THE THREE-DIMENSIONAL MAPPING OF THE SURFACE ANALYSIS OF ELECTROMAGNETIC NAVIGATION SYSTEMS USING SURFACE REGISTRATION IN ETHNIC MALAYSIAN FEATURES

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DISCLAIMER

I hereby certify that the work in this dissertation is my own except for the quotations and summaries which have been duly acknowledged.

Date:

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TABLE OF CONTENTS

ABSTRAK

Pengenalan

Sejak diperkenalkan, sistem navigasi pembedahan telah menjadi bersepadu dalam amalan pembedahan, termasuk prosedur hidung endoskopik yang rumit untuk mengelakkan komplikasi yang serius seperti kecederaan kepada saraf optik, arteri karotid, membran otak dan isi otak.

Objektif

Kami bertujuan untuk menentukan ketepatan imej sistem berpandu (IGS) dengan menggunakan selang masa yang berbeza bagi imbasan tomografi berkomputer sinus paranasal dan pengalaman kami dalam melaksanakan penandaan permukaan.

Kaedah

Ini adalah satu kajian keratan rentas. Petunjuk-petunjuk telah diambil dari pesakit yang dirancang untuk pembedahan sinus endoskopi dengan IGS. Pesakit-pesakit ini telah memenuhi kriteria kemasukan dan pengecualian. Imej berpandukan ukuran navigasi dibandingkan dengan ukuran anatomi sebenar jarak intercantus (intercanthal) kedua-dua mata dan garis tangen segi tiga terbalik untuk filtrum. Masa yang dianggarkan mendaftari IGS direkodkan. Semua ukuran telah dilakukan pada masa yang sama seperti penentukuran IGS.

Keputusan

Jarak intercantus purata diukur oleh IGS adalah 38.17 mm (SD 3.34) manakala jarak intercantus sebenar ialah 38.17 mm (SD 3.37 mm). Garis tangen diukur oleh IGS adalah 46.62 (SD 3.39) manakala pengukuran sebenar garisan tangen adalah 46.47mm (SD 3.27). Penyelidik tidak mendapati perbezaan ketara dalam kedua-dua ukuran antara IGS dan ukuran sebenar anatomi (p¬ = 0,804 dan 0,496, masing-masing).

Kesimpulan

Walaupun dengan jangka masa yang berbeza, tidak banyak perbezaan dari jarak anatomi sebenar. IGS adalah tepat dan boleh digunakan untuk digunakan pada pesakit Asia.

Kata Kunci: sistem navigasi elektromagnet; pembedahan sinus endoskopi; Permukaan menandakan; ketepatan pendaftaran

ABSTRACT

Introduction

Since its introduction, surgical navigation systems have become integrated into surgical practices that include complex nasal endoscopic procedures to avoid serious complication such as injury to the optic nerve, the carotid artery, the dura mater and the brain parenchyma.

Objective

We aimed to determine the accuracy of image guided system (IGS) by using different timing interval of computed tomography scan of paranasal sinus and our experience in performing the surface marking.

Methods

A cross sectional study was done. Subjects were recruited from patients planned for endoscopic sinus surgery with IGS, who met the inclusion and exclusion criteria. The image guided navigation measurements were compared to the actual anatomical measurements of intercanthal distance of both eyes and the tangential line of inverted triangle to the philtrum. The estimated time to register the IGS was recorded. All measurements were done at the same time as the calibration of the IGS.

Results

The mean intercanthal distance measured by IGS was 38.17 mm (SD 3.34) whereas the actual intercanthal distance was 38.17 mm (SD 3.37 mm). The tangential line measured by IGS was 46.62 (SD 3.39) whereas the actual measurement of the tangential line was 46.47mm (SD 3.27). The was no significant difference in both measurements between IGS and actual anatomical measurements (*p*=0.804 and 0.496, respectively).

Conclusions

Even with the different intervals there was not much deviation from the actual anatomical distance. The IGS is accurate and is applicable for use in Asian patients.

