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Image Guided Surgeries

Navigation and Surgical Technologies

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<p>This study is an introduction to the Image Guided Surgery (IGS) and Navigation Technology with an aid of practical and literature reading. It describes the use, techniques and properties behind IGS and the area of its use.</p> <p>Navigation is a quite new technique in the surgical field, and not many have experienced using it. It displays challenges on understanding how to navigate three-dimensional anatomical volumetric. Passing over these obstacles, it opens a variety of new research methods and innovative approaches.</p> <p>For a surgical solution, this research indicates that by using computerised tools, it will offer enormous opportunities to pre-plan surgeries accurately and solves problematic issues relating to complicated surgical cases. The study tries to present the concept primarily via sets of clear, approachable notions to comprehend the use of the navigation technology.</p> <p>Near the end, this study concludes benefits and disadvantages. It will raise and highlight some questions regarding to new possibilities for further way of usage of IGS that could be implemented.</p>	
Keywords	Navigation, Accuracy, Surgery, Imaging

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<p>Tämä opinnäytetyö esittelee kuvaohjattua kirurgiaa sekä navigointitekniikkaa käytännön kokemusten ja kirjallisuuden avulla. Tässä opinnäytetyössä esitetään navigaattorien käyttöä, tekniikkaa sekä niiden ominaisuuksia ja käyttöaluetta.</p> <p>Navigointitekniologia on suhteellisen uutta kirurgian alalla, eikä monella ole kokemusta sen käytöstä. Navigointitekniologian haasteina on navigointi kolmiulotteisessa anatomisessa rakenteessa. Näiden esteiden ylitsepääsemisen myötä aukeaa uusia tutkimusmenetelmiä ja innovatiivisia lähestymistapoja.</p> <p>Kirurgiselle ratkaisulle tämä työ osoittaa, että tietokoneistettujen työkalujen käyttö avaa valtavia mahdollisuuksia leikkausten esisuunnittelun tarkkuudessa sekä ratkaisee monimutkaisiin toimenpiteisiin liittyviä ongelmatapauksia. Tämä tutkimus yrittää esittää käsitettä ensisijaisesti selkeästi sekä helposti lähestyttävien käsitysten kautta, navigointitekniologian käytön omaksumiseksi.</p> <p>Lopuksi, tässä työssä paneudutaan kuvaohjatun kirurgian hyötyihin ja epäedullisuuksiin, erityisesti nostoen esiin kysymyksiä uusista mahdollisuuksista, joissa tietokoneita voitaisiin jatkossa hyödyntää kirurgisissa toimenpiteissä.</p>	
Avainsanat	Navigointi, Tarkkuus, Leikkaus, Kuvantaminen

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1. Introduction

Few years ago, I started my work at a medical device company called Medtronic while being at the end of my studies. I worked as technical and clinical consultant in navigation and imaging department, which is part of overall surgical technology division. At the time, navigation was entirely alien to me. However, I gain a lot of knowledge within a course of a year. Going through many training and onsite training, my knowledge of navigation principle and in-depth use increased, especially in clinical use. While I was consulting the surgeons and passing my knowledge forward on to the new users, I realized that navigation was quite a foreign idea to many, in particular for those who don't like relying on a computer. So I decided to write my thesis on this subject and explore further my knowledge. I also wanted to expand my understanding on the technology applied to create the navigation. Image Guided Surgery (IGS) field is considerably new and hope my research will unfold overall technical and clinical usage of the navigation.

2. History

In the history of the surgical field, there were three main obstacles that had plagued medical profession up until the modern surgery, bleeding, pain and infection. Now these barriers are less of a worry because after discovering methods and ways to stop the necessary restrictions, new opportunities arose and with them challenges as well. Until the discovery of x-rays, it was virtually impossible to diagnose internally without an incision. So the use of X-ray in 1895 as a medical diagnostic tool, it allowed a surgeon to perform preparation, with the skeletal structure to be captured on a photographic plate before surgery [a]. It was a revolutionary concept, and we can think of this as start of the technological era in medicine. Since then, a number of technologies have had a significant impact on surgical practices. These include electrosurgery, endoscopy, laser surgery, computer assisted surgery and robotic surgery, of which the two latter were developed in 1980s [a].

Computer assisted surgery (CAS) is an umbrella term which describes a medical technology that uses sets of ideas on computer powered tools. These includes planning, guiding or/and performing surgical and medical cases that were first developed for neurosurgery. It comprises varieties of sub-methods like Computer Assisted Intervention, Image Guided Surgery and Surgical Navigation of which the latter will be covered. The aim at the time was to improve the accuracy of the surgical procedure and to provide a

most accurate presentation of the critical structure of the brain. It does not only comprise from computer calculation but a compatible instrumentation and especially dedicated techniques as well. Later on, technology evolved to be implemented in other medical areas like Spine, Cranial and ENT (Ear, Nose and Throat).

3. Image Guided Surgery

Image Guided Surgery (IGS) and surgical navigation work hand in hand and most cases provides the best outcome. These techniques have improved over last years. They started from laboratory experimentation, then transformed into a tool for specific cases and now are a routine procedure in most well-equipped hospitals. Image Guided Surgery and particularly surgical navigation could be found in a several applications.

The first reference ever made on the use of computer in a medical journal was in 1958 and by 1961 several authors mentioned the usage of it as a patient care management or diagnostic assistants. Within few years, computers grew to be applied in medical care settings that created sort of uncertainty among physicians who felt threatened by the new technology that might make their job antiquated. Eventually computer started to be used more than just for surgical records keeping and where slowly applied to assist in pre-operative and later in intra-operative surgeries, first helping neurosurgeons. Soon after computers were confidently adopted in mainstream business technology. [a.]

The surgeons who recognised the potential of computers pioneered the ability to capture and organise massive data to assist in describing, categorise and diagnosing patient conditions. By 1980s computer and computed tomography (CT) scanner had become common devices and these improved imaging techniques and provided advanced help. [a.]

The number of physicians using digital radiography, patient records managements and data calculation in hospitals is growing. During past decades, there have been great strides in computer-assisted surgeries, moving from simple applications to assisting role as real-time intra-operative decision-making machines. Particularly in minimally invasive total hip and total knee replacement procedures, placement of canted hip screw, spine fixations and list goes on.[a.]

Image Guided Surgery and Surgical Navigation has emerged from these environments as an important and reliable aspect of computer-assisted surgeries and transformed

surgical interventions into safer and less invasive procedures. It evolved from simple locations tool to a centrepiece of modern surgery. Surgical Navigation has employed in a broad area of operations to pre-plan, visualise accurately and operate invasively, IGS can utilise Medical Imaging technologies. In following, will cover navigations use in these three surgical field.

