The Accuracy of Stereolithography Medical Model of Sinonasal Anatomical Structures compare to 3D CT scan measurement.

By

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Abstrak (Bahasa Melayu)

Ketepatan model hidung and rongga muka stereolithografi di bandingkan dengan model 3-dimensi CT skan.

Pengenalan

Stereolithografi adalah suatu kaedah baru dalam bidang perubatan. Ia telah di gunakan untuk membina model anatomi di bahagian-bahagian lain. Ia perlu mempunyai ketepatan yang tinggi supaya dapat dijadikan sebagai bahan gantian dan untuk menjimatkan masa sesuatu pembedahan.

Tujuan

Tujuan penyelidikan ini adalah untuk membina model stereolithografi bagi kawasan hidung dan rongga muka bagi tujuan pengajaran di dalam bidang Telinga, Hidung dan Tekak dan Craniofacial. Ia juga bertujuan untuk menilai ketepatan model stereolithografi yang di hasilkan oleh mesin stereolihografi kami. Selain dari itu, ia bertujuan untuk menilai keberkesanan model stereolithografi untuk digunakan sebagai perancangan pra-pembedahan endoskopi dengan menggunakan System Panduan Bergambar. Jika ianya bertepatan, ia juga boleh digunakan sebagai kaedah latihan pembedahan endoskopi bagi calon-calon sarjana.

Kaedah

Data yang mempunyai anatomi normal bagi hidung dan rongga muka di ambil dari kumpulan data craniofasial USM. Data itu di proses dengan menggunakan kaedah tertentu dengan menggunakan perisian MIMIC. Kemudiannya model stereolithografi dihasilkan dari data tersebut. Model stereolithografi berkenaan di bandingkan dengan model 3D CT skan menggunakan penanda-penanda tertentu. Penanda-penanda itu dibahagikan kepada ukuran craniofasial umum dan ukuran hidung dan rongga muka. Model berkenaan di cuba untuk simulasi pembedahan endoskopi degan menggunakan system panduan bergambar.

Keputusan

Model stereolithografi menunjukkan ketepatan 99.68%untuk ukuran craniofasial umum dan 99.68% untuk ukuran hugung dan rongga muka. Ketebalan lamina papyracea menghasilkan ketidaktepatan terbesar iaitu 28.71%. Tidak ada corak yang menunjukan ukuran dalaman adalah berbeza dari coral ukuran luaran. Model stereolithografi tidak sesuai untuk digunakan sebagai perancang pembedahan endoskopi.

Kesimpulan

Model stereolithografi adalah sangat tepat pada ukuran-ukuran yang diukur. Model ini sangat sesuai untuk pembedahan craniofacial tetapi untuk pembedahan endoskopi ia masih belum lengkap lagi. Pembaikan bahan yang digunakan dalam stereolithografi perlu ada sebelum ia dapat digunakan sebagai model untuk perancangan pembedahan endoskopi rongga.

Abstract

The Accuracy of Stereolithography Medical Model of Sinonasal Anatomical Structures compare to 3D CT scan measurement.

Introduction

Stereolithography is a relatively new tool in medicine. It has been used to produce many anatomical models in various fields. The accuracy of stereolithography is thus essential to provide real replacement and time saving procedure.

Objectives

The objectives of this study are to develop stereolithography model for sinonasal region for ENT and craniofacial teaching and to assess the accuracy of stereolithography model produced by our stereolithographic apparatus. It is also to evaluate the suitability of stereolithography model to be used as pre surgical planning for endoscopic sinus surgery together with an Image Guided System. If appropriate the model also will be used for surgical training for resident.

Methodology

Data with normal paranasal sinus was collected from USM craniofacial CT scan database. The images were processed with a specific procedure using MIMIC software. A stereolithography model was produced using the data. The model was compared with 3D CT scan image using specific landmark. The landmarks were divided into general craniofacial measurements and sinonasal measurements. The model was tried for simulated endoscopic sinus surgery using Image Guided System.

Results

The stereolithography model shows an accuracy of 99.82% for general craniofacial measurement and 99.68% for sinonasal measurement. Lamina papyracea thickness produces the largest error of 28.71%. There is no pattern to indicate internal measurement group is opposite to the value of external measurement group. The stereolithography model is not suitable to be used as planning of endoscopic sinus surgery, since the anatomy requirement is very critical in the related area.

Conclusion

Stereolithography model is accurate in the dimensions that were measured. The model is suitable for planning in craniofacial surgery. However to be used as presurgical planning in endoscopic sinus surgery, it is still not detail enough. Further improvement in material used in stereolithography is needed before it can be utilised as presurgical model for endoscopic sinus surgery.

