

**Testing Gerasimov's Two-Tangent Nose
Projection Method in Craniofacial
Approximations of Children**

by

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Abstract

Craniofacial approximation is an artistic process in which a potential face is created over the skull of an unknown individual in order to assist with identification. It is often not performed on children due to the lack of research in this area. There are currently several methods in use to predict the nose pronasale position, the oldest and purportedly most accurate and precise of which was the two-tangent method proposed by Mikhail Gerasimov in 1955 (13, 14, 17, 23, 24, 27, 28). To determine if this method is accurate for children of different age groups, 280 (140 male, 140 female) lateral cephalograms were imported into Adobe Photoshop® 7 where the soft tissue outline is removed to estimate the position of the pronasale using Gerasimov's two-tangent method. The soft tissue outline layer was reapplied, and the predicted pronasale was compared to the actual pronasale using a Cartesian system. ANOVA and t-tests were performed to compare the position of the actual and predicted pronasale between age groups of the same sex, between sexes, and age groups of different sexes. Results show that this method only is accurate and precise for male juveniles between the ages of 9-12. According to these findings, Gerasimov's two-tangent method should probably not be used for facial approximations on children.

Keywords: Facial approximation; nasal projection prediction; two-tangent method; children

*This thesis is dedicated to my partner, Travis Shaw,
who believes in me the most no matter what I do.
I also dedicate it to my family in California and my
family-in-law in Vancouver, both of whom have
supported my decisions for my education throughout
the years.*

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Table of Contents

Approval	ii
Abstract	iii
Dedication	iv
Acknowledgements.....	v
Table of Contents.....	vi
List of Tables.....	vii
List of Figures.....	vii
Chapter 1. Introduction.....	1
Chapter 2. Materials	5
Chapter 3. Methods.....	8
Chapter 4. Results.....	11
Chapter 5. Discussion and Conclusion	18
References.....	25

List of Tables

Table 2.1.	Age ranges for the age groups of females and males.	7
Table 4.1.	Summary statistics for female and male sub-samples broken down by age groups for mean distances and mean absolute distances in pixels between the estimated and real pronasale on the X-axis (standardized X-values).	11
Table 4.2.	Summary statistics for female and male sub-samples broken down by age groups for mean distances and mean absolute distances in pixels between the estimated and real pronasale on the Y-axis (standardized Y-values).	12
Table 4.3.	Summary statistics in pixels for female and male sub-samples broken down by age groups for standardized Z-values.	13

List of Figures

Figure 1.1.	Diagram of the external and internal nose.	2
Figure 3.1.	Triangulation of the actual to predicted pronasale.	9
Figure 4.1.	Sample of a close predicted pronasale at 0 by 3 pixels versus a predicted pronasale that was 65 by 78 pixels from the actual pronasale.	15
Figure 4.2.	Comparison of female vs. male predicted pronasales in age group 1 (6-8.9 years of age).	16
Figure 4.3.	Comparison of female vs. male predicted pronasales in age group 2 (9-11.9 years of age).	16
Figure 4.4.	Comparison of female vs. male predicted pronasales in age group 3 (12-15.9 years of age for females and 12-14.9 years of age for males).....	17
Figure 4.5.	Comparison of female vs. male predicted pronasales in age group 4 (16-19 years of age for females and 15-19 years of age for males).....	17

Chapter 1.

Introduction

Craniofacial approximation (also called reconstruction or estimation) is a process in which an artist or technician creates a rendition of the face of the deceased by using the skull as a bony framework for soft tissues. This is used when the identification of the individual is unknown, or in other cases it is used to confirm the identity of a known historical individual (20, 33). This is often done in the hopes of sparking recognition in those who knew the deceased individual in life (20, 21, 24). Craniofacial approximation is used in tandem with other methods or when all other efforts fail to produce a positive identification (21). If the individual is recognized it may lead to a positive identification through other means, such as dental records or DNA analysis. The process of identification can be initiated by craniofacial approximation (7, 9, 24).

There are multiple methods of craniofacial approximation, including hand drawing over a photograph of a skull covered in tissue depth markers, using computer software to create a 3D model, and physically placing clay over a skull to simulate soft tissue (26). Often these methods are used in the context of forensic art, which includes composite imagery, image modification and image identification, demonstrative evidence (in the form of a physical object rather than real evidence, testimony, and other forms of evidence used at a trial), and reconstruction and post-mortem identification aids (26). Often the craniofacial approximation is accurate enough to trigger the memories of the deceased by those who survive them, and while craniofacial approximation is not a method of identification it can assist in widespread circulation and lead to recognition of the individual (9). As such, the eyes, nose, and mouth are important in recognition as they make up the gestalt of the face; that is to say, the overall appearance of the face is more important to identification than any one feature individually (3, 26).

The birth of craniofacial approximation is credited to Kollmann and Büchly in 1898 when they attempted to recreate a face from a skull without first seeing the appearance of the individual (21, 28). However, His and Schaffer are often credited as being the first to perform craniofacial approximation three years prior, though they did so with several picture references of Bach and therefore their efforts cannot be considered facial prediction (20, 21, 28). One of the most influential individuals in facial approximation was Russian anatomist Mikhail Gerasimov, who began experimenting in the 1920's with creating methods of reconstructing facial features by modeling muscles and skin onto a skull using clay (22). Despite his thorough research, this information did not make it beyond the USSR until much later when facial approximation was made popular by Wilton M. Krogman in the 1960's (13, 22, 26, 33).

The nose in particular is a difficult feature to approximate due to the lack of a bony framework underneath the soft tissue, along with the interconnected nature of the muscle, tissue, and fat to the nasal bone structure, which is made up of the nasal bones and the frontal processes of the maxillae, along with the vomer and ethmoid bones (2). The profile is made up of the root, dorsum, tip, and columella, and the other parts of the nose are made up of the ala, alar sulcus, and nostrils (see Figure 1.1) (2).

