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Cosmetic

Three-dimensional Analysis of Normal Facial Morphologies of Asians and Whites: A Novel Method of Quantitative Analysis

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Background: The purpose of this study is to compare 3-dimensional facial averages of Asians (Koreans and Chinese) and Houstonian white faces using a (3-dimensional) surface imaging system.
Methods: Three-dimensional images of Korean adults (Seoul, Korea) with class I malocclusion captured using the 3dMDface. The images of 138 Koreans were processed to generate average male and female facial shells using Rapidform 2006 plus pack 2 software and then superimposed and compared with the average shells of Chinese adults (Xi' An, China) and white adults (Houston, Tex.).
Results: The average Korean male and female faces were wider with prominent malar and zygomatic areas when compared with the white faces. The average white male and female faces showed more protrusion in the glabella, nasion, rhinion, and the soft-tissue pogonion than the Korean faces. The average Korean male face was retrusive at masseteric region while having more prominent lips, nasal tip, and supraglabella than the Chinese counterpart. The average Korean female face was narrower than the average Chinese female face, but there was more protrusion in the periorbital, nasal tip, and malar region seen in the Korean female face.
Conclusions: Although the average faces of Chinese and Korean populations in this study showed remarkable similarities, there were distinct differences seen in the facial morphology of the 2 Asian groups. Three-dimensional imaging can be effectively used to establish population facial norms and to quantify the variations seen between different ethnicities. This information may be used in the clinical environment for plastic, oral, and maxillofacial surgery and orthodontics. *(Plast Reconstr Surg Glob Open 2016;4:e865; doi: 10.1097/GOX.0000000000000853; Published online 20 September 2016.)*

Nearly 300 million people live in the United States, and the population is continuing to increase. According to the 2010 US Census Bureau, the Asian population grew faster than any other ethnicity within the United States between 2000 and 2010.[1] Specifically, the Korean American population surged 33%, making Koreans the fourth fastest growing Asian group in 2010.[2] This recent rise in the Asian American population in the United States implies that there might also be an increase in the number of Asian patients seeking facial plastic surgery, orthognathic surgery, and orthodontic treatment; therefore, there is a profound need for clinicians to better understand the facial morphology of diverse Asian groups. Understanding the differences in various Asian facial morphologies is essential in providing a more individualized treatment plan and clinical care for the patients. This study attempts to determine the average facial morphology of the adult male and female Korean population, then to compare the average Korean faces with those of Chinese and white adults. Such information can be utilized in orthognathic and facial reconstructive surgery planning, and the field of forensic science.[3]

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MATERIALS AND METHODS

Three hundred nine subjects were recruited from 3 areas (Seoul, Xi' An and Houston). The selection criteria of this study are shown in Table 1.

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Table 1. Inclusion Criteria

Age: 19–35 y old
Body mass index: 18.5–24.9
No skeletal discrepancies
No craniofacial anomalies
No history of major accident or injury to the face
No history of plastic surgery to the face or injections
No history of orthognathic surgery
No history of orthodontic treatment

Approval was given by the University of Alabama at Birmingham and Kyung Hee University at Seoul, Korea. All subjects were given a consent form and questionnaire if they met the inclusion criteria. The final breakdown of the sample size and age for each population group may be found in Table 2.

Image Acquisition and System

Images of all 3 populations, Koreans, Chinese, and Houstonian whites, were taken by 3dMDface system (3dMD LLC, Atlanta, Ga.) at different time points. The 3dMDface system uses a combination of the structured light and stereo photogrammetry techniques.[4] Three medical-grade, machine-vision cameras are mounted within pods that are assembled on each side of the device to capture an image. The sensors on the cameras are much more sophisticated and consistent than those of consumer and professional single-lens reflex camera. These cameras are designed for industrial applications, thus engineered in such way to tightly synchronize the camera capture speed with the flash.[5] The system works by projecting random patterns of light onto a face while simultaneously taking pictures with the 6 cameras in fixed distances and angles that optimize the image acquisition. The capture time is 1.5 ms, which is applicable for younger subjects.[4] There is no "stitching" of the data set, enabling an ear-to-ear coverage with 1 coordinate system.[5]

Simultaneous capturing of the image with 6 cameras allows for acquisition of realistic picture.[5,6] The manufacturer accuracy is reported to be less than 0.5 mm with the clinical accuracy of 1.5% of the total observed variance.[7] Previous literature has documented the accuracy and reliability of the 3dMDface system.[4,5,8–10] Moreover, some authors concluded that this technology can be a great tool in the evaluation of facial soft-tissue contours in orthodontic and surgical cases.[3,8,9]

Using 3dMDface system, each subject was asked to relax and look into the eyes of one's own reflection on a wall mirror. Such external source of eye reference has proven to be reliable and repeatable method to position a patient in a natural head posture.[11]

Any images that were distorted, incomplete, obstructed, or showing artifacts were excluded from the study. The usable images imported to Rapidform 2006 Plus Pack (RF6 PP2, Geomagic Korea, Seoul Korea) software for further analysis.[6,12] Average facial shells were generated following 6 steps that are extensively described in previous studies.[6,12–14]

Table 2. Sample Size and Mean Age

Populations	Male	Female	Total	Mean Age
Korean	75	63	138	26.8
Chinese	32	39	71	26.5
White	50	50	100	23.5
Total	157	152	309	25.7

Subgroup Comparisons

Average facial shells of the population subgroups are shown in Table 3. Subgroups were generated with each shell having 1 +SD and 1 −SD. The next step was to plot 5 predetermined anatomical landmarks on the faces of the 2 subgroups to be compared. These 5 points were the inner canthus of the eyes, outer commissures of the lips, and the tip of the nose (Fig. 1). Once the 5 landmarks were selected on both faces, the 2 shells were superimposed using the best-fit algorithm for the comparisons to be made. The average facial shell comparisons are shown in Table 4.

The parameters measured were linear measurements between 2 faces, color histograms, and surface areas and shapes.

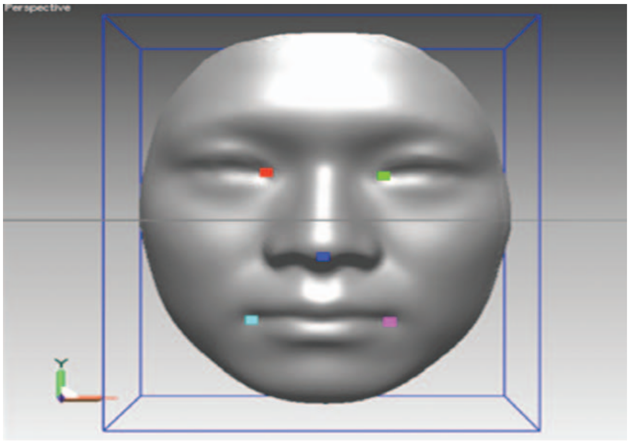

Fig. 1. Plotting the 5 anatomical landmarks for superimposition.

Table 3. Average Facial Shells of the Population Subgroups

1. Korean male (KRN-M)
2. Korean female (KRN-F)
3. Chinese male (CHNCHI-M)
4. Chinese female (CHNCHI-F)
5. White male (CAU-M)
6. White female (CAU-F)

Table 4. Average Facial Shell Comparisons

1. KRN-F vs KRN-M
2. KRN-M vs CAU-M
3. KRN-M vs CHI-M
4. KRN-M +SD vs CHI-M
5. KRN-M −SD vs CHI-M
6. KRN-M vs CAU-F
7. KRN-F vs CHI-F
8. KRN-F +SD vs CHI-F
9. KRN-F −SD vs CHI-F

Linear Measurements

The mean of all linear measurements was calculated by taking an absolute value of the average difference between the surfaces of 2 shells. These values are always positive, providing only quantitative information about the absolute distance between the 2 faces rather than providing directional information, such as positive or negative.[6] The linear measurements consisted of the maximum and minimum values, average distance, and the SD in millimeters. The minimum values are always 0 mm because they are expressed in absolute values of the differences.

