Using Computers for Assessment of Facial Features and Recognition of Anatomical Variants that Result in Unfavorable Rhinoplasty Outcomes

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ABSTRACT

Rhinoplasty and facial plastic surgery are among the most frequently performed surgical procedures in the world. Although the underlying anatomical features of nose and face are very well known, performing a successful facial surgery requires not only surgical skills but also aesthetical talent from surgeon. Sculpting facial features surgically in correct proportions to end up with an aesthetically pleasing result is highly difficult. To further complicate the matter, some patients may have some anatomical features which affect rhinoplasty operation outcome negatively. If goes undetected, these anatomical variants jeopardize the surgery causing unexpected rhinoplasty outcomes. In this study, a model is developed with the aid of artificial intelligence tools, which analyses facial features of the patient from photograph, and generates an index of "appropriateness" of the facial features and an index of existence of anatomical variants that effect rhinoplasty negatively. The software tool developed is intended to detect the variants and warn the surgeon before the surgery. Another purpose of the tool is to generate an objective score to assess the outcome of the surgery.

Keywords: Fuzzy logic, Fuzzy modeling, Rhinoplasty, Harmony index, Facial proportions, Facial harmony, Low radix and Low dorsum.

1. INTRODUCTION

Assessment of facial features seems like an inexact and subjective process. There is a complex interaction of facial features which gives sensation of facial beauty. One may argue that the concept of beauty is both gender and race dependent. Although it is found that notion of facial beauty may differ slightly with respect to the ethnic background of observers, it is surprising to see that perception of facial attractiveness is mostly independent of race. An online study conducted by researchers in University of Kent indicated that US and UK experimenters differ slightly in judging what is considered "attractive" [1]. Even though what should be considered as "ideal good look" is disputed, what can be accepted as "normal" is very well established. Medical professionals devised several parameters to describe crucial facial angles and proportions of "normal" faces. These angles and proportions are expected to be within certain range for them to be accepted as "normal". These parameters are studied extensively for certain race and genders and decisive enough to be part of medical teaching curriculum [2].

In this study, a fuzzy logic based model is constructed for computer based evaluation of facial features of patients to generate an index value which reflects how well the facial features of the patient blend into the face. The index value will be called "facial harmony index" throughout this article. Model is also used for generating another index which is called "negative anatomical variant index". The second index is developed to sense the presence of anatomical variants which affect the outcome of rhinoplasty surgery negatively. The model generates these indices for a patient based on frontal, base and side view photos of the patient. Since the ideal parameters are different for male and female genders, different fuzzy models are generated for male and female subjects.

2. ANATOMICAL VARIANTS THAT AFFECT RHINOPLASTY RESULTS NEGATIVELY

Troublesome Anatomical Features

Rhinoplasty is considered one of the most difficult surgeries since it requires both surgical and aesthetic capabilities from the surgeon. Underlying structure of nose which is made up of several cartilage and bone pieces present a coupled model where changing a parameter may affect the function and the look of the nose. There are about 23 parameters that describe the physical outline of the nose [3]. Being a difficult surgery, sometimes the result may not be satisfactory so that patient has to go through a secondary rhinoplasty. A retrospective study conducted by Constantian [4], indicated that among the 150 patients to go through secondary rhinoplasty, 93% of the patients had low radix/ low dorsum problem [5,6], 87% of the patients had narrow middle vault problem [6,7,8] and 80% of the patients had inadequate tip projection problem [6,9]. When considered as a group, 40% of the patients had all three of the problems together. The study concludes that, these anatomical variants mentioned above, if present, can generate unfavourable rhinoplasty outcomes. Therefore, it is important for the surgeon to recognize those anatomical variants in advance and take proper course of action by fixing those

problems first. In some cases, fixing those problems may answer aesthetic concerns of patient.

The Fig. 1 below indicates location of some of the important parameters that will be used for defining those anatomical deficiencies.