3.1 Spine surgery

Human spine could be unstable, affected by disc disease, abnormal deformity, abnormal narrowing (stenosis), forward displacement of a vertebra (spondylolisthesis), fractures, tumours or even infection. For spinal fusion procedures, computer software (see figure 1) could be used for assisting spine surgeons to place implants like medical screws to stabilise spinal cord.

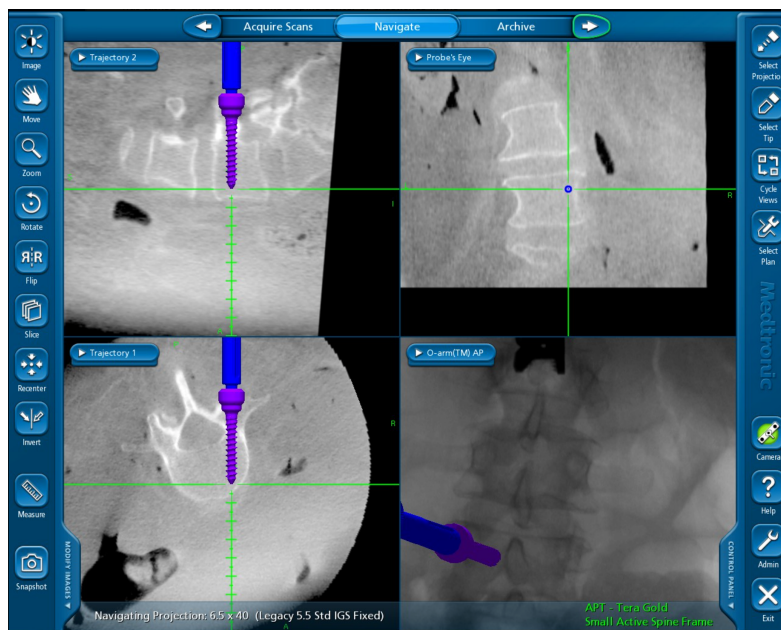


Figure 1. It shows Medtronic's Synergy Spine program is displaying patient's spine from tree views[1].

3.2 Neurosurgery

Out of all surgeries, neurosurgery would be the most crucial to use IGS technology. The surgeon uses computerised assisting (see figure 2), to help them pinpoint the anatomy of interest accurately by guiding surgical targets while adjusting traumatic risk. It could be used to conduct biopsies (taking a sample from the brain) by calculating trajectory and depth.



Figure 2. It shows Medtronic's Synergy Cranial software is displaying patient's head with tumour [2].

3.3 ENT Surgeries

Ear, nose and throat operations could be difficult due to complex sinus passage that requires the surgeon to be precise to avoid unintentional damage to delicate anatomy such as brain, eyes, nerves and vessels. Even with detailed knowledge of anatomy, it would give a challenge to perform a safe surgery caused by such as diseases, distorted sinus anatomy or nasal polyposis. For instance, small cavities and passages of the sinus (see figure 3) can be difficult to look inside only with optical visualisation. A functional endoscopic sinus surgery - FESS - which is a surgical method, implements navigation to avoid such challenges. Also, one of the primary goals is to prevent critical structures like an orbital floor.

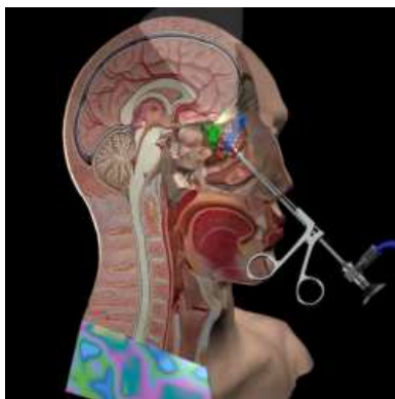


Figure (3). ENT endoscopic sinus injection. [3]

4. Navigation

Navigation in surgery means simply to be able to use a specified instrument inside the patient's body and to be able to guide the course of the instrument accurately through acquired image of the anatomy. It answers a question to where an anatomical target is or "How to reach a target" safety (see figure 4). Navigation surgery is based upon stereotactic principles, that is to be able to locate a point or points relative to a reference. A typical navigation system consists of a stereoscopic camera, computer platform with display, dedicated software and dedicated navigable instruments. Marker spheres are attached to this instruments to enable an exact localization in space. Then the movements of the instruments are displayed on a screen.

Image-guided navigation is a combination of various techniques, which would ease tremendous work with complicated surgeries. By acquiring images and matching specific points of the anatomy with the corresponding point on the images, surgeons can use the image as a map to navigate. This helps to visualise a structure that is not visible directly, like a brain tumour, on the image acquired from the patient. To understand more, one must understand the imaging technique that will be used as roadmap to navigate.

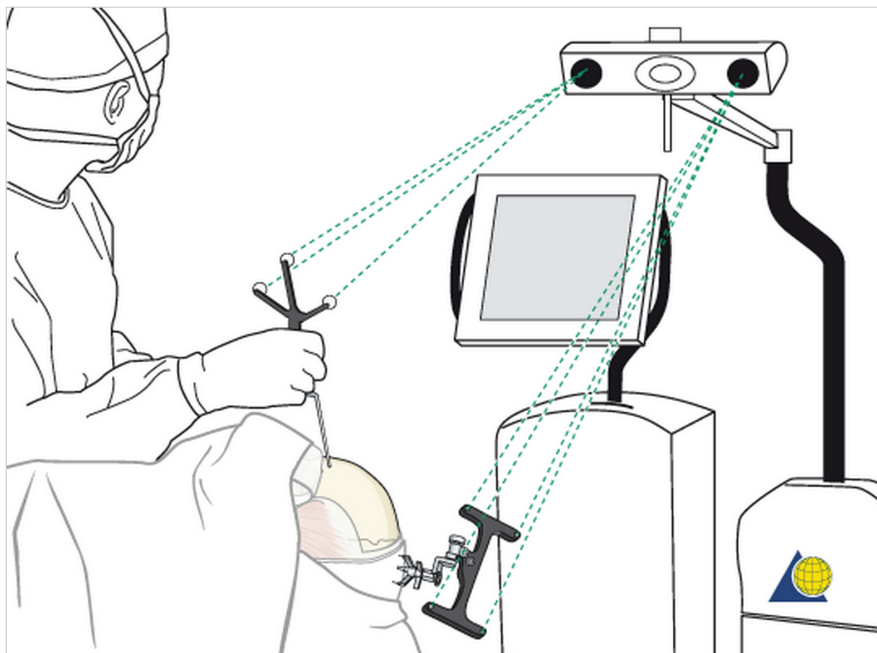


Figure 4. Detecting camera detects patient's frame and navigation a probe instrument [4].