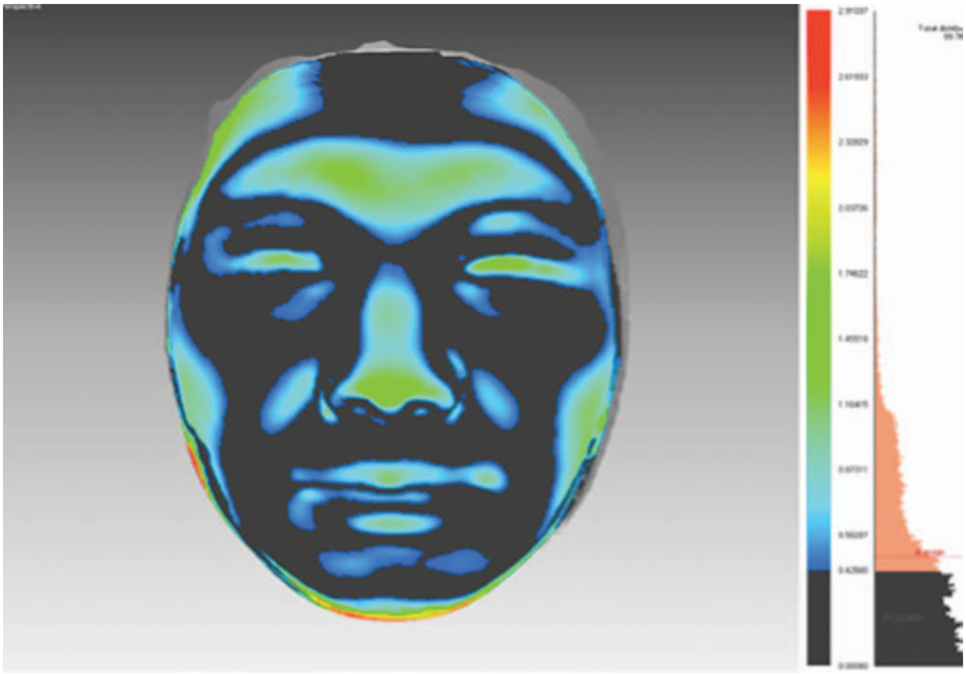

Fig. 2. Absolute color histogram.

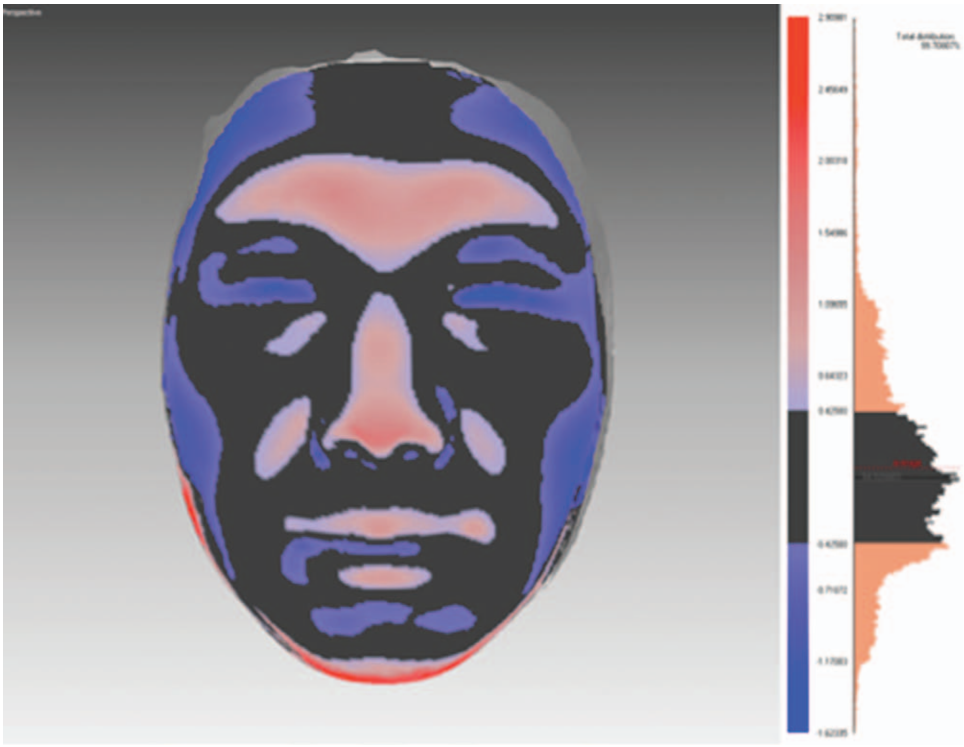

Fig. 3. Signed color histogram.

Tolerance Level

The tolerance level of 0.425 mm was used for this study when the average facial shells of 2 population subgroups were compared. The tolerance level indicates that any values within 0.425 mm are considered "similar" and were based on a previous study.[15]

Color Histogram

The color histograms visualize the differences seen between 2 faces. Two types of color histograms were generated: absolute and signed color histograms. The second shell would always represent the "reference shell" (i.e., white male (CAU-M) is the reference shell in "Korean male (KRN-M) vs (CAU-M)").

In an absolute color histogram, as shown in Figure 2, gray areas are considered similar. The differences are represented with a color spectrum, ranging from blue to red. The blue represents the least amount of absolute linear difference, and the red represents the largest amount of difference between 2 faces.

In a signed color histogram, as shown in Figure 3, the differences are expressed as vector values, showing either retrusion (negative value) or protrusion (positive value) of 1 facial shell in relation to the reference shell. The areas of blue represent retrusive or deficient regions of 1 face versus the reference facial shell, whereas the red areas show more protrusion in relation to the reference shell. Similar to absolute color histograms, the gray area would mean that the 2 faces are considered to be similar.

RESULTS

The total sample size for this study included 309 subjects with the mean age of 25.7 years. Korean subjects were 138, 75 males and 63 females, and the Chinese participants were 71, 32 males and 39 females.[16] Houstonian white group consisted of 50 males and 50 females, comprised of 100 subjects.[13] The captured images of all individuals were processed, and the average facial shells of each population subgroup were generated for comparisons (Figs. 4–9).

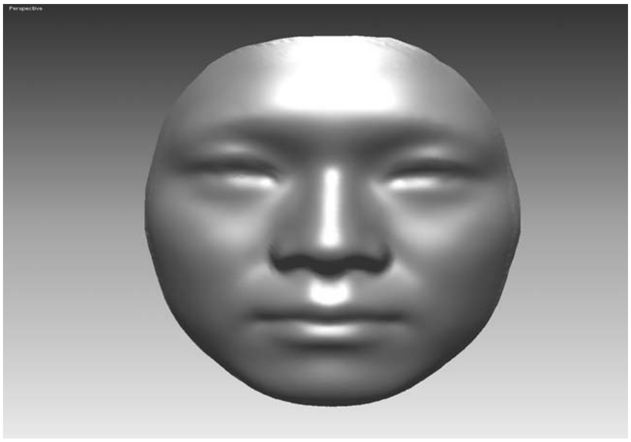

Fig. 4. Average facial shells for KRN-M.

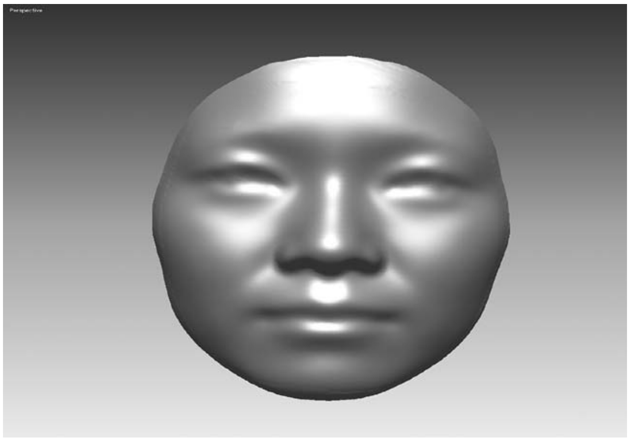

Fig. 5. Average facial shells for KRN-M.

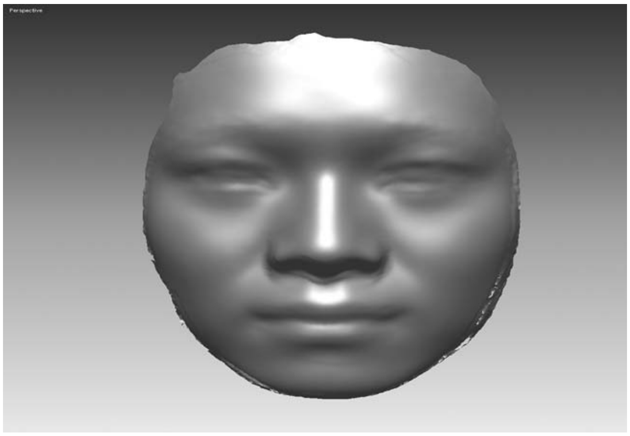

Fig. 6. Average facial shells for CHI-M.