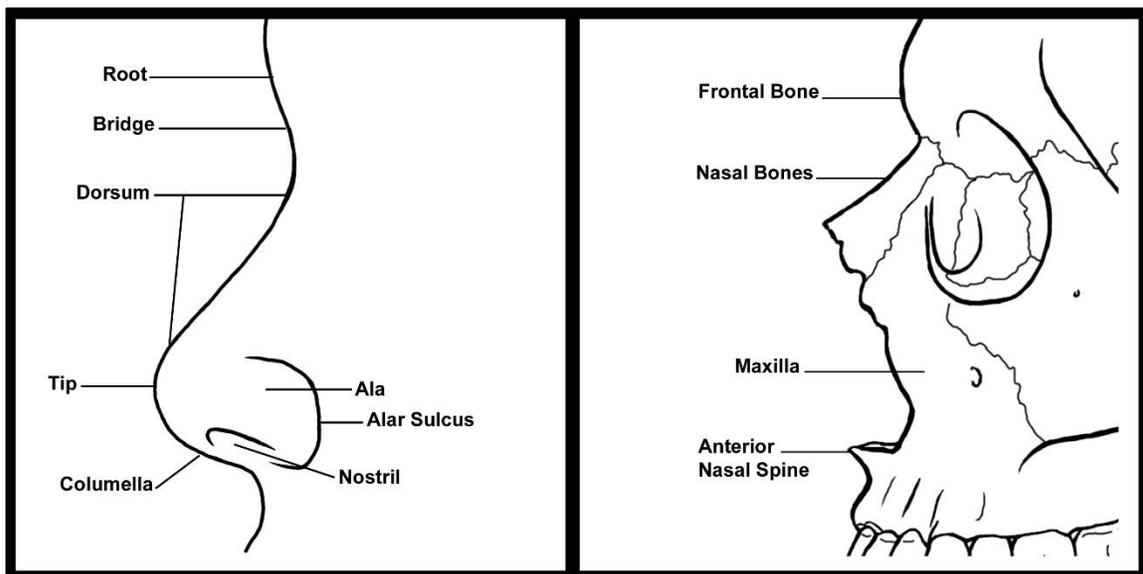


Figure 1.1. Diagram of the external and internal nose.

There are currently several different methods (13, 14, 15, 17, 23, 24, 27) in use to determine the projection of the nose and the location of the pronasale – the most protruding point of the nose, also called the tip of the nose. Having multiple options for finding the pronasale can cause difficulties, not only with the facial approximation itself but also with the credibility of the discipline since having no set standard means that each artist or technician is working with methods that may not have been thoroughly tested (22). Multiple options also means that since there is no one set standard method for achieving a facial approximation, the final rendition often relies on the experience and abilities of the artist or technician (22).

Gerasimov's two-tangent method was described in *The Face Finder*, which was written by Gerasimov two years before his death in 1970 (14):

The profile of the nose is projected by two straight lines, one at a tangent to the last third of the nasal bones and the other as a continuation of the main direction of the point of the bony nose. The point of the intersection of these two lines will generally give the position of the tip of the nose.

Several papers have examined Gerasimov's method for predicting the pronasale on adults, and analyze the original documentation's interpretation from Russian to English and new understandings of the method (16, 24, 26, 29). In the last few years it has come to light that perhaps Gerasimov's method has been interpreted incorrectly from the original 1955 translation, and both Rynn and Wilkinson (24) and Ullrich and Stephan (29) have interpreted the instructions in ways that are more specific, but when performed correctly it yields more precise and accurate results than other methods. This includes using the last 2mm of the nasal bone instead of the last 1/3 of the nasal bone. Because this study included individuals of a variety of ages and the facial proportions of children are not the same as those of an adult, the last ¼ of the nasal bone was used to test Gerasimov's two-tangent method. Rynn and Wilkinson's 2010 study showed that while testing the two-tangent method, 40 out of 45 subjects of European ancestry from Belgium showed results of the predicted pronasale within 2mm of the actual (24). Contrarily, Lapointe *et al.* tested Gerasimov's two-tangent method on 137 individuals from a modern Danish population using Ullrich and Stephan's new interpretation and their findings indicated that while the new interpretation was more accurate and precise, it was still not able to predict the pronasale (16, 29). Lapointe *et al.* also indicated that it was possible for their results to

have been skewed by inexperience, as Ullrich and Stephan had mentioned that finding the right placement while identifying the direction of the nasal floor may be difficult (16, 27).

To complicate matters further, there are few studies that document the average soft tissue thicknesses for children (33). This can be problematic since children do not have the same tissue depths or facial proportions as adults and many artists/technicians use tissue depth averages to assist with their craniofacial approximations (30, 31, 33). There is an even greater disparity in the amount of data that has been collected in regards to whether the methods that are currently in use for adults work for children (33). The lack of information and data for facial approximation on children can lead to facial approximations that do not look like the child or are “not quite right” because they look too much like miniature versions of adults (33). This can mean that the family members will not recognize their loved one and the individual will unfortunately never be identified (6). Many artists and technicians do not feel comfortable attempting facial approximations on children due to the lack of information on the facial proportions of children (26, 33).

Due to this disparity of data, the focus of this study is on the reliability of Gerasimov’s (12, 13) two-tangent method on juveniles in an attempt to clarify for artists and technicians whether this method is worth using. Since the method was developed on adults, the accuracy and precision should improve as the subjects grow towards the maturity of adult facial proportions. Because of the morphological integration of human facial growth throughout childhood, there are several goals involved in testing this method. The overarching goal of this research is to test whether Gerasimov’s method is accurate and precise on children whose noses are still growing. Another goal is to determine if there is a difference in how accurate and precise the method is on male versus female children and teenagers. Finally, this research will test whether or not there is a difference in accuracy and precision within the same sex depending upon age group.

Chapter 2.

Materials

A total sample of 280 lateral cephalograms were selected from the American Association of Orthodontists Foundation (AAOF) Legacy Collection (1), which consists of nine separate databases of longitudinal craniofacial growth records from the United States and Canada. The AAOF Legacy Collection database can be found online¹. These collections were obtained by hundreds of investigators over the course of 75 years, each independent of each other and with their own collection methodology (1). The data were collected in order to document the growth of the human face in the same individual at yearly intervals (1). The collections consist of longitudinal lateral cephalograms of children who did not receive orthodontic treatment, including many individuals incrementally documented from early childhood through adult ages (1).

Of these nine databases, the Bolton-Brush, Iowa, Mathews, Oregon, Denver, Fels, Michigan, and Forsyth Twin Growth collections were selected based on the visibility of the soft tissue outline and the pronasale in the images. The sample consists of 97 Bolton-Brush, 69 Iowa, 20 Mathews, 46 Oregon, 21 Denver, 6 Fels, 21 Michigan, and 1 Forsyth Twin.

According to Nelson *et al.* the demographic for the Bolton-Brush collection consisted of 92.2% Caucasian, 7.7% African American, and .1% children of other heritage that lived in Ohio between 1923 and 1959 (5, 19). According to the AAOF Craniofacial Legacy web site information, the demographics of the majority of the collections used in this study (Iowa, Mathews, Denver, and Michigan) were of Northwest or Northern European ancestry (1). The Mathews collection consists of some individuals whom have had orthodontic treatment, and all of the individuals in the Mathews collection had undergone surgery for Björk-type pin implants to monitor the growth of the facial bones throughout time (1). The AAOF Craniofacial Legacy Collection information states that the Oregon growth study consists of Caucasian individuals whom have not had orthodontic

¹ http://www.aaoflegacycollection.org/aaof_home.html

treatment (1). The demographic information for the Fels Longitudinal Study indicated that the majority of the participants were of Northern European descent, though it was noted that those documented were a randomly selected cohort in that individuals were not chosen to participate by any particular facial feature (1, 22).