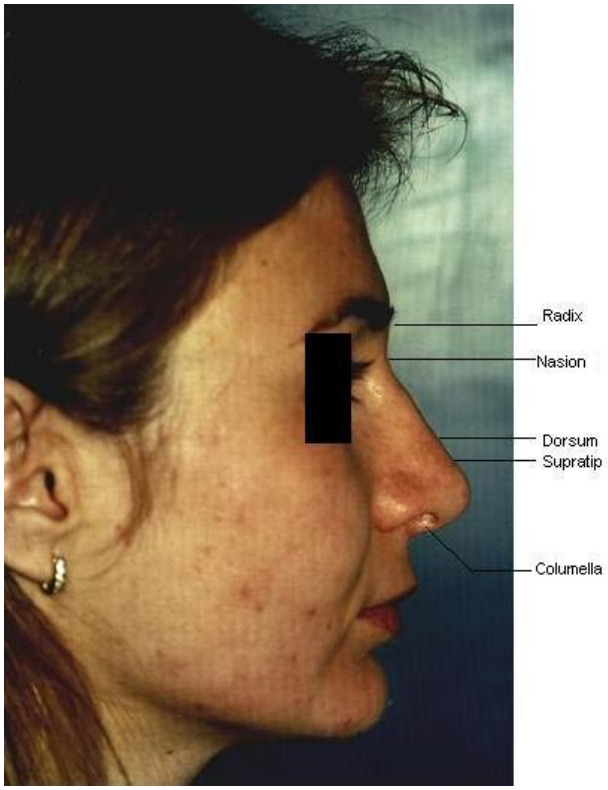

Fig. 1. Points of interest for defining anatomical variants.

Troublesome Anatomical Deficiencies

Low radix/low dorsum: Constantian [4] describes problem of low radix as "radix being caudal to the level of upper lash margin with the patient's eye at primary gaze". In male, dorsum is preferred to be at higher position than females. Fig. 2 shows a male patient with low radix problem.

Narrow middle vault: Narrow middle vault problem is defined as upper cartilaginous vault being excessively reduced in width (at least 25%) as it goes down 1/3 length of the nose. Fig. 3 shows characteristic look of a patient with narrow middle vault problem.

Inadequate tip projection: Inadequate tip projection problem is defined as a tip which does not project to the level of the anterior septal angle. Fig. 4 show as patient with inadequate tip projection problem.

3. ILLUSIONS ASSOCATED WITH ANATOMICAL VARIANTS

The problems stated in Section 2 above are problems of aesthetic concerns to patients. Unlike ordinary rhinoplasty problems, these problems require root causes to be fixed first. As an example, patient shown in Fig. 2 usually comes to the surgeon with the complaint: of nose sticking out too far or the problem of nasal hump. If the surgeon reduces the nasal hump just to fulfill the request, due to the anatomic imbalance, lower nose now appears even larger [4]. Trying to reduce the size of the lower nose by surgical procedure aggregates the problem even further and situation worsens. In such cases the primary cause of the problem, which is low radix, need to be fixed to solve the problem altogether.

Fig. 2. Male patient with low radix/low dorsum.

Fig. 3. A female patient with narrow middle vault problem.

Same sort of paradoxical problems occur with narrow middle vault patients and inadequate tip projection patients. Patient with inadequate tip projection problem (Fig. 4) appears before the surgeon as "nose too big" or "nose sticking out too far".

Unrecognizing the problem leads the surgeon to reduce the bridge (lower part of nose called columella) by shortening the size surgically. But in this case, surgical shortening does not solve the problem and a tip deformity problem arises [4]. Recognition of this problem requires procedures to strengthen the tip support rather than shortening the bridge length.

All these deficiencies stated above are reflected by at least one or more facial parameters that define the patient's facial features. The software model constructed for detection of these anatomical deficiencies use many facial parameters to detect those anatomical variants. These parameters and the philosophy of the model are explained in the coming sections.