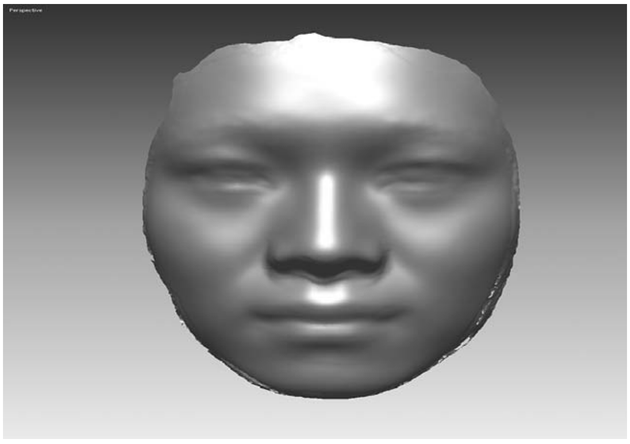

Fig. 7. Average facial shells for CHI-F.

Linear Measurements

The absolute linear measurements are shown in Table 5. The highest absolute average distance among all population comparisons was seen between KRN-M and CAU-M, with the average distance being 2.60 mm. The lowest absolute average distance was 0.49 mm seen

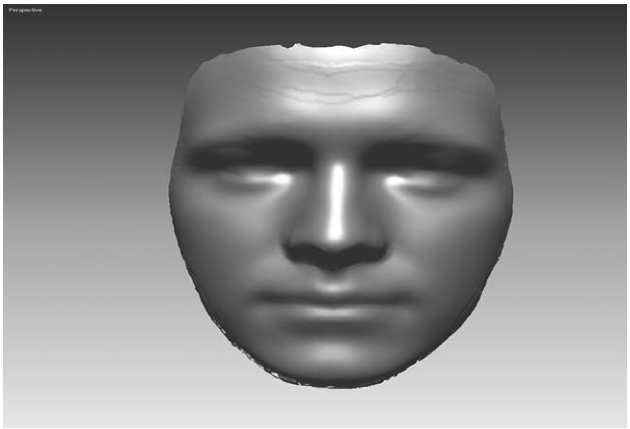

Fig. 8. Average facial shells for CAU-M.

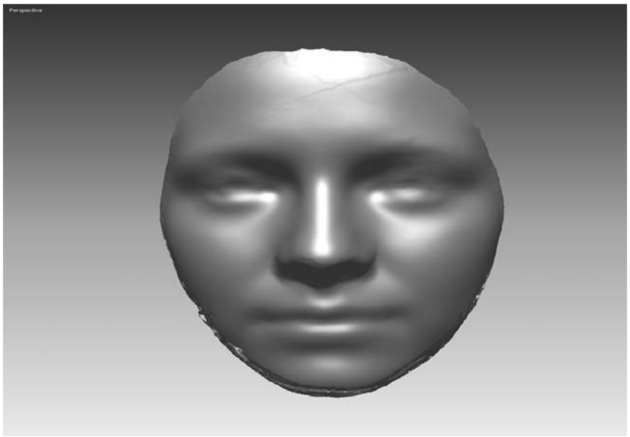

Fig. 9. Average facial shells for CAU-F.

between KRN-M and Chinese male (CHI-M). The maximum distance ranged from 2.70 to 8.18 mm between all the comparisons made.

Table 6 shows direction-specific measurements between 2 shells. The difference between absolute color and signed color histograms is that the signed color map measurements do not have a minimum distance of zero as opposed to the absolute linear measurements. Negative values denote the amount of retrusion of 1 facial shell to the reference shell, and positive values denote the amount protrusion of 1 shell to the reference. Also, the signed color map measurements show additional information, which is the percent similarity (% similarity). The % similarity shows the degree of similarity seen in the 2 average facial shells in comparison. The average linear measurements ranged from −0.32 mm (KRN-F −SD vs CHI-F) to +0.80 mm (KRN-M vs CAU-M). Among all the comparisons, KRN-M +SD versus CHI-M showed the highest % similarity (58.66%), whereas KRN-M versus CAU-M showed the least similarity (9.88%).

Color Histograms

Figures 10 and 11 show the signed color histograms. In the signed color histograms, as the color ranges from blue to red, the areas of 1 facial shell compared with the reference shell become more retrusive to protrusive.

Facial shell comparisons are shown in Table 7.

Figures 12 to 20 present the distinct differences between the following subgroups:

KRN-F versus KRN-M: the facial shell comparison showed 21.67% similarity.

KRN-M versus CAU-M: the % similarity was 9.88%, demonstrating the least amount of similarity among all the subgroup comparisons.

KRN-M versus CHI-M: Figure 14 displays the comparison between the Korean and Chinese male

Table 5. Absolute Linear Measurements Showing Differences Between the Facial Shells

Comparison Groups	Average Distance (mm)	SD (mm)	Maximum Distance (mm)	Minimum Distance (mm)
KRN-F vs KRN-M	1.28	0.94	4.99	0.00
KRN-M vs CAU-M	2.60	1.92	7.87	0.00
KRN-M vs CHI-M	0.49	0.45	3.87	0.00
KRN-M +SD vs CHI-M	0.55	0.66	4.50	0.00
KRN-M −SD vs CHI-M	0.81	0.56	4.53	0.00
KRN-M vs CAU-F	2.32	1.73	8.18	0.00
KRN-F vs CHI-F	0.60	0.50	2.70	0.00
KRN-F vs CHI-F	0.78	0.67	3.88	0.00

Table 6. Signed Color Measurements Showing Differences Between the Facial Shells

Comparison Groups	Average Distance (mm)	SD (mm)	Maximum Distance (mm)	Minimum Distance (mm)	% Similarity
KRN-F vs KRN-M	−0.02	1.59	3.75	−4.99	21.67
KRN-M vs CAU-M	0.80	3.13	7.87	−6.42	9.88
KRN-M vs CHI-M	0.06	0.66	3.87	−1.80	58.16
KRN-M +SD vs CHI-M	0.27	0.82	4.50	−1.45	58.66
KRN-M −SD vs CHI-M	−0.14	0.97	2.82	−4.53	29.51
KRN-F vs CAU-F	0.69	2.81	8.18	−6.36	10.25
KRN-F vs CHI-F	−0.18	0.76	2.42	−2.70	45.64
KRN-F +SD vs CHI-F	0.06	0.79	3.97	−1.71	45.59
KRN-F −SD vs CHI-F	−0.32	0.98	2.26	−3.88	34.83

Fig. 10. Signed histograms: KRN-M versus KRN-F, KRN-M versus CAU-M, KRN versus CHI-M, KRN-M +SD versus CHI-M, and KRN-M –SD versus CHI-M.

Fig. 11. Signed histograms: KRN-F versus CAU-F, KRN-F versus CHI-F, KRN-F +SD versus CHI-F, and KRN-F –SD versus CHI-F.

Table 7. Distinct Differences of Facial Shell Comparisons Between Subgroups

	More Prominent	Less Prominent
KRN-F vs KRN-M	Periorbital, zygion, malar regions	Supraglabella, rhinion, soft tissue menton
KRN-M vs CAU-M	Malar, zygion, width of face	Glabella, nasion, rhinion, soft tissue pogonion
KRN-M vs CHI-M	Supraglabella, rhinion	Width of face
KRAN-M +SD vs CHI-M	Tip of nose	Periorbital, rhinion regions
KRN-M –SD vs CHI-M	Supraglabella, malar, rhinion regions	
KRN-F vs CAU-F	Zygion, malar, width of face	Forehead, glabella, nasion, rhinion, soft tissue pogonion
KRN-F vs CHI-F	Glabella, rhinion, nasal tip, malar area	Masseteric, width of face
KRN-F +SD vs CHI-F	Rhinion, nasal tip	Masseteric
KRN-F –SD vs CHI-F	Supraglabella, malar, rhinion	Width of face

faces. There were large areas of gray seen, and these were the areas of similarity between the 2 subgroups with less than 0.425-mm difference. The comparison showed 58.16% similarity, which was the second most similar subgroups among the other subgroup comparisons.

