Assessment of the Cleft Lip Nasal Deformity Using Regression Equation and Neural Network

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December 2006

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의학공학교실의 많은 업무를 맡고 계시는 정숙이 누님, 여러 모로 감사했습니다. 그리고 저에게 항상 밝게 대해주시던 진이 누님께도 감사의 마음을 전합니다. 대학 시절부터 지금까지 함께 고생하고 즐거워했던 정훈이형, 정말 고마워. 미국에서 공부하느라 고생하고 있는 동생 소현아, 나중에 오빠가 맛있는 거 많이 사줄게 좀더 고생해라. 그리고 여러 곳에서 활약하고 있는 우리 패밀리 멤버들, 우리의 우정 영원하길 바란다.

마지막으로 제가 지금 이 자리에 오기까지 아낌없는 지원을 해주신 아버지, 어머니 정말 감사 드립니다. 자랑스런 아들이 되도록 더욱 노력하겠습니다. 아들이 준비한 조그마한 선물을 바칩니다.

2006년 12월

박중훈 드림

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Abstract

A cleft lip and palate is the second most frequently occurring congenital deformity after clubfoot deformity. It occurs in about 1 in 700 to 1000 births. Recent developments in surgical techniques have improved quality of life for individuals with severe cleft related facial deformity and made easier for them to get closer to the society. Over the past twenty years, there has been increasing interest in assessment of the outcome of cleft surgery and various methods have been developed for the assessment. Nevertheless, standard objective assessment method does not exist yet. Hence, this study utilized 12 parameters from the nasolabial area which are important components measure of success of surgical repair in cleft lip nose deformity.

The main objective of this study is to develop objective and quantitative assessment tool for the evaluation of surgical outcome by analyzing the parameters obtained from 85 on-screen digital photographic images. Five laypersons and five plastic surgeons participated in this study. Each layperson analyzed 85 on-screen digital photographs three times by using the developed assessment software. Each plastic surgeon evaluated photographs three times using 100 point scales with 10 point intervals. Three sets of assessment were performed in the interval of one week. To find out the consistency of assessments performed by five laypersons, ANOVA test was performed and no significant differences were found for 12 parameters measured ($p > 0.05$). Regression equation and neural network were applied to objectively and quantitatively evaluate the surgical outcome of cleft lip nasal deformity. As a result, the both regression equation and developed neural network provided the correlation coefficient value of 0.86. The plastic surgeon group showed high reproducibility when evaluating pictures of normal subjects but low reproducibility when evaluating pictures of repaired cleft lip nose deformity subject. The laypersons group showed better reproducibility than the surgeons when evaluating patients group.

Consequently, the developed assessment tool allows plastic surgeons to perform objective assessment and even non-specialists to perform the evaluation on clef lip nasal deformity subjects with consistency and accuracy.

Keywords: Cleft lip and palate, nasal deformity, regression equation, neural network, correlation, reproducibility

1. INTRODUCTION

A cleft means ‘split’ or ‘separation’ in a body structure. During early stage of pregnancy, separate areas of the face develop individually and join together. If some areas do not join properly, the cleft occurs. Clefts that occur in the craniofacial region usually involve the lip, the hard palate (roof of the mouth) or the soft palate (soft tissue in the back of the mouth). The types of craniofacial clefts mainly include cleft lip and palate, isolated cleft lip, and isolated cleft palate. A cleft lip is an opening in the upper lip and a cleft palate is an opening in the hard or soft palate [1]. Among these three types, cleft lip and palate is the most common which accounts up to 50 % of all clefts and occur together in the most cases. It causes nasal deformity which is a serious condition that could determine the life outcome of individual since its direct relationship with facial appearance and attractiveness. It leads individuals to possible impairment of speech, hearing, facial appearances, dental problems, and craniofacial growth [2]. With these handicaps, individuals with cleft lip nasal deformity are at risk for developing problems with social competence and personal adjustment [3-5]. In addition, they are at risk for social rejection as well as unrealistic perceptions about their facial appearance and behavior [6-8].

Recent developments in surgical techniques have improved quality of life for individuals with severe cleft lip nasal deformity and made easier for them to get closer to the society. Over the past twenty years, there has been increasing interest in assessment of the outcome of cleft surgery and various methods have been developed. These methods include visual inspection by plastic surgeon, assessment using two-dimensional photographs, three-dimensional imaging, or combination of these methods. The advantages of the evaluation using such imaging techniques are their accuracy and objectiveness. However, assessment using two dimensional photographs requires standardized photographic technique and three dimensional imaging requires specialized training and expertise to operate. From these reasons, visual inspection continues to be the primary method despite the availability of new imaging techniques. In most cases, visual inspection by plastic surgeons are evaluated into scale of four (mild, moderate, severe, and very severe) or five (bad, poor, moderate, good, and excellent) [9]. This method is often subjective and lacking objectivity in evaluating the repaired cleft lip nasal deformity.

Development of an objective assessment tool in evaluation of the condition of cleft lip nasal deformity may help in advancement and evaluation of surgical techniques. Nevertheless, standard objective assessment method does not exist yet [10]. Hence, this study utilized nasal asymmetry and labial shape which is an important component measure of success of repaired cleft lip nasal deformity. The main objective of this study is to develop objective and quantitative assessment tool by analyzing the parameters obtained from 85 on-screen digital photographic images. Various parameters were investigated to objectively evaluate the cleft lip nasal deformity. Subsequently, regression equation and neural network estimating surgeon’s grades were formulated and correlation coefficient between estimated and actual surgeon’s grade was found. The reproducibility of the evaluation grades obtained from both laypersons and plastic surgeons were also obtained to confirm their accuracy.

2. CLEFT LIP NASAL DEFORMITY

2.1 Definition

A cleft lip and palate is the second most frequently occurring congenital deformity after clubfoot deformity. It occurs in about 1 in 700 to 1000 births [2]. The word ‘cleft’ means split or separation in a body structure. During the early stages of fetal development, the upper lip and palate develop from tissues lying on either side of the tongue. These tissues grow towards each other and fuse in the middle [1]. When the tissues that form the upper lip fail to fuse in the middle of the face, a cleft lip occurs. A single cleft that does not extend into the nostril is called unilateral incomplete. A single cleft that extends into the nostril is called unilateral complete. A cleft that involves both sides of the lip and extends into two nostrils is called bilateral complete cleft lip. Different types of cleft lips are shown in Figure 1.

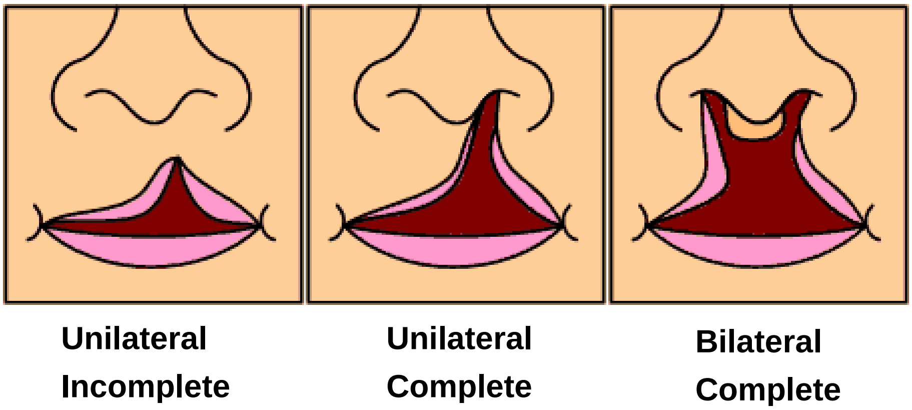

Figure 1. Types of cleft lips [Wikipedia]

Cleft palate is an abnormality in which the hard palate or soft palate does not completely form during fetal development. Refer to Figure 2 for the human palate anatomy. In most cases, cleft lip and palate occur together and accounts up to 50 % of all clefts followed by isolated cleft palate (30%) and isolated cleft lip (20%) [2]. Similar to cleft lip, cleft palate occurs in condition with complete, incomplete and unilateral, bilateral as shown in Figure 3.