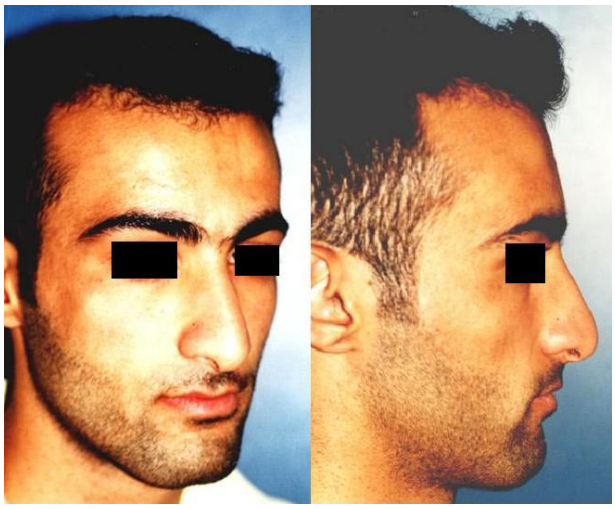

Fig. 4. A male patient with inadequate tip projection problem.

4. FUZZY LOGIC BASED MODELLING

Fuzzy logic, or multi-valued logic is a way of mimicking expert behavior. Fuzzy logic provides a way of making human like decisions through a computer program. Rules and membership functions provides a quick and effective way of embedding human like intelligence and decision making capability to computational environment. Even though it is possible to do the exact same decisions using traditional computing languages and algorithms, fuzzy logic provides a quick and clear way of imparting the idea to the machine environment. Extensive information can be found in the literature about fuzzy logic [10]. Fuzzy logic models are made up of linguistic variables, membership functions associated with linguistic variables, and fuzzy rules. In this study, Matlab Fuzzy logic toolbox version 6.5 is used for implementation and testing purposes. This study is an extension of a previous study where harmony of index of nose for rhinoplasty patients is studied [11]. The model generated in the nasal harmony index is enlarged to include all facial features including the anatomical variants which affect rhinoplasty outcome negatively.

5. MODEL PARAMETERS

While constructing the facial harmony index model, important facial and nasal parameters like nasal angles and proportions are taken as linguistic variables. Ideal nasal angles, lengths of facial features and proportions for male and female subjects are studied extensively by medical professionals and range of parameters is accepted as acceptable values [2]. These ranges of values are accepted as "normal" and taught as part of medical curriculum. In this study, these values are accepted as range of input parameters.

The parameters are extracted from the photographs of the patients which are taken in specific postures. Since some of the angle calculations are dependent on the orientation of the face, a standard way of photographing subjects is developed by medical community. According to this standard, a virtual line extending from the most superior point of auditory canal to the most inferior point of the interorbital rim is aligned parallel to the ground during photographing process. This line is called Frankfort plane and "before and after" operation photographs of patients are always taken with Frankfort plane parallel to the ground. Definitions of the parameters listed below can be found in medical literature [2].

Important facial parameters used in the model and acceptable ranges are as follows:

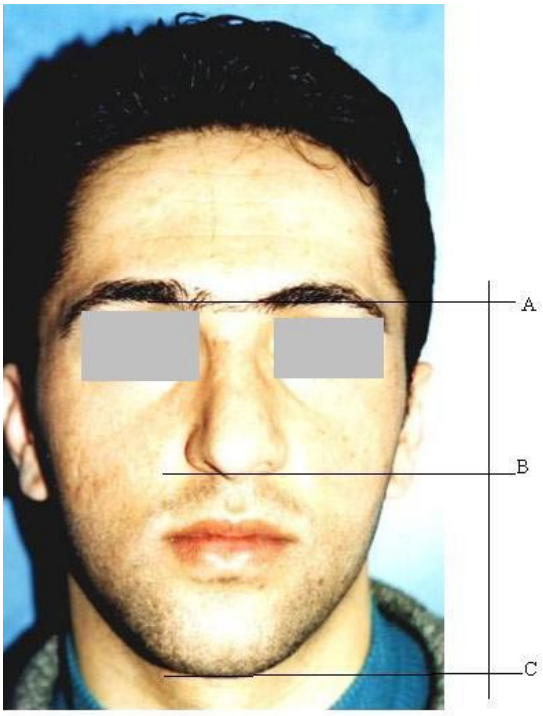

Fig. 5. Rule of the third.