4.1 Medical Imaging and Methods

The medical imaging concept is based on a two- or three-dimensional collection of image data using CT, MRI and surface-scan methods. Different structures of interest, especially bones, vessels, nerves and muscles are segmented. Medical imaging started as a military section of locating bullets by radiography and shortly after it was realised it could be used to support the stereotactic target of the skull. However, X-rays can not display soft tissue, so other methods were needed to overcome these problems, and thus new techniques were developed as the introduction of MRI that marked a milestone.

Medical imaging provides patient's specific pre-operative planning, simulation and training tasks that can be carried out by the surgeon using the image information present on the computer. The results of surgical manipulations can afterwards be visualised in the computer. In IGS, a simulation system would be used beforehand to predict surgical operation results. The benefit of the system will be the comprehension of risk-reducing simulation techniques to avoid injury of important body structures.

The first step in this surgical simulation is successfully acquiring a radiographic image data, which is received by use of CT and MRI. Then after uploading it to a computer, the system enables the surgeon to specify manipulations interactively in patient-specific models based on radiographic image data. Noise and artefacts are deleted from the images and after that possibly emerging the CT and MRI data by the algorithm to combine different information received by the distinct radiographic techniques.

It is possible to combine number of scanners and merge them into a single exam by data fusion techniques that will display pathological tissues and structures to produce the exact geometrical models of the anatomy of interest. In the resulting merged data, different types of tissue and segments are identified like the tissue classes bones, muscles and soft tissue can be distinguished. Explaining the difference between image technique would clarify understanding.

4.2 Differences between Imaging Technique

3.2.1 CT

CT (Computer Tomography) is a digitally processed x-ray, scanned from a specific object in 2D radiography like slices (Tomos) (see figure 5) and collectively used digital geometry processing to reconstruct three-dimensional images (see figure 6). Thus, it allows the user to see inside an anatomical volume. Its cross-sectional views are used for diagnostic and therapeutic purpose. It is the most common form of imaging in medicine due to quick scans (It takes fewer than 5 minutes) and relatively inexpensive. Thus, it is used in emergency rooms. CT Scans is best suited for viewing bone, diagnosing lung and chest problem.

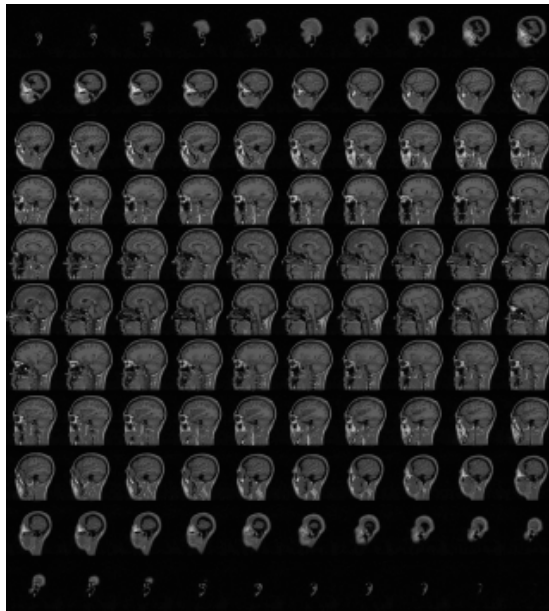


Figure 5. CT slices of a human head [5].

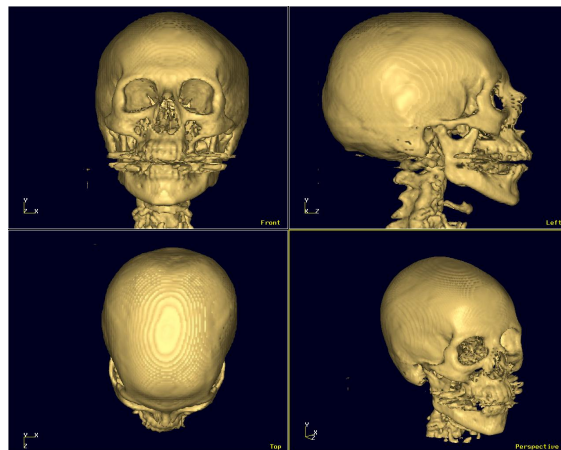


Figure 6. The reconstruction 3D image [6].

4.2.2 MRI

Magnetic Resonance Imaging (MRI) is an imaging technique used to investigate anatomy and physiology of the soft tissue in the body. It uses strong magnetic fields and radio waves to form images without exposure of ionising radiation however the scans take up to 30 minutes, and it cost typically more than CT scan. MRI is suited for examining soft tissue (see figure 7), tendon and veins and brain tumours.



Figure 7. A MRI of a head in a sagittal view shows only soft tissue [7].

4.2.3 Fluoroscopy

Fluoroscopy is a 2D X-ray imaging technique that can be used as a single scan shot (see figure 8) or by obtaining continuous scans, which it would form real-time moving scan of internal structure. This format can be used to highlight objects. In its simplest form, it consists source and detector that by absorbing radiation it prints out the scan.



Figure 8. A single coronal scan of human body [8].

4.2.4 Ultrasonography

Ultrasonography is ultrasound-based imaging technique that uses ultrasound waves for visualising internal object (see figure 9). In medicine, it could be used to see body organs like redound, muscles, joints for diagnostic and pathology. It provides radiation-free real-time imaging and a low cost a portable machine compare to other imaging devices. Howev-

er, it is limited to use for it has a limited field of view, difficulties to scan behind bones and air and it requires a skilled operator.

