 1; brace) by orthodontic interference, no matter which type of surgical process was used.

Table 4 shows the results of the analysis of method 3. The nose was separated into zones, with "a" toward the bridge of the nose, and "e" at the tip of the nose. In this case, the means of predicted and actual measurements

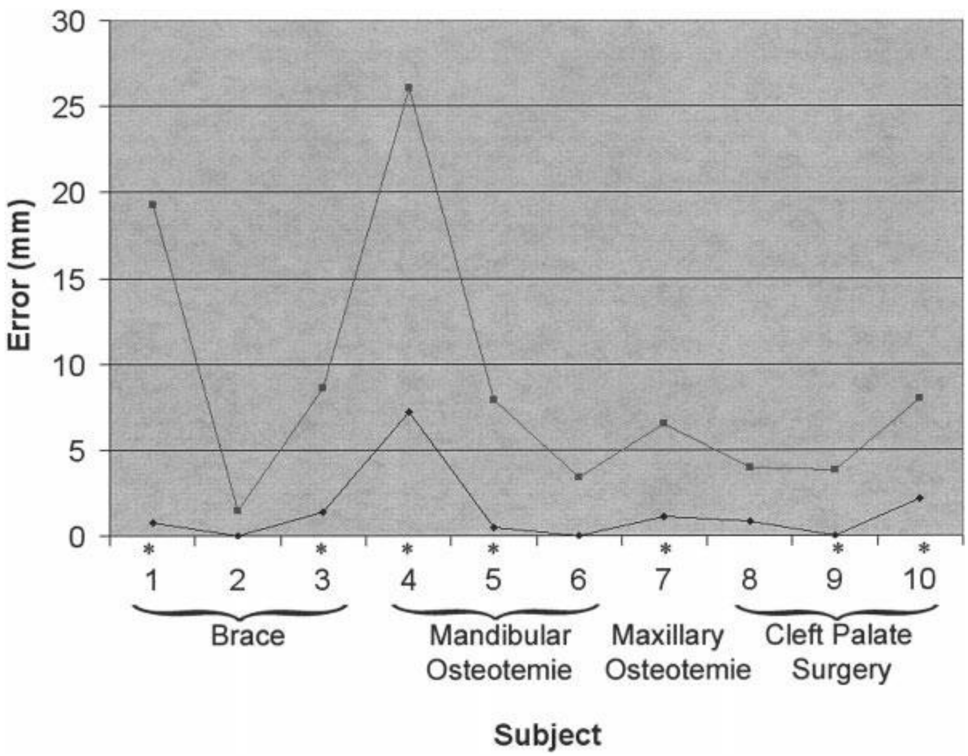


Fig. 4. Error of preoperative vs. postoperative subjects using method 2. ■ ¼ postoperative; ♦ ¼ preoperative.

were analyzed using paired *t*-tests. The method of Prokopec and Ubelaker (2002) appeared to work at first glance, since there was no significant difference between the means of predicted and actual dimensions in most areas on male and female noses. However, there was no significant positive correlation in any area. Therefore, the magnitudes of specific predicted and actual measurements were unrelated to each other, and the similarity between the means of the samples was coincidental.

The results of method 4 are shown in Table 5. The method of Macho (1986) only worked to predict the length of female noses of preoperative subjects in this sample, since the means of samples were not significantly different, and a significant positive correlation between predicted and actual dimensions was seen. However, there were significant positive correlations in all areas except for depth of male noses, which suggested a link between hard and soft dimensions (although not necessarily a causal link). The method significantly overestimated all dimensions except nose length in females.

Table 6 shows the results for method 5. There was a significant difference between predicted and actual nasal projection in preoperative patients, although significant positive correlation was apparent. This suggested a link between the nasion-point AA (line L) distance and nasal projection in preoperative subjects (Fig. 1e), but the ratios of 60.5% for males and 56% for females used in the method of George (1987) did not apply to the sample tested, and overestimated nasal projection by, on average, 1.4 mm in males and 0.9 mm in females. This amount is small in practice, despite being statistically significant. The lack of correlation in postoperative patients suggested the absence of a link between line L and nasal projection, although the sample was too small to draw statistically valid conclusions. The small size of the postoperative group may also explain why such a large mean error of 2.51 mm is not considered statistically significant.