For this study, ten male and ten female individuals in yearly increments were chosen between ages six and nineteen. The sample's age range reflects the ages that the lateral cephalograms were the most common. Lateral cephalograms before the age of six and after the age of 19 were rarer, and there were therefore not enough of them to warrant inclusion. Lateral cephalograms of living individuals have the advantage over post-mortem scans of avoiding the possibility of tissue slippage or distortion (16)

Criteria for selection included whether the outline of the soft tissue and the tip of the nose is visible in the lateral cephalogram. While the collections consisted of multiple lateral cephalograms of the same individuals taken over the course of several years, only one lateral cephalogram per individual was selected to avoid redundancy; each of the 280 lateral cephalograms sampled are of separate individuals. Only one lateral cephalogram of each subject was chosen since a cross-sectional sample was necessary for this study, which did not include longitudinal data throughout the growth of an individual. This was in done to sample between rather than within individual variation. Some of the collections contained twins and siblings, but one person per family was chosen to avoid including individuals with shared genetics and/or environment.

The 280 lateral cephalograms were broken down into age groups that correspond with the maturation of the face through childhood. During childhood the overall growth of the nose varies between males and females due to differences in the rate and age of maturity (22). According to Scheuer and Black, females are usually two years more mature than males of the same age, resulting in males maturing to around 20% larger than females (25).

Males and females mature at different rates after puberty and females also stop growing earlier than males do. As a result the age groups were not the same in males and females after age 11.9, and the nearest equivalent age group was compared. According to Ferrario *et al*, female overall facial growth reaches 93%~ of its total volume by age 14,

whereas at the same age males still have around 16% of the total overall facial volume still left to grow (10). There are different age ranges that represent the growth of the nose in in males and females. Buck and Brown (4) indicate that the soft tissue of the nose in males goes through a slight growth spurt from ages 6-9 years of age, another between 9-12, and then another between 12-15 (4). They also state that there is a slight growth increase in the soft tissue of the nose in females between 6 and 9 years of age, and then a maximum growth rate occurs between 9 and 12 years (4). A study by Van der Heijden *et al* indicates that the growth velocity of the nose reaches its maximum for girls around age 11 and around 12.6 for boys (32). According to the same study, growth is not significant after 16 years of age for females, and 17 years of age for males since female adolescents reach 98% of their maximum growth by age 15.8, and males reach 98% of their maximum growth by age 16.9 (32). Since several studies were available and many of the studies had overlapping data, the information was compiled. Taking these previous studies into consideration and to reflect the rates of change and the different chronological ages of males and females being equivalent in different developmental stages of their biological ages, the age groups are as follows:

Table 2.1. Age ranges for the age groups of females and males.

Age Group	Females	Males
Group 1	6.0-8.9	6.0-8.9
Group 2	9.0-11.9	9.0-11.9
Group 3	12.0-15.9	12.0-14.9
Group 4	16.0-19.9	15.0-19.9

Chapter 3.

Methods

Lateral cephalograms from the AAOF Craniofacial Growth Legacy Collection were requested from the database administrator in high resolution. Large versions of the lateral cephalograms were imported into Adobe Photoshop® 7 and adjusted to 3000 x 2400 pixels and 300 dpi. Adjustment was necessary on many of the lateral cephalograms as they were not the same resolution and having differing resolutions would cause the difficulties in finding proportions of the measurements. For this same reason the fiducials already in place on the lateral cephalograms were not used, as there was no way to accurately translate the fiducial distances for lateral cephalograms from each collection. In some cases the brightness and contrast were changed so the soft tissue outline and nasal bones were more visible. Preparing each image separately ensured the lateral cephalograms were all of the same resolution and quality.

Two additional layers were added to the file; one consisting of a white point indicating the actual pronasale, the other consisting of a small amount of “paint” covering the soft tissue portion of the nose while still leaving the nasal bones and anterior nasal spine visible. The layer with the paint is referred to as the blacked-out layer. All lateral cephalograms were treated in this manner before testing commenced in order to avoid bias in the data collection.

All cephalograms were all resized to 3000x2400 pixels at 300 dpi to facilitate data collection consistency before applying Gerasimov’s two-tangent method over the top of a blacked out layer containing the soft tissue outline of the nose. Using Adobe Photoshop® 7, a white dot was placed at the intersection of the two tangents, and then the blacked out layer removed to compare the predicted to the actual pronasale. The two straight lines were drawn on a separate layer located above the blacked-out layer, following the description of Gerasimov’s two-tangent method. According to Mikhail Gerasimov’s (13, 14) description, “The profile of the nose can be reconstructed with two straight lines: first straight line is the prolongation of the general direction of the 1/3 of the lower region of the nasal bones; second straight line is the prolongation of the general direction of the

subnasal thorn". One line began at and then followed the direction of the lower 1/3 of the nasal bones. The other line began at the anterior nasal spine, and then continued to follow the general direction of the anterior nasal spine. Where the two lines intersected was the location of the predicted pronasale of the nose. While more recent papers indicate that the last 2mm of the nasal bone is meant to be followed instead of the last 1/3 of the nasal bone, there was no way of translating the lateral cephalograms pixels to the size of mm (25, 27). Due to the disagreements in the interpretation of what Gerasimov's original method meant and the difficulty in identifying the last 2 mm of the nasal bone in translation to pixels, the last ¼ of the nasal bone was used instead.