A. The **nasofrontal** angle should be between 115-130 degrees. Within this range more obtuse is preferred for females and more acute preferred for males.

B. **Nasofacial** angle ideally should be between 30-40 degrees.

C. **Nasolabial** angle should be between 95-105 degrees for male gender.

D. **Nasomental** angle ideally should be between 120-132 degrees.

E. **Nasal projection** should be around 0.55-0.60.

F. Face should be divided into three equal portions vertically marked by tip of the chin, tip of the nose, eyebrows and top of the forehead. This rule is entered into the model as the ratio of AB/BC. Ideally this ratio should be equal to 1. (Fig. 5)

G. Face should be divided into five equal vertical portions marked by the tip of the ears, outer edge of the eyes and outer edge of the nose. This parameter is entered into the system as the ratio of intercanthal width to alar width and shown as the ratio of lines A-A/EN-EN in Fig. 6.

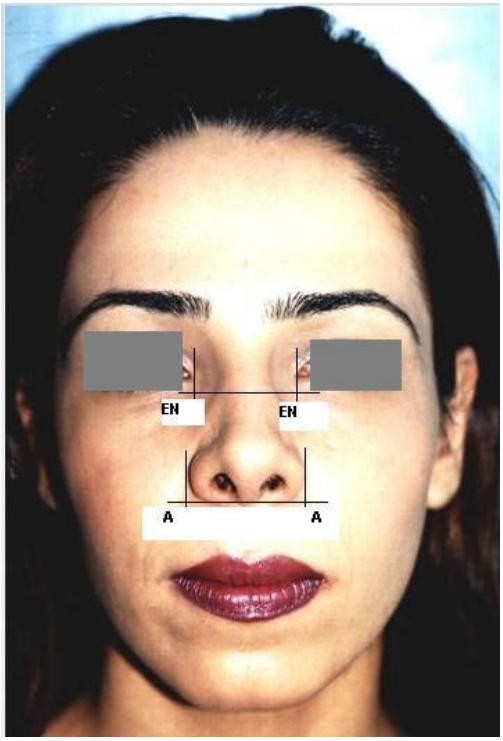

Fig. 6. Intercanthal width to alar width ratio as indicator of rule of fifth.

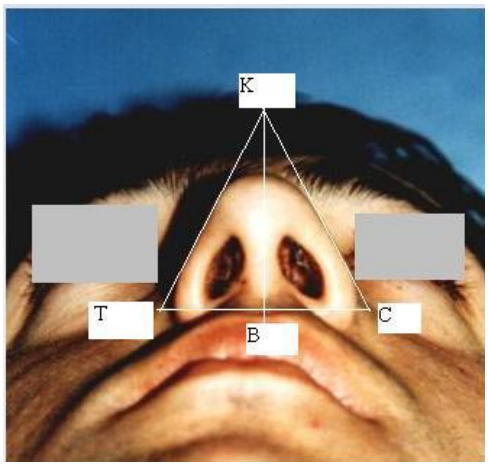

Fig. 7. Rule of equilateral triangle is entered into the model as the ratio of BK/TC.

H. Base of the nose should be confined to an equilateral triangle. This parameter is entered into the system as ratio of height to base of the triangle. (BK/TCX0.86) Ideally this ratio should be 1 for equilateral triangle. (Fig. 7)

I. **Mentocervical** angle is defined as the angle defined by glabella –pogonion line intersecting with menton cervical point line.

J. **Nasion level** is defined as the position of the nasion with respect to the pupil of the eye. Possible positions of the nasion is indicated in Fig. 8. In male preferred nasion level is first ST, then CM and then MP. In female, the preferred position is CM, then MP and then LL.

