A Computer Based Objective Grading System for Facial Paralysis

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Abstract

Abstract

A computer assisted objective grading system based on the asymmetry analysis of patient three-dimensional surface models obtained from a 3D facial imaging system is developed for facial paralysis diagnosis. To overcome the subjectivity of traditional diagnosis methods, facial asymmetry grading is carried out according to fine registration result of the original and mirror facial meshes which do not rely on any landmarks. As a higher order property of 3D surfaces, the Principal, Gaussian and Mean Curvatures, Shape Index and Curvedness are introduced for grading the asymmetry of the faces as descriptions of the surface local features besides examining the local differences in distance between the original and mirrored surfaces. The present results show that the proposed approach is able to objectively assess the asymmetrical of human faces as well as to detect the improvement of the patients quite well.

Keywords: Computational Methods, Facial expression, 3D curvatures, Bell's Palsy

Introduction

The face is three dimensionally complex consisting of many tissues namely, bone, soft tissue including fat and muscle, and overlying skin. The soft tissue of the face is unique to the whole body as the underlying muscles are densely enveloped in a continuous layer making up the superficial musculoaponeurotic system or SMAS, which has direct attachments to the facial skin allowing for displacement of the facial soft tissues for facial animation. This ability of animation makes us distinct from other primates and animals as we can produce a myriad of facial expressions. Another unique feature is the presence of two opposite sides which in the ideal situation are mirror images against a vertical midline that bears the nose. This kind of facial structure is the exception rather than the rule as a spectrum of asymmetry exists. The extremes of asymmetry can be due to facial trauma, facial nerve injury and also in birth defects. The physical and psychological suffering is immense as it is both a socially crippling disorder and also a possible functional disorder that can lead to problems with respect to vision, breathing, articulation, mastication, vocalization and many others. Common problems in childhood are cleft lip and palate seen in 1:700 live births and in adulthood facial trauma that is often in association with injury to the soft tissue and underlying bone. The loss of the soft tissue attachments between the bone, muscle and skin leads to descent of the affected site's soft tissues; together with loss of bone support and soft tissue scarring results in asymmetry and deformity. The descent of soft tissues besides bony and skin changes is seen with the commencement of facial aging from the later 20's and continues relentlessly to produce the stigmata of the aged face.

To date, the study on the soft tissue of the face has largely been limited to the two aspects, namely the bony changes via CT scan imaging and skin changes via external limited views of the other lying skin such as with 2D photography. This has allowed for a large body of work on bone changes in congenital and acquired disease and a myriad of surgical options for skin closure in congenital and acquired disease such as post tumor resection. Bone work and skin closure alone are not enough for the restoration of facial symmetry. Bone restoration creates a stable bony platform and skin closure very often creates an intact skin pocket. The contour of the soft tissue contents which are three dimensional may be different from the normal side leading to postoperative asymmetry. We believe that the next step to improving facial surgery and analysis as a whole is the understanding of the whole 3D contour of the facial soft tissues allowing for mirroring and comparison to the contralateral side. This will objectively quantify areas of excess and deficit, descent and contour change which can then be addressed appropriately for a full reconstruction.

Appraisal or rating of facial deformity is usually required to assess the severity of the initial facial injury as well as the degrees of improvement due to the surgical or medical treatments. The appraisal or grading procedures can be broadly divided into qualitative and quantitative methods. Many of the existing methods are qualitative in nature and the grading often suffers from the lack of consistency among different clinicians as well as the difficulty in evaluating marginal changes during the follow-up treatments. The quantitative method analyses the extent of abnormal facial morphology and the degree of disproportion through various facial measurements (for example, Whittle, 2004, Farkas et al., 1993, Sandy, 2003) based on numerical data obtained from photographs or digital models obtained using 3D imaging equipment.

With the proliferation of the use of computer systems and digital photography, a computer based system for the objective assessment of facial deformity or asymmetry based on 3D digital models is a viable solution for the clinicians having to assess the severity of the initial facial injury as well as the degrees of improvement due to the followed up medical treatments. The proposed solution will provide tangible improvements in health services delivery, patient care and health outcomes with a more repeatable and objective assessment of the patients' conditions.