CHAPTER 1

INTRODUCTION

1: Introduction

Stereolithography is a subset of procedures known as Rapid Prototyping. Rapid prototyping is a process used in converting digital three-dimensional (3D) data into solid objects. The principle is to build the solid object layer by layer. Currently, there are five types of rapid prototyping techniques available in the market with more than 30 brands (Worldwide guide to Rapid Prototyping, 2005). They are fused deposition machine, selective laser sintering, laminated object manufacturing, 3D printing and stereolithography. The concept of each type will be briefly mentioned below.

Fused deposition machine (FDM) builds model by extruding a semi-molten filament through a heated nozzle in a prescribed pattern onto a platform. When the first layer is completed, the platform lowers by one layer thickness and the same process will be repeated. The process continues layer by layer until the whole model is completed. The system was pioneered by Stratasys Inc.. It is considerably fast but less accurate.

Selective laser sintering (SLS) employs laser beam to selectively melt a tightly compacted thermoplastic powder and bond it to form a layer of an object. The powder is spread by a roller over the surface layer by layer. The system is designed so that the temperature in the processing chamber does not go beyond the melting point of thermoplastic powder. The process is fast but for larger objects, post processing cooling take many hours to days.

Laminated object manufacturing (LOM) is a rather coarse rapid prototyping but has the cheapest material available. The system uses laminated plastic coated paper. Cross section profile of an object or model is cut from paper by laser or knife. The paper unwinds onto manufacturing stack and binds to previous layer using heated roller. The plastic lamina melted and adheres to construction model.

The latest technology in rapid prototyping technique is 3D printing. The process starts by depositing a layer of powdered object material at the top of a fabrication chamber. A measured quantity of powder is dispensed from supply chamber. The roller then distributes and compresses the powder at the top of the fabrication chamber. Subsequently a multi-channel jetting head deposits a liquid adhesive in a two dimensional pattern onto the layer of the powder. Where the adhesive is deposited, the areas become bonded to form a layer of the object. This is arguably the fastest Rapid Prototyping tooling available, but the model produced is low in resolution and more fragile.

There are a few other new technologies surfacing in recent years such as laser engineering net shaping (LENS) and inkjet technologies. However, they are not yet widely marketed. By far, stereolithography is extensively used in field of medicine because it is the most suitable technique for manufacturing medical model with high accuracy, smooth surface and good transparency (Laoui and Shaik, 2003).

Stereolithography is a technique which builds 3D model using polymers and advanced laser technology. The model is build onto a platform within vat containing liquid photo-polymers. The photo-polymers instantaneously cured into solid when they are exposed to laser light. The model is built layer by layer as the platform descent within the vat to allow the solid model to be submerged in liquid resin which will be cured for the next layer. The process starts from bottom and continues to the top until the model is completed. (Figure 1.1) The software automatically provides supporting structure for floating parts which needs to be manually removed after the model is completed.

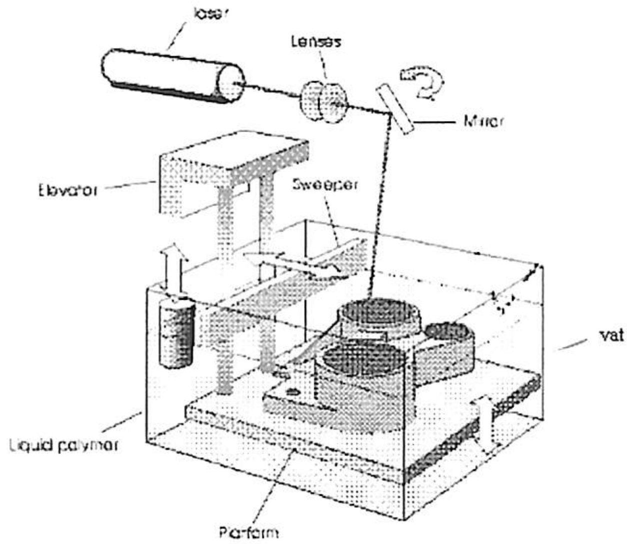

Figure 1.1 Principle of stereolithography apparatus

Stereolithography is a part of rapid prototyping technology which was developed for commercial product in early eighties. This technology spurred from computer aided design (CAD) technology which demanded a proper hardware to produce intricate 3D CAD design. Before rapid prototyping, the designers build their design with wireframes and surfaces. This method has many limitations and consumes a lot of time. The first rapid prototyping machine was stereolithography and developed by Charles Hull in 1986 who also co-founded 3D Systems Incorporation (Cooper, 2001).