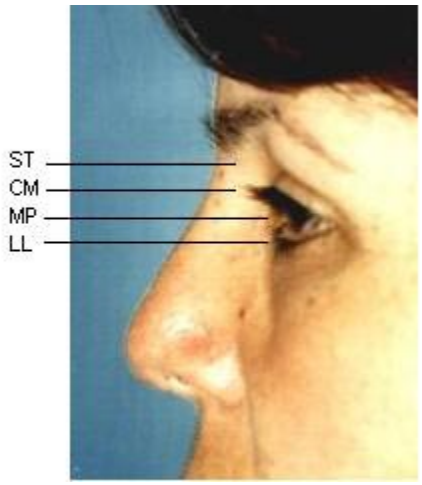

Fig. 8. Vertical nasion level at four different positions: (ST) supratorsal fold, (CM) ciliary margin of the upper pupil, (MP) midpupil, (LL) lower limbus.

K. **Nasion height** is defined as the projection of the nasion beyond the anterior corneal plane. Nasion height is illustrated in Fig. 9.

L. **Narrow vault index** is a parameter that reflects the severity of middle vault problem. It is measured by the centre angle of characteristic inverted V shape of the nose tip. This is illustrated in Fig. 10. The angle ACA gets more obtuse as the severity of the narrow vault problem increases.

M. **Anterior septal angle deviation** is a parameter that reflects inadequate tip projection problem. This parameter is illustrated in Fig. 11. The angle ABC reflects this parameter. Line CB follows the dorsum and extends beyond the tip, line AB starts from subnasale and follows the contour of columella.

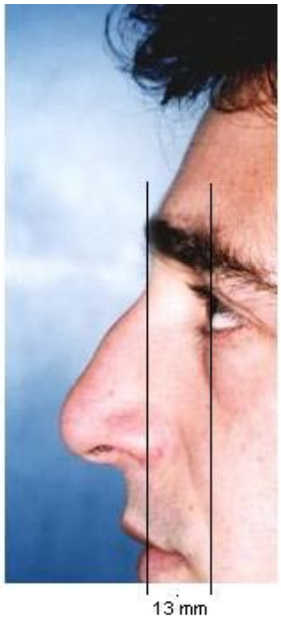

Fig. 9. Nasion height measurement for a patient defined as projection of the nasion beyond the anterior corneal plane. The vertical lines are drawn from corneal plane and the point of the nasion. In this specific case the distance is 13 mm.

6. DETERMINATION OF MEMBERSHIP FUNCTION VALUES

The extended facial harmony model which measures facial harmony and detects troublesome anatomical variants is constructed. Nine facial parameters, A to J which are listed in Section 3 make up the basic harmony index model. Anatomical variants recognition part of the model accepts the parameters K to N to detect the anatomical variants which troubles rhinoplasty operations. As a part of fuzzy modelling, these parameters are associated with linguistic variables which are labelled as nasomental, nasolabial, nasofacial, nasofrontal, nasal projection ratio, rule of third, rule of five, mentocervical and nasal triangle. Rule of fifth is interpreted as ratio of intrcanthal width to alar width ratio. Nasal triangle rule is interpreted as the ratio of height of the triangle to 0.86 X width of the triangle base. Rule of third is interpreted as ration of middle part to lower part.

The linguistic variables of anatomical variants model are labeled as; nasion level, nasion height, narrow vault index and anterior septal deviation.

In all cases, the middle value of the range is accepted as the ideal value in accordance with [12-14]. The values in each range of linguistic variables are represented by three membership functions. The first membership function covers the range below the "ideal" value is labeled as "less" and essentially covers lower value of the range. The membership function that covers the "ideal" value in the range is labeled as "ideal", and the membership function that covers the values above the "ideal" is labeled as "excess". Fig. 12 shows the membership functions for nasomental linguistic variable.

Nasion level parameters are different for male and female patients. Based on the study published by Mowlavi et al.[15], the ideal nasion level for females are determined to be CM (ideal), MP (acceptable) and LL, ST (undesirable). For male subjects ST is (ideal), CM is (acceptable), MP and LL (undesirable) Nasial height preferences for both male and female are determined by Mowlavi as 10 mm (best), 13 mm, 7 mm (worst) [15].

