Validation of the new interpretation of Gerasimov's nasal projection method for forensic facial approximation using CT data*†

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ABSTRACT

The most common method to predict nasal projection for the purpose of forensic facial approximation is Gerasimov's two-tangent method. It was recently argued that previous validation studies did not properly perform Gerasimov's original methodology and a revised set of guidelines was proposed. The aim of this study was to compare the accuracy of the different version of the two-tangent method using a sample of 66 postmortem cranial CT data. Intraobserver error was evaluated using a subsample of 10 individuals and the results demonstrated that experience affects the accuracy. Overall, the revised guidelines consistently resulted in smaller mean difference from the true tip. On the other hand, none of the methods were found to be statistically accurate ($p>0.05$) in positioning the tip of the nose (absolute distance > 5 mm). These results seem to support that Gerasimov's method was not properly performed and the new guidelines should be used instead.

Keyword: forensic science, forensic anthropology, facial approximation, nasal projection prediction, pronasale, two tangent method, computed tomography

Forensic facial approximation is the process of applying clay to the skull or replica to produce an estimate of the visage of an individual. The purpose is to create an approximation of the face of unidentified remains that is accurate enough to be recognized as a specific individual. Forensic anthropologists and forensic facial approximation practitioners emphasize that it is not a method of positive identification but a tool to generate leads (1-5). The rational behind facial approximation is the existence of a predictable relationship between the soft and hard tissues of the face. The existence of a predictable relationship was criticized early on and was said to be highly improbable and a mistake (6-8). Nevertheless, research has continued to demonstrate the existence of such a relationship, and improve the accuracy and precision of the facial approximation techniques. Cases have been reported where the facial approximation was successfully used for identification (9,10).

There are three approaches to forensic facial approximation: the anatomical method, the tissue depth method, and the combination method. The first approach emphasizes modeling the facial muscles on the skull (11) and is based on the theory that the skull provides enough information on the origins and insertions of the facial muscles to allow accurate modeling. The second approach uses data on average facial soft tissue thickness (12) and is favored by law enforcement agencies since the published soft tissue data can be referenced in court. Finally, the third approach combines facial muscles modeling and soft tissue depth (13). Overall, successful facial approximation is directly linked to the ability to recognize the face of an individual. Facial recognition is not only based on the overall shape of the face but the interrelationship between the different facial features (14). Consequently, the size, shape and position of the facial features are essential for successful forensic facial approximation. Regardless of the approach used, practitioners use some of the same techniques to determine the size, shape, and location of different facial features.

The three most significant features for recognition are the eyes, the mouth and the nose (15). The accurate approximation of the nose is the most important for profile and three-quarter views of the face. The size, shape and projection of the nose is determined by the underlying bone structure in addition to the skin, subcutaneous fat, muscles, cartilage and a ligament (16). The complexity of the nasal anatomy increases the difficulty in understanding variation in nasal shape, and the correlation between the hard and soft tissue. In addition, the nose is directly affected by age. The position of the tip of the nose changes with time due to gravity, the weakening of the lower lateral cartilage, and the loss of skin elasticity (17). Overall, the nasal region is particularly difficult to approximate for the purpose of forensic facial approximation because it is mainly composed of cartilage (16), which continues to grow throughout life (18). Nevertheless, a study using computed tomography (CT) scans has shown that the nose can be approximated reliably (19).

Numerous methods have been published to determine the position of the nose in profile. The two-tangent method (11) and the threefold-ANS method (12) were both developed based on the experience of the practitioner with craniofacial anatomy. The other methods, which were published by Macho (20), George (2), Prokopec and Ubelaker (21), Stephan, Henneberg and Sampson (22), and Rynn, Wilkinson and Peters (23), use a variety of linear distances and angles and were developed from the analysis of various craniometric measurements from radiographs or CT scans. The most commonly used method, and first published, is the two-tangent method developed by Mikhail Gerasimov (11). The two-tangent method is a simple and quick way to determine nasal projection. The tip of the nose in positioned at the intersection of two tangents.

The first tangent follows the general direction of the last third of the nasal bone, and the second tangent is the continuation of the anterior nasal spine (ANS) (11).