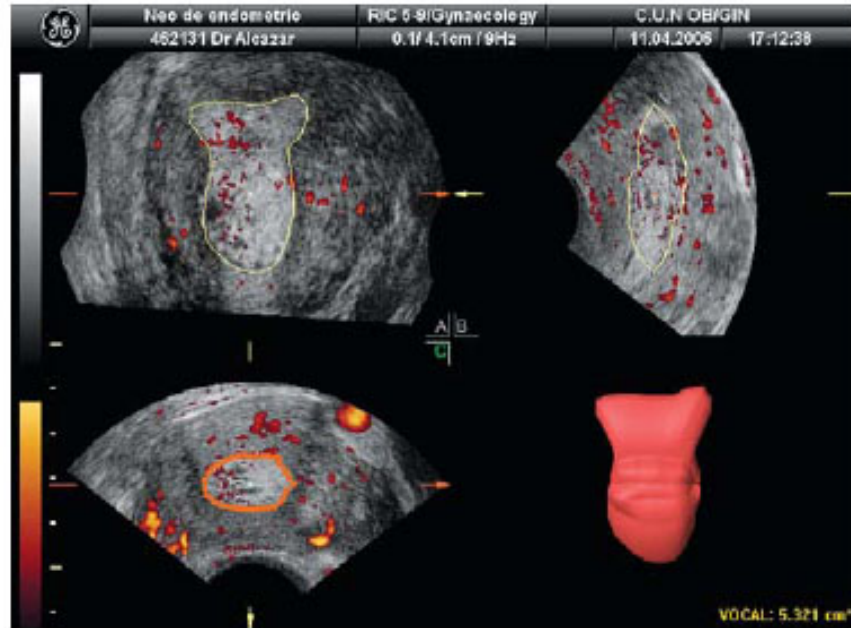


Figure 9. Orthogonal planes of a 3-dimensional sonographic volume with transverse and coronal measurements [9].

4.2.5 Cone Beam CT

Cone beam imaging technique consist of x-ray computed tomography where X-rays are divergent, forming a cone (hence the name). Compared to CT, Cone beam has flat panel detector and X-ray source rotating 360 degrees around a point of interest (see figure 10). As a result of the acquisition of two-dimensional projections of the rotation, only single rotation is needed to acquire information of the anatomy of interest. Imaging devices, like Medtronic O-arm, utilities this technique. By obtaining a single shot, virtually a system can produce fluoroscopy scan.

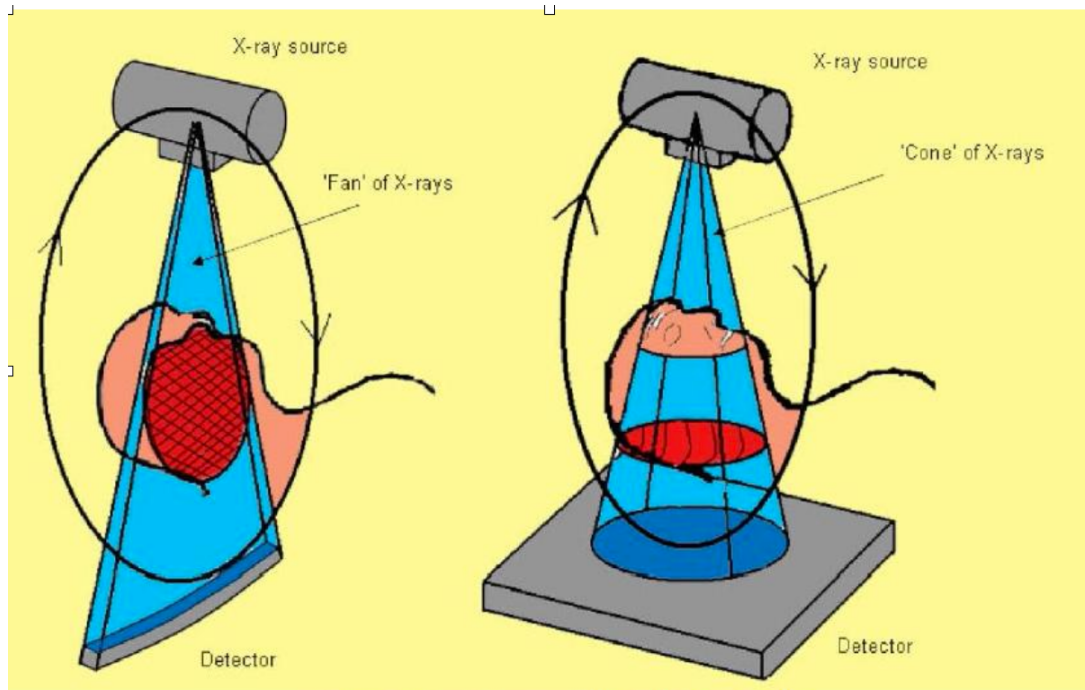


Figure 10. Difference between Cone Beam and CT [10].

4.3 Tracking and its Principles

Much like GPS system in automobile, navigation system allows a surgeon to guide instruments on 2D or 3D model of the patient in real time. There are two main techniques that are used in navigation, optical and electromagnetic, and these two are used in different applications, determined by surgeries' requirement.

4.3.1 Optical

An optical tracking is highly accurate and reliable in a clinical environment. Its basic idea is that it uses a camera (see figure 11) and markers to detect the position of the marker (see figure 12). The markers used to attach to an object and by detecting the marker, it allows the system to pinpoint virtually the object without seeing it. The system utilizes infrared technology, which be characterised as follows:

1. **Active Optical Tracking**
2. **Passive Optical Tracking**



Figure 11. Detecting/ray beam shooting camera [b,255].

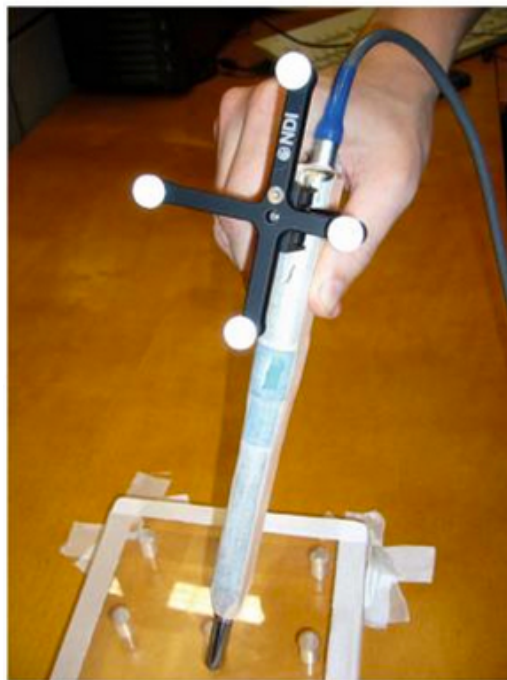


Figure 12. Markers mounted on instrument [b,255].

In passive tracking, the system operates near IR range. It uses infra-ray beam and an infrared detecting cameras to track retroreflective spheres (markers) which reflect infra-red light. The camera works as an “illuminator” and as a “detector”. In the optical tracking, a triangle is formed by two cameras (see figure 13). The distance of the camera is fixed and base on information received between spherical markers and the camera, the system can calculate angles of the geometric triangulation thus locating the target.[b, 253.]