KRN-M ±SD versus CHI-M: the comparison between KRN-M +SD and CHI-M showed greater areas of gray, demonstrating that there was even more similarity between these 2 subgroups than KRN-M versus CHI-M (Figure 15). The % similarity was 58.66%, showing the highest similarity among all the comparisons.

KRN-M –SD versus CHI-M: this average shell comparison presented with 29.51% similarity.

KRN-F versus CAU-F: Figure 17 depicts the discrepancies seen between the 2 subgroups. The 2 facial shells had 10.52% similarity, marking the second least similar subgroup comparisons among all the others.

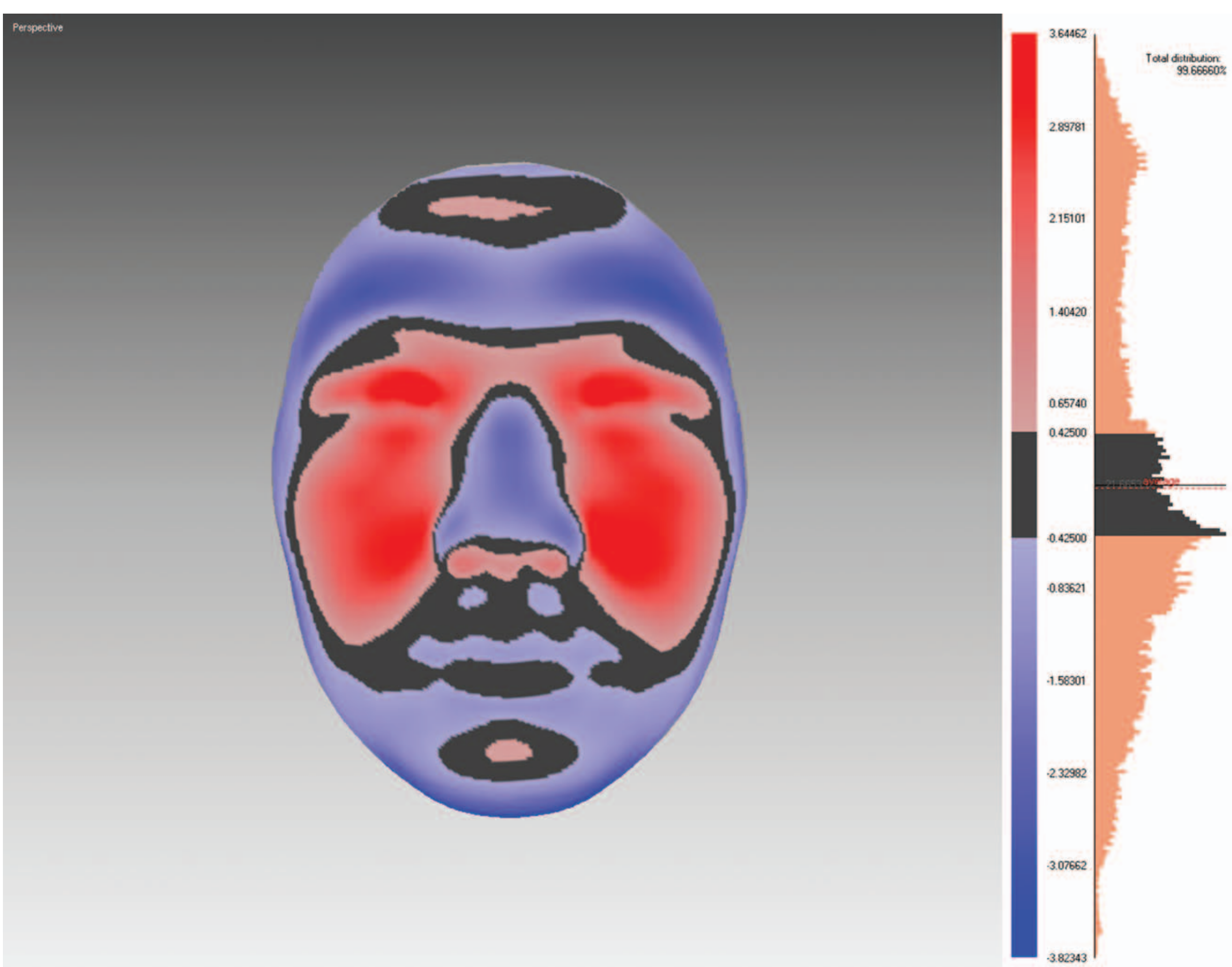

Fig. 12. Signed color map comparing KRN-F shell to KRN-M shell.

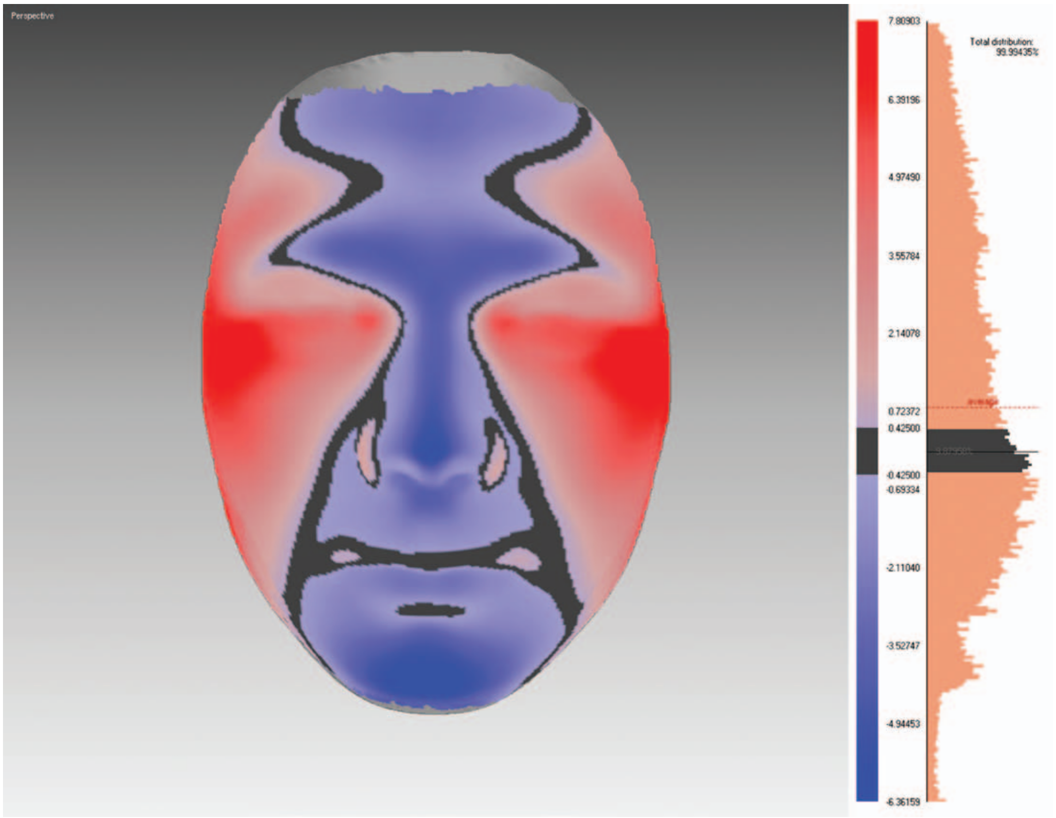

Fig. 13. Signed color map comparing KRN-M shell to CAU-M shell.