This development revolutionizes integration of engineering and medicine. First, rapid prototyping is utilised to create medical equipment such as inhaler and surgical equipment prototypes. Later on, advances in biomedical implant, in particular biomaterial and medical implant, which are used to replace human tissue and perform certain physiological functions, has also utilised stereolithography. The design and development of these technologies greatly associated with the use of stereolithography.

Human tissue 3D data are obtained by assembling sequential two-dimensional slices from any imaging modality that yields planar digital data, such as computed tomography (CT) and magnetic resonance imaging (MRI). The compilation of these sequential 2D data then assembled into 3D model using commercially available software. These softwares performed surface and volume rendering to predict and calculate the missing data in between the two slices of 2D images to build complete 3D finishing. (Figure 1.2) The human anatomical 3D images are much more complicated than CAD images used in engineering and industrial sectors.

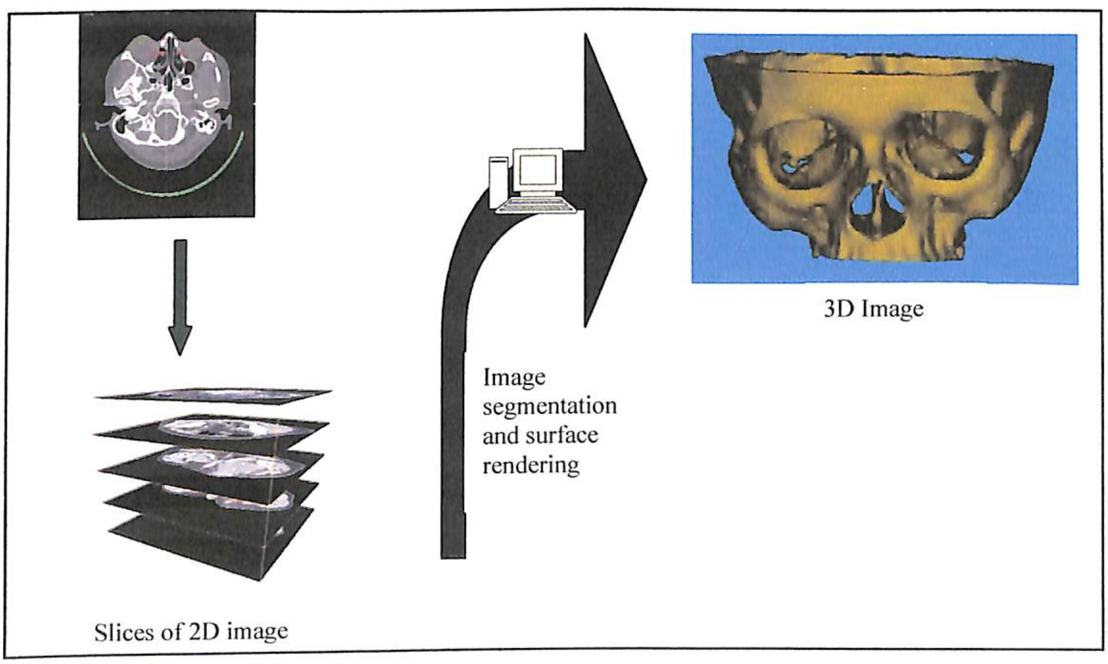

Figure 1.2 Image processing flowchart

Many surgeons analyze 2D images of CT scan and reconstruct the virtual 3D image using reconstruction software. They will then refer to those images while doing the operation. However, it is a virtual reality images on computer screen without tactile feeling of the object. The presence of rapid prototyping technology such as the stereolithography apparatus (SLA) has made planning task closer to real surgery and has tremendously assisted surgeons in accurately planning the operation as well as using it as a teaching tool for budding surgeons (Holck et al., 1999).

Initial assessment of stereolithography model was more accurate then milled model. However, at that time stereolithography was a very slow process owing to slow computer speed (Klein et al., 1992). As computer processor advances, the speed of the computer is no longer a major issue.

To our knowledge, craniofacial surgery is the first discipline to use stereolithography. In 1994, a group of Austrian surgeon operated on wide midline craniofacial cleft in a baby and they employed stereolithography model in preoperative planning and intraoperative management (Anderl et al., 1994). Later on surgeons in various fields, researchers, archaeologists, forensic medicine started to pose their interest in stereolithography.