The reliability and accuracy of the two-tangent method have been tested and compared to other methods with inconsistent results (22,24,25). Stephan et al. (22) used a European sample of 29 male and 30 female lateral head radiographs to test different nasal projection methods. The authors determined that Gerasimov’s method overestimates the position of pronasale, which is the most projecting point of the nose when the cranium is in the Frankfurt Horizontal Plane (FHP), and is therefore a highly unreliable technique. On the other hand, Rynn et al. (25) used a dataset of 122 Caucasian lateral cephalogram and observed that the two-tangent method was the most accurate at positioning a point on the tip of the nose, compared to other techniques. They concluded that the difference in results compared to Stephan et al. (22) is due to how the tip of the nose was defined, in either the Frankfurt Horizontal Plane (FHP) or nasion-prosthion plane. Finally, López Schilling and Galdames (24) compared the accuracy of all methods on a sample of 34 individuals, observing that Gerasimov’s approach performed second best. What is the best method remains undetermined, but methods necessitating numerous linear and angular measures are impractical (25). Consequently, the two-tangent method developed by Gerasimov is the most promising for determining the position of the tip of the nose from the skull and at least two studies found it to be the most or second most accurate (23-25). Additional research is needed to better understand the variability in accuracy for these techniques.

Recently, Ullrich and Stephan (26) criticized the validity of the studies performed by Stephan et al. (22) and Rynn and Wilkinson (25), arguing that the two-tangent method was performed incorrectly. The guidelines used in previous validation studies come from the English book, *The Face Finder* (11), published by Gerasimov and translated from German by Alan

Houghton Brodrick. The guidelines clearly state that the two tangents used follow the last third of the nasal bone and the general direction of the nasal spine. However, Ullrich and Stephan (26) argue that Gerasimov himself did not adhere to these guidelines but instead used the last 1-2 mm of the nasal bone and followed the general direction of the nasal floor beside the anterior nasal spine. As a result, they argue that previous validation studies should be dismissed (26). Rynn and Wilkinson (25) have demonstrated that the first tangent following the last third of the nasal bone results in an overestimation of the tip of the nose compared to using the last 1-2 mm only, which provides support to Ullrich and Stephan's claim. However, the definition of the second tangent is still from Gerasimov's translated work and is not valid according to Ullrich and Stephan. Consequently, the reliability and accuracy of Gerasimov's two-tangent method has not yet been accurately tested.

The purpose of this research was to determine if Gerasimov's (9) original or commonly used guidelines from his translated work are more accurate at positioning the tip of the nose compared to the revised method proposed by Ullrich and Stephan (26). This study is unique from most others to date in using computed tomography (CT) scans instead of lateral radiographs. CT scans provide definite advantages over lateral X-rays; the ability to isolate anatomical structures, take apart and reassemble the image, and to create an accurate 3D model of the skull (27). This study follows the work of Rynn et al. (23), which successfully used CT scans to investigate nasal projection methodology.

Materials and Methods

A sample of 137 anonymized postmortem CT scans of individuals of known age and sex from a modern Danish population was used. The CT scans were undertaken by the Department of Forensic Medicine at the University of Copenhagen and were collected as part of standard postmortem procedures. Ideally, CT scans from living subjects should be used to avoid the possible effect of loss of muscle tone and the supine position during scanning, on the true position of the facial feature. It is typically more difficult to obtain CT scans of living individuals compared to traditional radiographs due to the higher radiation exposure. Researchers have only recently started to use CT scans of living subjects with the more recent development of the cone beam CT, which allows scanning in an upright position with less radiation (28). Consequently, the availability of CT scans from living subject is still limited. The scans used in this study were typically taken within 24 hours after death and the postmortem process should have minimal effect on the soft tissue, and on the final nasal prediction. Each scan was examined to make sure the region of interest (nasal bone, nasal spine, floor of the nasal aperture and associated soft tissue) was visible. Scans were excluded when it was visually apparent that the nose was affected by antemortem trauma or a pathological condition, or clearly distorted by postmortem processes. After a preliminary examination of the scans, a total of 71 scans were excluded because of distorted or missing soft tissue, distortion of the nasal bone, and lack of individual information. Previous studies testing nasal projection methodology have used age as an exclusion criterion (22,23) because the nose continues to move forward and downward with age due to its cartilaginous composition (18,29), and facial approximation methods are ideal for an age range of 25 to 35 years (30). However, for this study it was decided to include all ages and to examine any correlations between age and sex with the predicted nasal projection. The final sample consisted of 23 females and 43 males (Table 1) for a total of 66 individuals with an overall mean age of 51.4 years.