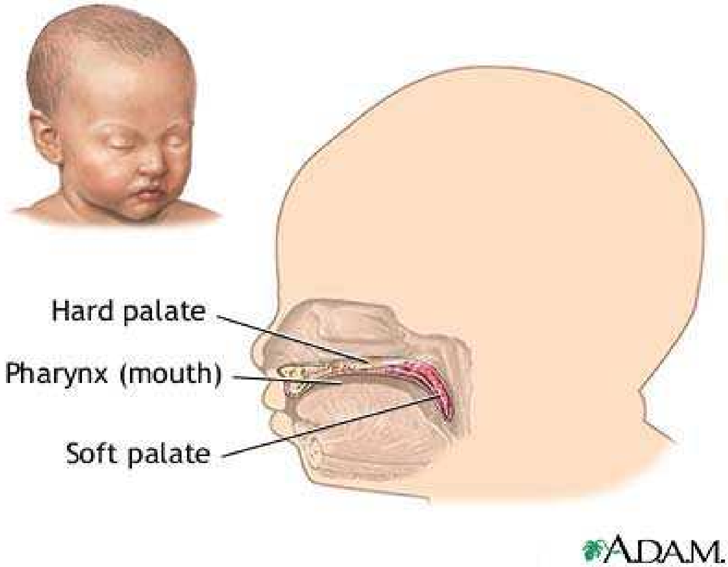

Figure 2. Palate anatomy of human [MedlinePlus Medical Encyclopedia]

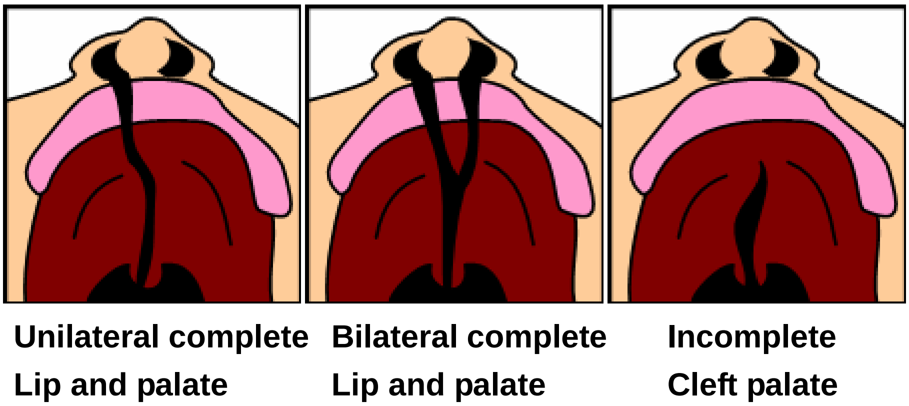

Figure 3. Types of cleft palates [Wikipedia]

2.2 Causes

Cleft lip and palate occurs in about 1 in 700 to 1000 births. It occurs more frequently in Asians, and certain groups of American Indians than Africans and African Americans. Cleft lip occurs more frequently in boys than girls while cleft plate occurs more frequently in girls than boys. The exact cause of clefts is unknown but mainly from genetic, environmental factors or genetic syndromes.

Some families have a history of cleft. It may caused by multiple genes inherited from both parents or inherited from generation to generation. However, only 1 out of every 5 clefts are inherited. There are many children born with cleft who have no family history of cleft. Environmental factors which cause a mother giving birth to a child with cleft lip and palate include exposure to infections such as German measles, certain medications, alcohol and illegal drug usage, cigarette smoking, and certain vitamin deficiencies, especially during early stages of fetal development. Cleft lip and palate can also occur by genetic syndromes such as Sticker’s syndrome and Loeys-Dietz syndrome

2.3 Complications

Table 1 summarizes the various complications of cleft lip and palate. Such complications may lead individuals to possible impairment of speech, hearing, facial appearances, dental problems, and craniofacial growth [2].

Table 1. Complications of cleft lip and palate

Complications
Feeding Problem
Speech development
Dental problems
Ear infections
Hearing problem
Nasal deformities
Emotional and social competence

Among these complications, nasal deformity is serious condition which could determine the individual's life outcome since its direct relationship with facial appearance and attractiveness. With cleft lip nasal deformity, individuals are at risk for developing problems with social competence and personal adjustment [3-5]. In addition, they are also at risk for social rejection as well as unrealistic perceptions about their facial appearance and behavior [6-8]. To avoid such problems, proper management of complications and objective assessment of cleft lip nose deformity after surgery are necessary.

2.4 Treatment

The surgery of the cleft lip is carried out at about ten to twelve weeks of age. Different opinions exist whether it is better to do an early repair [12-15] or later than twelve weeks of age [16-17]. The surgery involves making incisions and merges the pieces of lip together to form a full lip. The surgery of the cleft palate is carried out at about nine to eighteen months of age. There exist a number of different techniques from which the surgeon can choose depending on the nature of the clefts. Additional surgeries are usually carried out to achieve the best results. Since clefts can develop variety of complications, child may need to see different specialists such as otolaryngologist, dentist, and speech pathologist.

3. ASSESSMENT METHODS

Recent developments in surgical techniques have improved quality of life for individuals with severe cleft lip nose deformity and made easier for them to get closer to the society. Over the past twenty years, there has been increasing interest in assessment of the outcome of cleft surgery and various methods have been developed. These methods include visual inspection by plastic surgeon, assessment using two-dimensional photographs, three-dimensional imaging, or combination of these methods.

3.1 Visual inspection by plastic surgeons

In most cases, the visual inspections by plastic surgeons are evaluated into scale of four (mild, moderate, severe, and very severe) or five (bad, poor, moderate, good, and excellent) [9]. Plastic surgeons use photograph images of patients or real person as an evaluating media. This method is often subjective and lacking objectivity in evaluating the surgery outcome of cleft related facial deformity because each plastic surgeons have different opinions on surgery outcome. Evaluation can also be affected by time and space. However, visual inspection continues to be the primary evaluation method because of its simplicity with no equipment cost [18].

3.2 Two dimensional imaging technique

Assessment using two dimensional media uses black and white photographs, color photographs, projected color transparencies, or on-screen digital photographs [19-25]. These methods are trying to achieve objective assessment of cleft related facial deformity by measuring parameters from photographs such as nasolabial angle, nasal tip angle, width of nose, philtrum, columella, and etc. When assessing with two dimensional media, views of the photographs are critical factor. These include frontal and lateral facial views, views below eye, views of only nasolabial area, or inferior views of the nose [20, 23, 26]. Two dimensional imaging techniques are widely used along with clinical examination because of its simplicity and low cost. However, the major disadvantage of two dimensional imaging techniques is the loss of image information errors caused by projection of a three dimensional object onto a two dimensional image [18]. Qualitative and quantitative approaches have been used in assessments made from two dimensional images. Most of approaches have taken qualitative approaches without taking performing any measurements. This means most of two dimensional studies were subjective assessments.

3.3 Three dimensional imaging technique

Assessment using three dimensional imaging techniques uses laser scanning, computer-assisted tomography, range cameras, optoelectronic instruments, three-dimensional morphoanalysis, three-dimensional digitizer, and stereophotogrametry [27-34]. These methods are proven to be more reliable and accurate than clinical examination and two dimensional imaging techniques. However, three dimensional imaging systems are expensive and require specialized training and expertise to operate. In addition, patient cooperation is required while recording of the three dimensional image which normally takes long time. Figure 4 shows an example of three-dimensional laser measurements. This three-dimensional imaging system requires eyelid closure to protect the eyes from the laser. For the precaution, upper and lower eyelids of children need to be fixed using tape causing discomfort to the subjects. Figure 5 shows obtained facial images from the three-dimensional laser scanner. Obtained images need to be handled from the software for the data analysis which requires specialized training and expertise to operate.