Fig. 10. Characteristic look of patient with narrow middle vault problem. Narrow vault index is the angle ACA. This parameter is applicable only to patients with this problem, it should not be measured for the other patients.

Narrow vault index is a parameter which is valid only with patients with narrow vault problem and varies from 100 degree (severe problem) to 70 degree (slight problem) cases. Anterior septal angle index varies from 90 degrees (no tip problem) to 60 degree (inadequate tip projection problem).

All membership functions are selected to be as gaussian-bell type since the results generated by this type of membership function are found to resemble the actual results more accurately [11]. Table 1 gives the membership functions and parameters for each linguistic variable.

Fig. 11. The angle ABC reflects Characteristic look of patient with narrow middle vault problem. Narrow vault index is the angle ACA. This parameter is applicable only to patients with this problem; it should not be measured for the other patients.

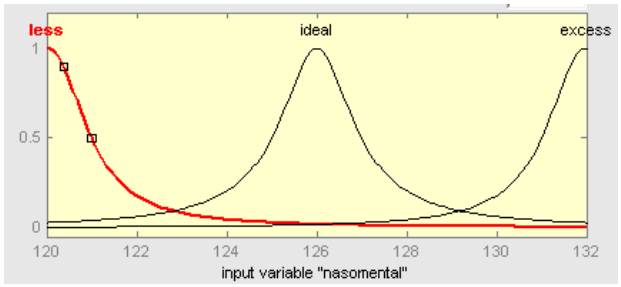

Fig. 12. Membership functions for "nasomental" linguistic variable.

Membership curves of “Nasion level”, “Nasion height”, “Narrow vault index” and “Anterior septal deviation angle” membership curves are given in Figures 13, 14, 15 and 16 respectively.

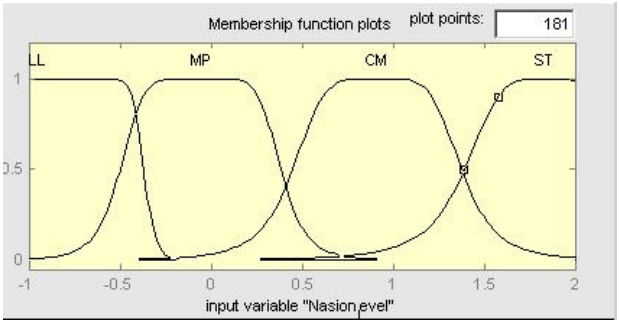

Fig. 13. Nasion level membership functions. Nasion level is measured in cm’s, center of pupil corresponding to 0 point. Locations lower than mid pupil center are represented as negative numbers and locations above the mid pupil are represented by positive numbers.

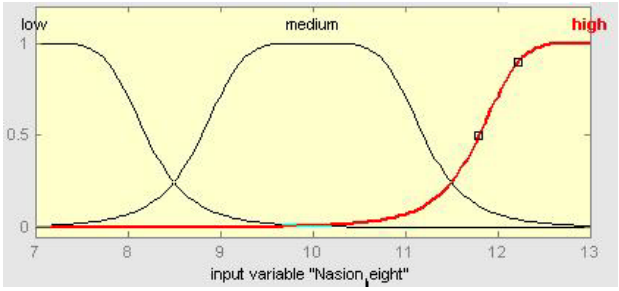

Fig. 14. Nasion height membership functions. Nasion height typically varies between 7 to 13 mm, 10 mm being ideal for both male and female.

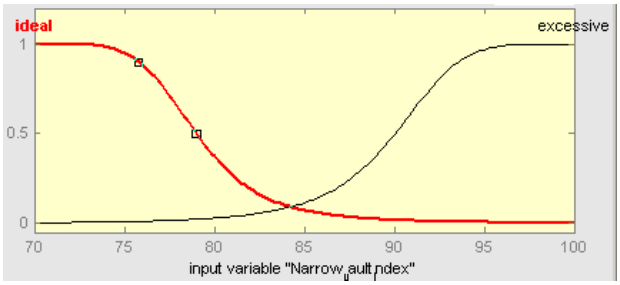

Fig. 15. Narrow vault index membership functions. Narrow vault index is measured by measuring the angle of characteristic inverted V shape associated with these patients which varies from 70 to 100 degrees.