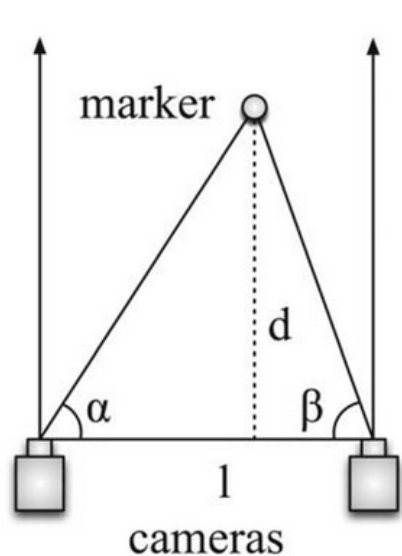


Figure 13. The formula is: $D = L / (1/\tan \alpha + 1/\tan \beta)$ and L stand for distance between the cameras[b,254].

To track a tool, it requires a measuring position and orientation of the tool. To do so, orientation can be two-dimensional, where to detect the rotation around the axis it requires a three-dimensional representation. A full three-dimension measurement of the orientation can tell which direction of the particular side of the tool is facing. The choice between those two determines how many tracked markers should be on the optical instrument. For instance, three-dimensional measurements of orientations require at least three markers to obtain three different position information from tree independent non-overlapping infra-red light lines. [b,253-255.]

Active trackers, on the other hand, utilize active sterilised LEDs as markers, that is tracked by charge-coupled device cameras. The LEDs are fired in sequence and are processed by a central computer unit to calculate and form triangulation based on known geometric configuration of the sequence received. Traditionally active systems

require a power source to power the LEDs. Active markers, in general, produce a higher accuracy of tracking. [b,253-255.]

Optical tracking technique has been predominantly used in surgical navigation because it can be used with metal (Electromagnetic can not) and camera tracking could be quite far away, as far as 3 meters, which it won't disturb already crowded operating room. However, it has its limitation. For instance, markers have to be visible to the camera at all time, which give "line of sight" problem. Anything that is blocking the view of the tracker or holding the instrument while blocking the markers could interrupt tracking thus discontinuing the navigation. Also patients frame must be positioned in an angle to face the detecting camera at all time, which may cause difficulties at the surgery. And for that, the position of the optical tracking system has to be pre-planned before surgery. [b,253-255.]

4.3.2 Electromagnetic Tracking

Electromagnetic tracking is an alternative for a tracking system. Its main advantage is that it has no line-of-sight limitation. However, the disadvantage is included distortion from nearby metal and limited accuracy comparing optical tracking. EMT incorporates three-orthogonal coil magnetic field generator (see figure 14). By running a current, it would generate magnetic flux of known geometry that with small electromagnetic field sensors is used to calculate both location and orientation of the marker in three-dimension. Comparing to optical tracking, it will require multiple markers. It is a very simple technique and quite reliable. [b,255.] [g,142-143]

Figure 14. Electromagnetic emitter creating electromagnetic field and EM-instruments. [11]

5. The need for Surgical Navigation

Before computer technology evolved, a surgeon had to prepare surgery in advance by taking scans and collecting data regarding the anatomy of interest for instance in a biopsy (see figure 15). It is called preoperative planning for pre-operative surgery.

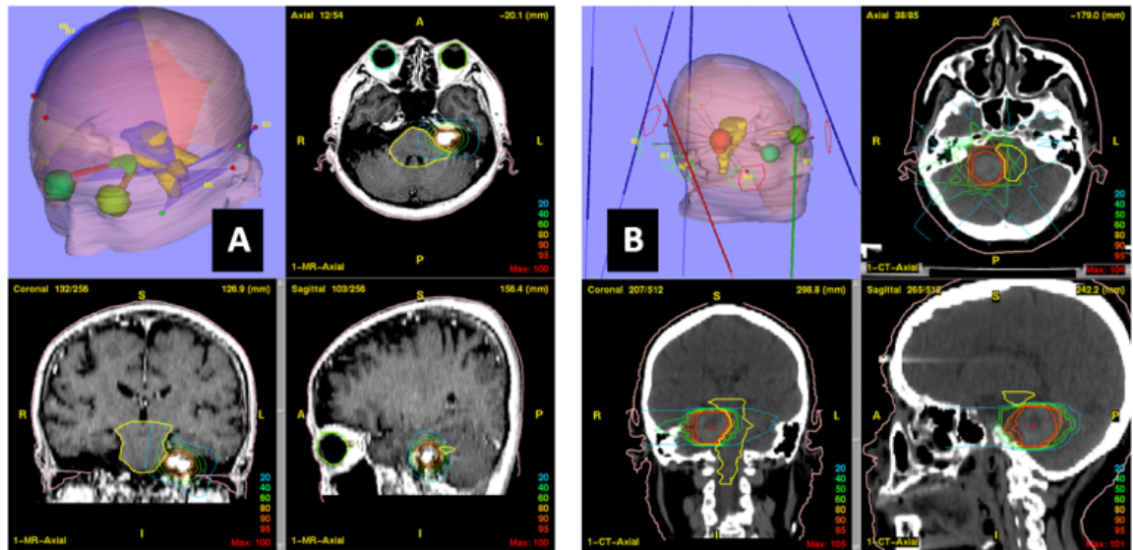
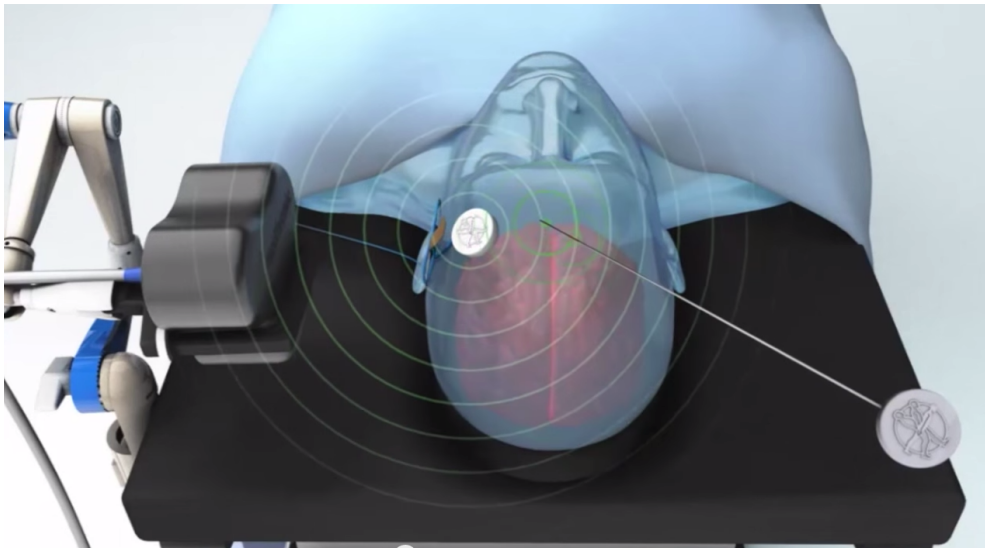


Figure 15. Dedicated computer software calculated and plans entry to the brain. [12]

A biopsy means taking a sample from unhealthy tissue for be tested. Before navigation, procedures like biopsies of a deep brain were performed using guiding stereotactic frame. Stereotactic means a target in three-dimensional space and a stereotactic frame (see figure 16-17) is like cage attached to the head through holes into a skull with twist-drill prior the operation. There are few different stereotactic frames.