Figure 4. Laser measurements on child’s face

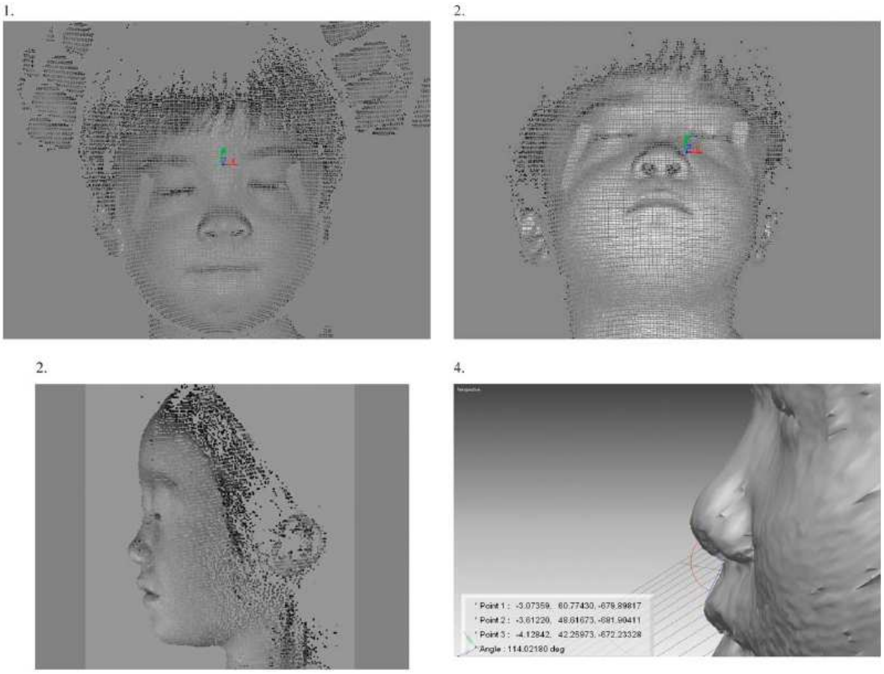

Figure 5. Example of a three dimensional imaging analysis

4. RESEARCH DESIGN AND METHODS

4.1 Subjects and Assessors

In this study, two-dimensional imaging technique was used for the assessment of the on-screen digital photographs of 20 normal subjects and 65 subjects with repaired cleft lip nasal deformity. 65 cleft lip nasal deformity subjects were randomly selected who underwent correction surgery at the Department of Plastic & Reconstructive Surgery, Severance Hospital in Seoul, Korea. Two different views of photographs were taken from each subject. Worms-eye and front view images were taken for the assessment of nasal and lip parameters, respectively.

Five laypersons and five plastic surgeons were participated in this study. Laypersons were comprised of graduate school students and each of them analyzed 85 on-screen digital photographs three times at one week interval by using the developed assessment tool. Each measurement set consisted of the same 85 images but they were shuffled in order to minimize the bias when evaluating the images. Five plastic surgeons were comprised of professionals who were familiar with cleft lip nasal deformity. Each surgeon evaluated photographs three times using 100 point scales having 10 point intervals. Three sets of assessment were performed in the interval of one week.

4.2 Assessment parameters

Nasal symmetry has always been a fundamental factor when evaluating the surgical outcome of cleft lip nasal deformity patients [35]. It can be determined by visual inspection of the symmetry of both nostrils. In addition to the nasal symmetry, labial shape can be utilized as a factor for the evaluation. In this study, the asymmetry of nose was analyzed and compared using area of nostril, central point of nostril, angle between the long axis of nostril and the horizontal line under nose, and distance between the central points of the nostrils as shown in Figure 6. In addition, the labial shape was analyzed and compared using the distance of normal and abnormal Cupid’s bows to the horizontal line of labial fissure and angle between connected line of Cupid’s bow and horizontal line of labial fissure.

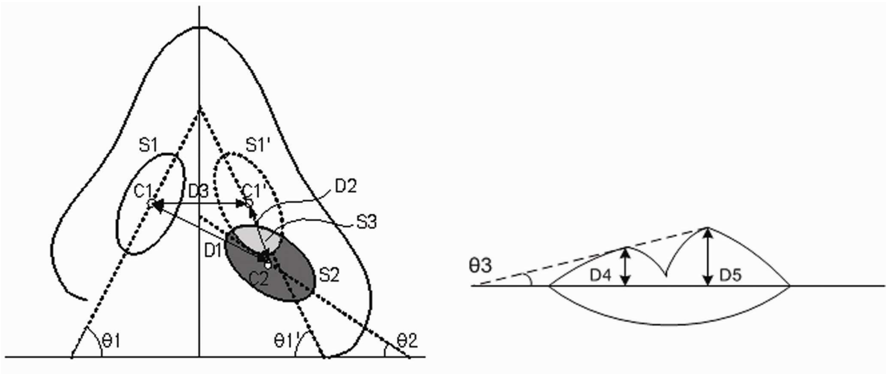

Figure 6. Measurement items for the evaluation of cleft lip nasal deformity

Items in Figure 6 are defined as following.

S1: Area of normal nostril
S1': Mirrored image of S1 symmetrical to columella nasi
S2: Area of abnormal nostril
S3: Overlapped area of S1' and S2
C1: Central point of normal nostril
C1': Central point of S1'
C2: Central point of abnormal nostril
θ1: Angle between the long axis of the normal nostril and the horizontal line
θ2: Angle between the long axis of the abnormal nostril and the horizontal line
θ1': Angle between the long axis S1' and the horizontal line
D1: Distance between C1 and C2
D2: Distance between C1' and C2
D3: Distance between C1 and C1'
D4: Distance between normal Cupid’s bow and horizontal line of labial fissure

D5: Distance between abnormal Cupid's bow and horizontal line of labial

θ3: Angle between connected line of Cupid's bows and horizontal line of labial fissure

The following parameters were considered to evaluate the cleft lip nasal deformity. Symmetry of the nostril angles; θ_1 / θ_2 is a ratio between the angles of the abnormal to the normal nostrils. It was calculated by the ratio of the greater value against the smaller value between two angles. In the perfect case, θ_1 equals θ_2, hence, the value closer to 1 becomes normal. $|\theta_1 - \theta_2|$ is an angle difference between normal and abnormal side nostrils.

Symmetry of the nostril position; Depending on the different magnification of individual images, even the same distance between the nostril centers can be differently calculated. Therefore, to reduce such incidence, the ratio of distance rather than the difference of distance was adopted. D_2 is a parameter proportional to the abnormal level, while D_3 is the distance of the cases with a normal symmetry. D_1/D_3, D_2/D_3, and D_2/D_1 can be considered as parameters and as the nostrils become to be perfect, D_1/D_3 becomes 1 and D_2/D_3 and D_2/D_1 become 0.

Symmetry of nostril area; Five parameters, S_2/S_1, S_3/S_1, S_3/S_2, $S_3/(S_1+S_2)$, and $S_3/(S_1+S_2-S_3)$, were considered. The more perfect the nostrils are, the more S_1, S_2, and S_3 become equal, therefore, the closer S_3/ (S_1+S_2) becomes 0.5, and the other four parameters become 1.

Labial distortion; D4/D5 and θ3 were considered to evaluate the labial distortion. In the perfect case, D4/D5 and θ3 become close to 1 and 0, respectively.

By utilizing above mentioned parameters, On-screen digital photograph assessment tool was developed using LabVIEW 6.1 and NI-IMAQ Vision (National Instruments, USA). Laypersons manually establish the data such as boundaries of two nostrils, the symmetrical axis, the columella nasi, and the horizontal line under the nose. Analytical results pertinent to parameters were automatically obtained.

4.3 Measurement software

On-screen digital photograph assessment tool was developed using LabVIEW 6.1 and NI-IMAQ Vision (National Instruments, USA). Figure 7 shows the interface of the developed assessment tool.