In craniofacial surgery, each case often unique and each operation need to be tailored to individual anomaly. As such, each operation can be considered as first operation to the surgeon. With stereolithography model, surgeon can do rehearsal and refer to the model during operation. Additional information can be gained when compared to CT scan or 3D CT alone (Sailer et al., 1998). Such cases as hypertelorism, severe asymmetries of the neuro- and viscerocranium, complex cranial synostoses and large skull defects benefit most from stereolithography. Reports of successful operation which made use of stereolithography model for presurgical planning includes congenital malar hypoplasia correction (James et al., 1998) and midline craniofacial cleft (Anderl et al., 1994). Brisbane craniofacial biomodelling group also reported the use of stereolithography model to facilitate operative planning and subsequently reduced operation time (Arvier et al., 1994). Moreover, the final outcome in craniofacial surgery which is aesthetic features, is better with stereolithography model assistance (Bill et al., 1995).

Ongoing interest in mandibular prosthesis leads to the use of stereolithography model as well. Pre-operative model allows better planning of metallic implants framework and give excellent contour planning for grafting (Kernan and Wimsatt, 2000; Morris et al., 2000). Presurgical planning in distraction osteogenesis also allows for better accuracy in congenital micognathia and transverse arch deficiency corrections (Whitman and Connaughton, 1999).

In the orbital region, (Holck et al., 1999) reported the use of stereolithography model in reconstruction of delicate orbital frame. Defect of the orbital floor and wall was corrected using custom made plate which made possible by the stereolithographic model of the orbit. In the case of orbital brachytherapy, stereolithography model assisted in correct placement of implant and optimise the dose prior to the definitive surgery. Subsequently its minimise the risk to the opposite eye (Poulsen et al., 1999).

Apart from using the stereolithography model in craniofacial surgery, study of facial aging could benefit from this technology (Pessa, 2001). In proposing a concept of continual differential growth of maxilla, Pessa in his preliminary work in evaluating craniofacial features of different age group, proves that facial bone continues to undergo differential growth throughout life. Prediction of future human facial anatomy can be done by measuring the angles of maxillary wall and pyriform aperture relative to sella-nasion. This mean angles decrease as age advances and this is called 'angular change'. This study used a retrospective cohort analysis, it can be validated with prospective longitudinal study done to prove these changes. The concept of continual differential growth can be applied in many fields. Stereolithography combined with optical laser scanning system and 3D photography, may play a significant role in police investigation, forensic medicine, archaeological study and facial reconstruction surgery.

Cranioplasty is a common operation performed following craniotomy. Large craniotomy exposes brain substance to external injuries and predisposes it to Trephine Syndrome. This syndrome was first described by Dujovny et al in 1997. It is related to changes to cerebrospinal fluid and cerebral blood flow dynamics alterations. Cranioplasty offers protection for brain substance and treat the Trephine Syndrome. The operation is performed using various materials such as bone grafts, mineral grafts, metallic grafts and polymer grafts. Custom made cranial plate gives best fitting, excellent cosmesis, cheap and able to reduce operating time (D'Urso et al., 2000). Stereolithography, which offer such convenience, has been employed widely. In a case of meningiomas invading bone, single step operation can be performed. Removal of affected cranium is planned precisely and corresponding cranioplasty can be made accordingly in one setting (Perez-Arjona et al., 2003).

Orthopaedic surgeons have also found stereolithography useful in their practice. Standard orthopaedic teachings rely heavily on 2-dimensional X-ray films and compare them with unaffected side. With stereolithography model, surgeon has unique opportunity to look and feel the exact replica of affected bone-joint structure. (Brown et al., 2002) presented a series of eight complex acetabular fractures which was repaired with interposition template. They used reversed contralateral non-fractured pelvis stereolithography to help them planned accurately the position of fixation plate and screws trajectories. The operation time substantially reduced with such technique. Cases such as peri-acetabular osteotomy, hip overlapping with non union, dysplastic hip, and calcaneal fractures have shown better alignment and fusion (Kalc et al., 1997).

Furthermore, stereolithography is also making its way into vascular surgery. Replicas of abdominal aortic aneurysm was used for preoperative evaluation and stent placement simulation (Kato et al., 2001). They confirmed that this method is very useful for planning and simulating transluminal stent-grafting of aortic aneurysms with complicated morphology.

Besides the surgeons, researchers in pharmacology find stereolithography interesting. They thought that by replicating hollow tracheobronchial tree, they would be able to effectively evaluate aerosols drug delivery in airways (Clinkenbeard et al., 2002). By using airway model from standard "Visible Human Project", this stereolithography model could become gold standard in aerosol drug delivery research.