*TABLE 4. Paired* t*-test to compare predicted and actual projection using method 3 (Prokopec and Ubelaker, 2002) on preoperative subjects*

| | Differences between profile prediction lines and actual profile (mm) | | | | |
|---|---|---|---|---|---|
| | a | b | c | d | e |
| Males (n ¼ 23) | | | | | |
| Mean difference (mm) | -0.58[1] | 1.15[1] | 2.41 | 1.47[1] | 0.70[1] |
| *P*-values (two-tailed) | 0.53 | 0.35 | 0.02 | 0.07 | 0.46 |
| SD of difference | 3.35 | 4.24 | 3.91 | 3.27 | 3.66 |
| Standard error of mean | 0.90 | 1.18 | 0.95 | 0.77 | 0.92 |
| Correlation | 0.45 | 0.49 | 0.30 | 0.33 | 0.24 |
| Correlation *P*-values | 0.11 | 0.09 | 0.24 | 0.18 | 0.36 |
| Females (n ¼ 36) | | | | | |
| Mean difference (mm) | -0.31[1] | 0.33[1] | 2.74 | 1.49[1] | 1.48[1] |
| *P*-values (two-tailed) | 0.51 | 0.75 | 0.01 | 0.07 | 0.08 |
| SD of difference | 2.20 | 4.35 | 5.45 | 4.77 | 4.08 |
| Standard error of mean | 0.46 | 1.02 | 1.00 | 0.81 | 0.82 |
| Correlation | -0.08 | 0.14 | -0.32 | 0.01 | -0.10 |
| Correlation *P*-values | 0.71 | 0.57 | 0.09 | 0.97 | 0.65 |

[1] Indicates no significant difference between means of predicted and actual values.

Table 7 shows the results of method 6. The difference between the means of predicted and actual projection showed that the method of Stephan et al. (2003) underestimated nasal projection by, on average, 2.2 mm in males and 1.1 mm in females in this sample: again, not a great deal in practice despite being statistically significant. This is compared to an overestimation by 0.2 mm in males and an underestimation by 0.1 mm in females in the sample from which the regression equations were derived (Stephan et al., 2003). In both cases, the error was 11 times larger in the current sample. A significant positive correlation in females suggested a link between the craniometric measurements used for prediction and the actual pro-

*TABLE 5. Comparison of predicted and actual projection using method 4 (Macho, 1986) on preoperative subjects*

| | Height | Length | Depth |
|---|---|---|---|
| Males (n ¼ 44) | | | |
| Mean difference (mm) | 3.66 | 2.26 | 1.20 |
| *P*-values (two-tailed) | 0.00 | 0.00 | 0.03 |
| SD of difference | 3.14 | 3.07 | 3.49 |
| Standard error of mean | 0.47 | 0.46 | 0.53 |
| Correlation | 0.65[2] | 0.66[2] | -0.11 |
| Correlation *P*-values | 0.00 | 0.00 | 0.47 |
| Females (n ¼ 53) | | | |
| Mean difference (mm) | 2.12 | 0.14[1] | 1.24 |
| *P*-values (two-tailed) | 0.00 | 0.71 | 0.00 |
| SD of difference | 2.53 | 2.72 | 1.69 |
| Standard error of mean | 0.35 | 0.37 | 0.23 |
| Correlation | 0.80[2] | 0.79[2] | 0.68[2] |
| Correlation *P*-values | 0.00 | 0.00 | 0.00 |

[1] Indicates no significant difference between means of predicted and actual values.
[2] Indicates significant positive correlation between predicted and actual values.