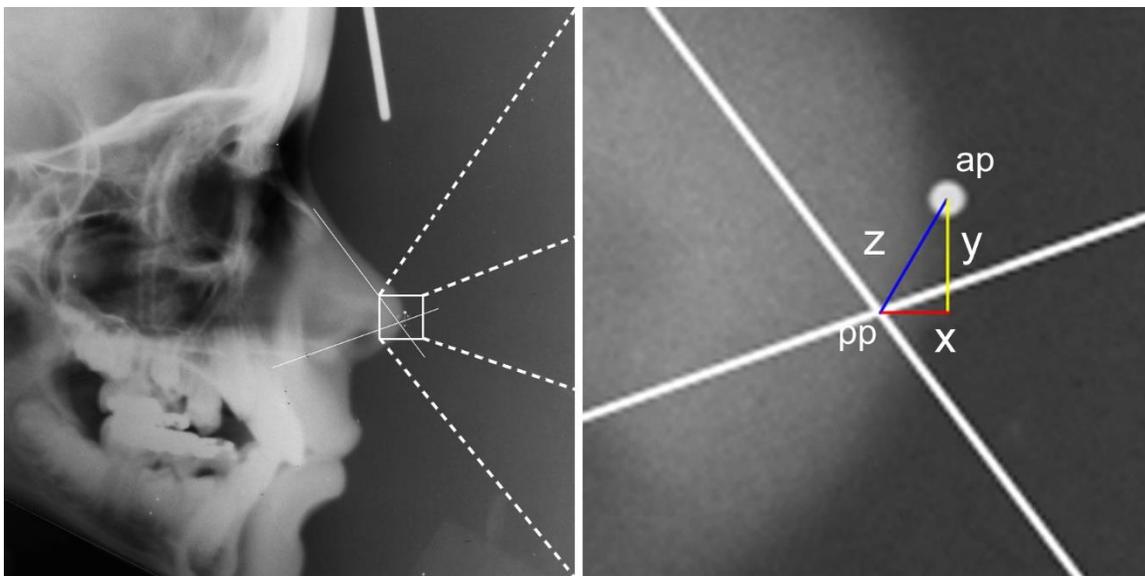


Figure 3.1. Triangulation of the actual to predicted pronasale.
pp = predicted pronasale, ap =actual pronasale

The blacked out layer's visibility was then made transparent. The actual point of the pronasale was then compared to the point created by the intersecting lines. Measurements were taken using a Cartesian coordinate system on the X and Y axis in pixels for each individual representing the horizontal and vertical distances between the predicted and actual pronasale, with the actual pronasale acting as the origin. After the distance of the predicted pronasale was recorded on the X and Y axis from the actual pronasale, the Euclidean distance between those two points was calculated using the Pythagorean Theorem (Figure 1). The Z-distance was not measured directly since its accuracy depended upon the pixels of the image. Calculating the Z-distance directly using the Pythagorean Theorem allowed for accurate measurement without relying on the

quality of the image. Mean X, Y, and Z distances were calculated for each sex and age group as an estimate of accuracy, and absolute means of X and Y distances were calculated for each sex and age group as an estimate of precision. Since the lateral cephalograms were taken at different scales, a measurement was taken of the height of the nasal aperture from nasion to nasal spine. The resulting number was then used to divide the X, Y, and Z measurements to standardize them and ensure the lateral cephalograms could be compared to each other. Thus, X, Y, and Z measurements were collected as proportions of nasal height.

One-way ANOVA tests were performed to compare the mean X, Y, and Z distances between females and males for each age group, between the age groups within each sex. T-tests were also performed to determine whether the X and Y distances were statistically different from 0.

Chapter 4.

Results

Table 4.1. Summary statistics for female and male sub-samples broken down by age groups for mean distances and mean absolute distances in pixels between the estimated and real pronasale on the X-axis (standardized X-values).

Age Group	Female					Male					Female vs. Male	
	N	MD	SD (MD)	MAD	SD (MAD)	N	MD	SD (MD)	MAD	SD (MAD)	F	p
1	30	27.89*	46.47	43.93	31.11	30	27.52**	41.36	41.06	27.40	0.001	0.974
2	30	21.02*	36.82	34.90	23.50	30	3.99	35.70	28.95	20.60	3.306	0.074
3	40	35.33**	50.05	49.57	35.56	30	18.33*	40.01	37.58	22.07	2.340	0.131
4	40	27.74**	40.90	37.42	32.022	50	12.65*	39.72	29.78	25.61	3.298	0.073
F	-	6.27	-	-	-	-	10.97	-	-	-	-	-
p	-	0.001	-	-	-	-	0.000	-	-	-	-	-

N = sample size; MD = mean difference; SD = standard deviation; MAD = mean absolute difference; F-values in last column = one-way ANOVA for female vs. male x-values; F-values in before last row = one-way ANOVA for comparisons between all age groups within each sex; p = probability.

Mean values for females and males are also tested against zero using a t-test (* = $p < 0.05$, ** = $p < 0.01$). See text for details about how each age group is defined.

Table 4.2. Summary statistics for female and male sub-samples broken down by age groups for mean distances and mean absolute distances in pixels between the estimated and real pronasale on the Y-axis (standardized Y-values).

Age Group	Female					Male					Female vs. Male	
	N	MD	SD _(MD)	MAD	SD _(MAD)	N	MD	SD _(MD)	MAD	SD _(MAD)	F	p
1	30	2.49	44.01	33.75	27.66	30	-2.98	40.23	31.05	25.11	0.253	0.617
2	30	-5.72	45.90	37.42	26.32	30	-12.53	38.66	30.96	25.80	0.386	0.537
3	40	24.92**	52.12	43.30	37.83	30	11.41	46.19	36.27	30.13	1.269	0.264
4	40	43.26**	44.26	51.82	33.53	50	39.78**	45.39	48.79	35.39	0.133	0.716
F	-	3.725	-	-	-	-	1.93	-	-	-	-	-
p	-	0.013	-	-	-	-	0.126	-	-	-	-	-

N = sample size; MD = mean difference; SD = standard deviation; MAD = mean absolute difference; F-values in last column = one-way ANOVA for female vs. male x-values; F-values in before last row = one-way ANOVA for comparisons between all age groups within each sex; p = probability.

Mean values for females and males are also tested against zero using a t-test (* = $p < 0.05$, ** = $p < 0.01$). See text for details about how each age group is defined.

Table 4.3. Summary statistics in pixels for female and male sub-samples broken down by age groups for standardized Z-values.

	Female			Male			Female vs. Male	
Age Group	N	MD	SD	N	MD	SD	F	p
1	30	60.06	34.29	30	57.17	27.21	0.130	0.719
2	30	56.13	26.34	30	48.11	23.52	1.547	0.219
3	40	72.19	42.35	30	56.50	30.24	2.850	0.096
4	40	71.43	33.27	50	63.37	36.32	1.179	0.280
f	-	1.77	-	-	1.55	-	-	-
p	-	0.156	-	-	0.205	-	-	-

N = sample size; MD = mean difference; SD = standard deviation; F-values in last column = one-way ANOVA for female vs. male z-values; F-values in before last row = one-way ANOVA for comparisons between all age groups within each sex; p = probability.

Mean values for females and males are also tested against zero using a t-test (* = $p < 0.05$, ** = $p < 0.01$). MAD was not calculated since it is the mean distance for Z-values. See text for details about how each age group is defined.