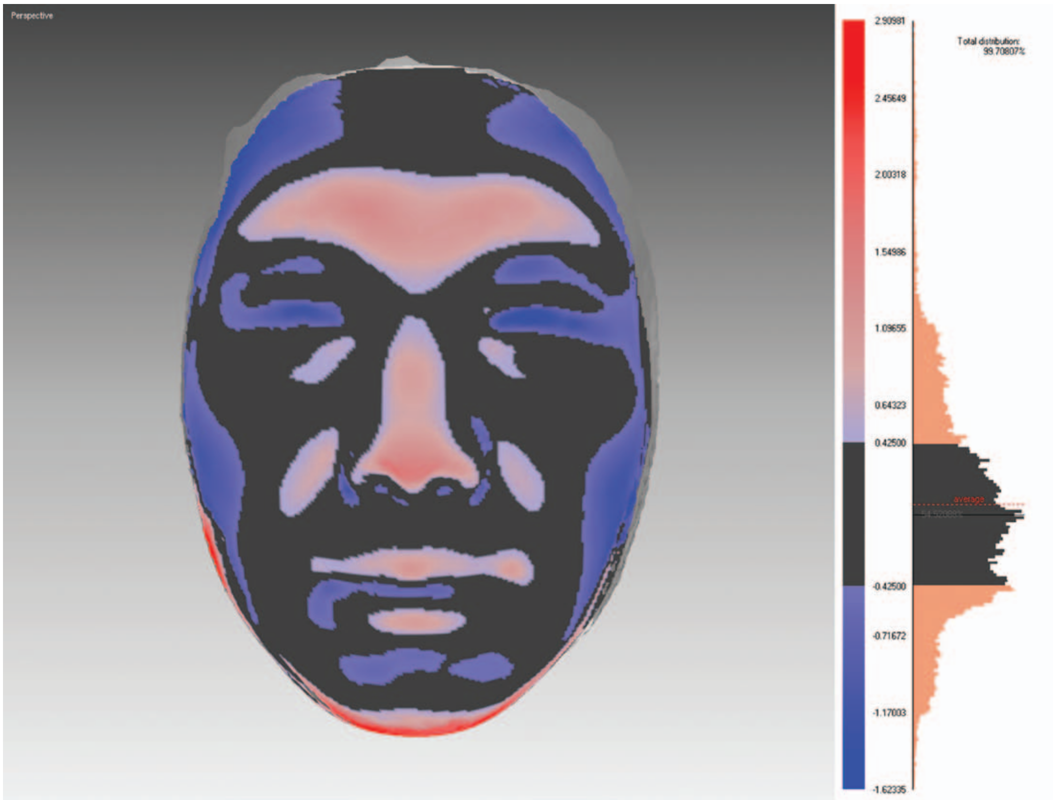

Fig. 14. Signed color map comparing KRN-M to CHI-M shell.

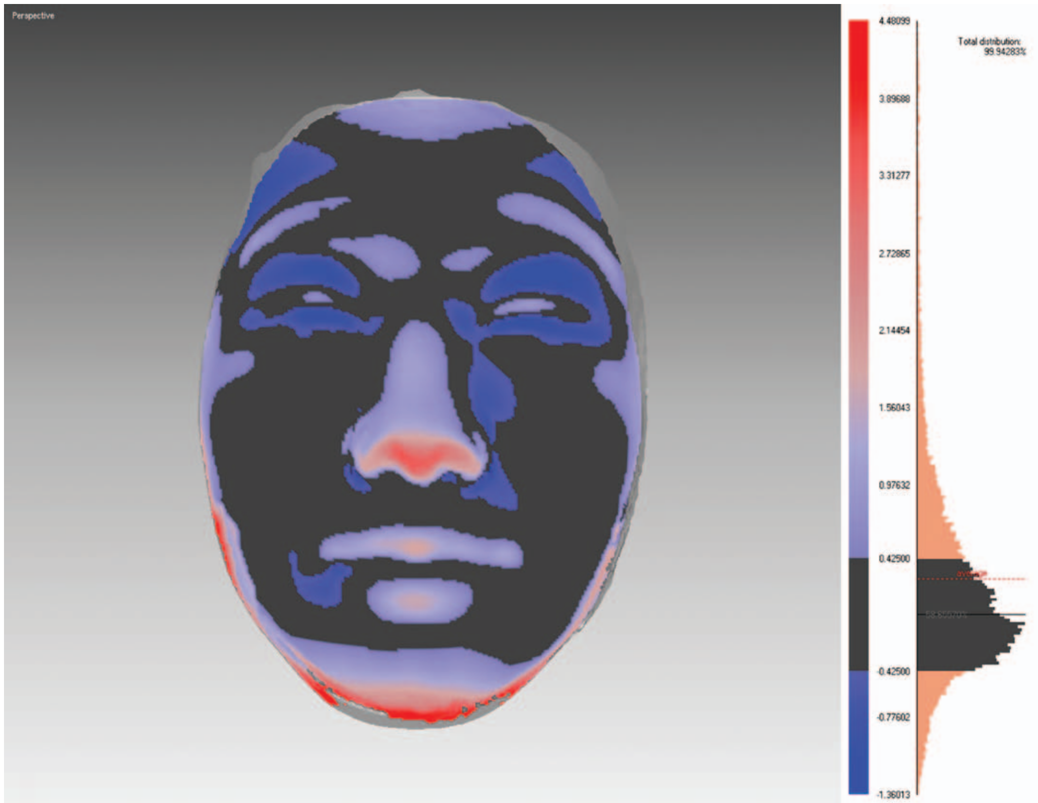

Fig. 15. Signed color map comparing KRN-M +SD shell to CHI-M shell.

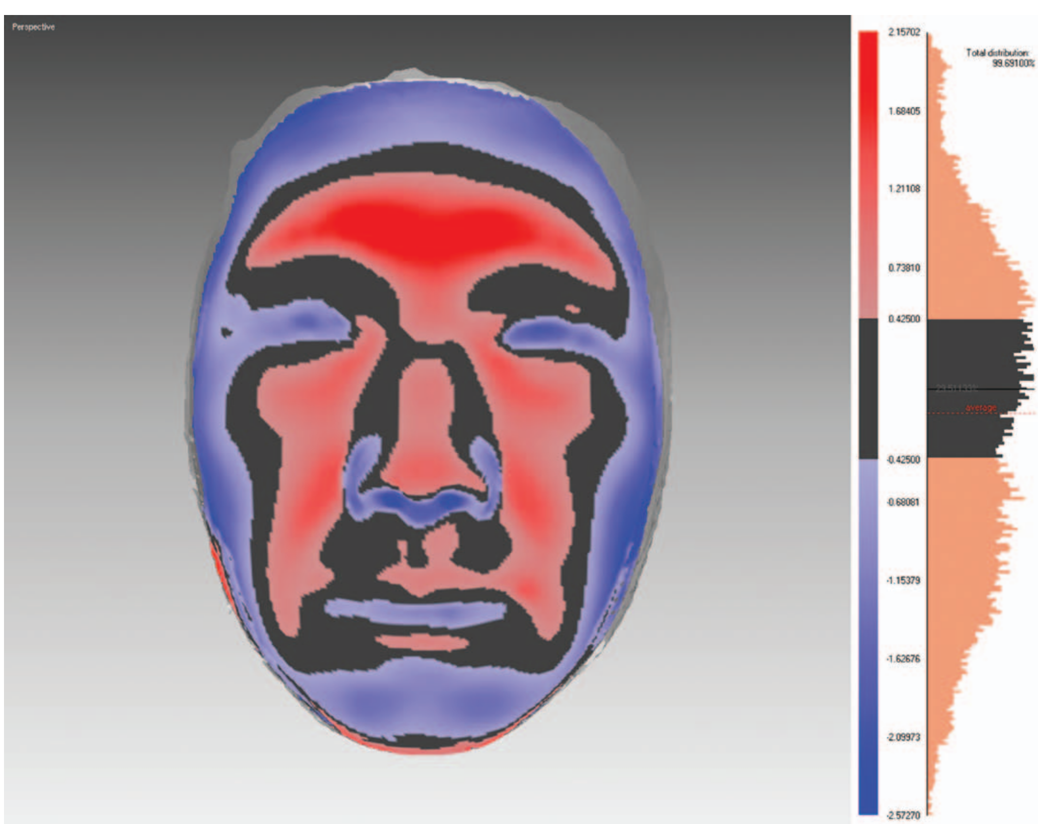

Fig. 16. Signed color map comparing KRN-M –SD shell to CHI-M shell.