The CT data were processed using Materialise MIMICS medical imaging software to both visualize the anatomical structures and render 3D models. The regions of interest were selected and soft and hard tissues were defined by segmentation using MIMICS' predefined threshold, -700 to 225 Hounsfield Units (HU) for the soft tissue and 226 to 3071 HU for the skull. The nasal cartilages were not included to allow visual clarity of the bony structure. The segmented sections were then used to render two 3D models. The first model was the skull only to test the nasal projection methods without being biased by the presence of the soft tissue. The second model combined the skull and the associated soft tissue to determine the accuracy of the nasal projection (Figure 1).

The 3D models were positioned in the Frankfurt Horizontal plane (FHP) and two images (Image A: 3D model of skull, Image B: 3D model of skull and soft tissue) were saved and imported in Adobe Illustrator. Image B was taken immediately after image A, despite the risk of bias by seeing the soft tissue, to maintain identical positioning of the 3D model. A measurement was included on each image to allow the image to be scaled accurately using the integrated rulers within Illustrator's worksheet. The rulers also allow the user to identify the exact position of objects of interest. The origin point of both the horizontal and vertical rulers can be moved anywhere in the worksheet. For the purpose of this study, the origin was placed on nasion, previously identified in MIMICS. As a result, the position of the tip of the nose (predicted or true) was determined as a distance in millimeters (mm) in X (horizontal) and Y (vertical) from nasion.

Four tangents were drawn on Image A (skull only) of each individual to evaluate how the position of each tangent influenced the resulting nasal projection and to determine if the new guidelines presented by Ullrich and Stephan were more accurate. Tangent 1 (T1) follows the last third of the nasal bone and tangent 2 (T2) follows the general direction of the anterior nasal spine, both taken from Gerasimov's book (11). Tangent 3 (T3) follows the last 1-2 mm of the nasal bone and tangent 4 (T4) follows the direction of the nasal floor to the right of the anterior nasal spine, as suggested by Ullrich and Stephan (26). The different tangent combinations resulted in four different version of the two-tangent method. The intersection of T1 and T2 is the method commonly used and described in Gerasimov's translated work (11). T3 and T4 represents the revision proposed by Ullrich and Stephan (26). The remaining two tangent combinations are a mix of Gerasimov's and the new guidelines (Table 2). The four combinations represent the possible position of the tip of the nose (Figure 2).

For each method, the estimated point was compared to a reference point or true position of the nasal tip to assess the accuracy of the method. Gerasimov did not specify how to position the cranium and if the most projecting point of the nose is defined by the FHP (25). As a result, the position of the predicted nasal tip was compared to two different reference points (Figure 3). Reference point 1 (R1) was defined as the most projecting point when the skull was in the FHP, which is commonly used (22-25) and is also known as pronasale. Reference point 2 (R2) was the point where the nasal spine line, which is the equivalent of the tangent following the anterior nasal spine (T2), crosses the surface of the nasal soft tissue (25). The distance between the estimated position of the nasal tip and the true nasal tip was then calculated. A positive difference indicates that the method underestimated the nasal projection and a negative difference means the method overestimated the projection along the X or Y axis. The horizontal and vertical differences were also used to calculate an absolute distance between the estimated nasal tip and true tip to better assess the accuracy of the method without being biased by directionality.

The results were analyzed using IBM SPSS statistics version 20. First, repeated-measures one-way analysis of variance (ANOVA) with pair-wise comparisons was performed to determine if there was a significant statistical difference between each method and to identify which method was better based on the mean differences. A Bonferroni correction was utilized to control for the problem of increased family wise error rates and keep the Type I error rate to $p<0.05$. A total of six ANOVAs were used to analyze the absolute distance, and the difference in X and Y for reference points 1 and 2 independently. Additionally a one-sample t-test was performed to determine if the methods could accurately position the tip of the nose. Overall, the ANOVA identifies if there is a difference between each method and the t-test evaluates the accuracy of the methods.

In addition, independent samples t-tests were performed to determine if age, sex and the shape of the nasal bone had an effect on the accuracy of the two-tangent method. Individuals were classified as having either a straight or curved nasal bone, being male or female, and <50 or >=50 years old. The cut off point of 50 years of age was used as this has been shown to be the age when age-related nasal soft tissue changes start to be visible (17). Finally, the nasal projection was repeated twice on a subsample of 10 individuals to assess intraobserver error. This was important due to the fact that the two-tangent method was developed based on the experience of Gerasimov with craniofacial morphology. The results were compared using a repeated-measures ANOVA with post-hoc procedures to identify if there was a statistical difference between each trial and evaluate the possible effect of experience.

