In recent times a growing number of orthopaedic surgeons throughout the world are gaining hands-on experience with Computer assisted orthopaedic surgery tools in their clinics. Hence this technology is predicted as the surgical toolbox of the future orthopaedic surgeon. So many years of continued research and hard work has brought the Computer Assisted tools and technologies from the drawing board of the research labs to routine use in surgical theatres. It has been introduced in a number of hospitals world wide approximately 10 years ago. The basic principle follows the concept of frame less stereo taxis.

CAOS based technologies represent a spectrum of devices including three-dimensional image guided and non-image based navigation systems, intra-operative fluoroscopic navigation, robotic assistive tools and new intra-operative visualization devices. The new paradigm of CAOS tools couple simulations with real time evaluations of surgical performance, couple and tightly integrate planning and imaging with the surgical intervention, and permit simulation and optimizations of a patient specific pre-operative plan and integration of medical images directly into the operating room. It will also
provide a new generation of measurement devices and sensors providing intra-operative information to surgeons, as well as become a great educational and training tool, thus navigating into future generation.

CAOS tools and technologies assist and compliment. They do not replace surgeons. With the recent interest in less invasive and minimally invasive joint replacement and the re-discovery of partial joint resurfacing, CAOS based tools have the potential to impact daily clinical practice the same way that fiber optic technology has revolutionized the way we currently practice in many orthopaedic sub specialties. CAOS technologies have the potential to be used as research and training tools and as an enabler for less and minimally invasive surgical techniques.

There are 3 steps necessary to navigate. The first phase is Data Acquisition pre-operatively or during surgery. The next two steps – Tracking and Registration – are necessary to take that information and use it during surgery. Data acquisition may be done pre-operatively or during surgery and include pre-operative CT images, fluoroscopic images or kinematics information such as the determination of center of rotation or anatomic landmarks during surgery. Registration is the ability to relate images to the anatomical positions on the surgical field. Registration is the process to teach the navigation system the same process. (To relate images to the actual position on surgery table)
Several techniques have been developed for registration process. The early
technique required the use of pins or fiducials for robotic type devices. Due to
the drawbacks, developers introduced pin less type registration in which the
unique shape of the bone was used to achieve the same goal and did not
require pins or separate procedures or incisions. The surface based
registration has become the gold standard for CT based navigation because
of its high level of accuracy and reliability. Using this technique, the surgeons
can collect a cloud of surface points on the bone using a tracked probe. The
unique shape of the bone is then used to match the pre-operative plan with
the position of the patient in the operating room. In fluoroscopic navigation
the registration process is automatic and is performed online as long as the
bone and the fluoroscope are tracked when the images are obtained.
Registration with an imageless system is a matter of identifying the joint’s
center of rotation through kinematic testing or by having the surgeon visually
collect important landmarks points.

Tracking becomes important because we need sensors and measurement
devices that can provide feedback during surgery on the orientation and
relative position of tools to bony anatomy so that we can act on that
information in a timely manner. By attaching optical or electro magnetic
trackers to regular surgical tools, we can convert our current tools to smart
tools in which we can know the position and orientation of the tool’s
alignment with respect to the bony anatomy of interest in real time.
In general, each CAS system involves three major components. The therapeutic object denotes the anatomic structure that is treated with the help of CAS system—the bony structure. The virtual object is any representation of the therapeutic object (CT or fluoroscopic or surface morphed images). The navigator links the two objects and allows the automatic transfer of position data from one into the other. Such data exchange represents the core functionality of any CAS systems. A navigator can either act actively or passively. In the active case, the navigator itself carries out a certain operative task—it acts as surgical robot. Passive navigators observe the position and orientations of instruments that the surgeon is using. Such measurement is carried out based on optical tracking technologies using infra-red light reflecting markers or infra-red light emitting diodes (LEDs). These elements are attached to the instruments to be measured as well as to the bone that is operated on.

Relating the acquired position data on the instrument and anatomy to the virtual object allows the visualization of surgical action in real time on a computer monitor. This configuration provides precise feedback to the surgeon and helps performing difficult interventions with increased accuracy. Navigation systems have received a large attention in recent years and have been applied to a wide range of orthopaedic and traumatological problems including spine surgery, total hip arthroplasty, total knee arthroplasty, knee ligament replacement, fracture fixation and even tumor resection. The
advantages of the system includes precise feedback back to the surgeon, enabling him to perform difficult interventions with increased accuracy. Less invasive and minimally invasive surgery is facilitated since visualization of surgical action is possible in real time on a computer monitor. The decrease in radiation exposure is an added advantage. Balancing these new capabilities are the potential negative aspects – of increased cost and operating time, need for accuracy and validation and surgeon’s acceptance.

Figure.58 - Computer Assisted Spine Surgery, permitting the surgeon to have real-time evaluation of surgical procedure on the Computer Screen.

In contrast to surgical navigation systems, robotic devices carry out certain...
steps of surgery highly precise according to a pre-operative plan. There are systems available for THR & TKR. Experiential work has been presented in the field of spine surgery.