The first step in neurosurgery cases such as tumour removal, an exam was acquired pre-operatively with a stereotactic frame attached to the patient, which then would be transferred into dedicated computer to:



- manipulate scans manually
- Identify the location of the anatomy of interest

- Adjust desired level of visibility of the anatomy of interest
- Opportunity to combine images from multiple modalities (CT, MRI)
- Display aspect of the anatomy and simultaneously visualise soft tissue, vessel and hard bones
- Locate coordinates of the targeted tissue to create surgical plan
- Precisely treat the target while avoiding healthy surrounding tissue.

The patient were then taken to operating theatre to start surgery procedure.



Figure 16. Simple Orthogonal Stereotactic frame [13].

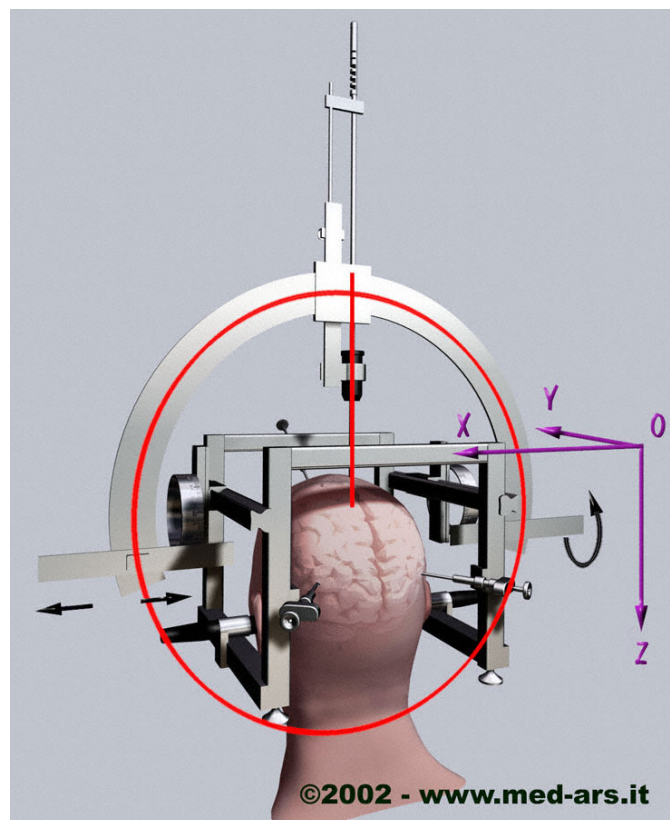


Figure (17) shows the X, Y, Z coordinate [14].

Patient's parting the hair an entry is made by sterile drill into the skull, about the size 3 mm diameter. A needle compatible with either MRI or CT is fixed at the entry (see figure 18) using data taken from the computer and inserted inside to take a sample. While the needle is advancing, before navigation it was virtually impossible to know where or how deep exactly the needle was. All is based on the data received prior the surgery. One method to track movement was to take constant fluoroscopy intra-operatively via C-arm to determine the location of the needle, which it would result in relatively massive amount of exposed radiation into the patient. [c.]

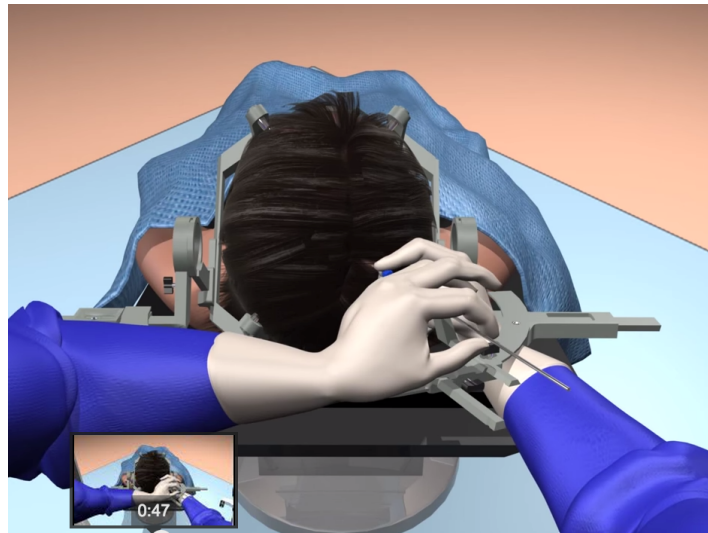


Figure 18. Surgeon performing biopsy by using stereotactic frame[15].

Though this is still in use in many cases and it has many disadvantages. A frame - based stereotaxy procedure had limited application just as biopsies and electrode placement (see figure 19). Other disadvantages include patient discomfort and limited surgical field view. When navigation first implemented, the idea was to be able to exact pinpoint and follow needle's location through the monitor. For that fiducial markers were either on a stereotactic frame, on the patient or separate frame. Shortly after the technique was advanced, it was realised that navigation made it possible to acquire scans without attaching stereotactic frame, which in some cases it oppose challenges due to frame had to be sterilised at all time.



Figure 19. Typical Stereotactic frame fastened to the patient's head prior to surgery with the fiducial marker attached to the face. In this case, the scan has been taken before attaching the frame. Later the scan were matched up by registration using navigation as the guiding tool. [16.]

By fiducial marker reference frame became in use in the 1990s the concept of frameless stereotaxy was developed, which since then technology has evolved to allow us to employ real-time tracking constantly visualising instruments position with reference

frame on pre-operative scans. This has naturally opened up doors even further to explore anatomical landmarks, offering intraoperative orientation, 3D measurements and implementation of navigated implant.