Research of fluid dynamic in the area of cardiovascular previously has been using 'glass blowing' technique to produce human equivalent anatomical model. This technique is operator dependent and not very accurate (de Zelicourt et al., 2005). The availability of clear resin makes stereolithography model a better alternative than clear glass in studying cardiopulmonary blood flow dynamics study.

Ultimately, it is not only surgeons or scientist who would gain the benefit, the patient can see and feel the defect themselves and the expected outcome (Finkel, 1996). The patient together with family can have greater understanding of the problem and this would further facilitate discussion with surgeon. It gives a different dimension of informed consent and patient can have a more realistic expectation of the surgical outcome.

The use of stereolithography models in the area of Otorhinolaryngology is being evaluated. Its application in training of temporal bone dissection will certainly be the answer for scarce cadaveric temporal bone. A few countries have restricted cadaver harvesting due to moral and ethical issues. Early on, a group of German surgeon claim that stereolithography of petrous bones are able to provide an alternative to cadaveric specimen (Begall and Vorwerk, 1998). Practising on these model are corresponds to human cadaveric specimen in term of material characteristics and anatomic details of human structures (Vorwerk and Begall, 1998). On the other hand other group claim that resin used does not look like bone or handles like ones (Mills and Lee, 2003). The differences may be due to different types resin and techniques used to produce the stereolithography models.

Cases of microtias have been managed with the help of stereolithography. The normal side was used as a template. The image of normal ear was extracted from MRI imaging and digitalized and reformatted into a 3-dimensional mirror image. The data then is used to produce a stereolithographic model of the corresponding ear. A model wax ear is created by pouring molten wax into a silicone mold of the resin model ear (Coward et al., 1999). The model can be referred to when reconstructing cartilage framework for auricle grafting (Park et al., 2000).

Operations of neck region also gain additional benefit from stereolithography. By using a model which combines bone and soft tissues structures, (Santler et al., 1998) claimed the model provides anatomical bony landmarks for orientation during the operation and the exact distance to the pathological structures. Colour stereolithography further enhance the identification of the extended area of tumour (Kermer et al., 1998).

In rhinology area stereolithography model of sinonasal airway was used to compare the accuracy of two rhinometries (Djupesland et al., 1999). Because the model of sinonasal constant and its true volume is known, it becomes the constant value to compare the two variables. Moreover it is a true replicate of sinonasal airway thus provide the "gold standard" in rhinometry validation.

The important character of stereolithography model is how much it resembles the actual anatomy or in other words its accuracy. The accuracy of stereolithography model of orbit is ranging from 97.7% -99% (Poulsen et al., 1999). However it was noted that area of midface is more prone to error than those of other craniofacial region because of the presence of thin walls and small projections (Chang et al., 2003). The minute structures of sinonasal are critical in endoscopic sinus surgery. The accuracy of stereolithography model to represent the detailed paranasal sinus and lateral wall of the nose has not been evaluated.

Image guided system currently has become an integral part of endoscopic sinus surgery especially in United States. Initially it was used in limited neurosurgical procedures but now its application has involved wider surgical community such as Otorhinolaryngology, Maxillofacial, Dental and Orthopaedics. The reasons are due to its function in aiding the surgeon to perform surgery in difficult anatomical places as well as due to legal requirement. In endoscopic surgery, surgeon has tunnel view of the area operated and it only shows 2-dimensional views of complex 3-dimensional anatomical structures. It also lacks of depth perception (Sethi and Pillay, 1995). If not careful adjacent structures can be injured. The image guided system assists surgeon the see the area surrounding the working field.

The system allows the surgeon to compare the 2-dimensional endoscopic view with preoperative imaging information. It provides multiplanar views which are coronal, saggital, axial and reconstructed 3-dimensional images. Apart from providing bird eye view of operating field most importantly it depicts the position of the tip of the instruments. Once the skull base areas of clivus and orbital apex were only accessible through external approach and endoscopic approach poses great danger. Nevertheless now the surgeon can navigate through these complex structures and avoiding dangerous structures such as carotid arteries, basilar arteries, optic nerve, pituitary and brain stem (Kingdom and DelGaudio, 2003).

There are a few Image Guided Systems available in the market. All of them have four basic units for operation: (1) a data set in three dimensions, such as a CT scan and or MRI, (2) a computer to process the CT data and allow it to be used in interactive fashion, (3) a mechanism to register the data set to the patient, such as a headset or fiducial markers, and (4) a mechanism to calibrate instruments so that while they are manipulated inside the registered surgical field, the movements are traced and translated to the data imaging set.