Today, approximately eight to ten companies offer surgical navigation systems for various types of interventions along the spine that involve the placement of screws. The purpose of this chapter is to give an overview of computer assisted spinal surgery. In addition, one topic of most recent research is elucidated that addresses a critical aspect of this technology.

4.1 CT-BASED SPINAL NAVIGATION

CT scans play an important role in the preoperative diagnosis of spinal diseases. Since the image data precisely represents the three-dimensional topology of the spine and is usually available in a digital format, CT scans were the basis of the first spinal navigation systems to be developed in the mid-nineties [Amiot, Foley96, Glossop96, Kalfas, Merloz, Nolte96]. Nowadays, CT-based navigation is recommended for more challenging cases involving the placement of screws at the cervical and upper thoracic spine or in pre-operated patients with difficult anatomical situations. The application of a CT-based navigation system involves both preoperative and intraoperative steps.

4.1.1 PREOPERATIVE STEPS

The digital CT data of the patient is loaded into the navigation computer. A number of mandatory and optional planning steps are then carried out. For the registration of the patient with the CT scan using paired-points matching
(see below), anatomical landmarks are marked. Their counterparts need to be identified as precisely as possible in situ. It is therefore recommended to select points which are prominent and easily accessible during the operation. Optionally, the position and axis of one or more screws can be defined. Intraoperatively, these trajectories serve as the goals to be reached during navigation. As a last step, all planning data is stored and transferred onto the intraoperative navigation computer.

![Screw Navigation using Brain Lab System](image)

*Figure.59 – Screw Planning using Brain Lab System*

After preparing the system and the navigated tools the surgeon performs the required checks of the hardware and software. As soon as the vertebra to be
instrumented is exposed, the dynamic reference base (DRB) is affixed to the processus spinosus. In order to allow for instrument visualization, a registration, also known as "matching", is carried out. For a paired-points matching the preoperatively defined landmarks need to be identified on the patient's anatomy. A total of 4 to 6 points are recorded, and the resulting registration is calculated. Due to unavoidable inter-vertebral motion, it is highly recommended to perform a per-vertebra registration acquiring landmark data on one spinal level only. For multi-level instrumentation it is necessary to move the DRB and redo the registration after the placement of all screws at one level [Glossop97]. In order to improve an insufficiently accurate paired-points matching, a so-called surface matching can be carried out [Lavallée, Maintz]. Subsequently, the desired screws can be placed under navigational guidance.

Figure.60 - Technique of paired-point matching
4.2 FLUOROSCOPY-BASED SPINAL NAVIGATION

Surgical navigation based on intraoperatively acquired fluoroscopic images has been introduced as a complementary technique to CT-based navigation [Foley01, Hofstetter, Joskowicz, Nolte00]. Today, fluoroscopy-based spinal navigation is recommended for "standard" cases involving screw placement into the lower thoracic or lumbo-sacral spine in the presence of normal morphology. Since the images used for navigation are acquired intraoperatively, no preoperative computer aided planning is necessary.

4.2.1 INTRAOPERATIVE STEPS

As for CT-based spinal navigation a DRB has to be affixed to the processus spinosus after exposure. Then one or more single fluoroscopic images of the operated vertebra are taken. Fluoroscopic navigation feedback is possible immediately after transferring the images onto the navigation system without any extra registration or verification. Another advantage of fluoroscopy-based navigation is the fact that the images are copied onto the navigation computer. Not only does this procedure allow removal of the C-arm from the operation field after image acquisition, but it also permits visualizing of the instruments in several projections simultaneously.
4.3 ALTERNATIVE METHODS AND FUTURE TRENDS

Although both presented techniques are well-established in many clinics all over the world, there is certainly room for technical improvements and new fields of application. A number of researchers and manufacturers have presented solutions or suggested ideas to overcome some of the disadvantages still existing in today's navigation systems. One of these aspects shall be presented here.

The intraoperative registration of CT images is still a crucial step. A number of alternative methods try to solve this problem. A-mode (amplitude mode) ultrasound has been suggested as a "virtual pointer" [Maurer] for the acquisition of single points that then could serve as input to the established registration algorithms. Although this appears to be straightforward in theory, it
is lacking practicability. B-mode (brightness mode) ultrasound in contrast is easier to handle because it scans a fan-shaped area rather than a single axis. From a technical standpoint, the resulting two-dimensional images are noisy, and the automated detection of bone contours is a challenging image processing task. As a consequence, only experimental results are available [Amin] of the application of this technique to anatomical areas other than the spine. Another alternative registration technique involves the fusion of pre- and intraoperative imaging. Calibrated fluoroscopic images can be analyzed to identify the visualized bony topology and to use this data for a registration with a preoperative CT scan. As for B-mode ultrasound registration, automating the bone contour finding in a reliable way is difficult. Although one manufacturer offers this feature for spinal surgery already, the method does not seem to be applicable in every case [Verheyden].
Reference