On the mathematical methods for facial analysis in terms of asymmetry or facial deformity, many methods have been proposed for characterizing the parameters of a beautiful face and analyzing the differences between male and female faces, and between faces of people with different racial backgrounds. These methods can be grouped into two main categories: anthropometric studies using either 2D or 3D data, and studies using geometric algorithms using 3D data. Wang et al. (2009) measured nasal length, nasal tip-projection, dorsal height, radix height, nasolabial angle, and nasofrontal angle on 2D photos. These measurements were used to compare the nose shapes of healthy young Koreans with those of rhinoplasty patients. Choe et al. (2006) used 22 standard measurements from 2D photos to compare the differences in nose shapes between Korean American women and North American white women. Szychta et al. (2011) analyzed 3D face models to compare the aesthetic results of post traumatic rhinoplasty. The analysis is based on two indices of the nasal proportions and four angles of the region computed from 18 anthropological points. Dong et al. (2010) used nine linear measurements, three angular measurements and seven proportions derived from a set of 17 landmark points on 3D face models to characterize Chinese nose and find the differences between males and females.

The main objective of the present research is to develop a computer based system based on 3D images taken from patients using 3D imaging technique for objective and quantitative assessment of facial and nasal deformity. The proposed computer based system will be developed and tested for three clinical conditions and applications – facial deformity due to stroke and cleft lip and palate, congenital nasal deformity or nasal deformity due to facial or nasal trauma, and objective assessment of the mid face infra-orbital hollow and upper and lower cheek fullness, lower face lower lip fullness, lip wrinkles (at rest and dynamic) and the oral commissure for facilitating facial reconstructive surgery. As a preliminary report, we will focus on the analysis of the facial symmetry of healthy human subject as a benchmark for future research.

Methodology

For the proposed study, a total of 100 healthy human subject volunteers have been recruited for the initial study from NUS students and staff. The approval from the relevant Institutional Review Board has been obtained for this study. Another 100 volunteers will be selected from the patients visiting the clinics of Otolaryngology and plastic and reconstructive surgery at the National University Hospital. These human subjects and patients will form the database for the analysis. The 100 patients are expected to be recruited from patients with cleft lip and palate, facial paralysis and patients with facial deformity due to facial trauma.

For the first phase of this study, 100 healthy (without any facial deformities) participants were recruited. Participants involved in the study were at least 18 years old and students from the National University of Singapore. Among the scans, 55 were males and 45 were females. Most of the scans are Chinese with 3 Malays, 1 Indian and 1 Eurasian. Participants were required to remove their spectacles or clip up any hair that is covering their face to aid the measurement taking process that will be performed later on in the study. Before the facial scanning was carried out, 3 photographs were required to be taken from each participant, the frontal, profile and the oblique views (Figure 1).

Figure 1 Frontal, Profile and Oblique View of Participant

The facial scanning was done using the Artec3D EVA white light scanner (Figure 2) acquired at the beginning of the proejct. It makes use of the white light technology which will not present any safety risk to people and does not produce the kind of magnetic radiation that can damage medical instruments. There is also no need for any special markers. Each facial scan lasts for about 20 seconds. The scans were taken in a quiet environment with good lighting to minimise the noise disturbances and to optimise the scans taken. The scans were taken at an optimal distance in order for them to be more accurate.

Figure 2: Artec3D Eva white light scanner

The facial scans were initially proposed to be taken with the participants' eyes open. However, due to the white light which may result in discomfort to the eyes and also due to the continuous blinking of the eyes by the participants, it might lead to inaccuracy and inconsistency of the scan. Hence, it was decided that the scans should be done with participants having their eyes closed. Two scans were also taken per participant and the scan of a higher quality and accuracy was chosen for data analysis.

The scanned data had to be processed before they can be used. Fine alignment procedure was done by applying fine serial registration on the scan for a quality model. Then the model had to go through global data registration where the global registration algorithm converted all one-frame surfaces into a single coordinate system using information on the mutual position of each pair of surfaces. Upon successful global registration, all the processed data could be fused into a polygonal 3D model. After which, tools in the software were used to correct any surface defects either due to scanning or registration errors. Lastly, texture will be applied to the scans.

Before proceeding to take the facial measurements from the 3D scans, the scans had to be orientated in the right direction with respect to the axis. All facial scans were normalized to natural head posture with the origin set at the subnasale point, the x-axis pointing left, from right to left eye; y-axis pointing vertically upwards, from chin to forehead; z-axis pointing outwards, in the nose direction.
Landmarks were then manually placed on the scans using Artec Studio 9 software as shown in Figures 3 to 7.