Results

Intraobserver error was evaluated using a repeated-measures ANOVA with pairwise comparisons. The ANOVA demonstrated statistically significant differences between trials. Pairwise comparisons determined that trial 1 was statistically different from trials 2 and 3 ($p<0.001$), but there was no difference between trials 2 and 3 ($p=0.728$). This suggests the presence of an initial learning curve by the inexperience practitioner after which the methodology is reliable and repeatable.

The calculated horizontal (X axis) and vertical (Y axis) differences between the estimated nasal tip and the true tip were visualized with scatter plots for each method (Figure 4 - 7). The majority of the data is situated forward and downward (anterior and inferior) when the position of the nose was estimated using Methods 1 and 2 (Figure 4 and 5). In comparison, Methods 3 and 4 resulted in the majority of the data to be situated backward and downward (posterior and inferior) (Figure 6 and 7). There is also an overall decrease in data dispersion, or increase in precision, from Method 1 to Method 4. In addition, the vertical difference between the estimated tip of the nose and reference point 2, clusters around zero for all four methods. This pattern was expected because the position of reference point 2 is defined using the tangent that follows the general direction of the nasal spine exactly how it is used for the two-tangent method. Finally, one individual was consistently identified as a statistical outlier when the data were visualized using a boxplot, while two additional individuals were outside the majority of the data for Method 1 relative to reference point 1 (M1 R1) and for Method 3 relative to reference point 2 (M3 R2). The statistical analysis was performed both including and excluding the three outliers with no resulting change in the relationship of the data. Since it is not possible to determine if the outliers were caused by subtle postmortem soft tissue distortion or natural variation in nasal projection, and because the relationship of the data is unchanged, the results presented here include the outliers.

The X and Y position of the true nose for male and female was compared using a t-test to determine if there is sexual dimorphism in nasal projection. It was found that males tend to have a significantly ($p<0.01$) more projecting nose than females. On the other hand, the mean difference between the predicted and true position of the tip nose between males and females was not statistically significant with the exception of M2 R1 ($p = 0.030$). In other words, the presence of sexual dimorphisms does not have an effect on the accuracy of the two-tangent method. In addition, no correlation between age and the true position of the nose was found for either axis. Lastly, neither age (over-50 versus under-50) nor nasal bone morphology showed statistically significant differences in accuracy of prediction. Given that age, sex and nasal morphology did not show an effect on the accuracy of the prediction of the nasal tip, the statistical analysis was performed on the total sample as a whole (N=66).

The ANOVAs of the absolute distance from both reference points indicated that there was a statistically significant difference between the mean differences of the four versions of the two-tangent method. The pairwise comparisons of the mean difference from R1 indicated that Method 1 was statistically different ($p<0.001$) from all the other methods, and Method 3 was statistically different ($p<0.001$) from Method 4. Finally, the mean difference using Method 2 was not different from Method 3 ($p=0.159$) and Method 4 ($p=0.544$). In comparison, when the estimated tip is compared to reference point 2 using the absolute distance, Method 2 and Method 4 are statistically different ($p<0.001$), and Method 3 and Method 4 are not ($p=0.078$). The repeated measures ANOVA using the mean difference along the X-axis and Y-axis resulted in all pairwise comparison to be statistically significant with the exception of one. The vertical mean difference (Y-axis) compared to reference point 2 is not statistically significant between Methods 3 and 4 ($p=0.300$).

Table 3 summarizes the results from the t-test using the vertical (Y) and horizontal (X) mean differences from both reference points (R1 and R2), to determine if the methods (M1 to M4) over- or underestimated the true nasal tip and the direction of the error. Only two mean differences were not statistically different from zero, but were statistically significant when using a nonparametric test to compensate for the skewed distribution of the data. In addition, almost all mean differences were larger anteroposteriorly compared to vertically. Similarly, the absolute distance was statistically significant across all methods and reference points (Table 4), using either a t-test or the non-parametric equivalent. The majority of the data were found to not be normally distributed, however, both parametric and nonparametric analysis of the data provided the same results and conclusions. Consequently, the t-test and associated mean differences were used and reported here as a more meaningful method for evaluating the magnitude of error of the nasal projection estimates.