Tables 1-3 show the sample size, the mean, and standard deviations of the standardized X, Y, and Z values for male and female sub-samples broken down by each age group, respectively. Distances were measured from the location of the actual pronasale at 0, 0, and were either a positive or negative amount based on if they had over- or under-shot the actual pronasale. The MD (mean distance) and the MAD (mean absolute distance) were calculated for each age group. The mean distance includes both the positive and negative distances, where the mean absolute distance only includes the absolute version of these numbers. These tables also provide the results of the one-way ANOVA results for the comparisons between females and males by age, and the one-way ANOVA for comparisons between age groups within each sex. T-test results for comparisons of the male and female means for each age group against zero are also provided in Table 1 and 2 by highlighting whether the probability of the test is below 0.05 or 0.01.

The results of the ANOVA test between males and females indicated that there were no significant differences between males and females of age groups 1 and 3 in the standardized X-, Y-, and Z-values. There were also no significant differences between males and females in age groups 2 and 4 in the Y- and Z-values. The sexes only differed in X distances for age groups 2 and 4. The exceptions to this were the X-values for age groups 2 and 4, which showed borderline significant differences at a p-level of 0.05 (0.074 and 0.073 respectively).

In comparing the female age group values of the Tukey post-hoc to each other, there was a significant difference in the X-values between age groups 1 and 2 ($p=0.029$), 2 and 3 ($p=0.037$), and 2 and 4 ($p=0.000$). Age groups 1, 3, and 4 did not show a statistically significant difference from each other. There were also significant differences within the female age groups in the Y-values between age groups 1 and 3 ($p=0.008$). The differences between group 1 and 4 were borderline significant ($p=0.061$). Age groups 1 and 2, 2 and 3, 2 and 4, and 3 and 4 did not show a statistical difference from each other. There were also no differences between any of the female age groups for the standardized Z-values. For females the only age group that differed in X distances was for age group 2, and the only age group that differed in Y distances was for age group 1.

There were significant differences in the X-values for males between age groups 1 and 4 ($p=0.000$), 2 and 4 ($p=0.000$), and 3 and 4 ($p=0.029$). Males in age group 1 differed in the X distances, the common factor was age group 4, which differed from all of the other age groups. Within the Y-values there were no significant differences between male age groups, except between age groups 1 and 2 where the significance was borderline ($p=0.088$). The differences between the predicted and actual pronasale in X do not seem to be increasing with increasing age, but in the Y values there does seem to be an increasing distance between predicted and actual with increasing age. This reflects a growth in height rather than projection of the nose. The standardized Z-values also showed no statistical differences between males in any of the age groups, or between sexes. The image below (Figure 4.1) shows the difference between a predicted pronasale that came very close to the actual (within 3 by 0 pixels) and one that was 65 by 78 pixels away from the actual pronasale.

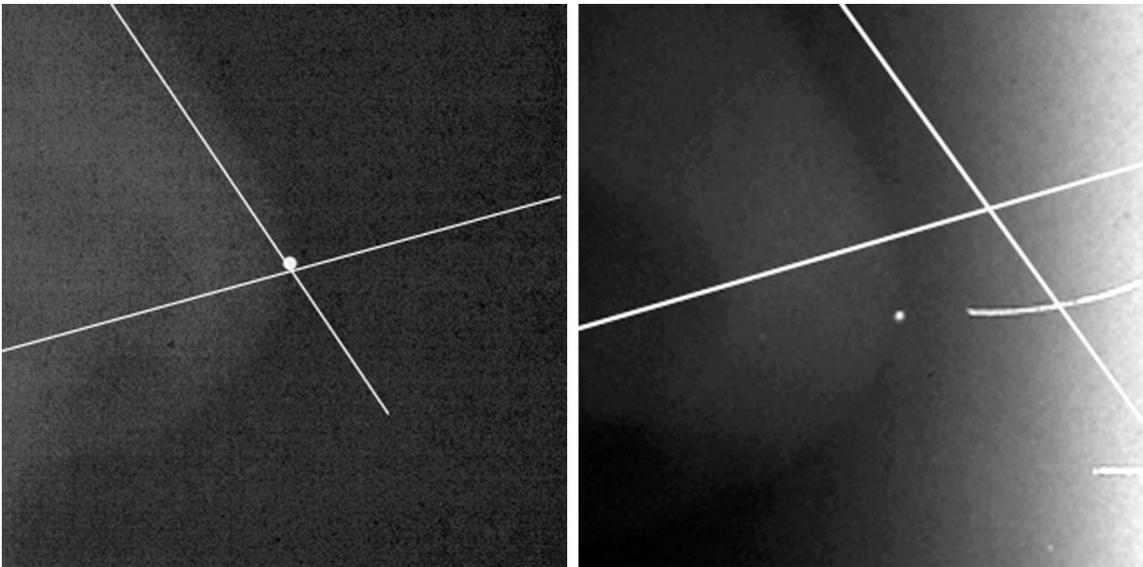


Figure 4.1. Sample of a close predicted pronasale at 0 by 3 pixels versus a predicted pronasale that was 65 by 78 pixels from the actual pronasale.

The scatterplots below (Figure 4.1, Figure 4.2, Figure 4.3, and Figure 4.4) show the locations of the predicted pronasale in comparison to the actual pronasale, which is represented by the coordinate 0,0. The triangle in each graph represents the mean for each age group.

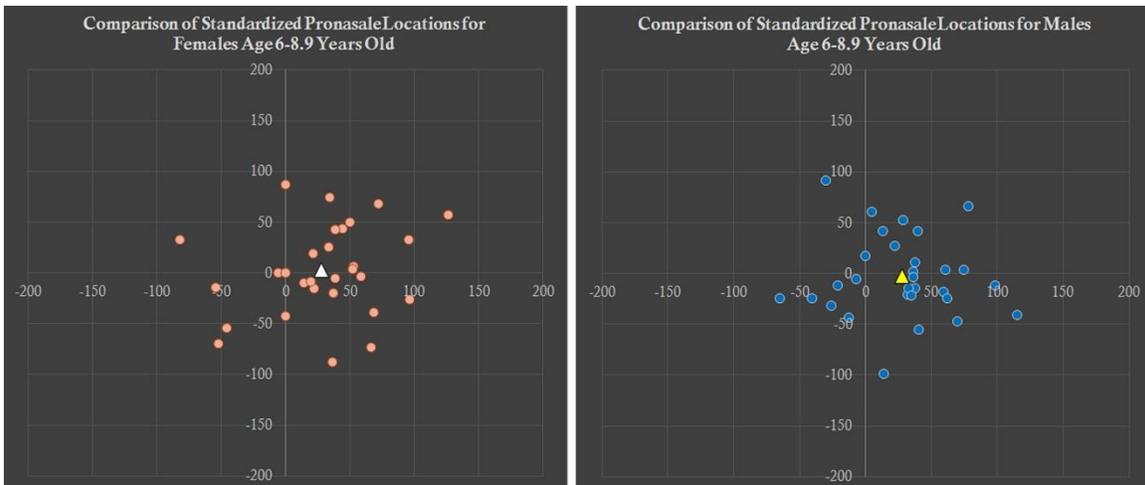


Figure 4.2. Comparison of female vs. male predicted pronasales in age group 1 (6-8.9 years of age).