Prior to the existence of CT scanning, stereotaxy surgery; which is precursor to image guided system, rely on plain radiograph, anatomical landmark and standard anatomic atlases of brain. Even after the introduction of CT scan in 1970s, the headset frame only serves to guide trajectory path of an instrument, not the depth of the tip of the instrument (Palmer, 2005).

The CT scan data for each patient is quite large and requires a powerful computer to process the images and provides instrument tracking. In the past, this kind of task usually need big workstation computer such as SUN Inc. workstation. With the advent of more powerful computer processor, a personal computer is adequate to allow faster interactive imaging and image updates. Latest system provides movie-speed scrolling through images to provide improved understanding of multiplanar anatomy.

When the system was first introduced, it employed headset frame for registration. Registration refers to a process where a marker on a patient would be consistently matched with the specific marker or coordinates on the image. The headset was fixed onto patient head and CT scan was performed. This method was superseded by a frameless technique. In frameless technique, few fiducials are placed on patient skin at specific points. These fiducials are radio opaque and form coordinates on the images. The latest system uses surface optical laser registration which is a much faster process.

Early machine utilised rigid arm probe with servo-position joints and pointer end. This machine calculates the angle of each joint to estimate the position of the pointer end. The probe was difficult to use thus did not gain popularity. An early machine which uses electromagnetic devise also was found to have unacceptable inaccuracy. Soon after that, machine which uses optical devices started to enter the market. This system is more accurate but early machine was too bulky and expensive. Current optical tracking systems in the market are more portable and comparatively cheaper.

The accuracy of the system has consistently shown to be within 2 mm of actual anatomical position (Metson, 2003). However the surgeons are recommended to periodically check their position against surface marker. Needless to say the technology is there not to replace human expertise but rather to complement the clinical judgement.

In recent years, surgical training has become major concern due to lack of cases and arising medical litigation. This has prompt some company to come up with surgical simulators as to provide as real environment for surgery it self. These machines have inherent problem, its does not feel real even though the visual images are as good as real surgery. There is no tactile feed back or terminology used in the industries called haptic feedback, that usually occurs when one doing the actual surgery. There are several system in market such as SensAble PHANTOM, the Laparoscopic Impulse Engines from Immersion, and the VS-One virtual endoscopic surgery trainer (Maass et al., 2003). The systems provide flexible and stable haptic feedback. (Hochberger et al., 2005) in their clinical trial found that simulation surgery has improves the performance of fellows training. Even though surgical simulator does not provide hundred percent real feed back, it does give benefit in early endoscopic surgical training.

This study hopes to assess the accuracy of our stereolithography apparatus in producing anatomical model of sinonasal region. Furthermore the model will also be evaluated for the use in endoscopic sinus surgical training with image guided system. We hope that if suitable, the stereolithography model also will be used for rehearsal of difficult skull base surgery with endoscopic approach.

CHAPTER 2

STUDY OBJECTIVES

2: Study objectives

The general objectives of this study are:

- To develop an educational surgical model of sinonasal region for ENT and craniofacial teaching.

The specific objectives of this study are:

- To assess the accuracy of stereolithography model of sinonasal tract developed from CT images.
- To develop stereolithography model of sinonasal anatomy.
- To investigate the efficiency of stereolithography model in the field of ORL in particular for simulation endoscopic sinus surgery.

CHAPTER 3

METHODOLOGY

3: Methodology

3.1 Model Preparation

The protocol flow chart is shown in the figure 3.1. One set of CT scan from USM craniofacial database with normal paranasal anatomy was selected. The CT data was acquired using CT scan machine GE LightSpeed (GE Medical System, WI, USA) with 1.25 mm interval slices using spiral scanning mode. The scanning was carried out with a current of 200mA at 120 KVP. The data output was DICOM mode with 512 x512 matrix. The images was in 2D format consist of 182 slices.

Data collected is transferred to craniofacial workstation online. The data then copied to a compact disc and transferred to an Intel Xeon 1.7Ghz powered workstation computer with Mimics software version 7.3.(Materialise, Harislee, Belgium).

Because of the thin bone nature of midface and sinonasal region, the software has difficulties in differentiating bone and soft tissues. The 2D images were edited manually by drawing the thin bone. The method is as follows. First two set of masks were selected; one with threshold value of 700 and the second set is 1049. The first set was selected because is a standard threshold used in previous studies (J.-Y. Choi et al., 2002) however this threshold does not lineate sinonasal region very well (figure 3.2). The second set was selected based on our density analysis (figure 3.3) in the MIMIC programme which is best for differentiating the bony structures and soft tissue mucosa. This threshold however makes dense muscle appears as bony structures (figure 3.4).