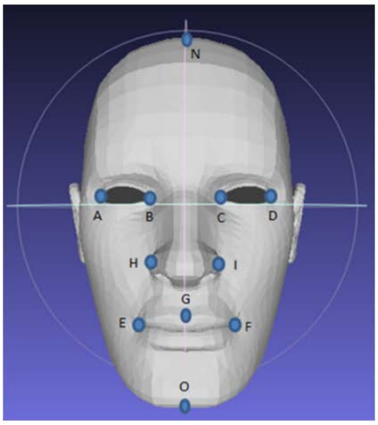

Figure 3

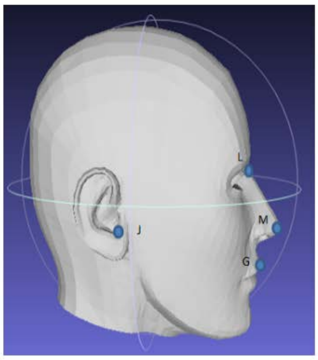

Figure 4

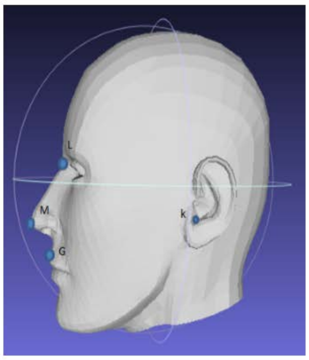

Figure 5

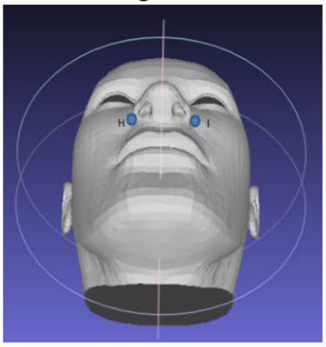

Figure 6

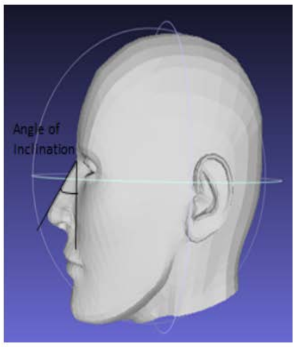

Figure 7

Figures 3-7 Landmarks on facial scan

In total, 16 landmarks were manually identified and placed on each scan. The x, y and z coordinates of each landmark were recorded (48 coordinates in total).

Brief Description of the landmarks are as follows:

Ectocanthion : The point at which the outer ends of the upper and lower eyelids meet
Endocanthion : The point at which the inner ends of the upper and lower eyelid meet
Cheilion : The lateral most point at the angle of the lips
Labiale Superius : Midpoint of the vermilion line of the upper lip
Alare : The most lateral point on the ala of the nose
Intertragic notch and earlobe : The small groove between the bump of cartilage between the ear and temple
Nasion : The craniometrical point at the bridge of the nose where the frontal and nasal bones of the skull meet
Pronasale : The most prominent point on the nasal tip
Trichion : Point where the hairline meets the midpoint of the forehead
Gnathion : Lowest median landmark on the lower border of the mandible

The coordinates were used to get the measurements for various dimensions of the facial features which includes the length of the right and left eyes, width and height of the face and others. There were 45 scans for females and 55 scans for males. The various dimensions measured for both the left and the right side of the face include the length of the eye, distance between the Intertragic Notch and Cheilion, distance between the intertragic notch and nasion, and lastly the distance between intertragic notch and ectocanthion.

Results and Discussion

The measurements for the various dimensions for the left and right side of the face did not tally. This suggests that all the participants do not have a perfectly symmetrical face.

	Average (mm)	Std. Deviation
Distance between the eyes	37.65	3.05
Length (right eye)	27.24	2.02
Length (left eye)	27.43	1.77
Face Height	184.16	7.96
Face Width	140.09	5.35
Height/Width of face	1.32	0.07
Length of Lips	44.94	3.38
Angle of inclination of nose	13.34	3.96

Table 1 Average and standard deviation for females

T-tests were performed on different groups such as distance between the length of the right and left eyes, distance between the Intertragic notch (Left and Right) and Nasion, Distance between Left and Right Intertragic notch and left and right Cheilion respectively and lastly distance between right and left Intertragic notch with right and left Ectocanthion respectively. An alpha value of 0.05 was used. From the t-tests, the P values are all more than 0.05, showing no statistical significance in all of the measurements.