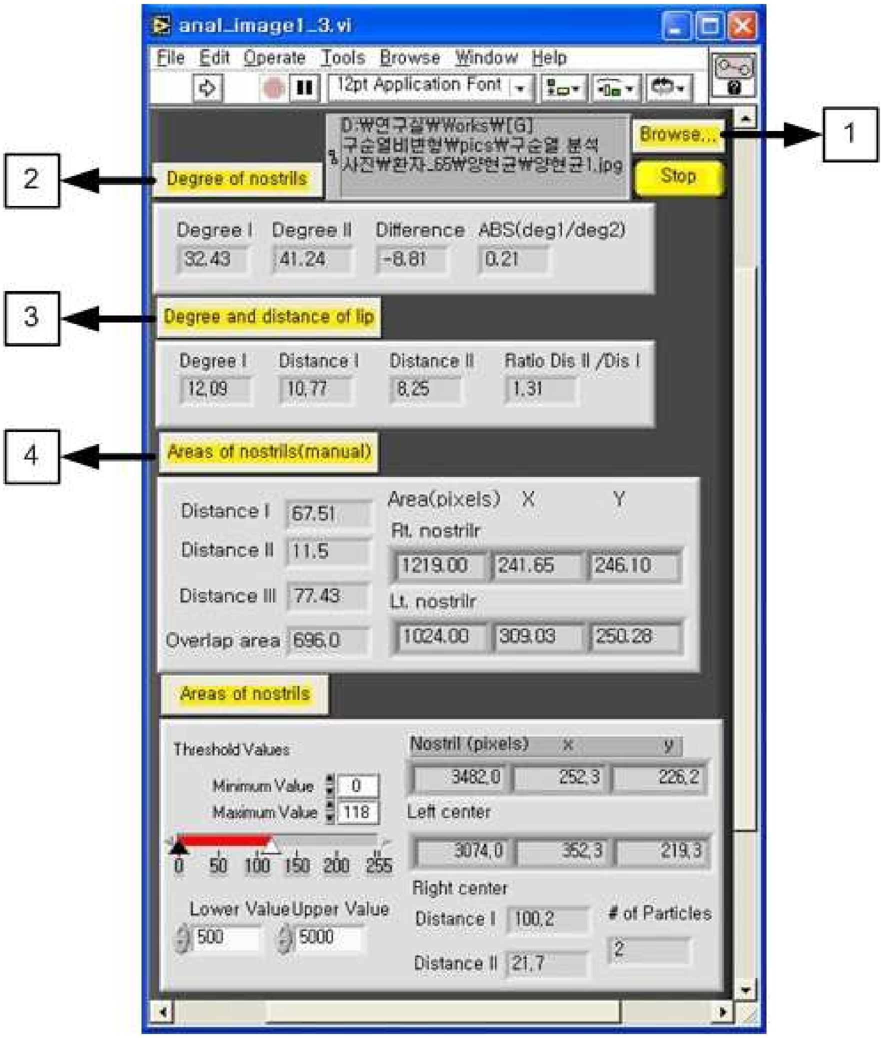

Figure 7. Interface of the developed assessment tool

Each of 5 laypersons took three measurements at one week interval. Each measurement set was consisted of same 85 images but they were shuffled in order to minimize the bias when evaluating the images. Laypersons measured the items described in section 4.2 by utilizing steps 1, 2, 3, and 4 in figure 7. Step 1 is for loading photographs. Step 2 is for obtaining the angle between central point of the nostril and the horizontal line under nose. Laypersons were directed to draw a horizontal line under nose then draw two lines on the nostrils. Figure 8 represents the process of obtaining nostril angles.

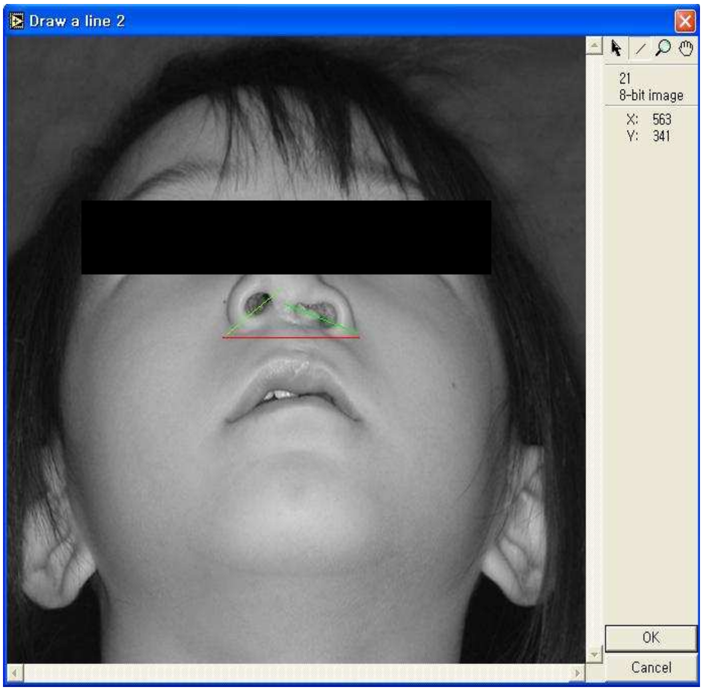

Figure 8. Picture of obtaining nostril angles

Step 3 is for obtaining distance of normal and abnormal Cupid's bows to horizontal line of labial fissure and angle between connected line of Cupid's bow and horizontal line of labial fissure. Laypersons were directed to draw a horizontal line of labial fissure, line which connects two Cupid's bows, and straight line from Cupid's bow to horizontal line. Figure 9 represents this process.

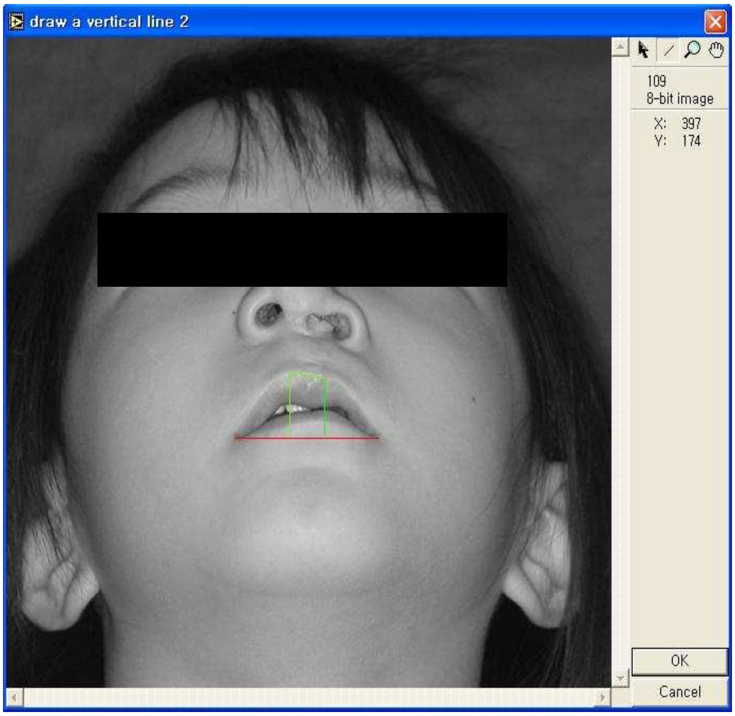

Figure 9. Picture of obtaining lip values

Step 4 is for obtaining area of normal and abnormal nostrils. Laypersons were directed to draw circles around two nostrils and then draw a vertical line on the nasal septum. The developed program automatically creates symmetrical image of the normal nose. Figure 10 represents the process of obtaining area of nostrils.

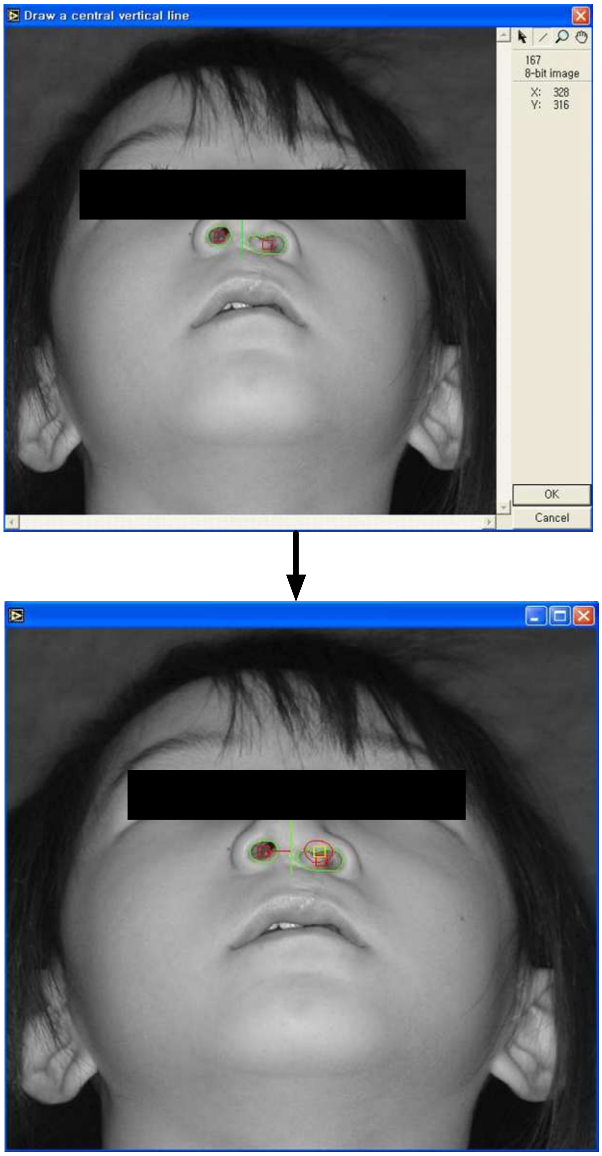

Figure 10. Picture of obtaining nostril areas

After completing steps 1 through 4, all of the measured items were calculated and these values were manually recorded in Excel spreadsheet (Microsoft, USA). 12 parameters were then calculated automatically in Excel for further statistical analysis.