*TABLE 6. Comparison of predicted and actual projection using method 5 (George, 1987)*

| | Male preoperative (n ¼ 44) | Female preoperative (n ¼ 62) | Postoperative subjects (n ¼ 10) |
|---|---|---|---|
| Mean difference (mm) | 1.36 | 0.86 | 2.51[1] |
| *P*-values (two-tailed) | 0.01 | 0.03 | 0.18 |
| SD of difference | 3.01 | 3.09 | 5.45 |
| Standard error of mean | 0.48 | 0.39 | 1.72 |
| Correlation | 0.65[2] | 0.39[2] | -0.01 |
| Correlation *P*-values | 0.00 | 0.00 | 0.97 |

[1] Indicates no significant difference between means of predicted and actual values.
[2] Indicates significant positive correlation between predicted and actual values.

*TABLE 7. Comparison of predicted and actual projection using method 6 (Stephan et al., 2003) on preoperative subjects*

| | Male (n ¼ 25) | Female (n ¼ 38) |
|---|---|---|
| Mean difference | -2.22 | -1.14 |
| *P*-values (two-tailed) | 0.03 | 0.03 |
| SD of difference | 4.91 | 3.19 |
| Standard error of mean | 0.98 | 0.52 |
| Correlation | 0.07 | 0.69[1] |
| Correlation *P*-values | 0.07 | 0.00 |

[1] Indicates significant positive correlation between predicted and actual values.

jection. No positive correlation, and hence no link, was shown in males.

Figure 5 gives a summary of relevant results for all methods tested. The method was more accurate, the closer the mean difference between predicted and actual measurements was to zero, on the condition that a significant positive correlation was apparent. Only regions c, d, and e are included for method 3, since these are closer to the tip of the nose.

## DISCUSSION

### Method 1: Krogman and Iscan (1986)

This method performed the worst, underestimating the projection of the nose by a relatively large amount in all cases: 9.3 mm in males, and 8.9 mm in females (Fig. 5). However, Stephan et al. (2003) found the method to underestimate nasal projection by just 1.9 mm in males and 4.1 mm in females. The significant error, along with the fact that there was no significant positive correlation between predicted projection and actual projection, illustrates the high variability of this method's accuracy and the lack of a relationship between nasal spine length (as measured from the lateral border of the piriform aperture in profile) and nasal projection. As Stephan et al. (2003) noted, the method may well perform better when used on actual skulls as opposed to lateral radiographs, since the length of the nasal spine could be measured directly from the vomer-maxillary junction rather than the lateral border of the piriform aperture.

Further study needs to be carried out, using actual skulls rather than lateral radiographs, to determine if there is a significant positive correlation between nasal spine length measured from the lateral border of the aperture and from the vomer-maxillary junction. If this is the case, combined with these results, it would suggest that the length of the nasal spine is not linked to the projection of the external nose.

### Method 2: two-tangent technique (Gerasimov, 1955)

This method gave the most accurate results and predicted the position of a point on the tip of the nose on the NSL to within 1 mm. The angle of projection was also determined by the direction of the projected line from the nasal spine (as with method 1). Stephan et al. (2003) found that this method performed poorly, overestimating nasal projection by 6.3 mm in males and 4.3 mm in females. There may be a number of factors causing this interstudy inconsistency, including intersample variation, variation in the placement of landmarks, the use of postoperative subjects, and/or problems associated with small sample size.

In addition, since the FHP is a plane of skull alignment which does not take into account the direction of nasal projection, the use of this plane may have shown false error. The inconsistency between the two sets of results may also be due to alignment of the tangent to the nasal bones, which could cause overestimation of projection, as described in the introduction (Fig 2b), or differences in the angle of NSL, since Stephan et al. (2003) reported that their NSL was "hardly related to the general direction of the columella (male $r^2$ ¼ 0.07, female $r^2$ ¼ 0.05)," and that defining NSL was rather subjective.

Gerasimov (1955) did not specifically state that the nasal tip should be defined in the FHP. In actuality, the "tip" of the nose covers quite a substantial area on the end of the nose, and defining the tip on the nasal spine projection plane appears reasonable, since the NSL follows the nasal angle quite closely, and always crosses the skin surface in the area of the tip of the nose. This could imply a relationship to the direction of growth of the septal cartilage, which is related to the nasal spine, and which gives the nose its profile form.

