Title: Morphological differences of facial soft tissue contours from child to adult of Japanese males: a three-dimensional cross-sectional study

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Running title: Three-dimensional study of facial soft tissues (41 characters)

ABSTRACT:

Objective: To evaluate morphological differences of the facial soft tissue surface between male Japanese adults and children.

Design: 20 adult Japanese males (average age 28 years) and 20 Japanese boys (average age 5.5 years) with normal occlusion were selected for this study. The images of the subjects' facial surface were obtained with a 3-D laser scanner. To evaluate the three-dimensional morphological differences of the facial soft tissue, we transformed the coordinates of 16 facial landmarks to a new reference plane and compared the adults' and children's facial form drawn to the same scale in the same coordinate system.

Results: The morphological difference ratio of the lower facial area was higher than in the upper facial area, and the nose and lower face changed more forward than downward. The morphological difference ratio of the mid face width was smaller than other areas.

Conclusion: Our study suggests that the morphological facial soft tissue differences between Japanese adults and children are more forward and downward than laterally, manifesting in a facial form of adults that is deeper and narrow.

INTRODUCTION:

Craniofacial morphological development is of interest to pedodontists and orthodontists because they engage in occlusal guidance and orthodontic treatment professionally, and their treatment can influence facial skeletal and soft tissue growth[1, 2]. Although there have been a substantial number of studies about facial morphological changes from child to adult, most of these used measurements in only two-dimensions[3, 4], and few have used three-dimensional measurements[5, 6]. Furthermore, compared to the number of studies of the facial skeleton, there have been few studies of the facial soft tissue.

Three-dimensional measuring technology has improved during the last few years, and newer techniques support measurement of the facial surface. For example, direct measurement methods such as moiré techniques, stereo-photogrammetry, computerized tomography, and so on are now available[7, 8]. In recent years, methods to capture facial images using a laser scanner have become a mainstream method because of their ease of use and high accuracy[9, 10]. All of these three-dimensional methods of measuring distances and analyzing angles of the face have been used to evaluate clinical outcomes of treatment, cross-sectional growth change, and normative population values[5, 11]. However, the morphological evaluation of facial soft tissue in the reference coordinates system obtained by these methods, like an analysis of facial skeletal differences by using cephalograms, is insufficient.

It is well known that there is a strong relationship between facial soft-tissue form and the underlying bony structure[2, 12]. For example, the form of facial soft tissue can be altered by changing orientation of the teeth and position of the facial skeleton by clinical orthodontic treatment and orthognathic surgery. Additionally, the patients and the people around them evaluate the success of treatment or changes in growth mainly by changes of the facial surfaces. Because the facial soft tissue has a three-dimensional configuration the morphological analysis should be carried out three-dimensionally. Moreover, a three-dimensional coordinate system is not only useful for evaluating changes of maxillomandibular relations and growth by angles and distances but also by direction. The purpose of this study was to consider the three-dimensional contour differences of the facial surface between adults and children.

MATERIALS & METHODS:

<Human subjects>

20 Japanese adult males (average age 28 years; SD 5 years) and 20 Japanese boys who were highly cooperative (average age 5.5 years; SD 4 months) participated in this study. The total number of screened children was 26. Only those children who could maintain a resting state with their eyes open during scanning were selected for scanning. Children who cried or moved with fear and had a playful attitude were judged "poor cooperators" and were not used. As the result of screening, 20 children were selected as analysis objects. Subjects had no obvious signs or symptoms of temporomandibular joint dysfunction or asymmetry of the face, and their occlusion was normal. None had a history of orthodontic treatment. Informed consent to participate in this study was obtained from all subjects and parents of all children. Prior to beginning the study, approval by the clinical ethics committee of Kagoshima University Hospital had been obtained (No. 378).

<Three-dimensional imaging system>

Three-dimensional laser scans were taken with a Vivid® 910 laser scanner (Konica

Minolta, Tokyo, Japan) that operates as a stereo-pair and has an accuracy of 0.3 mm. This camera emits an eye-safe Class I type laser beam (rated safe for eyes by the US Food and Drug Administration, maximum 30 mW, 690 nm) with an object to scanner distance of 0.6 m to 2.5 m and a fast-mode scan time of 3.0 sec. The laser scanner automatically focused on the subject, and a middle lens (focal distance f=14 mm) was used. The system used a one-half-frame transfer CCD and acquired 307,000 data points. The scanner's output data was 640 × 480 pixels for three-dimensional data. Data was recorded on a desktop workstation. The scanner was controlled with Polygon Editing Tool (Konica Minolta, Tokyo, Japan) and data coordinates were saved in a Vivid® file format. Coordinate data was transferred to 3D-Rugle software (Medic Engineering Corporation, Tokyo, Japan), which manipulated the facial image.

<Data capture technique>

During the scanning, subjects sat relaxed in a revolving chair with their heads in a natural head position. The subject-to-scanner distance was set at 1.5 m. The scanning procedures were performed in a room under four fluorescent lights. The subjects were instructed to keep their jaw in the intercuspal position just before the scans were taken. The total scan time was approximately 3.0 s.

To test the scan error due to possible movement by the children during the scan, scans of the 20 boys were repeated after 1 week by the same person, and Dahlberg's formula was used for the calculation of the acquisition accuracy:

$$\text{acquisition accuracy} = \sqrt{\frac{sd^2}{2n}}$$

where d is the difference between the first and second scans and n is the number of subjects. The errors ranged from 0.29 to 0.87 mm (mean, 0.61 mm), corresponding to 0.77% of the total variance, indicating that these errors were negligible.