Key Words: Electromagnetic navigation system; Endoscopic sinus surgery; Surface marking; Regisration accuracy

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The advent of endoscopic sinus surgery in the 1980s as a minimally invasive head and neck surgery has brought about a revolutionary advancement from the open sinus surgery to the now minimally invasive approach to surgery for sinusitis. It has also prompted the development of image guided systems to assist the surgeon with intraoperative anatomical localization.[1] In the past decade, since its introduction, surgical navigation systems have become integrated into surgical practices that include complex nasal endoscopic procedures.[2] The use of image guided systems and the development of computer aided sinus surgery has markedly improved the field of endoscopic sinus surgery and its complication rate.[3]

The navigation system consist of a navigation screen, navigation module and tracking pointer. There are 4 windows displayed on the screen, 3 of which that shows raw CT or MRI data of cross sectional image of axial coronal and saggital planes of the patient. And the 4th window displays the endoscopic images of the surgical field. The registration is done by which the position of the instrument or tracking pointer in the surgical field is correlated with the CT images of the patient. The tracking probe is registered with respect to the CT images of the patient.[4] The registration markers or anatomical markers are set by selecting bony prominences that are located directly beneath the skin. It is due to the anatomical differences between the preset template of the navigation system and the Asian patient’s anatomy that the surgeon encounters an inaccuracy between the landmarks and the markers compared to the images provided by the CT scan.

Although morbidity is low in endoscopic nasal surgery, there is a risk of serious complication due to anatomic proximity of the sinus cavities, the optic nerve, the carotid artery, the dura mater an the brain parenchyma.[5] Endoscopic sinus surgery presents a challenge to surgeons of all levels of experience. It has paved a way to treating diseases of the nose, skull base and orbit.[6] Most navigational systems have been prototyped and designed with Caucasian patient templates. This proves to be inconvenient to surgeons operation in the Asian patient, causing more inaccuracies in surface registration and inaccuracies in local anatomy.

The use of image guided surgery has played an important and expanding role in endoscopic sinus surgery in the past 2 decades. It is generally perceived that IGS is critical to certain cases for verifying the location of vital structure surrounding the paranasal sinus and minimalizing the risk of injury.[7] Interest in the use of image guided systems in otolaryngology increased with the development of endoscopic sinus surgery and the development of frameless systems.[8]

The localization unit uses preoperative CT or MRI data to provide the surgeon with a real-time 3-D visual localization of the surgical instruments relative to the patient's anatomy during the image guided procedure.[8] IGS does not display anatomical changes that occur during surgery because it relies on computed tomography (CT) scans obtained preoperatively.[9] Image guidance systems were designed to identify surgical instruments, calculate the position of instrument tip in relation to the patient, and project the instrument location on the previously obtained imaging study.[10]

Registration accuracy was checked visually for every patient by repeatedly pin-pointing the anatomical landmarks. Registration errors can be caused by shifting, or unfavourable spatial distribution of the markers. Calibration using anatomic landmarks is not precise enough and could lead to 2 to 5mm divergence.[11] A drift in the accuracy of the system may develop during the course of the procedure and frequent corroboration with known clinical landmarks is

advised.[10]

Image guidance systems were initially developed for neurosurgical procedures that required hear fixation in a stereotaxic frame, however the newer image guidance systems have been introduced that allows free head movements during surgery. [12] While stereotaxic frames and bone implanted markers are rigidly attached to bone, skin markers and markers implanted into soft tissue can move due to skin elasticity or soft tissue deformation.[13]

Depth cues are limited by the 2 dimensional monitor. The sinus cavities are a complex 3 dimensional environment surrounded by critical structures. The use of virtual reality to aid surgical training is heavily pursued and rapidly evolving. Virtual views have been designed to match a real model in terms of spatial cues and anatomical relationships. However, manual contouring of preoperative scans is labour intensive.[14] The problem of finding corresponding landmarks in 3D and 2D is avoided by curve-to-curve and surface-to-curve registration.[13]

Calibration is a process by which the navigation system matches the surgeons' reference points on the patient with those in the scan registered in the navigation system. Calibration systems involving surface scanning of the patient's face need to take into account of soft tissue malleability. Hydration and tension differences in facial tissue between image acquisition when patient is awake and surgery under general anaesthesia can cause significant difference (up to 2mm) in the position points.[15, 16,17]

Three anatomical markers are set by selecting bony prominences that are located beneath the skin and a triangular field is created by selecting this reference point. Two of the reference points are the lateral canthi of the right and left eye and the third point is the philtrum.[2] The dominant characteristics of the Asian face were a wider intercanthal distance in relation to a shorter palpebral fissure, a much wider soft nose within wide facial contours, a smaller mouth width, and a lower face smaller than the forehead height, when compared to Caucasian face.[18]

Previous studies by Chang et al, regarding the three-dimensional analysis of the surface registration accuracy of electromagnetic navigation systems in live endoscopic sinus surgery had the sample size of 40: 20 men and 20 women, of which there were no racial predisposing factor.[19]

CHAPTER 2: OBJECTIVES OF THE STUDY

2.1 General Objectives

We have studied the three dimensional surface registration of patients undergoing endoscopic sinus surgery with image guided navigation in Hospital Universiti Sains Malaysia and in Hospital Raja Permaisuri Bainun, Ipoh population.