Flowchart of methodology

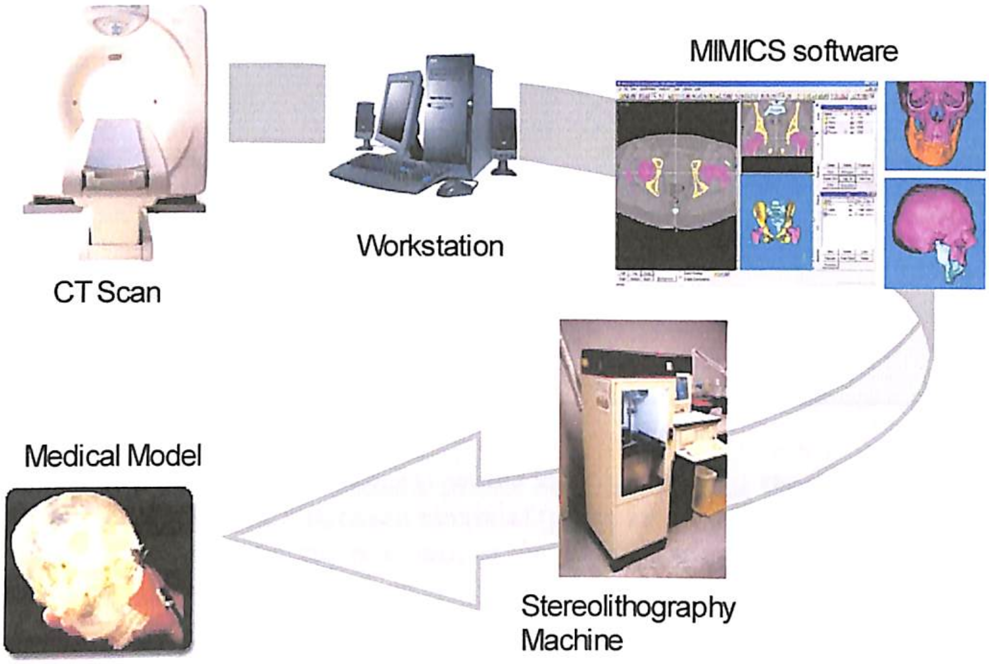

Figure 3.1 Flowchart of methodology

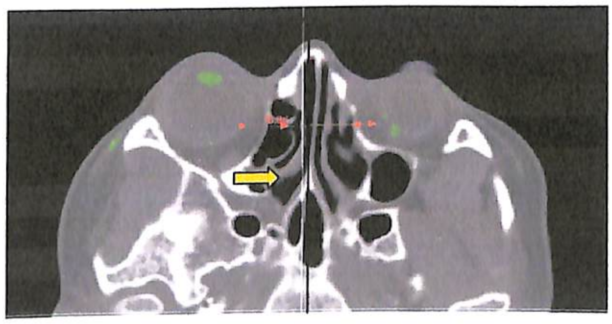

Figure 3.2 Regular threshold value, note that (yellow arrow) thin bones of sinonasal region do not appear white.

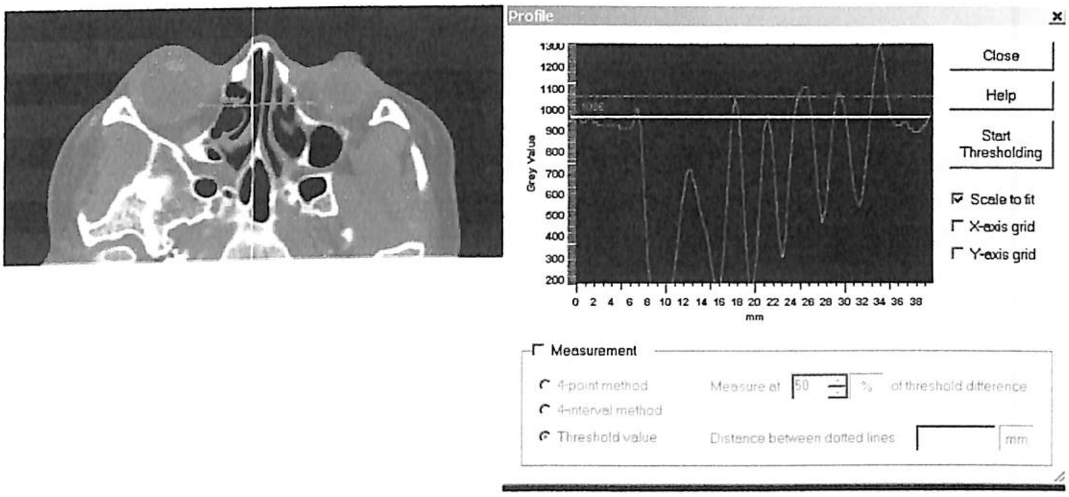

Figure 3.3 Cross sectional profile analysis of image threshold value. Note narrow window between maximal (green line) and minimal (white line) of threshold value for thin bone in sinonasal region.