<Date preparation>

1. Transformation to new reference plane

To evaluate morphological differences of facial soft tissue form, we transformed the facial coordinates to a new reference plane. First, the three-dimensional coordinates of the 16 facial landmarks (Table 1, Fig. 1) were established and identified on the three-dimensional facial image by a single investigator (D.M.) using the 3D-Rugle program. The coordinates from each subject were then transformed to a standardized plane (Fig. 2) using our custom-made program written in Microsoft Visual C++® (Microsoft, Redmond, Seattle, USA). The direction of the X-axis was defined as lateral, the Y-axis as anterior-posterior, and Z-axis as vertical. A regression line, obtained from the X and Z coordinates of points N, Prn, Sn, Ls, Li and Pog, defined the midline (sagittal reference plane (Fig. 2B)). The coronal reference plane was established parallel to the regression plane defined by the points Acr, Acl and N (Fig. 2C). The axial reference plane was defined as perpendicular to both the sagittal and coronal reference planes. All coordinates were then transformed to a reference plane in which the midpoint between right and left endocanthions (Enr and Enl) was the origin. Finally, the transformed coordinate values (X, Y, Z) of each landmark were transferred to Microsoft Excel®.

2. Scale adjustment

To evaluate the three-dimensional morphological differences direction and volume of the facial soft tissue, we compared the adults' and children's' facial form drawn to the same scale in the same coordinate system. Procrustes fitting was used to transform the images to the same scale. The mean of 16 points in each dimension were calculated, and this mean was translated to the origin. The scale component could then be removed by scaling the object so that the root mean square distance from the points to the translated origin was 1unit. The scale became 1 unit when the points' coordinates were divided by the object's initial scale. Finally, all coordinates were transformed relative to the origin at the midpoint between Enr and Enl.

<Statics analysis>

The landmarks of all subjects were digitized five times by a single operator. To assess the reproducibility of this method and reference plane, we calculated the standard deviation and variation of each landmark's coordinate values for all subjects after transformation to the new reference plane. Next, the standard deviations and variations of the coordinates of each landmark were averaged separately for the adults and children.

The mean values and standard deviations of the coordinate values (X, Y, Z) and distances between the origin and each landmark of each adult and child were calculated, and a three-dimensional grid was superimposed on the reference face of the adults and children (Fig. 3). The Wilcoxon signed-rank test was used to test for differences in the coordinates of facial soft tissue landmarks that were scale-adjusted between the adults and children. Significance was set at $p < 0.003$ after Bonferroni correction.

RESULTS:

For the five repeated measurements of each landmark, the standard deviation and variance of each three-axis coordinate in the children were lower than in the adults (Table 2). The standard deviation and variation of Y-axis coordinates were the lowest among the three axes in both adults and children.

Means and standard deviations of the coordinate values (X, Y, Z) and distances from the origin to each landmark of the children and adults are shown in Table 3 and

Table 4, respectively. Three-dimensional reference meshes of frontal and lateral views, respectively, for adults and children are compared in Figure 4 and Figure 5. In this case the midpoint between right and left endocanthions was the origin.

The morphological difference ratio (adult/child) from the origin to Sn was 141% and to Prn was 153%. Both of these landmarks participate in nose growth (nose area), and the morphological difference ratio of N was the highest at 176%. The morphological differnce ratio from origin to the points Ls, Sto, Li, Sl and Pog, which participate in the growth of the lower face (lower facial area) ranged between 132% and 136%, and the morphological difference ratio of the three-dimensional distance from the origin to Acr and Chr, in which the growth factor of soft tissue was high, was about 130%. The morphological difference ratio of the three-dimensional distance from the origin to each endocanthion and exocanthion, which participate in the growth of the upper face (upper facial area), was about 120%.

The coordinate values (X, Y, Z) of adults and children which were fitted to the same scale in the same coordinate system are shown in Table 5, and the three-dimensional reference meshes of the corresponding frontal and lateral views after Procrustes fitting are shown in Figure 6. For the landmarks Sn, Prn, which are positioned under the nose, and landmarks Ls, Sto, Li, Sl, Pog, which participate in growth of the lip and lower face, the Y-coordinates of the scaled values for adults were higher than those for children. The Z- coordinate scaled value of N point was also higher for adults than for children. On the other hand, the X-coordinate scaled values of endocanthion and exocanthion were lower for adults than for children.

DISCUSSION:

Reference plane

A facial soft tissue analysis requires the use of a standard head orientation, and a three-dimensional rotated Camper's plane passing through the nasal ala and both tragus points, is often used as the X-Y reference plane[13].

The laser scanning system can quickly scan the facial surface form in a short time [11, 14-16], however, it is difficult to scan both tragi in a single frontal scan. To show the hidden areas in a one-sided scan, many investigators scan each subject from two or three horizontal directions. This might be more difficult in children than adults because children have more difficulty maintaining their position during multiple scans. Therefore we chose our reference planes to allow the best results from a single frontal scan.

We selected the X-Z reference plane parallel to the regression plane defined by the points Acr, Acl and N. In past reports, changes of facial form that occurred over a short period were determined using the four points at right and left endocanthion and exocanthion along with one point on the nasal tip.[6] Even though the nose tip is an important distinguishing landmark of the face, it is inappropriate to use it for establishing databases for normative populations or for evaluating growth changes because long-term growth of the nose tip is affected more by the soft tissue and nasal cartilage than other facial parts.[3, 17, 18] Some investigators have used the plane established by the right and left alar crests and N point as a reference plane, and described normal nasal growth changes and long-term growth patterns.[19] The three points, Acr, Acl and N are relatively stable landmarks on the facial surface.

The endocanthion points selected to establish the origin of our reference frames are all closely related to the cranial base rather than any landmarks of the facial soft tissue.[13, 20] We selected these because the growth of the cranial base is considered to be complete at almost 6 years of age and to be less dependent on epigenetic factors than the facial skeleton or soft tissue.

The scan time 3 seconds of this laser scanner is faster than past methods of direct measurement [7, 21], and many facial morphological studies have used the same measuring system as ours[6, 9-11, 14, 16]. However, the accurate scanning of poorly cooperating subjects is difficult even with a scanning time of 3 seconds. So our study was limited to those children who could maintain a resting state during scanning.