Comparison of age group 1 (6-8.9 years of age) between males and females shows that the distribution is comparable, and the location of the mean for each sex is similar.

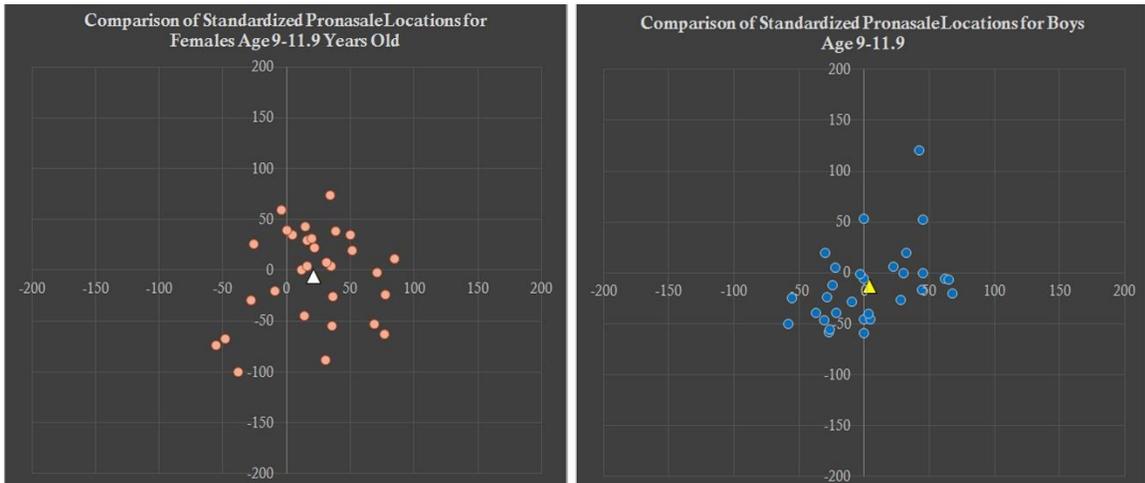


Figure 4.3. Comparison of female vs. male predicted pronasales in age group 2 (9-11.9 years of age).

When comparing males and females in age group 2 (9-11.9 years old), the males are clustered more closely around the actual pronasale, and the mean is almost at 0, 0. Females have a looser cluster and there are less similarities to males of the same age.

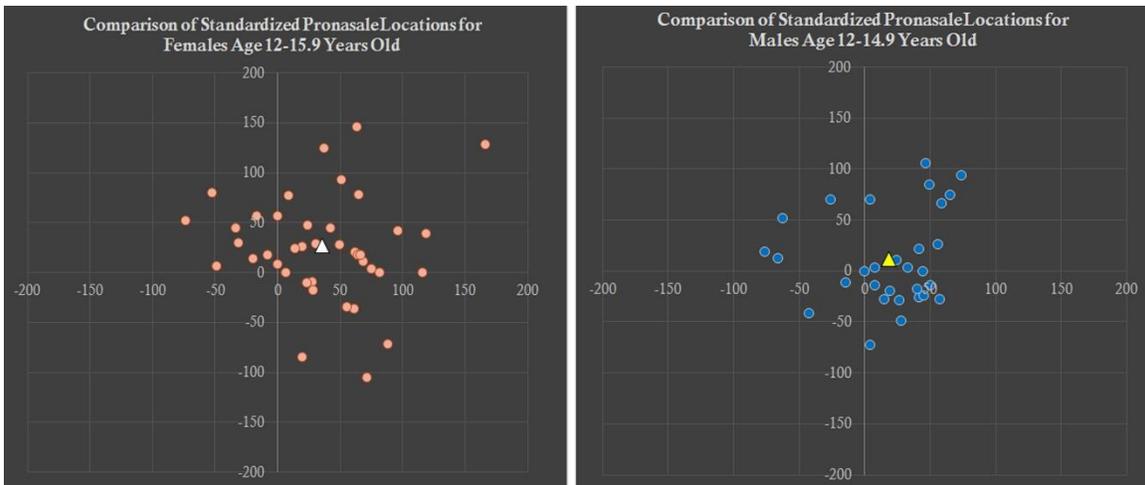


Figure 4.4. Comparison of female vs. male predicted pronasales in age group 3 (12-15.9 years of age for females and 12-14.9 years of age for males).

Visually there is a marked difference between females age 12-15.9 years old and males age 12-14.9 years old. The predicted pronasales for males are clustered more closely around the actual, whereas females are in a much looser cluster. The means for each sex are similar despite females having more extreme values.

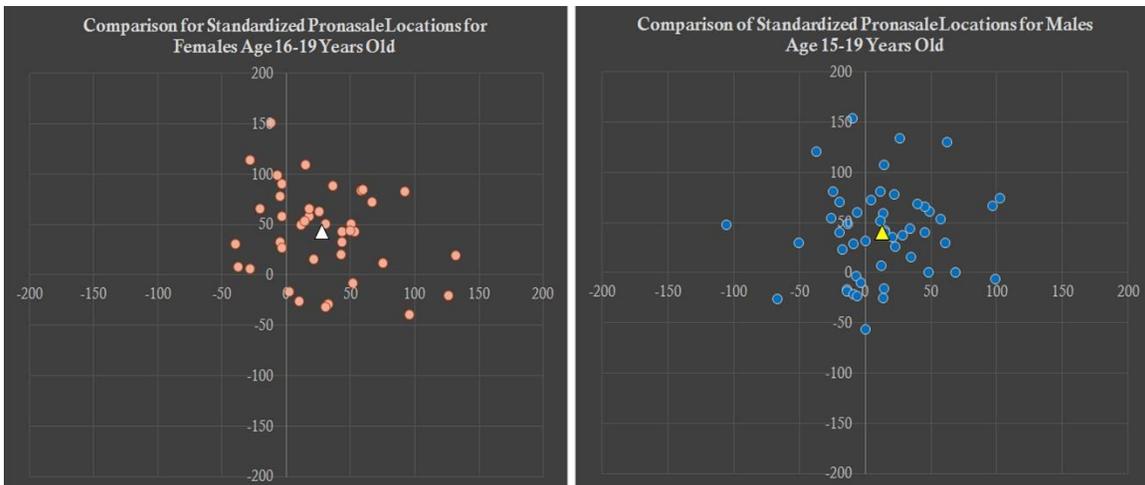


Figure 4.5. Comparison of female vs. male predicted pronasales in age group 4 (16-19 years of age for females and 15-19 years of age for males).