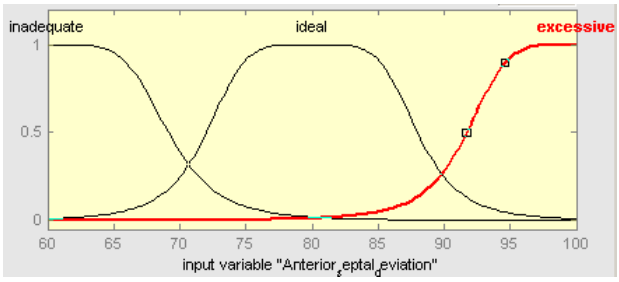

Fig. 16. Anterior septal deviation angle membership functions.

Table 1
Linguistic variables and associated normal value ranges.

Linguistic	Function type	Variable range	Memb. Function "less"	Memb. Function "ideal"	Memb. Function "excess"
Nasomental angle	Gaus-bell	120-132	1, 1.1, 120	1, 0.98, 126	1, 1.1, 132
Nasofrontal angle	Gaus-bell	115-130	1, 1.1, 115	1, 0.98, 119	1, 1.1, 130
Nasal projection ratio	Gaus-bell	0.55-0.6	0.004, 1.1, 0.55	0.04, 0.98, 0.575	0.04, 1.1, 0.6
Nasofacial angle	Gaus-bell	30-40	1, 1.1, 30	1, 0.98, 35	1, 1.1, 40
Nasolabial angle	Gaus-bell	90-105	2.18, 1.1, 90	1, 0.98, 97.5	1, 1.1, 105
Rule of third	Gaus-bell	0.9-1.1	0.004, 1.1, 0.9	0.004, 1.0, 0.575	0.04, 1.1, 1.1
Rule of fifth	Gaus-bell	0.9-1.1	0.004, 1.1, 0.9	0.004, 1.0, 0.575	0.04, 1.1, 1.1
Mentocervical	Gaus-bell	85-100	2.18, 1.1, 85	1, 0.90, 97.5	1, 1.1, 100
Nasal base triangle	Gaus-bell	0.9-1.1	0.004, 1.1, 0.9	0.004, 1.0, 0.575	0.04, 1.1, 1.1
Nasion level (female)	Gaus-bell	ST – LL	LL MP	CM	ST
Nasion level (male)	Gaus-bell	ST – LL	LL MP CM	ST	
Nasion height	Gaus-bell	7-13 mm	7	10	13
Narrow vault index	Gaus-bell	100-70		70	100
Anterior septal dev.	Gaus-bell	100-60	60	90	100