Morphological facial soft tissue differences between adults and children

The morphological difference ratios of the three-dimensional distances from the origin to the nose area were higher than other parts, Sn was 141% and Prn was 153%. And the morphological difference ratio of the lower facial area (Ls, Sto, Li, Sl, Pog) was higher than the upper facial area (Enr, Enl, Exr, Exl) (Table 4).

Transforming the three-dimensional reference meshes of adults and children into the same coordinate system suggests that the facial soft tissue differences were forward and downward (Fig. 6). Moreover, it suggested that the morphological differences of the nose and lower face appeared more forward than downward, because the Y-coordinate scaled values of adults were higher than those of children at the nose and lower facial area (Table 5).

Morphological differences of the nose between children and adults have been evaluated by using lateral cephalograms. Foley et. al. evaluated the growth change of facial soft tissue, and reported that the nasal tip showed the greatest amount of growth among the soft tissue landmarks[22]. This same tendency for a larger morphological difference of the nasal soft tissue between adults and children than any other part of the face was also seen in our three-dimensional study.

Morphological differences of the lower face between adults and children have been evaluated both two-dimensionally and three-dimensionally[3]. In our previous cross-sectional study with two-dimensional cephalograms, lower facial soft tissue was also more downward and forward in a sagittal standard plane in adults, where sella was defined as the origin and the Frankfort Horizontal plane was made parallel to the anterior-posterior axis[23]. Kau and Richmond evaluated three-dimensional facial growth changes using contour color maps[6], and reported that the growth change of the facial surface was generally downward and forward with respect to soft tissue nasion. It is well known that the craniofacial skeleton grows downward and forward [23-25], and that the facial soft tissue profile and underlying bony structure are strongly related [1, 26]. Additionally, our cross-sectional result that the lower face is more forward than downward in adults than in children is a new finding in three-dimensional facial soft tissue analysis.

The morphological difference ratio of the upper facial area was smaller than other parts. In addition, because the X-coordinate values at endocanthion and exocanthion, and the Y-coordinate values at exocanthion, of scaled adults were lower than those of children, the mid face may not change as much as other parts of the face. A number of studies have shown width increases to be less than vertical changes from child to adult [3, 27]. Burke and Hughes-Lawson showed that intercanthal width is related to orbital growth, with little change during the growing period. Nute et. al. reported that growth in facial height was greatest, and mid face width changes the least, in their three-dimensional facial growth study[5]. The small difference in mid face width may relate to the small amount of change at the cranial base after 6 years of age.

It is very important to evaluate not only the three-dimensional morphological changes of the craniofacial skeleton that occur with growth and clinical treatment but also those of the facial soft tissue. The reference plane used in this study is applicable only to the evaluation of the facial soft tissue form in subjects without remarkable deformity and for calculation of normal average values of facial landmarks. This reference plane would be unsuitable for evaluation of facial asymmetry or evaluation of morphological changes before and after medical treatment of substantial facial deformity because the important landmarks used in the determination of this reference plane might be contained in the area of facial deformity. Therefore, the valuation reference plane must be selected according to the purpose of analysis. The reference plane used in our study is effective as an analytical method for 3-dimensional laser scanning. The methods presented here could greatly help evaluation of facial soft tissue in both the research and clinical settings.

The results of our study suggest that the morphological facial soft tissue differences between Japanese adults and children are more forward and downward than laterally, manifesting in a facial form of adults that is deeper and narrow. However, in this cross-sectional design the number of subjects might be too small to reach a broadly applicable conclusion. We plan to perform a large-scale longitudinal study using these scanning methods in the future to provide morphological standard values at different ages and values for growth changes of Japanese facial soft tissue.

CONCLUSION:

We evaluated the three-dimensional facial surface contour differences between adults and children using a new reference plane. Our results suggest:

1) The valuation reference plane must be selected to best fit the purpose of analysis, and the reference plane used in our study is effective in an analytical method for three-dimensional laser scanning.

2) The morphological facial soft tissue differences between Japanese adults and children are more forward and downward than laterally, manifesting in a facial form of adults that is deeper and narrow.

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Table and Figure Legend:

Table 1. Definition of soft-tissue landmarks.

Table 2. The averaged standard deviation and variance of each three-axis coordinate for five repeated measurements on each landmark.

Table 3. Mean and standard deviations of coordinate values and distances from the origin to each landmark of children.

Table 4. Mean and standard deviations of coordinate values and distances from the origin to each landmark of adults.

Table 5. The coordinate values of children and adults after fitting to the same scale in the same coordinate system.

Figure 1. Soft tissue landmarks.

Figure 2. The transformed coordinate system and origin.

Figure 3. Three-dimensional grid superimposed on a subject's face. A: frontal view. B: lateral view.

Figure 4. Frontal view of the three-dimensional reference meshes before scaling for adults (A) and children (B).

Figure 5. Lateral view of the three-dimensional reference meshes before scaling for adults (A) and children (B).

Figure 6. Three-dimensional mesh analysis of adults vs. children drawn to the same scale. Frontal (A) and lateral (B) views: mean adult (black line) and mean child (gray line).

Table 1 Definition of soft-tissue landmarks.

Landmarks	Abbreviation	Definition
Soft tissue nasion	N	Innermost point between the forehead and nose
Pronasale	Prn	Mosot protruded pint of the apex nasi
Subnasale	Sn	Midpoint at the conjunction of the lower border of the nasal septum and the upper lip
Labiale superius	Ls	Midpoint of the upper vermilion line
Stomion	Sto	At the intersection of the facial midline and horizontal labial fissure
Labiale inferius	Li	Midpoint of the lower vermilion line
Sublabiale	Sl	In the midline of the nasolabial sulcus
Pogonion	Pog	Most anterior point of the chin
Endocanthion	Enr, Enl	Inner commissure of the eye fissure
Exocanthion	Exr, Exl	Outer commissure of the eye fissure
Alar crest	Acr, Acl	Most lateral point in the curved base of each ala
Cheilion	Chr, Chl	Labial commissura

Table 2 The averaged standard deviation and variance of each three-axis coordinate for five repeated measurements on each landmark.