2.2 Specific Objectives

1. We have determined the anatomical measurements of the intercanthal distance of patients undergoing endoscopic sinus surgery with image guided navigation in Hospital Universiti Sains Malaysia and in Hospital Raja Permaisuri Bainun, Ipoh population.
2. We also have determined intercanthal distance between the right and the left eyes and measured the distance from the tangential line of the inverted triangle to the philtrum. (the distance is wider in Asian faces)
3. The three dominant ethnic groups (Malay, Chinese, and Indians) in the study population to be used as an Asian template.
4. We have estimated the duration taken to register the image guidance system.

CHAPTER 3: MANUSCRIPT

3.0 TITLE PAGE

Original Article

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3.2 ABSTRAK (Bahasa Melayu)
Pengenalan

Sejak diperkenalkan, sistem navigasi pembedahan telah menjadi bersepadu dalam amalan pembedahan, termasuk prosedur hidung endoskopik yang rumit untuk mengelakkan komplikasi yang serius seperti kecederaan kepada saraf optik, arteri karotid, membran otak dan isi otak.

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Ini adalah satu kajian keratan rentas. Petunjuk-petunjuk telah diambil dari pesakit yang dirancang untuk pembedahan sinus endoskopi dengan IGS. Pesakit-pesakit ini telah memenuhi kriteria kemasukan dan pengecualian. Imej berpandukan ukuran navigasi dibandingkan dengan ukuran anatomi sebenar jarak intercantus (intercanthal) kedua-dua mata dan garis tangen segi tiga terbalik untuk filtrum. Masa yang dianggarkan mendaftari IGS direkodkan. Semua ukuran telah dilakukan pada masa yang sama seperti penentukuran IGS.

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Walaupun dengan jangka masa yang berbeza, tidak banyak perbezaan dari jarak anatomi sebenar. IGS adalah tepat dan boleh digunakan untuk digunakan pada pesakit Asia.

Kata Kunci: sistem navigasi elektromagnet; pembedahan sinus endoskopi; Permukaan menandakan; ketepatan pendaftaran

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Since its introduction, surgical navigation systems have become integrated into surgical practices that include complex nasal endoscopic procedures to avoid serious complication such as injury to the optic nerve, the carotid artery, the dura mater and the brain parenchyma.

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We aimed to determine the accuracy of image guided system (IGS) by using different timing interval of computed tomography scan of paranasal sinus and our experience in performing the surface marking.

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A cross sectional study was done. Subjects were recruited from patients planned for endoscopic sinus surgery with IGS, who met the inclusion and exclusion criteria. The image guided navigation measurements were compared to the actual anatomical measurements of intercanthal distance of both eyes and the tangential line of inverted triangle to the philtrum. The estimated time to register the IGS was recorded. All measurements were done at the same time as the calibration of the IGS.

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Even with the different intervals there was not much deviation from the actual anatomical distance. The IGS is accurate and is applicable for use in Asian patients.

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3.3 INTRODUCTION

The advent of endoscopic sinus surgery in the 1980s has prompted the development of image guided systems (IGS) to assist the surgeon.[1] Surgical navigation systems have become integrated into surgical practices. [2] The use of IGS has markedly improved the field of endoscopic sinus surgery and its complication rate.[3] There is a risk of serious complication due to anatomic proximity of the sinus cavities, the optic nerve, the carotid artery, the dura mater and the brain parenchyma that can be avoided by IGS use. [4,5] The registration is done by which the position of the instrument or tracking pointer in the surgical field is correlated with the computed tomography (CT) images of the patient. The tracking probe is registered with respect to the CT images of the patient. [6] The registration markers or anatomical markers are set by selecting bony prominences that are located directly beneath the skin. However, the interval of CT prior to surgery and efficiency of surface marking have not been well studied. In this study, we aimed to determine the accuracy of navigation system in using different timing interval of CT and our experience in performing the surface marking in Asian patients.