When comparing females to males in age group 4, both males and females had several extreme values, though males were more tightly clustered around the origin point.

Chapter 5.

Discussion and Conclusion

In testing the MD and MAD as a measure of precision of Gerasimov's method using a sample of lateral cephalograms from children and adolescents, the results suggest that Gerasimov's method may not be precise or accurate for males and females in all age groups. In the case of the X distances, nearly all of the age groups showed statistically significant differences between the predicted and actual pronasale. In the cases of 12-15 year old and 16-19 year old females and males, the differences were even more significant. Only 9-11 year-old males did not show differences between the predicted and actual pronasale in the horizontal distances. In addition to being the only age group where Gerasimov's two-tangent method seems to be accurate, 9-11 year-old males were also shown to be the most precise. Gerasimov's method seemed to have performed better in the Y distances, particularly 6 to 8 and 9 to 11 year-old females, and 6 to 8, 9 to 11, and 12 to 14 year-old males. The vertical dimensions (Y-values) for both males and females have a tendency to decrease steadily from age group 1 to 4.

One of the goals of this study was to determine if there was a disparity between the results for females versus males throughout the age ranges. When comparing the mean X, Y, and Z distances, females were all equal to or larger than the means for the same distances for males. This indicates that while the method is not particularly accurate for either males or females, the difference between the real pronasale and the predicted is more pronounced in females in all age groups. This shows that the method likely works slightly better for males of all age groups than for females. This is also reflected in the Z-values, where female mean distances and the standard deviations for the mean distances exceeded those of the males for every age group, and the female mean distances were at least twice as large as the males in every comparison. However, Gerasimov's method seems to predict the pronasale accurately on both males and females age 6-8.9 (age group 1) and 9-11.9 (age group 2) on the Y-axis. This indicates that while the projection of the pronasale might not be as accurate according to the mean, the height of the nose was very close on average to the actual pronasale for age 6-8.9 (2.49 for females and -2.98 for males), and slightly less accurate for age 9-11.9 (-5.72 for females and -12.53 for

males). Accuracy decreased after 12 years of age in females, while accuracy for males stayed around the same for age 9-11.9 (-12.53) and 12-14.9 (11.40), and then decreased sharply for age 15-19 (39.78).

The sex differences above reflects information available about the growth of the nose. A study by Ferrario *et al.* (10) indicates that males and females have very similar growth patterns until females around 11 years of age, when the rate of female growth rapidly decreased and had finished growth relative to adult proportions by age 14-15. The same study concluded that the growth spurt in males continued from around age 11 until age 17 at nearly the same rate of growth (10). The information about male and female juvenile growth supports the data gathered in this study and shown in the X- and Y- values, since males and females did not show a statistical difference from each other in terms of precision and accuracy except in the case of females and males age 9-12 years old. The information regarding the growth spurts of males and females is also shown in the scatterplots, which are very similar from 6-8.9 years of age (32). This can be seen in Figure 4.2, in which the grouping and the mean are very close. Figure 4.3 shows the beginning of a disparity between males and females, as the male grouping is closer together and the mean is very close to the actual pronasale. This change reflects the age at which females begin going through puberty and their faces begin to mature at a faster velocity (32). Females 16-19 years of age and males age 15-19 years of age showed a borderline difference for the X-values, at 0.073 and 0.074 respectively. These two data sets indicate that there are differences between males and females age 8-12 years old, and then there is a slight difference between females age 16-19 years old and males age 15-19 years old. This is due to the differing rate of growth between females and males, and also the differing age at which the major facial growth spurts occur. As Ferrario *et al.* (10) states that the rate of female growth slows down by age 14, and that males enter their maximum growth rate at age 15 and are not finished with their growth spurt until around age 17. While the data in the study by Ferrario *et al.* (10) indicates that girls continue growing quickly past age 12, the changes in the X-values may suggest that the primary changes actually happen before age 12. Male X-values seem to start out higher and decrease, with the exception of age 8-11.9, which has the lowest mean absolute difference.

There was a marked difference in the means of the X- and Y-values between females age 12-15.9 and males age 12-14.9 (age group 3). The mean distances for the X-values for females were 35.33, versus 18.33 for males. The Y-values were 24.92 for females and 11.41 for males. This may be due to the end of the female growth spurt around age 12-14, whereas males from 12-14.9 have not yet gone through their growth spurt. Despite this marked mean difference, t-test comparisons did not show that there was a significant difference between males and females. The mean average distance and the standard deviation for the absolute difference for females (MAD=49.57) was larger than for males (MAD=37.58).

It is not possible to compare the accuracy and precision of Gerasimov's method (13, 14) in this study to the results of other studies as there have been no other known papers published on the reliability of the method on children. A study by Rynn and Wilkinson indicates that Gerasimov's two-tangent method was the most accurate at predicting a point on the tip of the nose (within 1mm) but indicated that it may not necessarily predict the pronasale directly (23). Rynn and Wilkinson's conclusion did not correspond with the results of this study, as Gerasimov's two-tangent method did not prove able to accurately predict nasal projection, and suggested that instead of the general direction of the nasal bone, the last 2mm be used instead. Another study by Ullrich and Stephan suggested that the interpretation of Gerasimov's two-tangent method was not correct due to the incomplete original translation (29). They suggested that instead of using the general direction of the nasal spine to determine the projection tangent, Gerasimov used the "general direction of the right or left nasal floor of the anterior part of the nasal aperture (maxillary bone) laterally adjacent to the anterior nasal spine and vomer bone", but this new interpretation has yet to be tested. As a result, Lapointe *et al.* tested both of the new interpretations of both Rynn and Wilkinson, and Ullrich and Stephan and concluded that neither of the interpretations accurately or precisely predicted the pronasale in adult subjects (16).

There are many differences between the skulls of juveniles and those of adults (33). Facial approximations on children are usually not attempted, since there are difficulties in establishing a biological profile, including determining age, sex, and ancestry (34). While there have been several studies on tissue depths of children of various

ancestries, the methods used in facial approximation were not originally developed on children, nor has facial approximation on juveniles been studied in detail (11, 18, 34).