	X axis		Y axis		Z axis	
	S.D.	Variance	S.D.	Variance	S.D.	Variance
Children	0.30	0.23	0.13	0.03	0.28	0.14
Adults	0.45	0.37	0.37	0.25	0.46	0.30

S.D. : Standard Deviation

Table 3 Mean and standard deviations of coordinate values and distances from the origin to each landmark of children.

	X axis		Y axis		Z axis		3-D distance	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
N	0.26	0.72	5.28	0.75	3.74	2.53	6.83	1.66
Prn	0.26	0.90	19.65	1.74	-22.23	1.85	29.73	1.92
Sn	0.44	0.99	10.69	1.81	-31.75	2.09	33.57	2.05
Ls	0.43	1.21	16.90	2.56	-45.63	2.18	48.76	1.95
Sto	0.54	1.44	10.38	3.24	-51.69	2.61	52.85	2.37
Li	0.51	1.52	14.11	3.59	-57.64	3.13	59.48	2.91
Sl	0.65	1.72	7.94	3.30	-62.44	3.51	63.06	3.32
Pog	0.76	2.12	7.30	4.07	-75.66	3.57	76.16	3.34
Enr	-15.42	1.22	0.09	0.42	-0.31	0.53	15.44	1.22
Enl	15.42	1.22	-0.09	0.42	0.31	0.53	15.44	1.22
Exr	-43.83	2.68	-9.90	1.94	1.33	2.59	45.05	2.95
Exl	43.52	2.74	-9.44	2.04	2.66	2.62	44.72	3.00
Acr	-16.25	1.41	5.28	0.75	-26.91	1.98	31.92	1.81
Acl	16.97	1.42	5.28	0.75	-26.85	2.06	32.26	1.80
Chr	-15.99	2.65	5.43	3.02	-54.24	2.43	56.96	2.21
Chl	17.9	3.20	5.19	2.86	-53.25	3.21	56.61	2.63

Table 4 Mean and standard deviations of coordinate values and distances from the origin to each landmark of adults.

	X axis		Y axis		Z axis		3-D distance		Adult/child
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	%
N	0.28	0.74	7.73	1.69	9.11	2.12	12.07	2.27	176
Prn	-0.07	0.66	33.56	2.44	-30.96	2.86	45.74	2.58	153
Sn	0.32	0.71	20.14	2.17	-43.03	2.54	47.59	2.19	141
Ls	0.27	0.72	26.20	2.93	-59.49	3.38	65.10	2.77	133
Sto	0.46	0.81	20.85	3.19	-66.81	2.94	70.08	2.38	132
Li	0.37	0.79	25.44	3.33	-76.36	3.65	80.58	3.06	135
Sl	0.54	0.87	19.31	4.18	-82.19	3.76	84.56	3.02	134
Pog	0.64	0.95	20.71	5.87	-101.96	3.71	104.23	3.27	136
Enr	-18.57	1.30	-0.06	0.69	-0.42	0.60	18.59	1.31	120
Enl	18.57	1.30	0.06	0.69	0.42	0.60	18.59	1.31	120
Exr	-51.88	2.62	-10.91	2.52	2.52	2.32	53.18	2.81	118
Exl	51.96	3.17	-9.21	2.69	3.75	2.30	53.02	3.25	118
Acr	-20.46	1.69	7.73	1.69	-36.11	2.69	42.31	2.26	132
Acl	21.13	1.34	7.73	1.69	-35.70	2.25	42.25	2.39	130
Chr	-23.53	2.83	10.25	4.05	-68.66	3.34	73.39	2.87	128
Chl	25.14	3.39	10.38	4.28	-68.09	3.05	73.54	2.80	129

Table 5 The coordinate values of children and adults after fitting to the same scale in the same coordinate system.

	X axis			Y axis			Z axis		
	Children		Adults	Children		Adults	Children		Adults
N	0.29		0.24	6.12		6.77	4.35	—*—	7.99
Prn	0.28		-0.06	22.84	—*—	29.43	-25.84		-27.16
Sn	0.51		0.27	12.42	—*—	17.67	-36.91		-37.76
Ls	0.49		0.23	19.63	—*—	23.00	-53.04		-52.18
Sto	0.63		0.40	12.07	—*—	18.34	-60.06		-58.61
Li	0.59		0.32	16.40	—*—	22.37	-66.97		-66.98
Sl	0.76		0.47	9.25	—*—	17.00	-72.55		-72.11
Pog	0.89		0.56	8.52	—*—	18.25	-87.92		-89.48
Enr	-17.92	—*—	-16.30	0.10		-0.04	-0.36		-0.36
Enl	17.92	—*—	16.30	-0.10		0.04	0.36		0.36
Exr	-50.93	—*—	-45.53	-11.48		-9.58	1.54		2.19
Exl	50.59	—*—	45.59	-10.95		-8.10	3.12		3.27
Acr	-18.88		-17.96	6.12		6.77	-31.29		-31.68
Acl	19.73		18.55	6.12		6.77	-31.21		-31.32
Chr	-18.58		-20.64	6.31		9.05	-63.04	—*—	-60.14
Chl	20.81		22.05	6.04		9.16	-61.86		-59.74