3.4 METHODOLOGY

Subjects

This was cross sectional study to evaluate the accuracy in surface registration of patients undergoing endoscopic sinus surgery with image guided navigation system in a tertiary hospital in Malaysia. Subjects were recruited from those scheduled to undergo endoscopic sinus surgery with image guidance system. All measurements were done at the same time for calibration of the machine to the patient's anatomy. The image guidance system used was Storz NAV1 Electromagnetic system. The inclusion criteria were age 18 years and above and scheduled for endoscopic sinus surgery. Whereas the following exclusion criteria were used; previous surgery to paranasal sinuses and skull base with facial anomalies, facial trauma, chronic maxillary atelectasis with significant orbital changes, craniofacial abnormality, non-Malaysian and pregnancy. Subjects would be withdrawn if the investigator deemed that it was detrimental or risky for the subjects to continue. All withdrawn subjects would attend the final study visit and withdrawn subjects would be replaced.

Study Procedures

Patient was intubated with the normal surgery requirements with throat pack inserted and the endotracheal tube anchored at the left and the patient's eyes half exposed (chloramphenicol eye ointment applied). The strap of the IGS headpiece was strapped on the patient and the magnetic receiver fastened onto the operation table. The IGS machine and monitor was then set up with uploading the CT scan in DICOM format into the system. Once uploaded, the machine was calibrated, and the reference points confirmed. After the intercanthal distance and its tangential distance taken and recorded, the surgery began. The intercanthal distance between the right and the left eyes were measured together with the distance from the tangential line of the inverted triangle to the philtrum. A comparison was made between right and left intercanthal distance and measurements different between genders. Day to operation was categorized into two categories: less than 90 days and 90 days or more. The difference between IGS and actual measurement was computed as well for both intercanthal and tangential line.

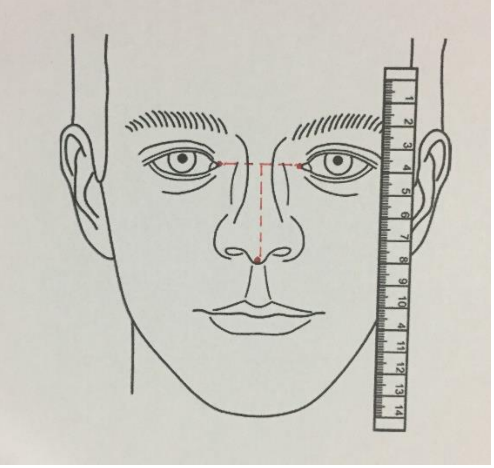

Figure 1: Intercanthal distance between the eyes and the columnella. All represented by the red dots.

Statistical analysis

Statistical calculation and evaluation were performed with SPSS software version 22.0. The sample size was calculated using Single Mean Formula and 2-Mean Formula. All data were anonymous and only accessible to the research team members. Data were presented as grouped data and the responders were not identified individually. All measurements were taken 3 times and the average was used in data analysis. When there was discordant opinion, further evaluation of the image was done by the specialists to obtain a mutual consensus. Mann Whitney U test was used to test where there is significant difference in outcome (IGS compared to actual for intercanthal distance and tangential line) between days to operation. Furthermore, Mann Whitney U test was applied again to test the difference in intercanthal distance and tangential line between gender for both measurements (IGS and actual) too. A *p* value less than 0.05 was considered statistically significant.

3.5 RESULTS

A total of 30 patients were recruited from those scheduled to undergo endoscopic sinus surgery with IGS (Table 1). Out of the 30 patients selected, 7 of them were female. The average age amongst the patients selected was 47 years old. The comparison of intercanthal distance and tangential line between IGS and actual measurements is shown in Table 2. The mean intercanthal distance measured by IGS was 38.17 mm (SD 3.34) whereas the actual intercanthal distance was 38.17 mm (SD 3.37 mm). The tangential line measured by IGS was 46.62 (SD 3.39) whereas actual measurement of the tangential line was 46.47 mm (SD 3.27). There was no significant difference in both measurements between IGS and actual measurements ($p = 0.804$ and 0.496, respectively).

Table 1. Characteristics of study population (n=30).