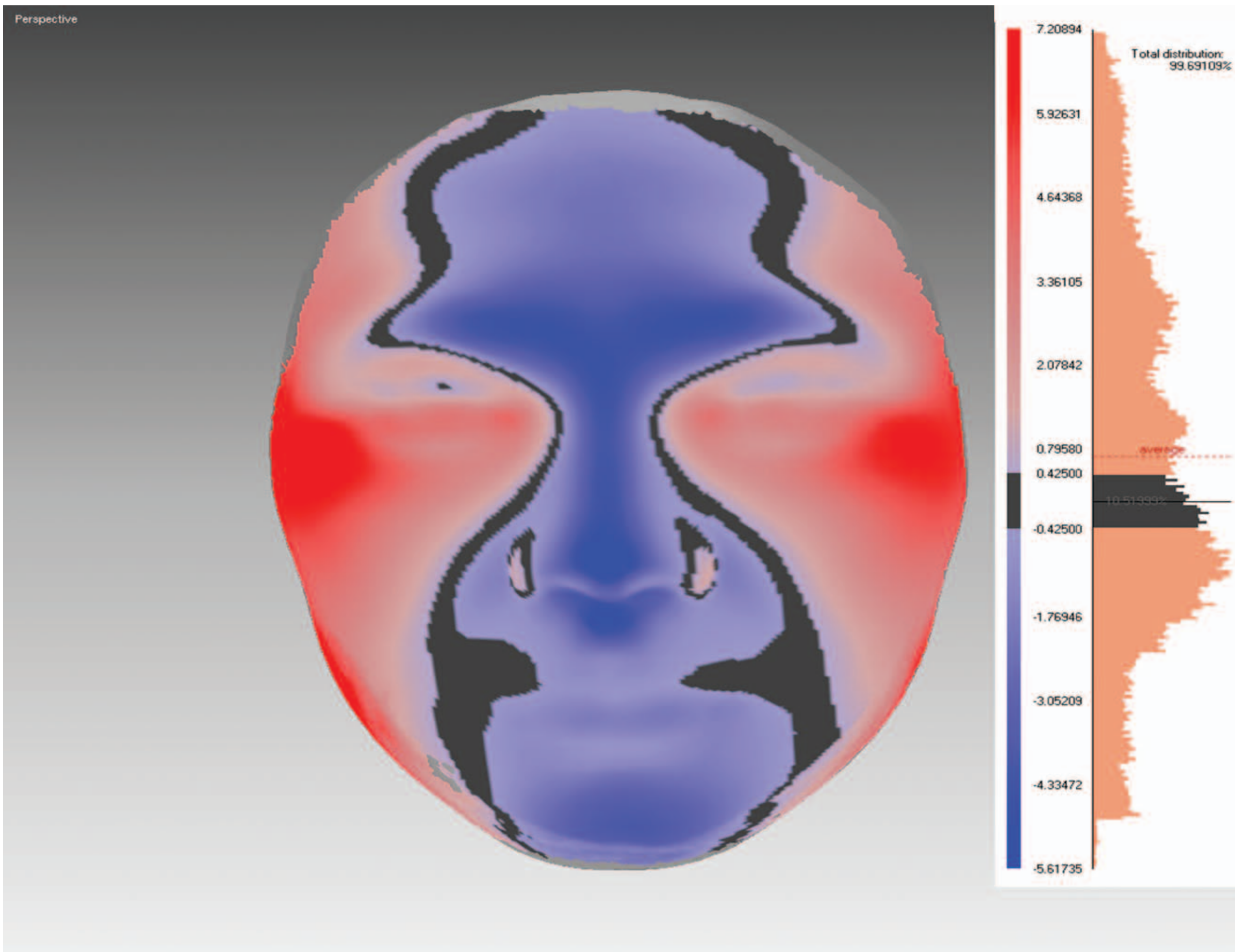

Fig. 17. Signed color map comparing KRN-F shell to CAU-F shell.

KRN-F versus CHI-F: KRN-F versus CHI-F comparison showed 45.64% similarity, being the third most similar subgroup comparisons.

KRN-F ±SD versus CHI-F: The comparison between KRN-F +SD and CHI-F showed 45.59% similarity.

KRN-F –SD versus CHI-F: Figure 20 shows the comparison between KRN-F –SD and CHI-F. The % similarity was 34.83%.

DISCUSSION

Several studies comparing Korean male and female facial morphology using 3-dimensional (3D) imaging technologies have been performed and reported. Hwang[17] described in his study that the Korean men showed thicker soft tissue at the supraglabella, nasion, rhinion, mid-philtrum, supradentale, and supraglenoid points. The Korean females exhibited thicker tissue at the lateral orbit, inferior malar, and gonion points. Our study showed similar results, demonstrating that the males had more protrusion in the supraglabella, rhinion, and menton. The females showed more protrusion in the periorbital, zygion, and the malar regions. Hwang et al[18] used cone-beam computed tomography to analyze the soft-tissue thickness between Korean males and females. The results from this study coincide with the results from our study regarding the protrusion of the zygion in the female population compared with the Korean males. In this study, both the average Korean male and female faces were wider with more prominent malar and zygion than the average white faces. The average white male and female faces had more prominent glabella, nasion, rhinion, and the soft-tissue pogonion than the Korean faces. These findings were similar to the results from the study by Hwang et al[19] that used a lateral cephalogram to compare the soft-tissue profiles of European Americans with Korean subjects. However, unlike the findings from our study, the study Hwang et al showed that there was a higher degree of lip protrusion in the Koreans than the whites. There could be 2 possible explanations for this difference. First, the white subjects used in the study by Hwang et al[19] were from Ann Arbor, Mich., whereas our samples came from Houston,

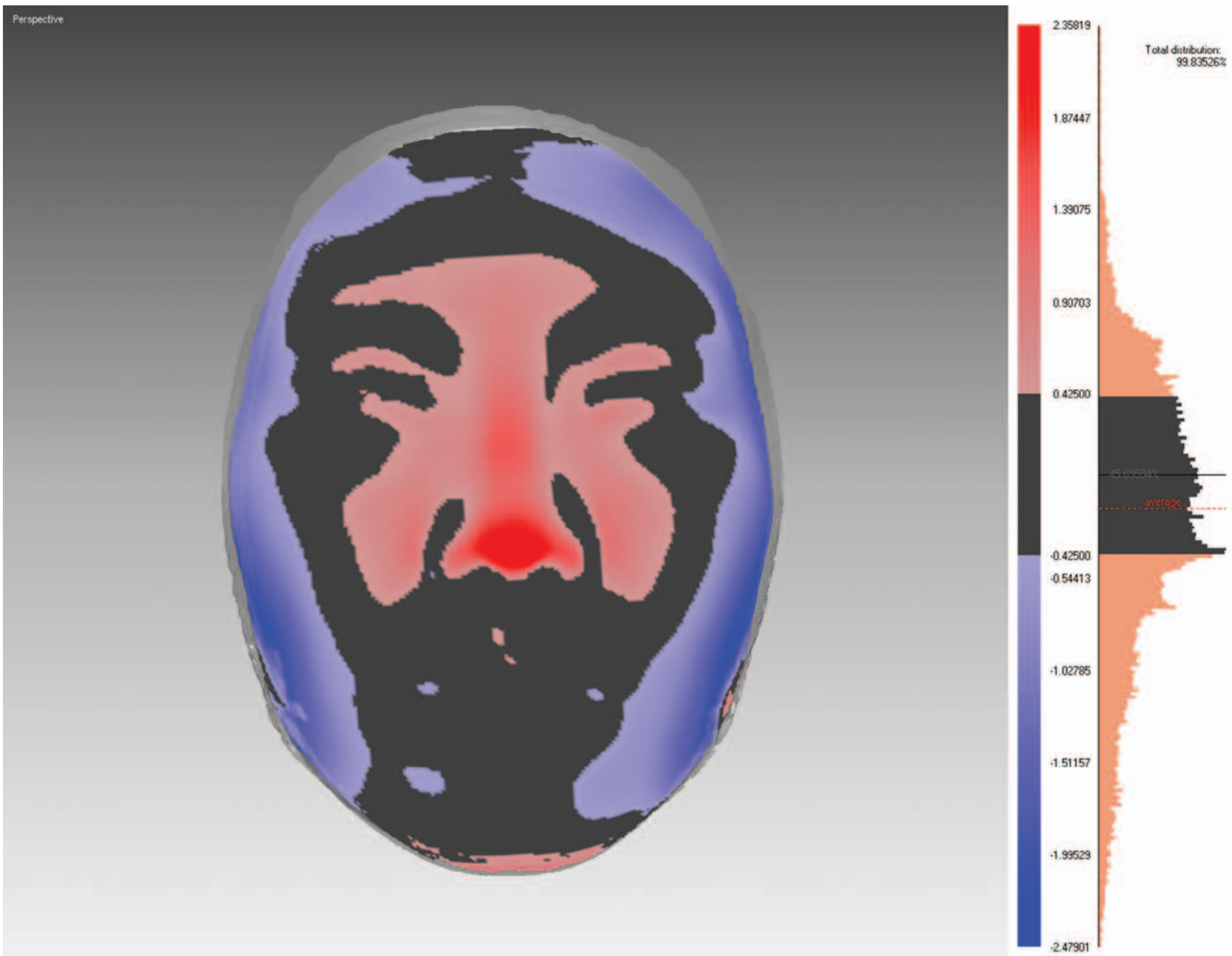

Fig. 18. Signed color map comparing KRN-F shell to CHI-F shell.