*: P<0.003

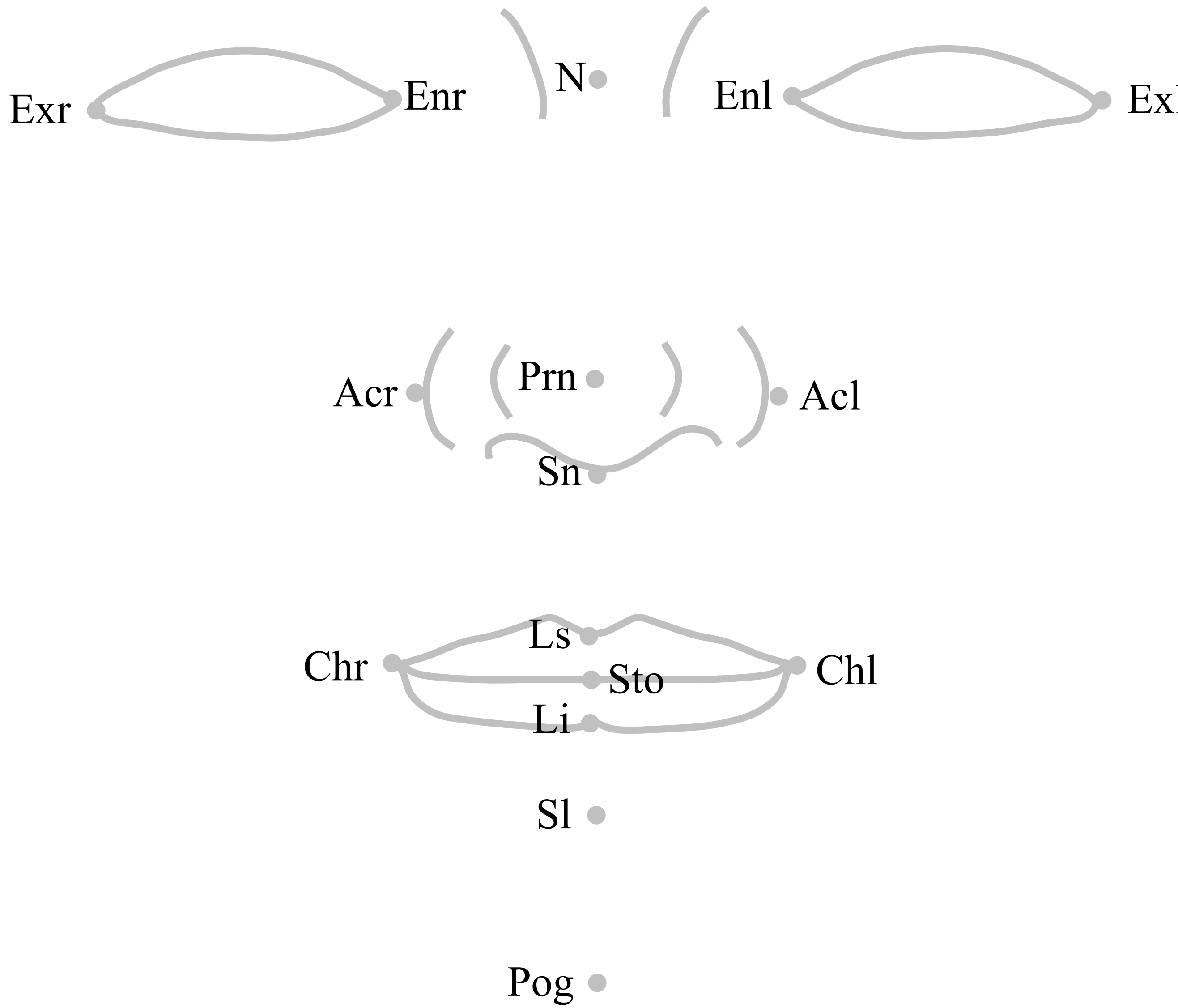

Figure 1. Soft tissue landmarks.