	Average (mm)	Std. Deviation
Distance between the eyes	40.19	3.43
Length (right eye)	27.86	1.78
Length (left eye)	28.08	1.78
Face Height	192.75	10.16
Face Width	150.12	6.42
Height/Width of face	1.29	0.07
Length of Lips	47.84	4.18
Angle of inclination of nose	12.76	3.74

Table 2 Average and standard deviation for males

Comparison of the difference in dimensions between females and males were tested using the t-test. Dimensions included difference between the length of the right and left eyes, Difference in the distance between the Intertragic notch (Left and Right) and Nasion, difference in distance between

Left and Right Intertragic notch with Left and Right Cheilion respectively, difference in distance between Right and left Intertragic notch with right and left Ectocanthion respectively, difference in the inclination of nose, difference in the face height and lastly the difference in face width. The alpha value of 0.05 was used. From the t-tests, the P values are all more than 0.05 except for 2 which is the face height and the width of the face. The T-test for face height between the males and females obtained a value almost equal to zero, showing that the results are statistically significant. The mean of the face height for males is 192.75mm while the mean face height for females is 184.16mm as shown in Table 3.

t-Test: Two-Sample Assuming Unequal Variances		
	Face Height (Females)	Face Height (Males)
Mean	184.16	192.75
Variance	63.38	103.29
Observations	42	51
Hypothesized Mean Difference	0	
Df	91	
t Stat	-4.57	
P(T<=t) one-tail	7.61E-06	
t Critical one-tail	1.66	
P(T<=t) two-tail	1.52-05	
t Critical two-tail	1.99154	

Table 3 T-test for face height between females and males

The T-test for face width has also proven to be statistically significant with the p value being close to zero. The face width mean for males is 150.12mm while for females is 140.09mm. This is shown in table 4.

t-Test: Two-Sample Assuming Unequal Variances		
	Face Width (Females)	Face Width (Males)
Mean	140.0859524	150.1156863
Variance	28.63356614	41.26434902
Observations	42	51
Hypothesized Mean Difference	0	
df	91	
t Stat	-8.214317689	
P(T<=t) one-tail	6.88149E-13	
t Critical one-tail	1.661771155	
P(T<=t) two-tail	1.3763E-12	
t Critical two-tail	1.986377154	

Table 4: T-test for face width between females and males

Hence, this shows that the male has a greater face height as compared to females. The software developed was used to test a typical healthy subject as well as a patient with facial deformity. The software will be used in the coming study for patients.

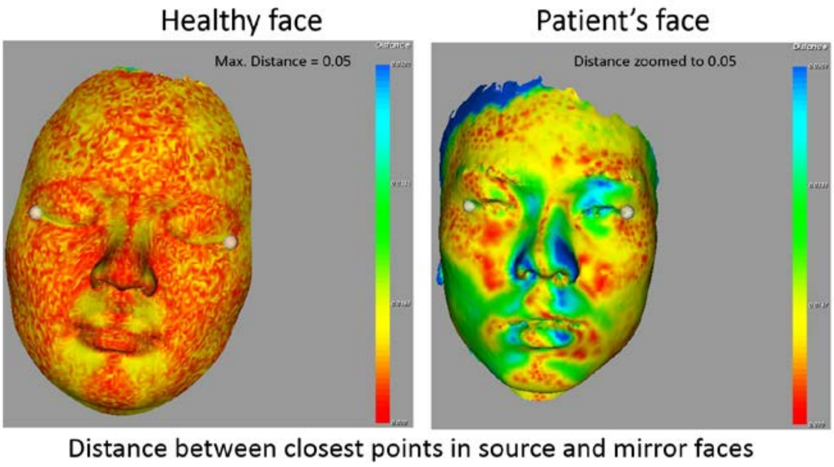

Figure 8 Sample output from the software developed

The software will be used in the coming study for patients.

Conclusions

From the results, it can be seen that there are no one with perfectly symmetrical faces even though the difference measured is not large. It was also observed that the face height and face width of males are generally larger than those of females. There is no other statistical significance between the other dimensions of facial measurements. 3D analysis using the Surface Analyzer indicated that RMS values of patients with facial deformities were generally larger than those of healthy participants. Distance Maps and Gaussian Maps also showed that faces of patients had higher asymmetry as compared to healthy participants.

It should be noted that when surgeons perform reconstructive surgery for patients with facial deformities, they should not do the surgery solely based on the symmetry of the face but rather also seek the opinions of the patients involved. In the era of modern orthodontics when the soft-tissue paradigm and patient perception often dictate the success of treatment outcomes, it is not acceptable for the orthodontist to simply identify problems and proceed with treatment. There is also a need to understand individual differences in the perception of face symmetry by surgeons, patients and those involved in the treatment process to get optimal results (Jackson, et al., 2013)

Acknowledgement

The authors would like to acknowledge the financial support from the Ministry of Education Academic Research Grant (R-265-000-458-112) AND ALSO Ms Charissa Loh for assisting with the collection of the data.

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