4.1 Registration

Registration is an essential requirement for all image guided navigation system. Simply it is as if dressing the image on to the patient anatomy. It is a computerised process used to match a three-dimensional position of the anatomy of interest. Thus before the first cut is made, pre-operative images are positioned by utilising reference points which are created by on-face fiducial markers or use mounted spherical markers reference frame to identify a relative position of the patient or anatomy (see figure 20). The reference frame which would be either attached to the anatomy of interest or place as close as possible in fixed position. The frame must not move during registration or after. Then using a various method of registration, to establish the correct response of the anatomy relative to the image acquired. The navigation system cannot see the patient nor the anatomy, only the frame, and by moving the frame, the image will move relative to it. So if patient's head is move and the frame is attached to the head firmly, the image will still correspond the anatomy. However challenges and risk would come if an issue is related to the spine. The spinal cord is very agile since virtually every vertebra moves relative to other. This can be overcome by utilising complex technique, like CT-Fluoro navigation, but an easier intraoperative technique was in demand. [d.]

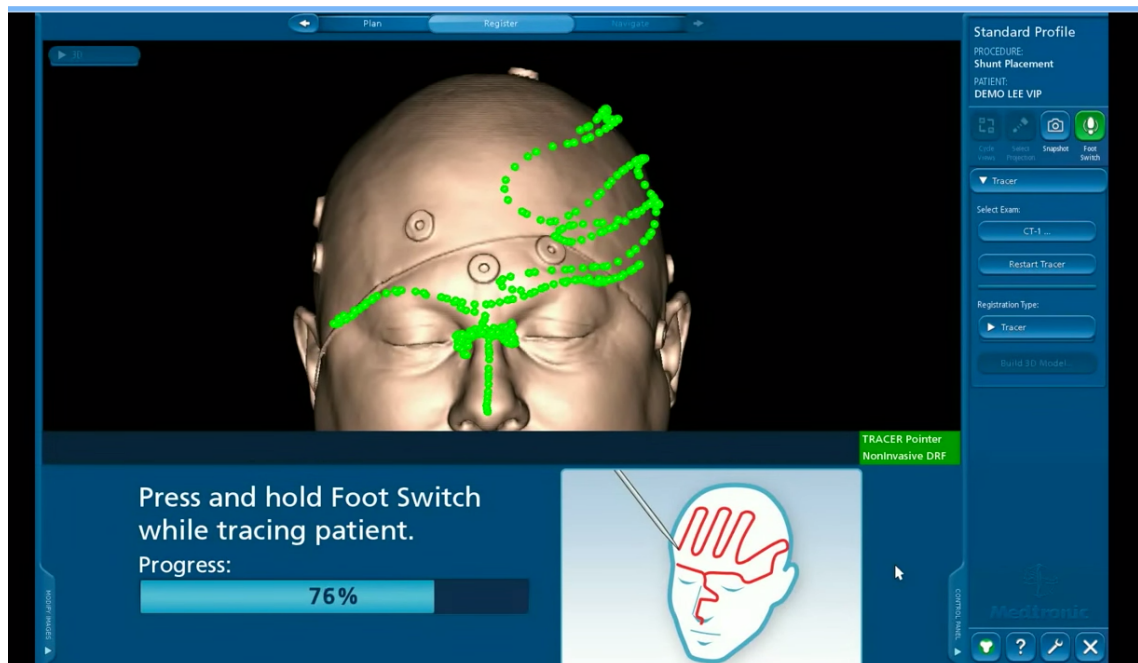


Figure 20. Medtronic's tracer registration method [17].

Common registration methods are:

- Point matching

In point matching, the idea is to register an image to the patient, involving the identification of common landmarks both in the images and on the patient. However, there might be difficulty in the identified locations of the landmark points on the patient and same locations within the patient's three-dimensional image. [d.]

- Surface matching

Some systems employ a surface-matching approach to complement the point matching method. This technique involves using the probe to sample points on the surface of the patient, and then determining the best match of this point-cloud to an extracted surface from the 3-D patient image.[d.]

4.2 Tracking system

Accuracy is the most important factor, which is a combination of correct registration, accurate tracking, image scanning quality and clinical instrument and with tracking probes provide the key to image-guided surgery. All types of methods have been employed to get the best accurate representation for the probe's position, but the use of optical trackers (both active and passive) has now become the most common one. Also, miniature magnetic sensors have their place and are evolving because so small that now it is possible to insert a catheter inside and track flexible instruments within the body. Whatever registration method, image technique and instrument used to track on the procedure, the same basic idea of coordinate transformation calculations will be employed to get as close "image-space" to those of "patient space" as possible. In the figure (see figure 21) below, it is displayed how the tracking workflow works.[d.]

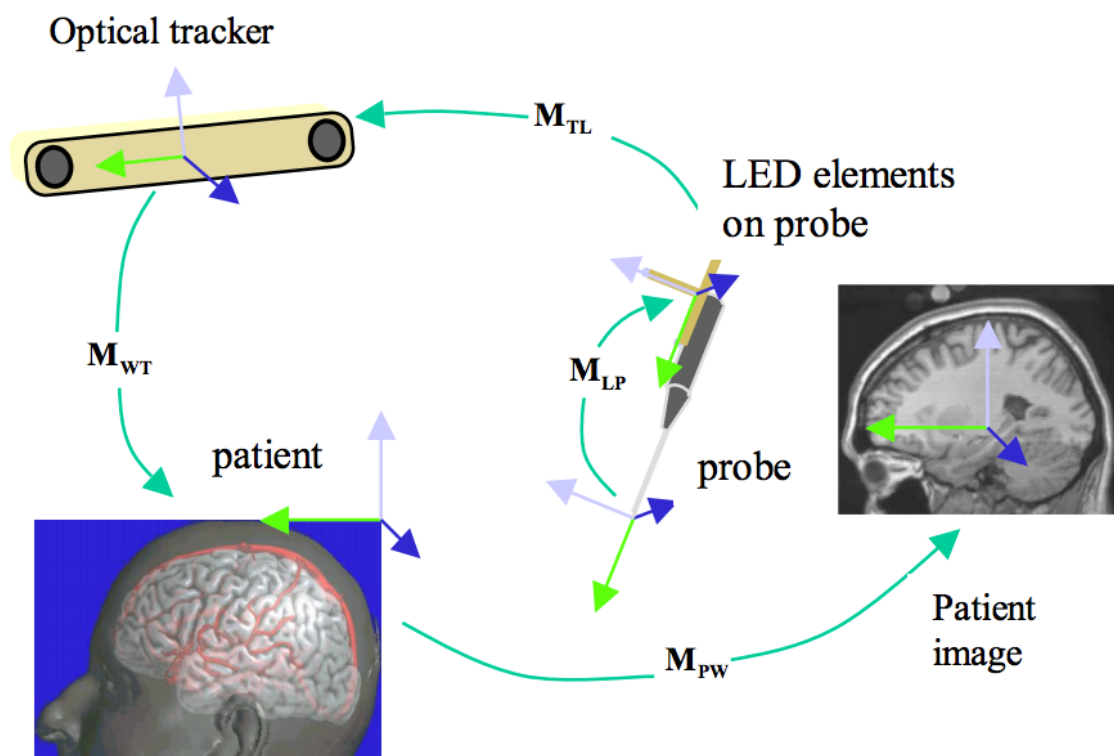


Figure 21. While moving the probes direction, the camera traces all motion and displace the movement on the monitor[18].