### Method 3: nasal profile method (Prokopec and Ubelaker, 2002)

It was clear from the lack of positive correlation between predicted and actual measurements that this method did

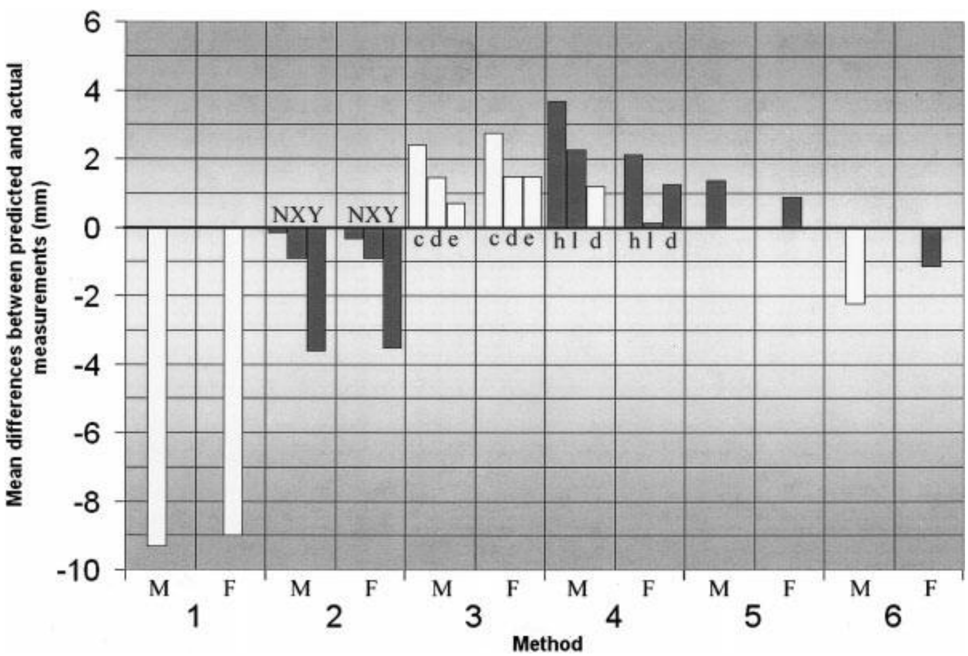


Fig. 5. Grey bars indicate significant positive correlation between predicted and actual measurements. M ¼ Male. F ¼ Female. 1 ¼ Krogman and Iscan (1986). 2 ¼ Gerasimov (1955): N ¼ tip in NSL; X ¼ X in FHP; Y ¼ Y in FHP. 3 ¼ Prokopec and Ubelaker (2002): c ¼ mid-nose; d ¼ lower nose; e ¼ tip of nose. 4 ¼ Macho (1986): h ¼ height; l ¼ length; d ¼ depth. 5 ¼ George (1987). 6 ¼ Stephan et al. (2003).

not accurately predict the shape of the nasal profile. The lengths of the projected perpendiculars between the lateral aperture border and line B were unrelated to the lengths of the perpendiculars between line B and the surface of the nose. This is true despite the coincidental similarity between the means of the two sets of perpendiculars.

Furthermore, in areas a, c, and e on female noses, there was a negative correlation, suggesting an inverse relationship between the lengths of the sets of perpendiculars at the top, middle, and bottom of the female noses tested (Table 4), i.e., the shorter the distance between aperture border and the "mirror line," the longer the distance between the "mirror line" and the surface of the nose.

This variation in types of correlation suggested a lack of a direct relationship between the shape of the lateral border of the piriform aperture and the shape of the nasal profile as mirrored about the proposed line from rhinion. Stephan et al. (2003) found that this method performed rather well at predicting projection in the FHP, and the interstudy inconsistency may be due to sample variation.

### Method 4: Macho (1986)

Significant positive correlation in all areas, except the depth of male noses, suggested a link between the craniometric dimensions measured in the method by Macho (1986) and the dimensions of the external nose. As it is, this method overestimated the height and depth of both male and female noses and the length of male noses in this sample by significant amounts, as shown in Table 5. The length of female noses was predicted accurately.