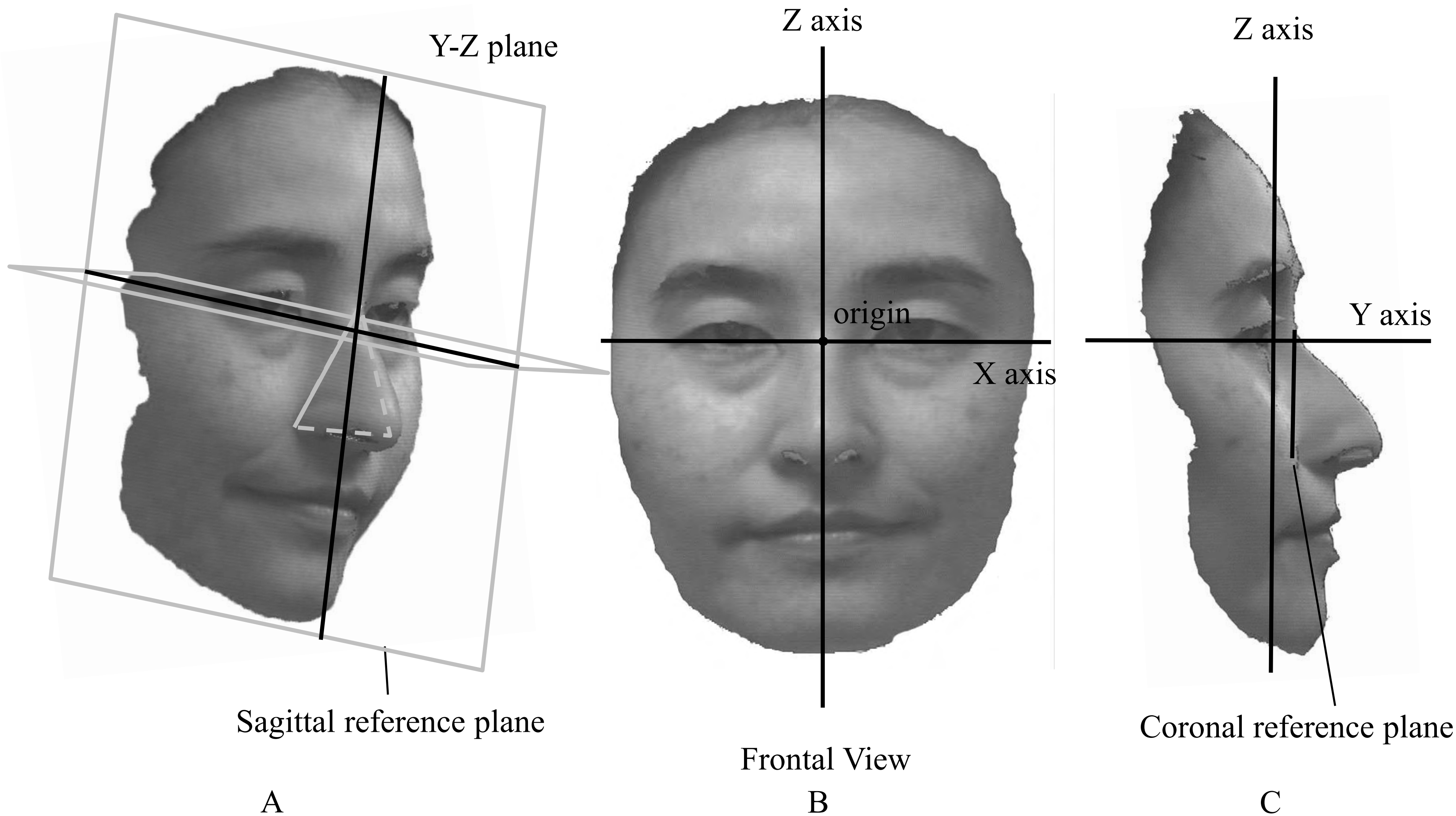

Figure 2. The transformed coordinate system and origin.

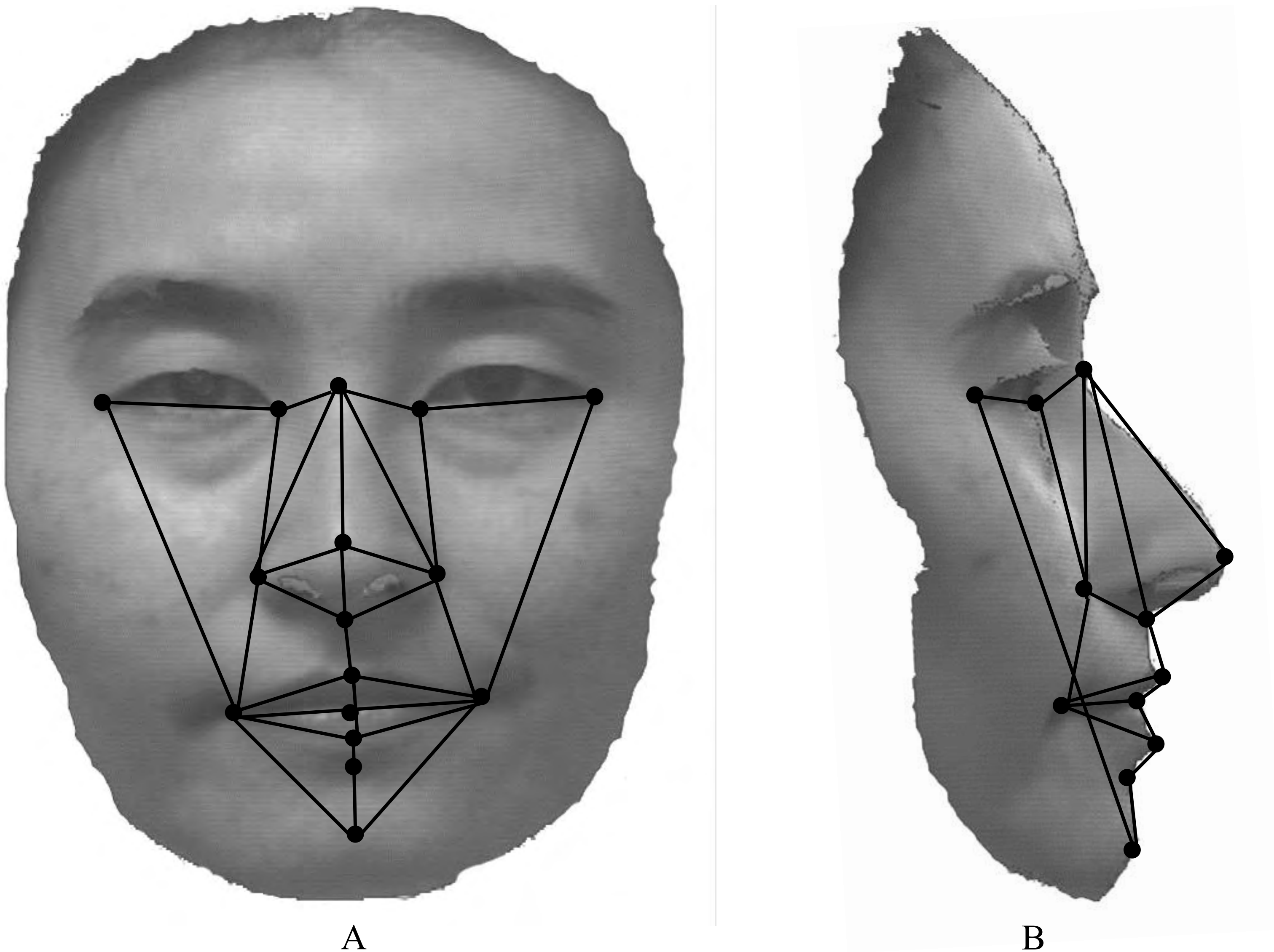

Figure 3. Three-dimensional grid superimposed on a subject's face. A: frontal view. B: lateral view.