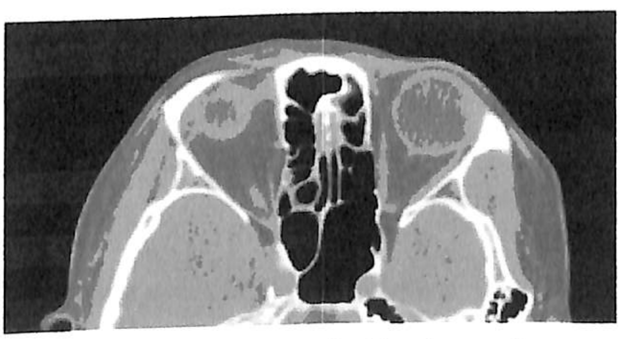

Figure 3.4 Higher threshold value makes thin bone appear as bone but trade of with muscle which appear as dense.

	Image editing process
1	Two masks are selected.
2	Profile analysis of the image.
3	The standard threshold value for sinonasal bony structure chosen as first mask.
4	Second threshold value with minimal noise to bone based on profile analysis as above chosen for second mask.
5	The two masks overlapped with second mask as an active mask.
6	Sinonasal wall of the first mask is traced on active mask using pen tool.
7	The drawing is performed to all CT slices.

Table 3.1: Summary of editing process

The two masks then overlapped with the first mask as the active mask. The thin bone was drawn as trace on the second threshold. This process was done layer by layer until all sinonasal regions are completely built. The images later processed into 3D image which then converted into .stl format. Summary of editing process as shown in table 3.1

The constructed images in .stl file are then imported to SLA machine (Viper SI2, 3D System Inc. CA, USA) to fabricate medical model. The material used was photo sensitive resin (RP Cure 550ND). Finally the model is allowed to dry under UV light for 72 hours and prepared manually to smooth the surface.

The model then cut into several pieces to for measurement of internal structures. The measurement was done using digital calliper (Absolute Digimatic, CD-6"CS, Mitutoyo Corp, Japan) on the SLA model while the constructed CT scan measurement was done using tool features inbuilt in MIMICS program.

3.2 Measurement

A landmarks were chosen as comparison with previous study (J.-Y. Choi et al., 2002). Additional landmarks were chosen as they represent the measurement of sinonasal region (Figure 3.5). Sinonasal region consists of nasal cavity and paranasal sinuses. The nasal cavity extends from nares, through the external nose and between the bones of the face, as far back as the posterior nasal apertures. Paranasal sinuses are certain bones that form the boundaries of the nasal cavities that are hollowed out (Sinnatamby, 2000). These land marks are divided into general and sinonasal landmarks for compatible comparison.

Anatomical landmark of sinonasal area measured are:

- Distance of the two inferior orbital foramina. (IOF-IOF)
- Distance of medial wall of orbit just behind lacrimal bone.(MO-MO)
- Length of hard palate at midline (ANS-PNS)
- Nasion to anterior nasal spine (Na-ANS)
- Nasal aperture width (LNA-LNA)
- Anterior nasal spine to anterior alveolus (ANS-AAl)
- Lateral pyriform aperture to zygoma (LNA-ZyP)
- Thickness of lamina papyracea
- Thickness of nasal bone
- Septum thickness

General landmarks

- Distance of bizygomatic width. (ZyP-ZyP)
- Distance between the two zygomaticofrontal sutures (ZyFS-ZyFS)
- Width of foramen magnum (RFM-LFM)
- Anteroposterior length of foramen magnum (AFM-PFM)
- Anteroposterior length of bony internal cranium.
- Distance between mastoid processes (MP-MP)
- Distance between foramen ovale (FO-FO)
- Distance between foramen spinosum (FS-FS)
- Width of one of defect on hard palate

For each landmark, 10 measurements were made on the model and reconstructed image respectively. The measurements were done by same person to reduce interpersonal variability.