### Method 5: George (1987)

The method of George (1987) produced similar results to method 4. A positive correlation was recorded between the distance from nasion to point AA, and the projection of the nose in the FHP in both males and females. The error was smaller than for methods 4 and 6, overestimating the projection by, on average, 1.4 mm in males and 0.9 mm in females.

Stephan et al. (2003) showed an underestimation of 1.5 mm for men and 2.8 mm for women using this method. The results of the two studies suggest that the method of George (1987) can predict nasal projection in the FHP reasonably well for Caucasoid skulls. In practice, this technique tells us nothing of the position of the nasal tip in a vertical plane or the shape of the nose in profile. Even though George (1987) found the nasal angle to be 228 from the FHP in both males and females in his sample, he commented on the large variability of this angle between individuals, and even throughout life. This method could be useful to predict nasal projection in the FHP of damaged skulls, where nasal bones and/or the anterior nasal spine were broken or obliterated completely.

### Method 6: Stephan et al. (2003)

This method underestimated nasal projection by, on average, 2.2 mm in males and 1.1 mm in females. The lack of a positive correlation in males suggested no link between the craniometric dimensions used and the projection of the nose in the FHP. However, a positive correlation was seen in females, so female pronasale projection could be determined on this sample quite accurately, using the regression equations derived by Stephan et al. (2003). However, the complexity of this method and the time taken to measure three distances and two angles, with the skull aligned in two planes, make it impractical when more accurate results can be achieved using either method 2 or 5, both of which are quicker and simpler to carry out.

## CONCLUSIONS

These results suggest that the most useful, practical method of nasal tip prediction is the two-tangent method (Gerasimov, 1955). On preoperative subjects, this method can predict a point that lies on the surface of the nose at the tip, in the plane of the projected line from the nasal spine. Where the nasal bones are incomplete or a postoperative subject is assessed, then the method by Gerorge

(1987) appears to be the most useful method of nasal projection prediction.

The nature of regression equations is to generate highly accurate results when tested on the sample from which they were derived. Therein lies an inherent flaw of regression analysis. These results showed that formulae elicited from regression analyses sometimes do not work on other population samples, even when comprised of subjects of similar racial origin and age. This applies to methods 1, 4, 5, and 6. In some cases there was no significant positive correlation between predicted and actual measurements in this sample (methods 1 and 4 for male nasal depth, and method 6 for males), which suggests the lack of a strong, direct link.

Perhaps techniques that rely on functional relationships or known growth patterns would be preferable to regression formulae, simply because they apply to a much broader cross section of the population, with the notable exception of postoperative subjects if the current sample is indicative of the norm. While regression equations may be useful for discovering links within a population (Stephan, 2003b; Stephan et al., 2003; Wilkinson and Mautner, 2003; Wilkinson et al., 2003), presuming their effectiveness outside of the sample population may be ill-advised, since they deal with abstract measurements. Further research into this area should attempt to find functional relationships between morphological skeletal and soft-tissue features.