Lastly, this study looked at the differences in the actual and predicted pronasale between age groups for each sex. For females, 8.9-12 years (age group 2) showed a statistically significant difference from the other three female age groups, though the other female groups were statistically similar to each other. This may reflect the growth spurt in girls until age 14, though the primary growth may happen actually before age 12. During this age range, the female juvenile facial proportions do not grow consistently when compared to each other – that is to say, the nasal changes that occur are due to several facial bones working in tandem with each other rather than the growth of one facial bone alone (4, 8). These results were unexpected, since Gerasimov's method is claimed to be very accurate and precise for those with adult proportions and it would stand to reason that it should increase in accuracy and precision instead of decrease with age, as this study shows (24, 27).

When comparing the Y-values for the different female age groups, there was only a statistically significant difference between females aged 6-8.9 years old, and females 12-15.9 years old which may indicate there is a variance as to the height of where the projected pronasale is located dependent upon age. Age 6-8.9 (age group 1) and 16-19 (age group 4) show a borderline significance when compared to each other. These differences may be due to the changes in the height of the nose and the shift in the overall proportions of the face, along with the growth of the nasal spine and nasal bones (4, 8, 10, 25). The growth of the nasal bones affects the anteroposterior position of the nose on the X-axis, where the nasal spine primarily affects the vertical position of the nose on the Y-axis (16).

When looking at the comparison of male X-values between age groups, age group 4 was different from all other groups. When comparing the Y-values, only age 6-8.9 (age group 1) and 9-11.9 (age group 2) showed a difference. This may mean that the projection of the nose is affected by the growth of the nasal bones after males reach their growth spurt, but that there is a rapid change occurring with the nasal spine at a younger age. This is reflected in what is known about growth of the human face at young ages, as the

maxillary changes and eruption of adult teeth happen primarily between ages 8 and 12 (24, 26).

Challenges in working with this sample included finding lateral cephalograms that were clear enough to see both the nasal bones and the soft tissue outline enough to identify the actual pronasale. Many of the lateral cephalograms needed to be sized to 3000x2400 pixels, as images from the same collections did not have a consistent size. Since identification of the last 2mm of the nasal bone was difficult as physical millimetres does not translate well to digital pixels, care was taken to use a smaller portion than the last 1/3 of the nasal bone, as has been discussed in the newer interpretations of Gerasimov's method (24, 27). The intention of this study was not to determine the exact distance of the predicted pronasale from the actual pronasale, but rather to determine if Gerasimov's two-tangent method developed for adults would be precise and accurate for subadults. In order to do this, percentage and proportion of error in comparison to the size of the nose for each individual through standardizing the measurements was found.

In future studies, it is possible that the individual utilizing Gerasimov's two-tangent method on a physical human skull would be able to measure the last 2mm of the nasal bones as suggested by Rynn and Wilkinson, and Ulrich and Stephan (27, 29). Future artists or technicians could also potentially improve at the identification of the general direction of the nasal spine through practice on lateral cephalograms or on the skull of a known individual may be needed before attempting an approximation on unidentified remains.

The age ranges chosen for this study were based upon the results found by Van der Heijden *et al.* in their 2008 study about the growth of the human nose, and were specifically broken up differently for males and females to reflect their growth spurts and the earlier facial proportion maturity of females. Due to the nature of the data that was collected through the different studies on the AAOF database collection site (1), many of the individuals represented were not enrolled until the age of 6, and many chose to no longer participate in the various growth studies after they became adults. As a result, the age range begins at 6 years due to the lack of suitable lateral cephalograms available on the AAOF database collection for ages younger than 6. Suitable lateral cephalograms

were also not available for different individuals after the age of 19, though it would have been valuable to include both younger and older individuals in this study.

While there were some difficulties in acquiring lateral cephalograms of high enough quality where the nasal bones and the soft tissue outline were both visible, 180 individual subjects were tested to produce these results. This study has determined that Gerasimov's method is generally neither particularly accurate nor precise when attempted on lateral cephalograms of juveniles and adolescents except in the case of male children age 9-12, though it should be noted that there may be differences between working with the general directions of the nasal bones and the nasal spine in a lateral cephalogram and doing so on an actual skull due to the physical condition of the remains. While it would certainly be easier to identify the last 2mm of the nasal bone on a skull as opposed to a lateral cephalogram, determining the general direction of the nasal spine may be more difficult as the nasal spine is delicate and may be broken off (27). Working with clear lateral cephalograms may provide difficulties in determining the general direction of the nasal spine or sill as there is often a shadow or double image where the left and right sides overlap, and as such there may be a difference in translating the method from lateral cephalogram to 3-D space. This study measured the distance in pixels and then calculated based on standardized measurements in order to find the percentage of error dependent upon facial proportion, since the ages of individuals in this study ranged from 6 years of age to 19 years of age. This was done due to the obvious proportional differences between a six-year-old child and a nineteen-year-old adult while still maintaining the same size lateral cephalograms. For instance, a 20-pixel distance for a 19-year-old might represent a much smaller percentage of the projection of the nose than for a 6-year-old. Through standardizing the numbers with a common measurement, this study has ensured that the percentage of error remain proportional.

While the fact that Gerasimov's method was taken from two translations of original documentation and were published as condensed versions with frequent errors and Gerasimov himself passed away in 1971 and so is no longer available for consultation make it difficult to fully understand his intentions, other researchers have confirmed with Gerasimov's former students in order to resolve those issues (27). The population upon which this method was originally developed is unknown and as such any differences that

may occur on those of various ancestries are also unknown, though the ancestries of the sample used in this study were primarily of European and Northern European decent.

Facial recognition is the primary way that humans identify each other as individuals (33). The nose itself is the third most 'important' feature in facial recognition, since that is where the eye travels to after the eyes and mouth respectively when examining the human face. (16, 34). Facial features in tandem with each other to create the overall gestalt of the face (27). This includes the size, shape, and location of each of the facial features, so it stands to be reasoned that changing the position of the tip of the nose could very much impact the rest of the facial features and overall recognisability in a detrimental way (16, 27). Although results in this study suggest that Gerasimov's method is inaccurate for the prediction of the pronasale location, it is still unclear what the impact an imprecise and inaccurate nose projection will have on the rest of the face during a facial approximation, or how a facial approximation performed with inadequate methods will influence the rate of positive identifications.

While other studies have proven the accuracy and precision for Gerasimov's method on adults, these studies did not test the accuracy and precision on children (24, 27). The AAOF Craniofacial Growth Legacy Collection's free and easily accessible lateral cephalograms have provided invaluable data that includes important biographical information, as well as material on the anatomy and development of the study subjects that is not available elsewhere. The insight from the information concluded in this study helps to clarify the question of whether this method is suitable to use on craniofacial approximations of children.

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