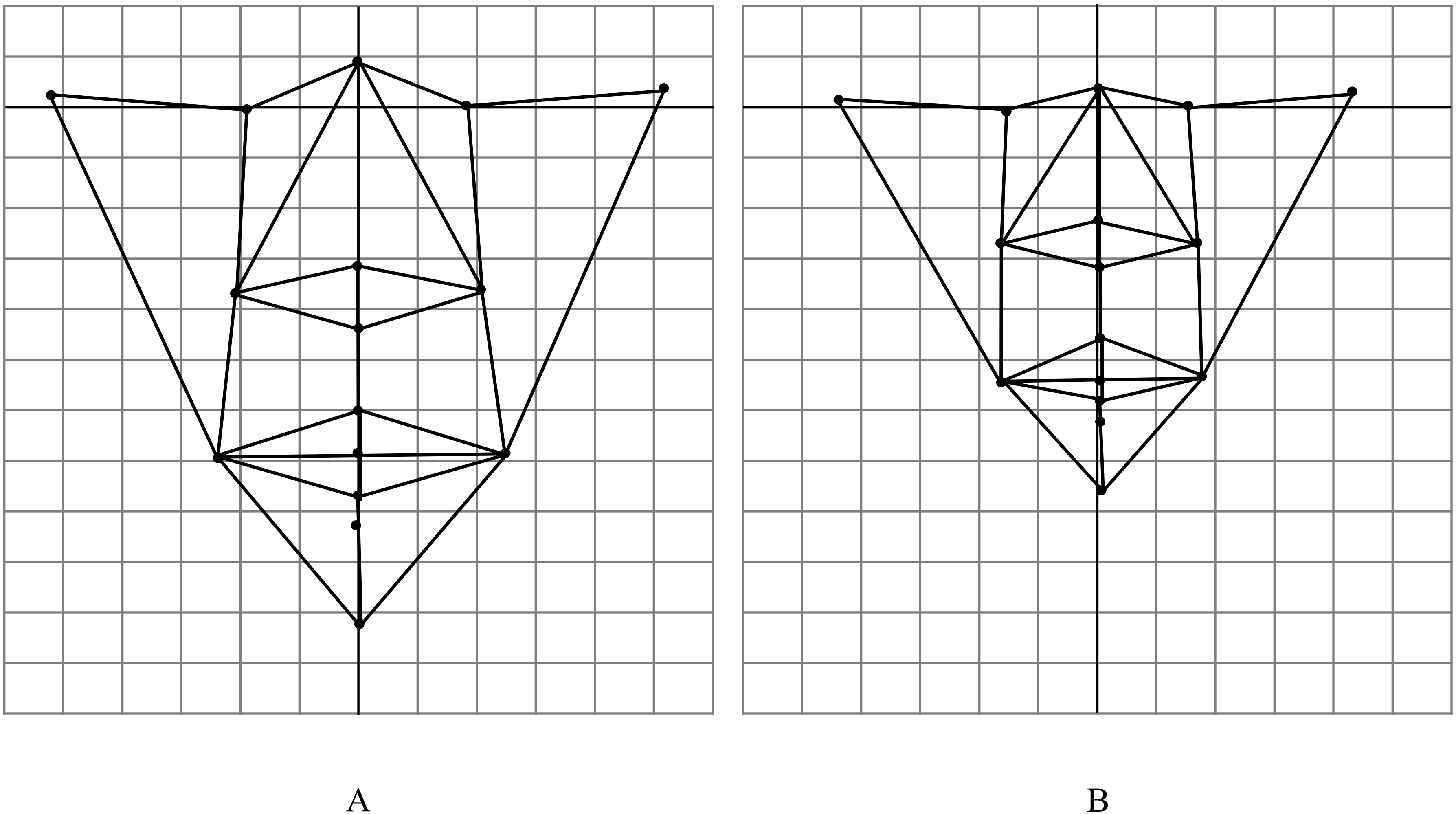

Figure 4. Frontal view of the three-dimensional reference meshes before scaling for adults (A) and children (B).