4.4 Regression equation and neural network

In this study, regression equation and neural network estimating surgeon's grades were formulated. For the regression analysis, statistical software SPSS (SPSS Inc. USA) was used to obtain the equation. By definition, regression equation is a statistical method used to predict the behavior of a dependent variable. In general, a regression equation takes the form of (1)

$$Y = Ax \quad (1)$$

In the equation, Y is the dependent variable that the equation tries to predict, x is the independent variable that is being used to predict Y [36].

Artificial neural network (ANN) was also used to estimate the evaluation grades of surgeons. By definition, ANN is the theoretical model of real biological neural networks. For instance, human brain is complicated biological neural networks with many brain cells which are highly interconnected each other. These interconnections of neurons produce great computation ability which is far better than computers. ANN tries to model real neural networks. ANN can learn to recognize certain inputs and to produce a particular output for a given input [37]. Matlab 7.1 and Levenberg-Marquardt algorithm (Mathworks Inc. USA) was used for the development of neural network. The neural network architecture used in this study was the multilayer model with feed forward-networks as shown in Figure 11. The first layer is called input layer (L) which are consisted of 10 parameters out of 12 parameters. Two parameters were excluded because of their statistical insignificance. The second layer is called hidden layer where data processing occurs. The third layer is called output layer which provides the results of the ANN.

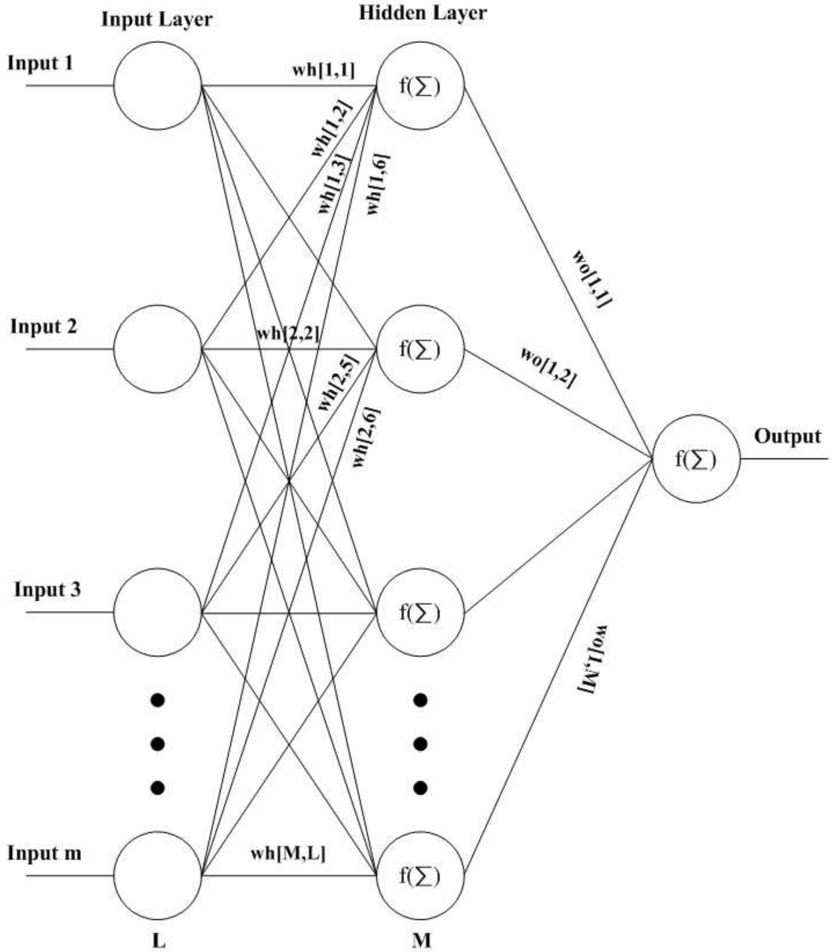

Figure 11. Structure of the multilayer neural network used in this study

The ANN must go through learning process to produce certain outputs. There exist many types of learning paradigm such as supervised and unsupervised learning. In supervised learning, the desired output (mean of five plastic surgeons grade) is known for the specific inputs (10 parameters). By introducing different inputs to the developed multilayer neural network with known outputs, evaluation grades were obtained. In this study, the input node (L) consisted of 10 parameters and the output node was consisted of the mean of five plastic surgeons grade to produce the grades from 0 to 100. The number of training (input) and test (output) data used was 1275 and 85, respectively. When obtaining evaluation grades, if number of hidden nodes are greater than or equal to the number of input nodes, neural network may overfit the results [38].

5. RESULTS AND DISCUSSION

5.1 Regression equation

Two-way ANOVA test was used to find out 1) whether there exists any difference in average of three measurements taken by five laypersons. 2) Whether there exists consistency among three measurements taken by each layperson. As a result, no significant differences were found from 12 parameters measured by five laypersons. All of the p-values were greater than 0.05. This result explains that five laypersons utilized the developed assessment tool appropriately with consistency when measuring each parameter. It was confirmed that in the analysis using the program, a subjective difference that may be introduced during the process of manually measuring the parameters was hardly present, and it was also confirmed that it was not influenced by the number of tests performed by laypersons. Table 2 summarizes the average and standard deviation of 12 parameters measured by laypersons.

Table 2. Descriptive statistics of each parameter and statistics on agreement of five laypersons

Parameter	**Average ± St. dev**	**p-value**
$\mid\theta_1 - \theta_2\mid$	10.73 ± 8.75	0.36
θ_1/θ_2	1.33 ± 0.99	0.24
D_2/D_1	0.09 ± 0.06	0.22
D_2/D_3	0.09 ± 0.06	0.26
D_1/D_3	1.01 ± 0.20	0.59
S_2/S_1	0.97 ± 0.39	0.66
S_3/S_1	0.68 ± 0.21	0.08
S_1/S_3	0.72 ± 0.20	0.13
$S_3/(S_1+S_2)$	0.35 ± 0.09	0.10
$S_3/(S_1+S_2-S_3)$	0.56 ± 0.19	0.08
θ_3	3.99 ± 5.82	0.27
D_4/D_5	0.99 ± 0.07	0.08

Among 12 parameters obtained by the computer analysis, which parameters best reflected the grades given by surgeons were determined, by obtaining the correlation coefficients (γ) between the parameter values and the surgeon's grades. In Table 1, both S2/S1 and D4/D5 shows insignificance with very low correlation coefficients, respectively (γ= -0.10; p=0.357, γ=0.12; p=0.293). Table 3 summarizes these results. The reason of insignificant correlations might be as follows: The repaired cleft lip nasal deformity subjects had D4 and D5 similar to the normal subjects. For the normal case, D4 = D5, D4/D5 becomes 1. In the case of S1=S2, S2/S1 is the ratio of the area unrelated to the symmetry and shape of nostrils, hence, even if it is close to 1, it does not assure perfect nostrils .