Discussion

The position of the tip of the nose estimated by the two-tangent method is directly correlated with the angle at which the tangents are placed. The angle of the first tangent, following the nasal bone, has a greater impact on the anteroposterior position of the tip of the nose. In comparison, the second tangent, following the nasal spine or nasal floor, mostly affects the vertical position of the nose (Figure 8). The ANOVA indicated that all the mean difference along the X-axis were statistically different from one another. Nevertheless, the anteroposterior (X-axis) mean difference of Method 1 was always larger than Method 3 and again for Method 2 compared to Method 4 (see Table 3). In other words, following the last third of the nasal bone to position the tangent consistently resulted in greater horizontal mean difference compared to using the last 1-2 mm of the nasal bone. This relationship was independent from the second tangent used or how the true position of the tip of the nose is defined. This is consistent with the conclusions reached by Rynn and Wilkinson (25) and the new guidelines proposed by Ullrich and Stephan (26) that the general direction of the last 1-2 mm of the nasal bone should be used.

A comparison of Method 1 to 2 and Method 3 to 4 helps determine the effect of using the nasal spine versus the nasal floor on estimating the position of the tip of the nose. An ANOVA of the vertical (Y-axis) mean differences demonstrated mean difference from each other with the exception of one. The mean difference compared to reference point 2 was not statistically different between Method 3 and Method 4. In other words, using the general direction of the nasal floor instead of the anterior nasal spine results in similar approximation of the nasal tip when defined using the nasal spine line and using the last 1-2 mm of the nasal bone for the first tangent. Nonetheless, all the other mean differences are smaller in magnitude for the methods that use the tangent following the general direction of the nasal floor. Overall, despite the fact that Methods 3 and 4 do not result in statistically different approximations, using the nasal floor is slightly better at vertically positioning the tip of the nose by approximately 1.5 mm.

The analysis of the difference along the X and Y-axes determined the effect of each tangent on the position of the estimated tip of the nose. The two tangents introducing the largest error are the ones following the last third of the nasal bone and the nasal spine line, which is how the same as the original guidelines by Gerasimov (11). On the other hand, the most accurate tangents are the one following the last 1-2 mm of the nasal bone and the nasal floor, as defined by Ullrich and Stephan (26). Consequently, Method 1 would perform the worst and Method 4 the best. The mean absolute distances support this conclusion, where Method 1 had the largest mean difference for both reference points (19.3667 mm / 11.926 mm) and Method 4 the smallest (8.8530 mm / 5.4379 mm). Overall, the new interpretation of Gerasimov’s two-tangent method is more accurate than the original guidelines. However, the new interpretation is not statistically different than using the tangent combination of the last 1-2 mm and the nasal spine (Method 3), with difference of 3.065 mm.

Despite the fact that Method 4 is more accurate than Method 1, the absolute distances were still significantly different from zero. In other words, the two-tangent method, regardless of how it was performed, could not accurately approximate the position of the tip of the nose. This is in partial contradiction with expectations based on the studies by Stephan et al. (22), Rynn and Wilkinson (25) and López et al. (24). First, as expected, none of the methods accurately determined the position of pronasale. Second, Method 3 was previously found to be highly accurate to predict the tip of the nose when defined using the nasal spine line (25) and this was not supported by the current study. Third, studies (22,25) reported significantly smaller vertical and horizontal mean differences from the true position of the tip of the nose compared to this research (Table 5). The use of a postmotem sample could explain some of the results. The supine position of the body during the postmortem scan combined with the effect of gravity could result in the soft tissue of the face to be more flattened. This would have increased the overestimation of Method 1 and 2 (increase error) but would have decreased the underestimation of Method 3 and 4 (decrease error). However, Method 3 and 4 continued to have larger mean differences.

Another explanation could be investigator experience. The guidelines for Gerasimov's (11) original two-tangent method seem easily performed, even by a beginner. However, Stephan et al. (22) stated that the wording "general direction" is imprecise and the technique is subjective. The issue of subjectivity was reemphasized by Rynn et al. (23) because of the difficulty in placing a tangent on a curved surface. A small error in the angle of the tangent can result in a large deviation from the true tip at the end of the tangent. Finally, the method have been said to be difficult to repeat (26,31). The current research does not support the latter statement. There was no significant difference between later trials 2 and 3, suggesting the presence of an initial learning curve after which the method can be reliably repeated with an average difference of

0.678 mm. In addition, accuracy could be increased by familiarity with nasal bone morphology and its associated soft tissue.