	Mean (SD)	**Range**	**25th Percentiles**	**(Median)**	**75th Percentiles**
Race[1]					
Malay	25 (83.3)				
Chinese	3(10.0)				
Indian	2 (6.7)				
IGS Intercanthal Distance (mm)[2]	38.17 (3.34)	33.66 – 44.92	34.92	37.84	41.33
IGS Tangential Line (mm)[2]	46.62 (3.39)	41.36 – 54.32	44.26	45.47	48.76
Actual Intercanthal Distance (mm)[2]	38.17 (3.37)	34.00 – 44.00	35.00	37.00	41.00
Actual Tangential Line (mm)[2]	46.47 (3.27)	41.00 – 54.00	44.00	45.50	48.50

SD: standard deviation

[1]Frequency(percentage) [2]Data were positively skewed.

Table 2. Comparison of intercanthal distance and tangential line between IGS and actual measurements (n=30).

	Mean (SD)	**Median (IQR)**	**z-statistic**	***p* value[1]**
Intercanthal Distance (mm)				
IGS	38.17 (3.34)	37.84 (6.41)	-0.25	0.804
Actual	38.17 (3.37)	37.00 (6.00)		
Tangential Line (mm)				
IGS	46.62 (3.39)	45.47 (4.50)	-6.81	0.496
Actual	46.47 (3.27)	45.50 (5.00)		

SD = Standard deviation; IQR = Interquartile range

[1]Wilcoxon signed ranks test was applied, normality of data distribution was not assumed.

Table 3. Correlation of intercanthal distance between IGS and actual measurements.

Variable	r	*p* value[1]
Intercanthal distance: IGS and Actual	0.974	<0.001
Tangential line: IGS and Actual	0.972	<0.001

[1]Spearman correlation test was applied.

Table 3 revealed the correlation of intercanthal distance and tangential line between IGS and actual measurement. There was significant, positive and good correlation of intercanthal distance between IGS and actual measurement (r = 0.974; p<0.001). Similarly, there was significant, positive and strong correlation between IGS and actual measurement of tangential line score (r=0.972; p<0.001). There was no significant difference on the registration time compared to the standard 15 minutes standard registration time (p = 0.156) (Table 4). There was no significant difference in median intercanthal distance and tangential line between days to operation (Table 5). There was no significant difference between gender for intercanthal distance for IGS (p = 0.390) and actual measurements (p = 0.390) and no significant difference for tangential line for IGS (p = 0.390) and actual measurements (p > 0.950) (Table 6).

Table 4. Difference of registration time from standard 15 minutes.

	Mean (SD)	**Mean Difference (95%CI)**	**t stats (df)**	***p* value**
Registration time	15.93 (3.51)	0.93 (-0.38, 2.25)	1.46 (29)	0.156

One-Sample Test

Table 5. Difference in the difference in intercanthal distance and tangential line between days to operation.

	Median (IQR)		*p* value
	<90 days n = 17	**≥90 days n = 13**	
Difference in			
Intercanthal distance	0.00 (0.86)	-0.45 (1.08)	0.462
Tangential line	-0.12 (0.82)	0.21 (0.70	>0.950

Mann Whitney U Test was applied, normality of data distribution was not assumed

Table 6. Difference in intercanthal distance and tangential line between gender.

	Mean (SD)		Median (IQR)		*p* value
	Female	**Male**	**Female**	**Male**	
Intercanthal					
distance	39.69 (2.11)	37.71 (3.54)	40.76 (4.11)	35.78 (3.54)	0.390
IGS	39.29 (2.43)	37.83 (3.59)	40.00 (5.00)	36.00 (6.00)	0.390
Actual					
Tangential line					
IGS	45.99 (3.74)	46.81 (3.34)	44.67 (6.02)	45.87 (4.01)	0.390
Actual	46.43 (3.82)	46.48 (3.17)	45.00 (7.00)	46.00 (4.00)	>0.950

Mann Whitney U Test was applied, normality of data distribution was not assumed

P value proven to be insignificant.