4.3 Intraoperative

A pre-operative surgery means preplanned surgery, typically used in cranial cases such as tumour removal. An exam acquired before surgery either with stereotactic frame or without, which then would be transferred into navigation system to be manipulated manually to adjust desired level of the anatomy of interest or tumour that would be removed. It also gives the opportunity to combine images from multiple modalities (CT, MRI) for surgical planning to proceed using information received from different aspect of the anatomy and ability to simultaneously visualise soft tissue, vessels and hard bones (see figure 22). After being satisfied with manipulated image, depending on whether a stereotactic frame is on or not, would determine what do next.[f.]

For instance in biopsy cases, the patient has stereotactic frame attached and used while scans were taken. Later on a dedicated program, like Medtronic FrameLink is

utilised before surgery to calculate X, Y, Z coordinates to get the angle and the entry points into the of anatomy of interest without causing possible damage to other tissue while taking a sample. Then the markers have to be visible if navigation is in question, either on the stereotactic frame or a separate reference frame. However the reference frame can not be too far from the interested target, due for any small inaccuracy, it will be multiplied the further instrument is from the reference frame. In any case, if navigation is needed a registration has to be performed.

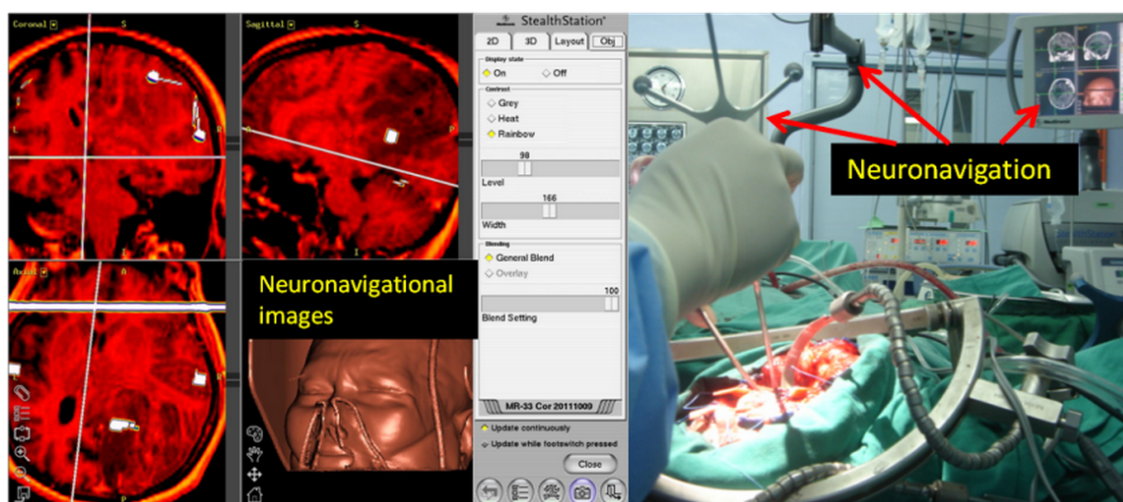


Figure 22. Neuronavigation system utilising Medtronic Framelink software and old Treon navigation system. [19]

In some cases, the frame may also present unnecessary clutter in the other procedure. In general it is desired to be a frames-less procedure as possible. Also, registration could be time-consuming, or there may be some small inaccuracies that would cause challenges.

Although navigation allows images-guided surgery to be performed without frames, this has its own challenges. The absence of a stereotactic frame might cause inaccuracy due the fact taking pre-operative scan without stable frame might cause changes in the tissue or anatomy. The Ideal produce would be to get real-time scan while the patient is in the operative position and transfer it into navigation system to be processed and navigate. This is generally called Intraoperative CT (IoCT). It eliminates the possibility of movement and any positional variance that degrades the accuracy of navigation. To do that, for instance, Medtronic utilises it's own portable cone-bean CT unit, the O-arm. The idea is when positioning patient frame on the patient, the O-arm has its one IR-bean active markers which indicates its own position relative to patient and to the camera so that system could triangulate patient's position to the images acquired which will result in automatic register of the patient.[f.]

6. Conclusion

Image Guided Surgery has become an important part of the medical field, and its sub-fields like Neurosurgery, Spine and ENT had shown rapidly evolving in utilising computer such as navigation. These major advance in the image-guided system provide new operative techniques and increase in accuracy while squeezing hardware size. Navigated accurate placement of implants creates more stable procedure and reduce or perhaps eliminates the need for postoperative checkouts.

I believe that in the future, IGS would most likely be further developed to incorporate projection of the internal organs to let surgeon view it on the patient. It is called Augmented Reality Surgery, which is pretty new technology. I also believe Robotic would be incorporated in the future, which has a lot of benefits, for instance, it could perform extremely longer procedures. Robotics would allow interventionist to control remotely telesurgical instruments, which allows distance operations. Also, pressure sensors embedded in the hand controllers enable the surgeon to feel the progress of the process.

The benefits of IGS would be that the technology allows sophisticated surgical intervention inside the body to carry out relatively ease that would typically demand open procedure. The disadvantage would be the process to success would require the need first to learn the strength and limitation of the technique. Doctors' surgical preferences and the need to learn new platform may impose challenges to get the new system used in the medical field. Surgeons must be willing to develop the procedure and new routine that incorporates the imaging and specialised instruments. It is not always the best option to use navigation due to the nature of the procedure.

One of the other disadvantages is that the medical equipment can not be sold to every hospital due to hospital's limited budgets. These medical devices are used on a living human body, which a particular type of caution and preparation must be taken. They go through all kind of legal tests as well to gain certification, which consumes a lot of time and will add a lot of costs. Medical Technologies is not up to date with the consumer technologies for this reason.

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