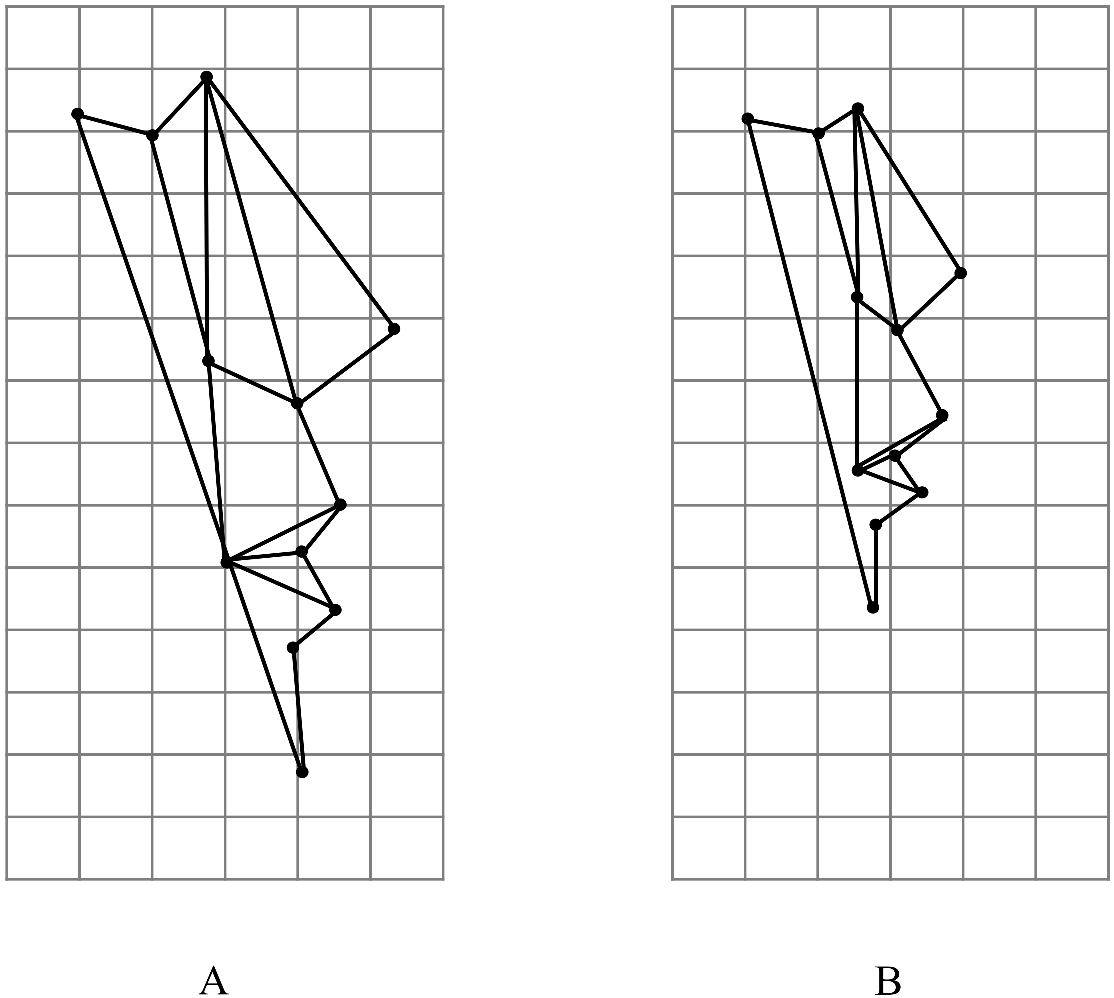

Figure 5. Lateral view of the three-dimensional reference meshes before scaling for adults (A) and children (B).

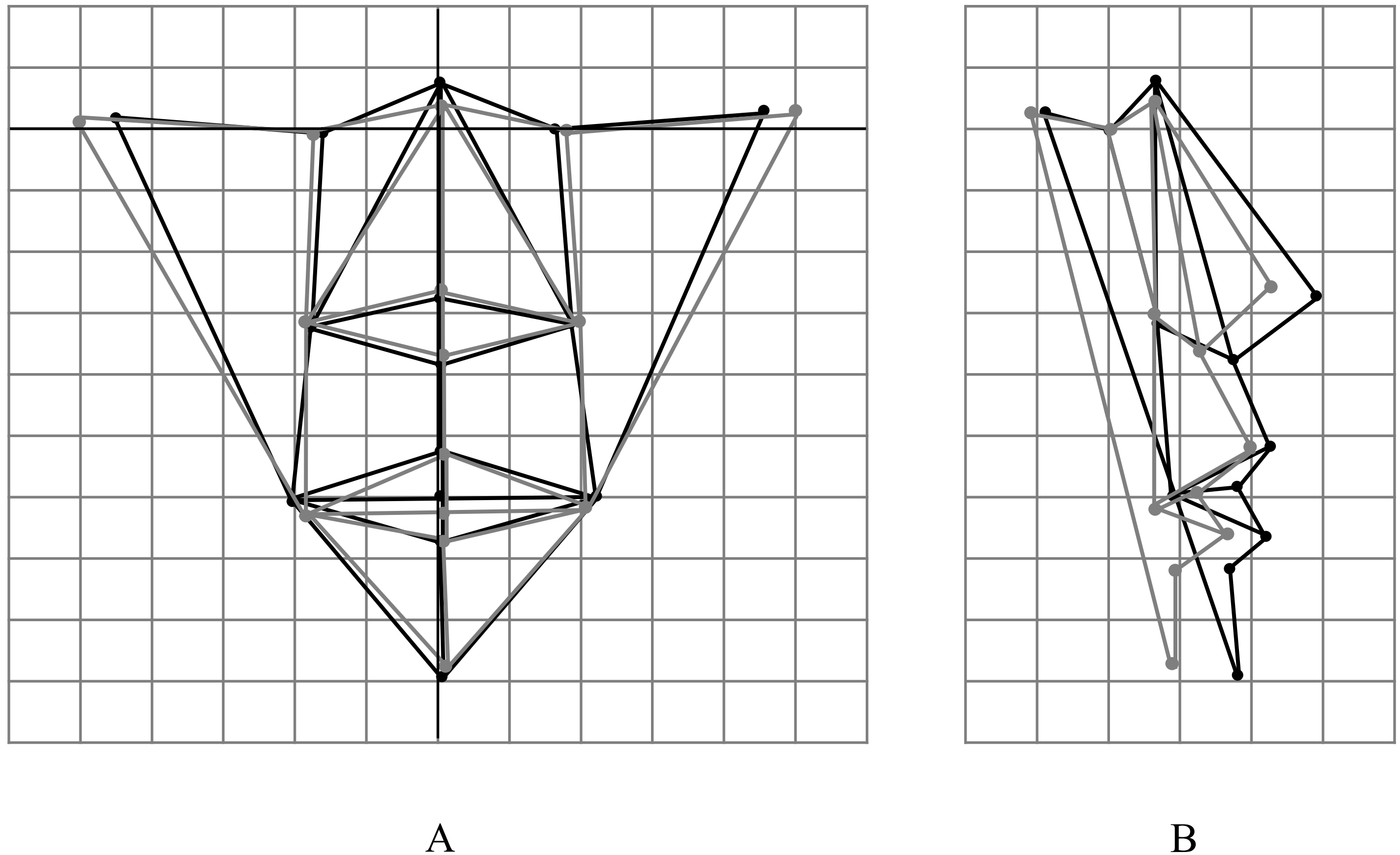

Figure 6. Three-dimensional mesh analysis of adults vs. children drawn to the same scale. Frontal (A) and lateral (B) views: mean adult (black line) and mean child (gray line).