3.6 DISCUSSION

The use of IGS is generally perceived that it is critical to certain cases for verifying the location of vital structure surrounding the paranasal sinus and minimalizing the risk of injury.[7, 8] The localization unit uses preoperative CT or MRI data to provide the surgeon with a real-time 3-D visual localization of the surgical instruments relative to the patient's anatomy during the image guided procedure.[8] IGS does not display anatomical changes that occur during surgery because it relies on computed tomography (CT) scans obtained preoperatively.[9] Image guidance systems were designed to identify surgical instruments, calculate the position of instrument tip in relation to the patient, and project the instrument location on the previously obtained imaging study.[10]

Registration accuracy was checked visually for every patient by repeatedly pin-pointing the anatomical landmarks. Registration errors can be caused by shifting, or unfavourable spatial distribution of the markers. Calibration using anatomic landmarks is not precise enough and could lead to 2 to 5 mm divergence.[11] A drift in the accuracy of the system may develop during the procedure and frequent corroboration with known clinical landmarks is advised.[12]
While stereotaxic frames and bone implanted markers are rigidly attached to bone, skin markers and markers implanted into soft tissue can move due to skin elasticity or soft tissue deformation.[13] Virtual views have been designed to match a real model in terms of spatial cues and anatomical relationships.[14] The problem of finding corresponding landmarks in 3D and 2D is avoided by curve-to-curve and surface-to-curve registration.[13]

Calibration systems involving surface scanning of the patient's face need to consider the soft tissue malleability. Hydration and tension differences in facial tissue between image acquisition when patient is awake and surgery under general anaesthesia can cause significant difference (up to 2mm) in the position points.[15, 16,17] Three anatomical markers are set by selecting bony prominences that are located beneath the skin and a triangular field is created by selecting this reference point. Two of the reference points are the lateral canthi of the right and left eye and the third point is the philtrum.[2]

The dominant characteristics of the Asian face were a wider intercanthal distance in relation to a shorter palpebral fissure, a much wider soft nose within wide facial contours, a smaller mouth width, and a lower face smaller than the forehead height, when compared to Caucasian face.[18] Previous studies by Chang et al, regarding the three-dimensional analysis of the surface registration accuracy of electromagnetic navigation systems in live endoscopic sinus surgery had the sample size of 40 (20 men and 20 women), of which there was no racial predisposing factor as it was equally distributed.[19] The main objective of current study was to determine the estimate of each anatomical measurements instead of comparing the difference between them. Since the study had enrolled 30 subjects as planned, it was able to provide an estimate of the mean measurement with a margin of error not exceeding 1.00 mm at significance level of 0.05.[20]

Although facial analysis and proportions are well discussed in Caucasians and Africans, only a limited number of studies exist for Asians.[21] Amongst landmarks were the intercanthal distance and nasal length. Most studies concluded that the distance in Asians are wider than Caucasians with the mean intercanthal difference of 5.1 and p value of < 0.001 and nasal length mean difference of 1.2 and p value of 0.01.[21] Brielmann et al, also noted the difference between Asians and Caucasian faces, noting the most obvious difference between the two races are the eye (intercanthal distance) and the length of nose by pointing out the point of fixations of gaze by 24 observers.[22, 23] as we have compared the data in our study, there were no significant difference noted between the races. Rhee mentioned the percentage ratio of facial width to facial height was 74.4 % for Caucasians and 72.0 % for Asians which showed that the Asian face is wider. [24] In terms of photogrammetric measurements, the intercanthal distance in Caucasian is 31.4 mm compared to 35.7 mm in Asians and the nose height is 45.3 mm in Caucasian compared to 49.3mm in Asians.[24]

In a review article by Gao et al, East Asian have wider intercanthal distance and nose width compared to Caucasians (Italians).[25] In another article by Le, they have noted that intercanthal width is wider in Chinese (mean 37.1 mm) and Vietnamese (mean 36.7 mm) than in North Americans (mean 32.3 mm) but smaller in Thais (mean 36.6 mm). As for nose length the Chinese have a mean of 52.6 mm, the Thais have 50.5 mm and the Vietnamese have a mean of 51.3 mm compared to the North Americans 52.1 mm.[26] In our patients, we have noticed that the IGS is accurate for Asians even though using the Caucasian template. The measurements are almost the same between the actual measurements and the IGS measurements.

The time lapse between the CT done prior to the surgery is the average of 87 days. The longest time lapse between surgery and the preoperative CT scan is 242 days and the shortest duration is 3 days. However, the measurements of the patients taken during the time of surgery and when it is compared in the IGS has proved that even after some time, the IGS is still accurate since we use the bony prominences as reference points. Thus, the bone is not influenced by edema and tissue fluctuations. There was no study done to determine any specific duration of preoperative CT should be used for IGS. However, all of them suggested preoperative CT scans should be obtained and used in the navigation system.