Conclusions

This research tested the claim by Ullrich and Stephan (26) that previous validation studies of the two-tangent method should be dismissed on the basis that the method was not performed as Gerasimov intended. They proposed to use the last 1-2 mm of the nasal nose instead of the last third, and to follow the general direction of the nasal floor instead of the anterior nasal spine. Overall, the majority of the different tangent combination overestimated the position of the tip of the nose and all had an absolute distance from the true tip above 5 mm (Table 6). The new guidelines resulted in smaller mean differences from the true nasal tip compared to Gerasimov's original guidelines, which seems to support Ullrich and Stephan's claim. However, there is no statistical difference between using the two-tangent method as performed by Rynn and Wilkinson (25) and the new interpretation discussed by Ullrich and Stephan (26). In addition, based on the statistical analysis, none of the methods could accurately approximate the position of the tip of the nose, which contradicts previous validation studies (24,25). Despite these negative accuracy results, this research provides three important conclusions about the two-tangent method:

1) The new interpretation is better than the original guidelines found in Gerasimov's book *The face finder* based on the mean difference.

2) The first tangent, following the general direction of the nasal bone (T1), causes most of the error when compared to the true tip with greater accuracy using the last 1-2 mm (T3).

3) Ullrich and Stephan's revision of the two-tangent method is better at

approximating a point on the tip of the nose defined using the nasal spine line (R2) compared to pronasale (R1).

The nasal floor is preferred for positioning the second tangent because the mean difference with the true nose was consistently smaller using the nasal floor compared to when using the nasal spine. However, comparison of both means was not statistically significant, with a difference between the means of 3.0651 and 3.5 mm. Consequently from a practical point of view, the nasal spine could be a good alterative if the nasal floor is damaged, and vice and versa. This is important to keep in mind since crania analyzed during actual forensic cases are affected by a wide range of postmortem processes and antemortem trauma. Regardless of how Gerasimov truly positioned the two tangents, what is important is that the method needs to be accurate.

It is important to emphasize that the method was not affected by intraobserver error, but that the level of experience of the practitioner seems to influence the accuracy. Subjectivity in placing the tangents has been identified in previous research (22,23). The issue of subjectivity has been newly addressed by combining regression equations and the two-tangents methods (23). Their approach is promising and could be used in combination with the revised guidelines provided by Ullrich and Stephan (26). In the future, data should be collected from CT scans of living subjects to investigate in more depth the relationship between the soft and hard tissue of the nose using multivariate statistics. This could help confirm the relational behind the two tangent method (11). This research helps to fill a gap in the knowledge of facial approximations by providing empirical data to fully understand the effect of tangent positioning and researcher experience on nasal projections using Gerasimov's two-tangent method. It also validated claims previously published in the forensic nasal approximation literature (25,26).

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Table 1: Descriptive statistics of the age (years) of the CT sample separated by sex

Sex	*N*	*Minimum*	*Maximum*	*Mean*	*Std. Deviation*
Male	43	21	87	49.98	16.995
Female	23	29	86	53.96	14.480

Table 2: Description of the tangents used for the four version of the two-tangent method tested

Method #	*1st Tangent*	*2nd Tangent*	*Method Description*
Method 1 (M1)	Tangent 1 (T1)	Tangent 2 (T2)	Commonly used
	Last 1/3 nasal bone	Nasal spine	
Method 2 (M2)	T1	Tangent 4 (T4)	Combination 1
		Nasal floor	
Method 3 (M3)	Tangent 3 (T3)	T2	Combination 2
	Last 1-2 mm nasal bone		
Method 4 (M4)	T3	T4	New interpretation