Table 3. Correlations and significances between average value of plastic surgeon's grade and 12 parameters

Parameter	Correlation coefficient	p-value
$\vert \theta_1 - \theta_2 \vert$	-0.55**	0.000
θ_1/θ_2	-0.28**	0.008
D_2/D_1	-0.70**	0.000
D_2/D_3	-0.71**	0.000
D_1/D_3	0.23*	0.035
S_2/S_1	-0.10	0.357
S_3/S_1	0.68**	0.000
S_3/S_2	0.63**	0.000
$S_3/(S_1+S_2)$	0.77**	0.000
$S_3/(S_1+S_2-S_3)$	0.80**	0.000
θ_3	-0.39**	0.000
D_4/D_5	0.12	0.293

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

All the remaining 10 parameters showed statistically significant correlation coefficients, ranging from -0.71 to 0.80, therefore, they were used as contributing parameters for the following regression equation. The fitness of the regression equation, the homogeneity against residual errors, the normality and the independency were all within 95 % confidence level. As a result of regression analysis, four parameters were retained in the regression equation (2).

Evaluation grade =

$$40.068 + 96.779\frac{S3}{S1+S2-S3} - 0.558\,|\,\theta 1 - \theta 2\,| - 0.915\theta 3 - 26.082\frac{S3}{S2} \quad (2)$$

From left to right in the regression equation, contribution weight of the parameter to the evaluation grade decreases. In the regression equation, $\frac{S3}{S1+S2-S3}$ is a parameter which normalizes the overlapping area of normal and abnormal nostrils. This normalization of the overlapping area contributes the evaluation grade the most among four parameters retained in the equation. This tells that the repaired cleft lip nose deformity subjects normally have noticeable nostril area difference. $|\theta 1 - \theta 2|$ is a difference in angles of central point of the two nostrils and the horizontal line under the nose. $\theta 3$ is an angle between connected line of two Cupid's bow and horizontal line of labial fissure. $\frac{S3}{S2}$ is a ratio of abnormal nostril and overlapping area. These four parameters were found to be contributing factors to the evaluation score. From left to right in the regression equation, contribution weight of the parameter to the evaluation grade decreases.

Another regression analysis was carried out to find out the contribution of labial shape to the evaluation grade. As a result, three parameters were retained in the regression equation (3).

Evaluation grade (without lip parameters) =

$$34.480 + 106.009\frac{S3}{S1 + S2 - S3} - 0.549\,|\theta 1 - \theta 2| - 30.840\frac{S3}{S2} \quad (3)$$

By applying appropriate values to the regression equation, evaluation grades of five laypersons were computed. Grades obtained from regression equations are listed in the appendix.

5.2 Correlation analysis

5.2.1 Plastic surgeons

Each of five plastic surgeons performed the visual inspection on 85 on-screen digital photographs three times using 100 point scales with 10 point intervals. Three sets of assessment were performed in the interval of one week. This eliminates bias when evaluating the same pictures of three sets. Correlation analysis was performed to find out the agreement between five evaluations performed by five plastic surgeons. Table 4 summarizes the obtained correlation coefficients values. Evaluation grades given by five plastic surgeons were strongly correlated since all of the coefficients values were greater than 0.7. Even though surgeon's grading was subjective visual inspection, each surgeon seemed to have relatively common grading standard. Mean of correlation coefficient values from all five plastic surgeons were 0.804.

Table 4. Correlation coefficients between evaluations performed by five plastic surgeons

Correlation coefficient	Surgeon I	Surgeon II	Surgeon III	Surgeon IV	Surgeon V
Surgeon I	1	-	-	-	-
Surgeon II	0.91**	1	-	-	-
Surgeon III	0.89**	0.90**	1	-	-
Surgeon IV	0.71**	0.79**	0.72**	1	-
Surgeon V	0.77**	0.79**	0.78**	0.80**	1

** Correlation is significant at the 0.01 level (2-tailed)

Note: Mean of all correlation coefficient values = 0.80

5.2.2 Laypersons

Each of five laypersons analyzed 85 on-screen digital photographs three times by using the developed assessment tool and evaluation grades were obtained from the regression equation (2). Each of five laypersons analyzed 85 on-screen digital photographs three times by using the developed assessment tool and evaluation grades were obtained from the regression equation. Correlation analysis was used to find out the agreement between five evaluation grades obtained from five laypersons. Table 5 summarizes the obtained correlation coefficients values.

Table 5. Correlation coefficient between evaluation grades obtained from five laypersons

Correlation coefficient	Lay I	Lay II	Lay III	Lay IV	Lay V
Lay I	1	-	-	-	-
Lay II	0.92**	1	-	-	-
Lay III	0.91**	0.90**	1	-	-
Lay IV	0.92**	0.89**	0.89**	1	-
Lay V	0.90**	0.90**	0.89**	0.86**	1

** Correlation is significant at the 0.01 level (2-tailed)
Note: Mean of all correlation coefficient values = 0.90

As shown in Table 5, evaluation grades by five laypersons were strongly correlated since all of the coefficients values were greater than 0.7. Mean of correlation coefficients from all five laypersons were 0.90 which was better than correlations of five plastic surgeons (0.80). In Figure 12, x-axis represents mean grades of five plastic surgeons, and y-axis represents mean grades of five laypersons using the developed assessment tool. Correlation coefficient between the two was found to be 0.86.

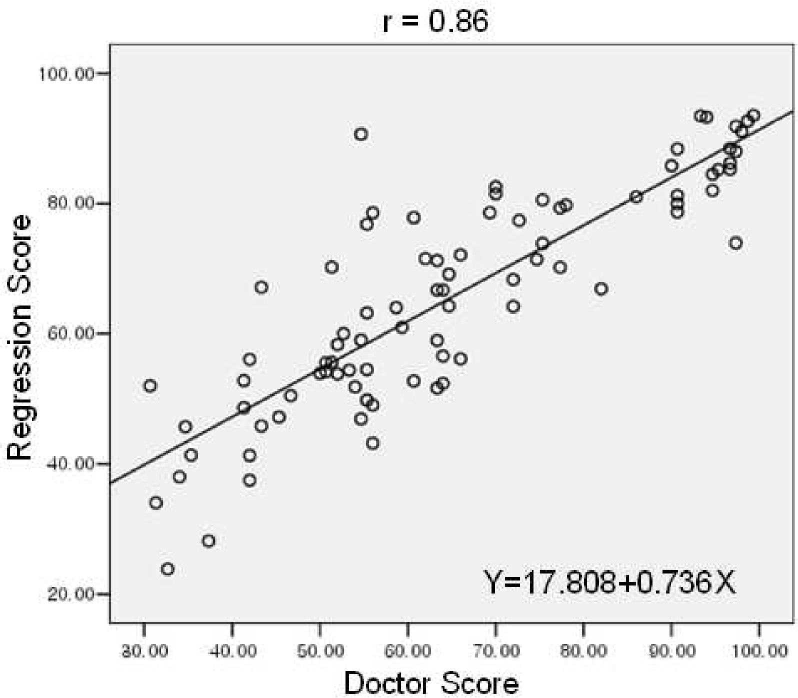

Figure 12. Graph showing correlation relationship between mean grades obtained from five plastic surgeons and five laypersons

Another graph of correlation relationship between mean grades of five plastic surgeons and five laypersons was obtained. In figure 13, x-axis represents mean grades of five plastic surgeons, y axis represents mean grades of five laypersons obtained from regression equation formulated without lip parameters. Correlation coefficient was found to be 0.84.