## LITERATURE CITED

Bron AJ, Tripathi RC, Tripathi BJ. 1997. Wolff's anatomy of the eye and orbit, 8th ed. London: Chapman & Hall Medical Publishers.
Bruce V. 1998. Recognising faces. Hove: Lawrence Erlbraum Associates.
Enlow DH, Hans MG. 1996. Essentials of facial growth. Philadelphia: W.B. Saunders.
Fedosyutkin BA, Nainys JV. 1993. The relationship of skull morphology to facial features. In: Iscan MY, Helmer RP, editors. Forensic analysis of the skull. New York: Wiley-Liss, Inc. p 199–213.
Fraser I, Parker D. 1986. Reaction time measures of feature saliency in a perceptual integration task. In: Ellis H, Jeeres M, Newcombe F, Young A, editors. Aspects of face processing. Dordrecht: Martinus Nijhoft.
Galen. 1956. Galen on anatomical procedure (De anatomicis administrationibus). Trans C. Singer. Oxford.
Gatliff BP. 1984. Facial sculpture on the skull for identification. Am J Forensic Med Pathol 5:327–332.
George RM. 1987. The lateral craniographic method of facial reconstruction. J Forensic Sci 32:1305–1330.
George RM. 1993. Anatomical and artistic guidelines for forensic facial reconstruction. In: Iscan MY, Helmer RP, editors. Forensic analysis of the skull. New York: Wiley-Liss. p 215–227.
Gerasimov MM. 1955. Vosstanovlieniia Litsa po Cherapu; Gos Izd-vo Sovetskaia [The reconstruction of the face on the skull]. Unpublished translation (1975) by Tshernezky.
Gerasimov MM. 1971. The face finder. New York: CRC Press.
Goldhamer K. 1926 Rontgenologische Studien über das menschliche Profil. I. Auszere Nasi. Z Anatom Entwickl 81:115–150.
Gosling JA, Harris PF, Humpherson JR, Whitmore I, Willan PLT. 1990. Human anatomy—text and colour atlas. 2nd ed. London: Gower Medical Publishing.
Haig ND. 1984. The effect of feature displacement on face recognition. Perception 15:235–247.
Haig ND. 1986. Exploring recognition with interchanged facial features. Perception 15:235–247.
Krogman WM, Iscan MY. 1986. The human skeleton in forensic medicine. 2nd ed. Springfield, IL: C.C. Thomas Publishers.
Larsen WJ. 2001. Human embryology, 3rd ed. Oxford: Churchill Livingstone.
Macho GA. 1986. An appraisal of plastic reconstruction of the external nose. J Forensic Sci 31:1391–1403.
Powell N, Humphreys B. 1984. Proportions of the aesthetic face. New York: Thieme-Stratton.
Prag J, Neave RAH. 1997. Making faces. London: British Museum Press.
Prokopec P, Ubelaker DH. 2002. Reconstucting the shape of the nose according to the skull. Forensic Sci Commun 4:1.
Sobotta J. 1983. Atlas of human anatomy 1: head, neck and upper extremities, 10th English ed. Ferner H, Staubesand J, editors. Baltimore: Urban and Schwazenberg.
Stephan CN. 2003a. Anthropological facial "reconstruction"—recognising the fallacies, "unembracing" the errors and realising method limits. Sci Justice 43:193–200.
Stephan CN. 2003b. Facial approximation: an evaluation of mouth-width determination. Am J Phys Anthropol 121:48–57.
Stephan CN, Henneberg M, Sampson W. 2003. Predicting nose projection and pronasale position in facial approximation: a test of published methods and proposal of new guidelines. Am J Phys Anthropol 122:240–250.
Stewart TD. 1983. The points of attachments of the palpebral ligaments: their use in facial reconstructions on the skull. J Forensic Sci 28:858–863.
Suk V. 1935. Fallacies of anthropological identifications and reconstructions: a critique based on anatomical dissections. Brno: Faculty of Science, University of Masaryk. p 1–18.
Taylor KTT. 2001. Forensic art and illustration. New York: CRC Press.
Vanezis P, Vanezis M, McCombe G, Niblett T. 2000. Facial reconstruction using 3-D computer graphics. Forensic Sci Int 108:81–95.
Van Rensburg MSJ. 1993. Accuracy of recognition of 3-D plastic reconstruction of faces from skulls. Abstract. In: Proceedings of Anatomical Society of South Africa. 23rd Annual Congress 20.
Virchow H. 1912. Die anthropologische Untersuchung der Nase. Z Ethnol 44:290–337.
Virchow H. 1924. Zur Anthropologie der Nase. Z Ethnol 56:94–121.
Warwick R, Williams PL, editors. 1973. Gray's anatomy. 35th ed. London: Longman Publishers.
Wilkinson CM. 2004. Forensic facial reconstruction. Cambridge: Cambridge University Press.
Wilkinson CM, Mautner SA. 2003. Measurement of eyeball protrusion and its application in facial reconstruction. J Forensic Sci 48:12–16.
Wilkinson CM, Motwani M, Chiang E. 2003. The relationship between the soft tissues and the skeletal detail of the mouth. J Forensic Sci 48:728–732.