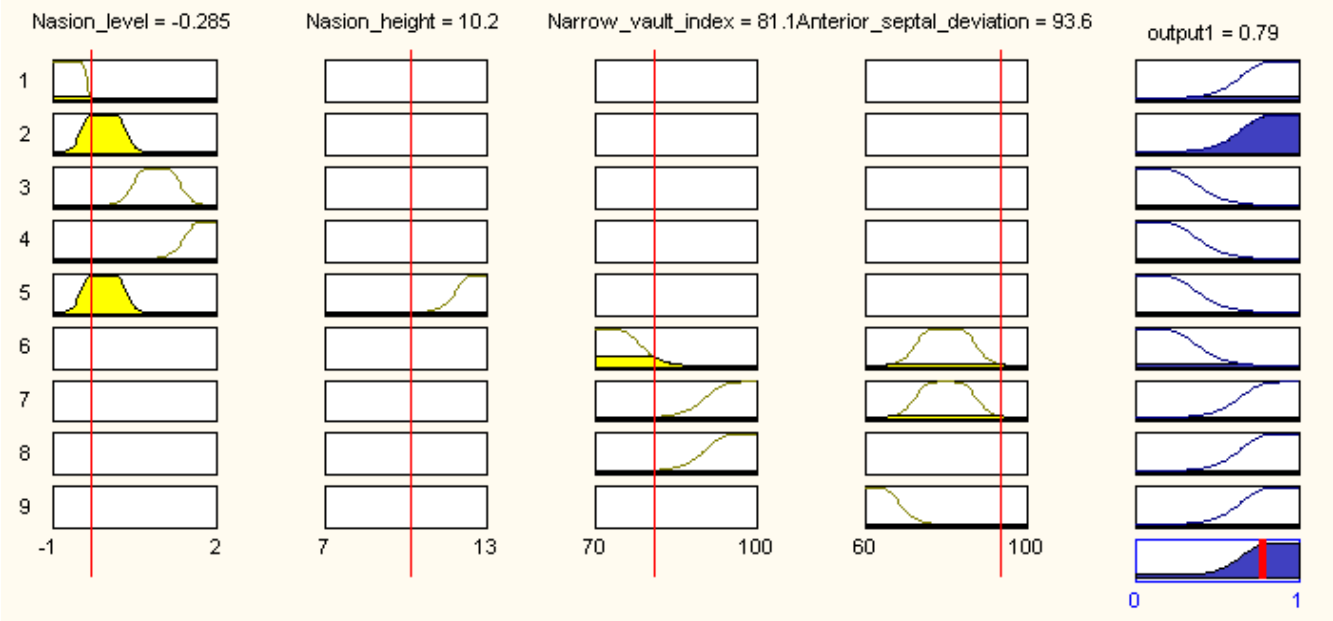

Fig. 16. Fuzzy model output for patient in Fig. 2. Note the output value which is close to value 1 indicating existence of an anatomical variant.

7. RULES OF THE MODEL

All fuzzy systems are made of verbal rules that use linguistic variables. In this study, separate models are developed for males and females since some of the critical parameters differ for genders. The rules make up the anatomical variants fuzzy model for male patients is as follows:

1. If nasion level is LL then output1 anatomical variants exists,
2. If nasion level is MP then output1 anatomical variants exists,
3. If nasion level is CM then output2 is no anatomical variant,
4. If nasion level is ST then output2 is no anatomical variant,
5. If nasion level is MP and nasion height is high then output1 is no anatomical variant,
6. If narrow vault index is ideal and anterior septal deviation is ideal then output1 is no anatomical variant,
7. If narrow vault index is excessive and anterior septal deviation is ideal then output1 is anatomical variant exists,

8. If narrow vault index is excessive then output1 is anatomical variant exists,
9. If anterior septal deviation is inadequate then output1 is anatomical variant exists.

The rules for female model are similar to male model with the exception of some rules that reflect peculiar female characteristics.

The output generated by the model does not specify the type of deficiency or the type of anatomical variant but simply raises the flag to indicate that there is a problem which surgeon needs to be careful. Some of the parameters are coupled, as an example; excessive nasal height counteracts the effect of nasal level. The rules are designed to reflect those dependencies.

The Fig. 16 shows the output of the system for patient shown in Fig. 2. As the final output figure indicates, output is close to 1 indicating existence of an anatomical variant which surgeon should be careful about.

8. CONCLUSIONS

A fuzzy logic model for assessment of anatomical variants that affect rhinoplasty operations negatively is constructed. The harmony model uses total of nine parameters and anatomical variant detection model uses five additional parameters to detect existence of anatomical conditions that cause difficulty in rhinoplasty operations. Detection of these anatomical conditions before the surgery is desirable since it directs the surgeon to fix those deficiencies before any other procedure is attempted. The model is constructed using Matlab fuzzy logic toolbox and the linguistic variables of the fuzzy logic model are selected as the common parameters used for describing facial features. In our model, we have utilized the theory of averages to set the ideal values. The parameters used in anatomical variant model are taken from specific studies involving problems associated with anatomical variations. The model can be a valuable aid by detecting troublesome anatomical features before the surgery is attempted.

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