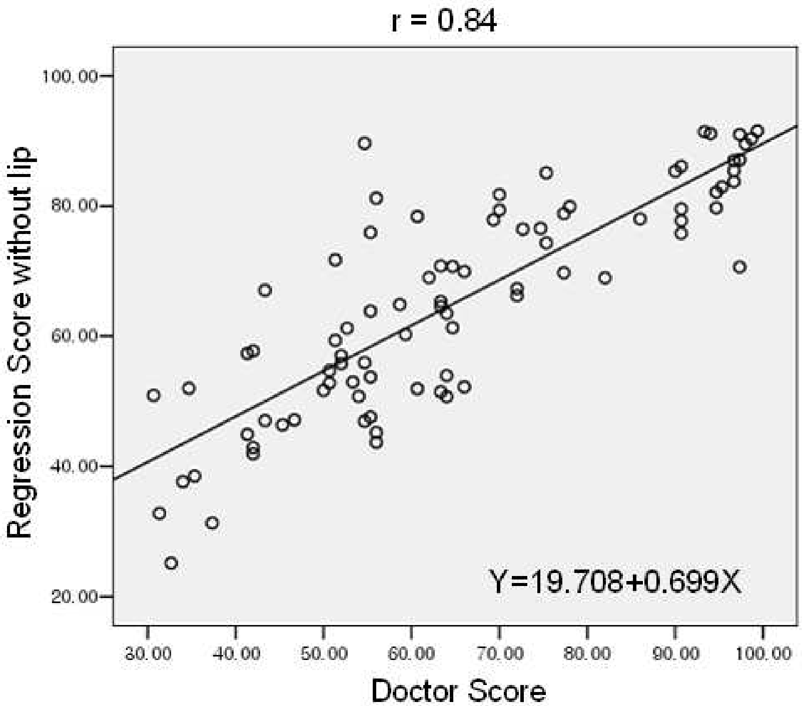

Figure 13. Graph showing correlation relationship between mean grades obtained from five plastic surgeons and five laypersons (without lip parameter)

Correlation coefficient obtained from Figure 13 was a little higher than that of Figure 12. This result tells that inclusion of lip parameters in the assessment tool provides more accurate evaluation grades regarding grades given by plastic surgeons.

5.2.3 Neural network

The developed multilayer neural network system predicting evaluation grades and its correlation coefficients to doctor's grade were obtained. Since the numbers of nodes in the hidden layer might affect output grades, training was carried out by altering the number of hidden nodes from 2 to 10. Table 6 summarizes the obtained correlation coefficients between grades of neural network and doctor.

Table 6. Correlation coefficients between grades of neural network and plastic surgeons

Number of Nodes	**Correlation coefficients to doctor's grade**
Node 2	0.83
Node 3	0.84
Node 4	0.84
Node 5	0.85
Node 6	0.85
Node 7	0.86
Node 8	0.86
Node 9	0.86
Node 10	0.87

The correlation coefficients of subjective grades by the surgeons and those estimated by the neural network were found to be 0.83, 0.84, 0.84, 0.84, 0.85, 0.86, 0.86, 0.86, and 0.87, respectively, for the increased number of hidden nodes from 2 to 10. The network with 10 nodes exhibited the best correlation coefficient of 0.87. However, in the case that the number of hidden nodes is greater than or equal to the number of input nodes, the case with overfitting may be developed [38]. Therefore, the optimum number of hidden nodes was determined to be 9 with the correlation coefficient of 0.86. Evaluation grades provided by the neural network are listed in the appendix.

Figure 14 represents the graph showing correlation relationship between mean grades obtained from five plastic surgeons and grades given by neural network. Regression equation and neural network provided the same correlation coefficient value of 0.86. This result tells that the both method formulated the best possible set of evaluation grades similar to the grades given by plastic surgeons.

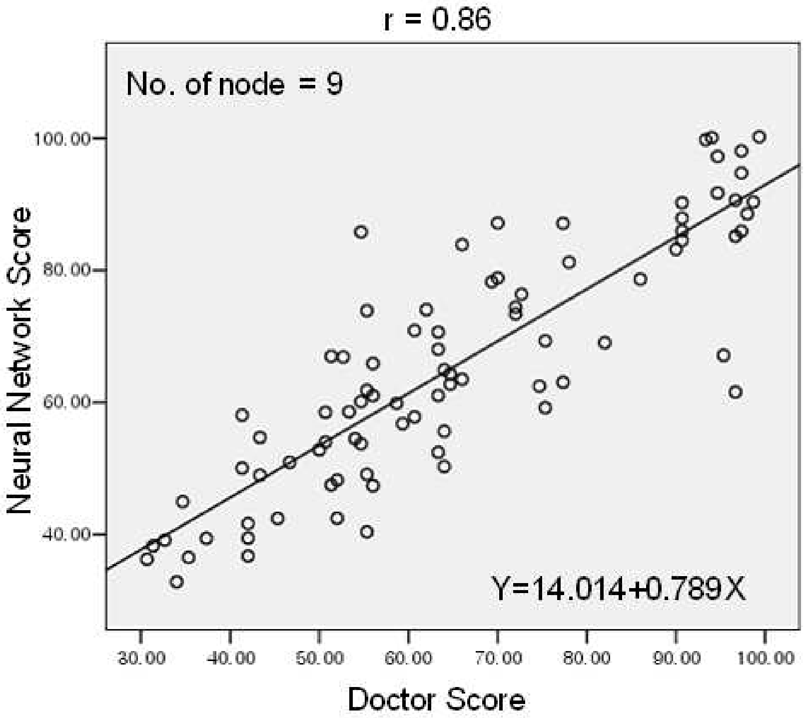

Figure 14. Graph showing correlation relationship between mean grades obtained from five plastic surgeons and neural network

5.3 Statistics on evaluation grades

Reproducibility refers to the ability of a test or experiment to be accurately produced by someone working independently. It is obtained by the following equation (4).

$$reproducibility = \frac{Std.Dev}{Mean} \times 100\% \quad (4)$$

Table 7 summarizes the reproducibility (%) obtained from five plastic surgeons. Mean grade and reproducibility of 20 normal subjects and 65 cleft lip nose deformity subjects were found to be 94.7, 3.2% and 56.4, 14.6%, respectively. Plastic surgeons gave significantly higher grades to the normal subjects than did the laypersons. This could be explained on the basis that normal subjects do not have any surgery marks on their faces. Both mean grades of 94.7 and 56.4 are reasonable. However, such a good reproducibility of 20 normal subjects compared to 65 cleft lip nose deformity subjects seems unusual. Evaluations performed by plastic surgeons were lacking consistency.

Table 7. Reproducibility of grades evaluated by five plastic surgeons

	Normal (n=20)		
	Mean	St. Dev	Reproducibility (%)
Surgeon 1	97.7	0.9	0.9
Surgeon 2	90.8	4.9	5.6
Surgeon 3	88.2	5.6	6.4
Surgeon 4	99.0	0.9	1.0
Surgeon 5	98.0	2.0	2.1
Total	94.7	2.9	3.2
	Patient (n=65)		
Surgeon 1	50.5	8.8	21.7
Surgeon 2	49.4	7.1	15.3
Surgeon 3	56.7	5.0	8.9
Surgeon 4	51.2	8.0	18.9
Surgeon 5	74.5	5.8	8.2
Total	56.4	6.9	14.6

Table 8 summarizes the mean grade and reproducibility obtained from five laypersons. Mean grade and reproducibility of 20 normal subjects and 65 cleft lip nose deformity subjects were found to be 86.2, 6.4% and 59.4, 9.6%, respectively. Evaluations performed by five laypersons were proven to be consistent with better reproducibility from both subjects compared to that of plastic surgeons.

Table 8. Reproducibility of grades evaluated by five laypersons

	Normal (n=20)		
	Mean	St. Dev	Reproducibility (%)
Layperson 1	85.8	5.6	6.6
Layperson 2	87.9	5.4	6.2
Layperson 3	88.1	2.8	3.3
Layperson 4	81.2	6.7	8.4
Layperson 5	88.3	6.5	7.4
Total	86.2	5.4	6.4
	Patient (n=65)		
Layperson 1	58.8	5.1	9.2
Layperson 2	62.1	6.1	10.7
Layperson 3	62.4	3.5	6.2
Layperson 4	54.7	6.1	12.2
Layperson 5	60.4	5.5	9.6
Total	59.7	5.3	9.6

Table 9 represents the summarized statistics on evaluation grades obtained from various methods used in this study. The mean grade of normal subjects by plastic surgeons was greatly differed from that of layperson and neural network. Both mean grades of normal subjects by layperson and neural network were very similar. From this table, conclusion can be drawn that plastic surgeons made a subjective judgment when evaluating normal subjects.