Table 3: Output for the t-test using the mean difference along both X and Y axis between predicted nose and the two reference points (R1 or R2) for each methods (M1 to M4)

	t	*df*	*Sig.*	*Mean Diff.*		*t*	*df*	*Sig.*	*Mean Diff.*
M1 R1 X	-8.614	65	<0.001	-14.3697	M3 R1 X	1.546	65	.127	2.0515
M1 R1 Y	-16.077	65	<0.001	-11.0939	M3 R1 Y	-18.199	65	<0.001	-9.2515
M1 R2 X	-11.545	65	<0.001	-21.7591	M3 R2 X	-3.566	65	.001	-5.3394
M1 R2 Y	-4.034	65	<0.001	-3.5152	M3 R2 Y	-2.155	65	.035	-1.6697
M2 R1 X	-7.865	65	<0.001	-7.8258	M4 R1 X	5.323	65	<0.001	4.5773
M2 R1 Y	-8.897	65	<0.001	-3.7394	M4 R1 Y	-11.049	65	<0.001	-4.3985
M2 R2 X	-9.577	65	<0.001	-10.3470	M4 R2 X	2.276	65	.026	2.0530
M2 R2 Y	4.138	65	<0.001	.5424	M4 R2 Y	-1.071	65	.288	-.1136

Table 4: Output for the t-test using the absolute distance (D) between predicted nose and both reference points (R1 and R2) for all four methods (M1 to M4)

	t	*df*	*Sig*	*Mean Diff.*		*t*	*df*	*Sig.*	*Mean Diff.*
M1 D R1	12.100	65	<0.001	19.3667	M1 D R2	11.926	65	<0.001	22.9333
M2 D R1	12.578	65	<0.001	10.3409	M2 D R2	10.989	65	<0.001	10.9470
M3 D R1	12.301	65	<0.001	12.4333	M3 D R2	5.720	65	<0.001	8.5030
M4 D R1	15.839	65	<0.001	8.8530	M4 D R2	8.238	65	<0.001	5.4379

Table 5: Comparison of the mean differences (mm) between predicted nasal projection and true nose defined by pronasale (R1) and/or nasal spine line (R2) for this study and previously published validation studies

	Method 1 (R1)		Method 3 (R1)		Method 3 (R2)	
	Stephan et al. (22)	*Current study*	*Rynn and Wilkinson (25)*	*Current study*	*Rynn and Wilkinson (25)*	*Current study*
X male	6.2	-13.372	-0.91	3.092	-0.16	-4.320
X female	4.3		-0.9		n/a	
Y male	7.5	-10.978	-3.61	-9.131	-0.34	-1.565
Y female	6.7		-3.54		n/a	

Table 6: Summary of the mean difference along X and Y axis between predicted and true position of the tip of the nose, and absolute distance, for all four method

Mean difference (mm), overestimate (+), underestimate (--)

	Pronasale / FHP (R1)					NSL (R2)				
Method*	X		Y		Absolute	X		Y		Absolute
M1	-14.370	+	-11.094	+	19.367	-21.749	+	-3.515	+	22.933
M2	-7.826	+	-3.739	+	10.341	-10.347	+	0.542	--	10.947
M3	2.052	--	-9.252	+	12.433	-5.339	+	-1.670	+	8.503
M4	4.577	--	-4.398	+	8.853	2.053	--	-0.114	+	5.438

* 1 = Commonly used guidelines, 2 = First combination, 3 = Second combination, 4 = New Interpretation

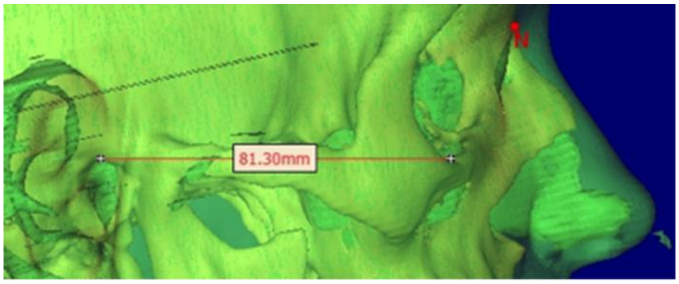

Fig 1

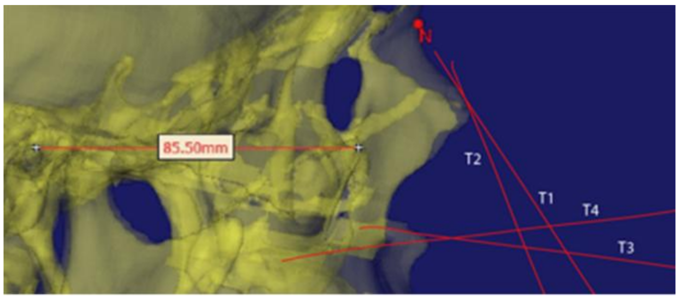

Fig 2