Tex.[21-23] It is speculated that the difference found in these 2 studies regarding the lip protrusion could be attributed to the fact that the white group from Houston may have different ethnic background than those from Ann Arbor. Taylor and Hitchcock[20] showed in the Alabama analysis that the Southern whites have more protrusive upper and lower incisors than the whites from other parts of the country, demonstrating that there were statistical differences in the profile even within the same race because of the different ethnic backgrounds. Therefore, it is plausible that because of the different ethnic backgrounds of the Houstonian whites, they showed more prominent lips than those of the Koreans as exhibited in our study. The other possible explanation for the different results in the lip protrusion in our study could be due to the way superimpositions were performed. In this study, the 2 average facial shells were superimposed using the best-fit algorithm of RF6 PP2 software using the 5 previously mentioned anatomical landmarks. On the other hand, the lateral cephalogram comparisons by Hwang et al[19] superimposed the 2 profiles using the anterior cranial base structures. The methods of facial superimposition in 3D versus 2D imaging systems were inevitably variable.

Our study demonstrated the degree of similarities and differences between the Korean and Chinese faces. The average Korean and Chinese male faces had 58.16% similarity, which was the second highest value among other subgroup comparisons. The average Korean and Chinese female faces, however, showed 45.64% similarity, having less similarity than the male groups. Even though the 2 ethnic groups had fairly similar facial morphology, there were distinct differences found between the 2 populations. The average Korean male face showed more prominent lips, nasal tip, and the supraglabella than the Chinese counterpart. However, the average Chinese male face was wider with more prominent masseteric area than the Korean counterpart. The average Korean female face showed more prominent periorbital, nasal tip, and malar region than the Chinese counterpart, whereas the average Chinese female face was with more prominent masseteric area, similar to the male group comparisons.

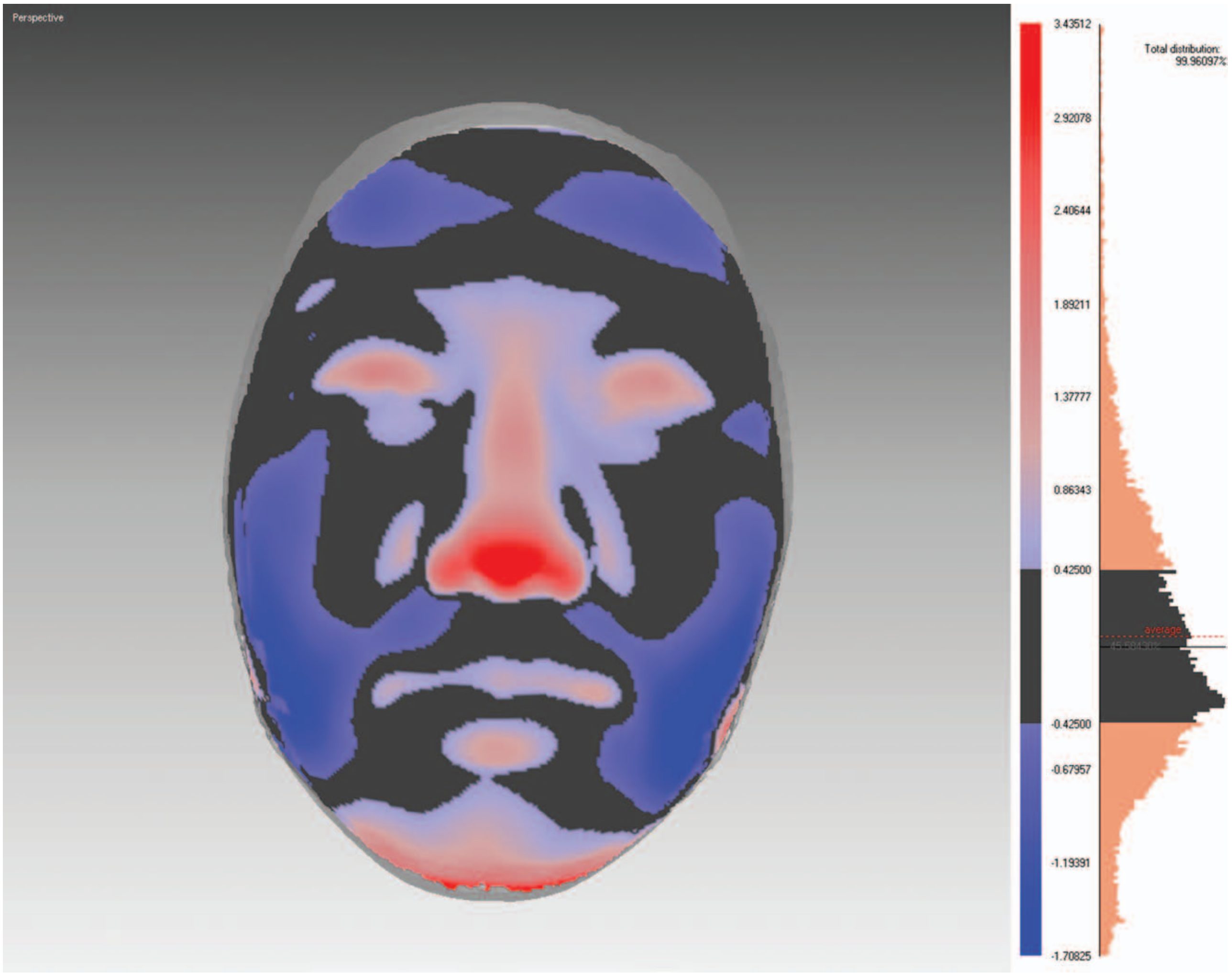

Fig. 19. Signed color map comparing KRN-F +SD shell to CHI-F shell.

The most interesting finding from this study was that the highest population similarity was shown between the CHI-M and KRN-M +SD. The % similarity between these 2 subgroups was 58.66%. On the other hand, the female subjects from these 2 populations did not exhibit the same degree of similarity.

The findings of this study are important because it allows for face visualization in 3 dimensions. Every doctor before performing plastic, reconstructive, or orthognathic surgery should evaluate the patient's face from many different perspectives. This study also shows the significant differences between Asians and whites. The morphological differences and the growth changes between each population and their subgroups can and should be taken into consideration before treatment planning is decided as each plan will determine the final facial result of a patient.

Limitations of the Study

Although every effort was made to match the sample sizes between the 3 population groups, there was the sample size variation among the ethnic groups and between the genders. Another important aspect to remember in the interpretation of the data is that the Korean samples are the representation of the people in Seoul, Korea, just as the distinction has been made for the Chinese subjects from Xi' An, which is geographically located in the middle of China and the white subjects from Houston, Tex.

CONCLUSIONS

Three-dimensional imaging systems have opened new ways for clinicians to diagnose and plan treatment for their patients. Three-dimensional technologies, such as 3dMDface, can help clinicians better understand the soft-tissue facial morphology of various patient populations.