Table 9. Statistics on evaluation grades

	Normal		
	Mean	Min	Max
Surgeon	94.7	86.0	99.3
Regression	86.2	73.9	93.5
Neural	88.1	61.6	100.0
	Patient		
	Mean	Mean	Mean
Surgeon	56.4	56.4	56.4
Regression	59.7	59.7	59.7
Neural	58.7	58.7	58.7

6. CONCLUSION

The assessment of the surgical outcome of cleft lip nasal deformity has been dependent upon subjective visual inspection of the plastic surgeons rather than being objective. Past assessment methods using two-dimensional media mostly have taken qualitative approaches rather than quantitative. This study applied regression equation to objectively and quantitatively evaluate the surgical outcome of cleft lip nasal deformity. This method has never been used in past studies. The plastic surgeon group showed high reproducibility when evaluating pictures of normal subjects but low reproducibility when evaluating pictures of repaired cleft lip nose deformity subject. The laypersons group showed better reproducibility than the surgeons when evaluating patients group. Consequently, the developed assessment tool allows plastic surgeons to perform objective assessment and even non-specialists to perform the evaluation on normal or clef lip nasal deformity subjects with consistency and accuracy. In the future study, further optimal analysis parameters should be developed to get more quantitative evaluation.

APPENDIX

Mean Grades obtained from various methods

	Plastic surgeons	Regression (2)	Neural network	Regression (3) without lip
1	94.00	80.76	91.09	75.82
2	98.00	90.02	85.56	87.10
3	46.00	47.55	44.25	42.90
4	78.00	83.54	81.92	77.88
5	64.00	64.09	54.92	51.93
6	42.00	57.72	55.29	50.93
7	64.00	82.60	59.26	75.94
8	48.00	44.05	52.14	41.94
9	68.00	64.10	67.81	51.47
10	60.00	59.27	53.56	45.23
11	60.00	60.28	49.16	55.80
12	96.00	88.43	85.33	82.96
13	52.00	71.97	58.19	67.06
14	84.00	82.19	85.75	78.84
15	72.00	76.62	73.39	61.31
16	94.00	84.54	91.78	77.74
17	62.00	60.87	61.41	43.71
18	58.00	75.14	57.00	63.86
19	96.00	95.11	94.56	91.41
20	100.00	94.81	96.93	91.53
21	78.00	84.34	85.11	79.39
22	48.00	67.73	49.82	44.93
23	48.00	62.29	47.15	57.36
24	94.00	86.66	96.06	79.72
25	70.00	89.56	77.80	81.76

26	34.00	43.22	32.91	32.80
27	56.00	61.85	52.67	50.76
28	36.00	56.15	52.80	52.00
29	34.00	57.48	43.65	37.66
30	36.00	38.48	36.47	25.16
31	62.00	84.19	71.38	78.40
32	98.00	93.57	98.71	90.99
33	98.00	94.53	99.77	90.35
34	60.00	61.34	46.81	46.95
35	70.00	70.58	66.55	65.33
36	94.00	94.95	96.32	91.13
37	76.00	76.19	67.61	76.57
38	72.00	79.54	69.30	67.29
39	58.00	76.77	67.83	61.24
40	58.00	67.81	55.16	52.97
41	70.00	78.31	70.24	69.95
42	54.00	65.62	57.67	47.15
43	86.00	76.16	72.50	68.96
44	96.00	90.88	86.79	86.98
45	68.00	77.51	59.85	64.56
46	68.00	77.54	66.20	70.73
47	82.00	78.93	76.02	69.75
48	76.00	82.64	80.90	74.34
49	96.00	90.71	99.48	86.09
50	58.00	81.75	69.83	81.21
51	56.00	66.40	52.11	55.96
52	68.00	73.49	62.12	53.97
53	62.00	70.84	63.58	60.27
54	48.00	66.53	56.70	59.36
55	56.00	61.75	55.46	53.74
56	54.00	61.75	55.67	47.58

57	92.00	87.96	81.71	82.12
58	50.00	74.23	52.91	52.81
59	74.00	84.56	70.60	76.45
60	54.00	71.61	51.91	54.72
61	64.00	80.46	69.27	70.81
62	98.00	92.28	94.16	89.53
63	74.00	77.14	63.65	66.25
64	56.00	91.27	86.50	89.65
65	54.00	78.51	61.19	71.73
66	44.00	57.58	46.90	47.04
67	68.00	61.92	64.25	52.22
68	84.00	84.61	77.85	78.02
69	48.00	54.58	50.03	46.39
70	96.00	88.35	89.71	85.46
71	38.00	53.57	38.87	38.53
72	64.00	77.20	64.59	64.87
73	96.00	89.98	89.55	83.77
74	64.00	81.19	78.62	69.01
75	60.00	69.90	58.48	50.72
76	86.00	83.65	88.05	79.57
77	80.00	84.34	85.75	79.93
78	56.00	63.12	55.01	57.02
79	90.00	86.29	88.40	85.36
80	50.00	60.40	54.97	51.70
81	44.00	63.82	55.39	57.74
82	38.00	40.08	37.30	31.32
83	76.00	81.32	69.44	85.10
84	96.00	79.12	75.89	70.64
85	68.00	77.76	75.60	63.50

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국문요약

구순열 비변형의 객관적 평가를 위한 회귀분석과 신경회로망의 적용

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생체공학협동과정

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구순 구개열은 두경부에 발생하는 선천성 기형 중 가장 흔한 기형 중의 하나로 안면변형으로 인한 비변형, 언어장애, 청각장애, 자신감 결핍등과 같은 다양한 문제를 발생시켜 환자들의 사회적응에 큰 어려움을 주어왔다. 최근에는 성형외과 수술법이 발전함으로써 환자들의 상태가 많이 호전되어 이들의 사회적응에 큰 도움을 주고 있다. 많은 의료기관에서 구순열 및 비변형의 일차적 수술 및 이차적 교정을 시도한 후 수술결과를 보고하고 있으나, 그 결과는 각각의 의사의 주관적인 결과이다. 이러한 보고는 객관성이 결여되어 결과의 분석에 많은 차이가 발생할 수 있다. 구순열 비변형 환자의 상태, 수술결과 등을 객관적으로 평가할 수 있는 방법의 개발은 구순열 수술

의 술기 등의 평가 및 발전에 많은 도움을 줄 수 있을 것으로 생각되나 아직은 부족한 단계이다.

본 논문에서는 정상인과 구순열 비변형 교정수술을 받은 환자의 사진으로부터 비변형 및 입술변형 정도를 분석하여 구순열 비변형 정도를 정량적으로 평가하고자 하였다. 이를 위하여 환자의 사진 영상만을 이용하여 비공 장축의 각도, 비공 간의 거리, 그리고 면적을 통한 코 변형의 비대칭성을 분석하여 비전문의도 쉽게 구순열 코변형 정도를 판단할 수 있도록 정량화된 값으로 표현할 수 있는 방법을 제안하였다. 또한 회귀분석과 신경회로망을 이용하여 임상의 평가점수를 재현함으로써 비교를 가능케 하였다.

총 12개의 분석요인을 이용하여 임상의 평가점수에 대한 회귀분석을 통하여 회귀식을 획득하였다. 구순열 환자의 수술경험이 많은 성형외과 의사 5명이 사진을 100점 만점에 10점 간격으로 판정하였다. 5명의 성형외과 의사로부터 얻어진 평가점수의 재현성은 정상인 평가의 경우 3.12%, 환자 평가의 경우 14.63%으로 환자를 평가할 때 재현성이 떨어지는 것을 발견하였다. 개발된 프로그램을 이용한 5명의 일반인으로부터 얻어진 평가점수의 재현성은 정상인이 6.37%, 환자가 9.57%로 개발된 프로그램을 이용한 분석이 환자의 경우에 더 일관

성이 있다는 것을 확인하였다.

평가 점수간 상관관계 계수는 5명의 성형외과 의사는 0.80, 5명의 일반인은 0.90으로 개발된 프로그램을 이용한 일반인 점수간의 상관관계가 더 높게 나타났다. 회귀분석과 신경회로망으로부터 얻어진 평가점수와 임상의 평가점수간의 상관관계는 0.86으로 두 방법 모두 우수함을 확인하였다.

본 연구 결과를 토대로 구순열 비변형 환자의 사진을 통하여 비공 중점 간의 거리와 비공간의 면적비 및 각도 등으로 비변형 정도를 정량화 할 수 있었으며, 비변형의 정도를 손쉽게 평가할 수 있는 지표를 마련할 수 있을 것으로 기대된다.

핵심 되는 말: 구순구개열, 비변형, 회귀분석, 신경회로망, 상관관계, 재현성