This study showed that perioral regions are similar for both Chinese and Korean populations. Therefore, the orthodontic treatment approach to address these areas can be very similar in both populations. However, distinct features exist in the width of the face, nose, and glabella regions. The orthodontic treatment cannot address these

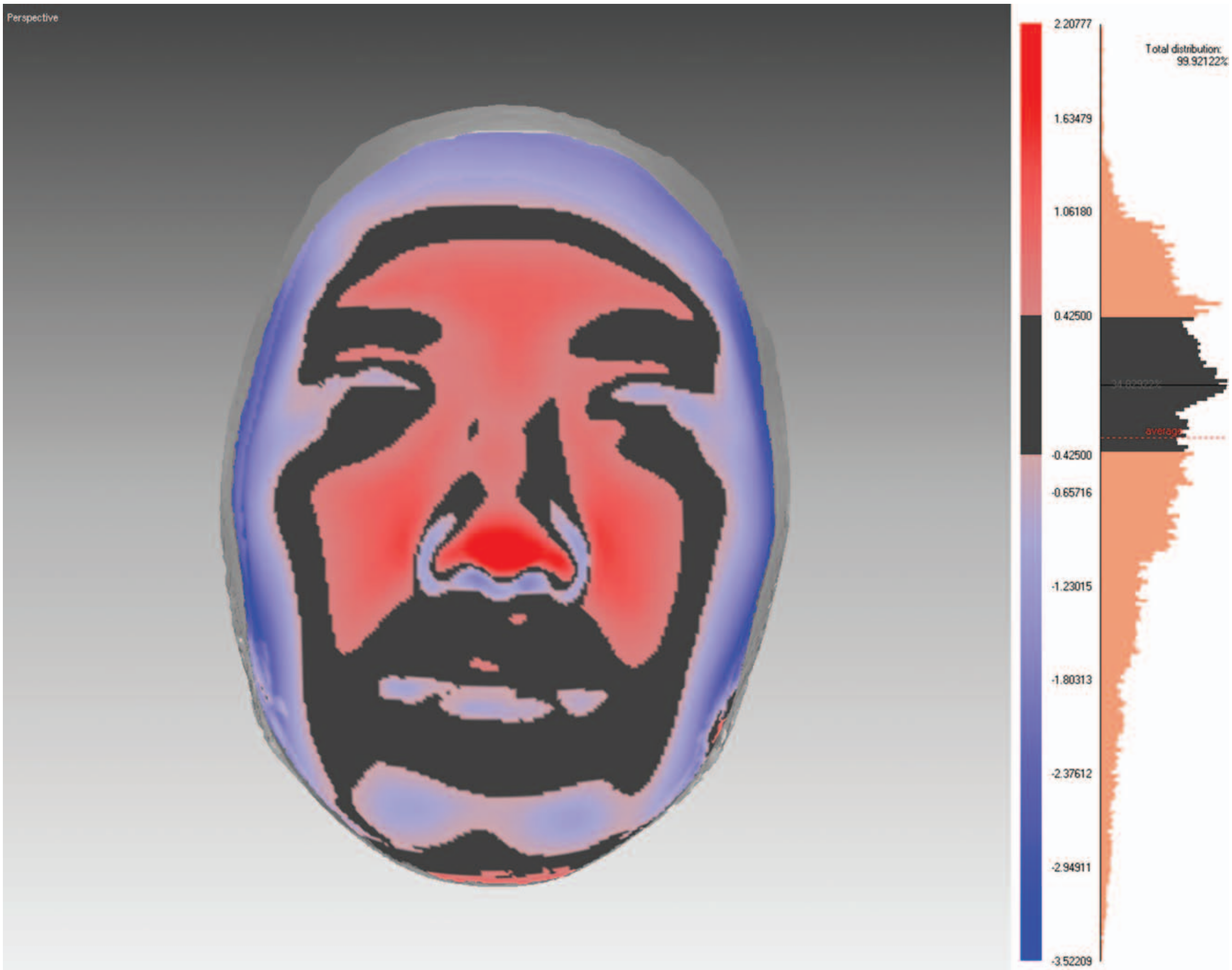

Fig. 20. Signed color map comparing KRN-F –SD shell to CHI-F shell.

areas in the face; therefore, any changes required in these facial areas are best to be left in the hands of plastic or oral and maxillofacial surgeons.

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REFERENCES

1. Humes KR, Jones NA, Ramirez RR. Overview of race and Hispanic origin: 2010. In: U. S. D. o. Commerce, E. a. S. Administration, U. S. C. Bureau, eds. *U.S. Census Bureau*. 2011.
2. Hoeffel EM, Rastogi S, Kim MO, *et al*. The Asian population: 2010. In: U. S. D. o. Commerce, E. a. S. Administration, U. S. C. Bureau, eds. *U.S. Census Bureau*. 2012.
3. Christou T, Kau CH, Waite PD, et al. Modified method of analysis for surgical correction of facial asymmetry. *Ann Maxillofac Surg*. 2013;3:185–191.
4. Kau CH, Richmond S, Incrapera A, et al. Three-dimensional surface acquisition systems for the study of facial morphology and their application to maxillofacial surgery. *Int J Med Robot*. 2007;3:97–110.
5. Lane C, Harrell W Jr. Completing the 3-dimensional picture. *Am J Orthod Dentofacial Orthop*. 2008;133:612–620.
6. Talbert L, Kau CH, Christou T, et al. A 3D analysis of Caucasian and African American facial morphologies in a US population. *J Orthod*. 2014;41:19–29.
7. Aldridge K, Boyadjiev SA, Capone GT, et al. Precision and error of three-dimensional phenotypic measures acquired from 3dMD photogrammetric images. *Am J Med Genet A*. 2005;138A:247–253.
8. Lübbers HT, Medinger L, Kruse A, et al. Precision and accuracy of the 3dMD photogrammetric system in craniomaxillofacial application. *J Craniofac Surg*. 2010;21:763–767.
9. Metzger TE, Kula KS, Eckert GJ, et al. Orthodontic soft-tissue parameters: a comparison of cone-beam computed tomography and the 3dMD imaging system. *Am J Orthod Dentofacial Orthop*. 2013;144:672–681.
10. Wong JY, Oh AK, Ohta E, et al. Validity and reliability of craniofacial anthropometric measurement of 3D digital photogrammetric images. *Cleft Palate Craniofac J*. 2008;45:232–239.
11. Cooke MS, Wei SH. The reproducibility of natural head posture: a methodological study. *Am J Orthod Dentofacial Orthop*. 1988;93:280–288.

12. Kau CH, Richmond S. Three-dimensional analysis of facial morphology surface changes in untreated children from 12 to 14 years of age. *Am J Orthod Dentofacial Orthop*. 2008;134:751–760.
13. Gor T, Kau CH, English JD, et al. Three-dimensional comparison of facial morphology in white populations in Budapest, Hungary, and Houston, Texas. *Am J Orthod Dentofacial Orthop*. 2010;137:424–432.
14. Kau CH, Zhurov A, Richmond S, et al. The 3-dimensional construction of the average 11-year-old child face: a clinical evaluation and application. *J Oral Maxillofac Surg*. 2006;64:1086–1092.
15. Kau CH, Richmond S, Zhurov AI, et al. Reliability of measuring facial morphology with a 3-dimensional laser scanning system. *Am J Orthod Dentofacial Orthop*. 2005;128:424–430.
16. Wirthlin J, Kau CH, English JD, et al. Comparison of facial morphologies between adult Chinese and Houstonian Caucasian populations using three-dimensional imaging. *Int J Oral Maxillofac Surg*. 2013;42:1100–1107.
17. Wong JY, Oh AK, Ohta E, et al. Validity and reliability of craniofacial anthropometric measurement of 3D digital photogrammetric images. *Cleft Palate Craniofac J*. 2008;45:232–239.
18. Hwang HS, Park MK, Lee WJ, et al. Facial soft tissue thickness database for craniofacial reconstruction in Korean adults. *J Forensic Sci*. 2012;57:1442–1447.
19. Hwang HS, Kim WS, McNamara JA Jr. Ethnic differences in the soft tissue profile of Korean and European-American adults with normal occlusions and well-balanced faces. *Angle Orthod*. 2002;72:72–80.
20. Taylor WH, Hitchcock HP. The Alabama analysis. *Am J Orthod*. 1966;52:245–265.
21. William E. Harrell, J. Three-dimensional diagnosis & treatment planning: the use of 3D facial imaging and 3D cone beam CT in orthodontics and dentistry. *Aust Dent Pract*. 2007;18:102–113.
22. Seager DC, Kau CH, English JD, et al. Facial morphologies of an adult Egyptian population and an adult Houstonian white population compared using 3D imaging. *Angle Orthod*. 2009;79:991–999.
23. Kau CH, Richmond S, Zhurov AI, et al. Reliability of measuring facial morphology with a 3-dimensional laser scanning system. *Am J Orthod Dentofacial Orthop*. 2005;128:424–430.