# Applicability of navigation in trauma

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The goal of virtual fluoroscopy is to supply an adequate means for intraoperative guidance in order to improve efficiency of image guided orthopedic procedures.
There is no need for preoperative planning steps such as image processing or interactive definition of anatomical landmarks. The system does not require intraoperative registration of preoperative image data (matching), which is mandatory for CT based navigation. Another advantage of virtual fluoroscopy is the ability to update the navigational image data at any time, which may appear necessary after changes to the anatomical situation due to fracture reduction maneuvers or osteotomies. The potential of the technique appears tremendous. Advantages that can be identified already now include the reduction of intraoperative radiation doses to the patient and surgical staff, as well as the improved operative precision providing more safety to the patient. Navigated osteosynthesis can overcome the disadvantages of minimally invasive procedures by visualizing reduction, implant placement, and fixation.

## *Introduction*

In the last decades, techniques in trauma surgery have changed tremendously. In former times fractures were treated with large incisions and stabilized with plates in similar dimensions. Today we know that the technique of minimally invasive osteosynthesis, with a reduction of the trauma by minimizing the incision and the related soft tissue damage, is an essential benefit for the patient, not only because of the cosmetic result but also the speed of recovery and functional results. Image intensifiers (C-Arms) are the most common and most used medical device for image acquisition in the trauma operating room. It is important for intraoperative diagnosis of results of actual fracture reductions, for monitoring the actual position of surgical instruments, and also for checking the correct position of materials for an osteosynthesis, and of other implants.

The challenge with minimally invasive techniques is that the surgeon has no direct view of the position of the implant relative to the bone, and of the actual result of the fracture reduction. Thus, the use of the image intensifier is much more demanding and causes significant radiation exposure for both the patient and the OR-team. The imaging with an image intensifier is also limited (6). The image is a two-dimensional composite image and, as there is only one C-arm in the OR, not more than one plane can be displayed simultaneously. During image acquisition, the C-arm is over the operating field and may disturb the surgical actions. Using surgical navigation techniques, some of these problems could be totally or partly solved (4,5).

Computer-assisted operation techniques in trauma surgery are becoming more and more widespread, developing from a stage of experimental and scientific approach to increasingly routine use. The principle is the combination of medical images with intraoperative instrument and implant positions. The medical images can be generated preoperatively, e.g. CT or MRI, but also intraoperatively with the use of a conventional image intensifier. In the present navigation systems, optical information is combined with tactile information gathered during the intervention. Without navigation, this combination of highly complex image data with the position of the instrument is performed in the surgeon's head.

Limitations to intra-operative two-dimensional imaging with C arms are often encountered, because complex three-dimensional bone structures, such as the spine, pelvis or joints, can only be inadequately imaged. In these cases, there remains uncertainty with regard to the correct reconstruction of bone structures and correct position of the osteosynthesis material.

## *Registration free navigation, virtual fluoroscopy*

Using C-arm images in different planes, it is possible to visualize the instrument position in relation to the patient's anatomy in different planes simultaneously. Displaying the instrument position dynamically in real-time and in different planes simultaneously is the key function of fluoroscopy-based navigation. With virtual fluoroscopy, up to four C-arm images can be displayed as a kind of simultaneous virtual constant radiography, providing optical information to the surgeons.

There are three essential criteria necessary to enable navigation in C-arm images. Firstly C-arm images are due to physical properties distorted (cushion effect) and they have to be geometrically corrected/undistorted by use of a mathematical algorithm. In addition, the distortion depends on the actual position of the C-arm. Further, the distortion is different for each single C-arm, so each C-arm has to be calibrated for navigational use (1,3,7,8) . Secondly, the navigation system and tracking of the different instruments have to combine the anatomical situation with the image information. In the last step, the instrument position is combined with the image information. Usually this is done by displaying two dimensional linear graphics, which is sufficient for the visualization of drilling processes and implant positioning in two dimensional virtual X-rays.

At the beginning of the intervention, after fixation of the reference base, the image intensifier images are taken. Then the C-arm can be removed from the operating field.

For the use of the system, no preoperative data such as CT or MRI is required. The image data will be generated in the OR, appropriate to the individual situation. A preoperative planning in the sense of working on CT data or definition of special landmarks, which have to be reproduced intraoperatively, is not required. The system works with automatic registration, meaning that the procedure to match the preoperative image data with the intraoperatively found anatomical situation is not necessary. A further advantage of the virtual fluoroscopy is the feature that images can be regained after modification of the anatomy by fracture reduction maneuvers. With this feature, updates of the actual situation are possible at any time, in sharp contrast to CT-based navigation.

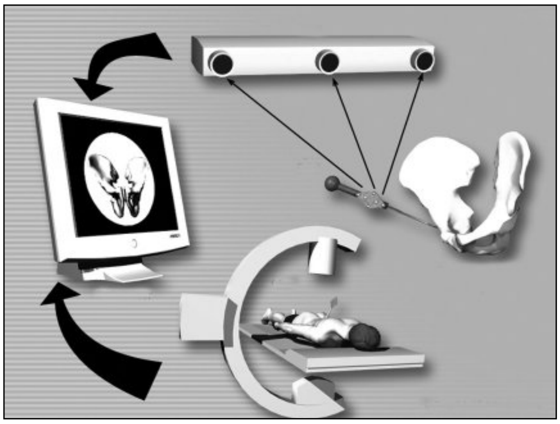


*Figure 1. Basic principle of c-arm based navigation.*

Several images can be transferred to the navigation system which are then geometrically corrected and stored in a library. Using the touch screen the surgeon can change magnification and contrast. Different calibrated instruments, e.g. drill, screw driver, pedicle awl etc., are connected to the system. During navigation, the image data of the C-arm is combined with the position of the instruments by projecting the instrument into the images.

By means of virtual fluoroscopy, linear surgical actions (i.e. screw placements, distal locking etc.) online guidance with significantly reduced fluoroscopy times can be provided easily and effectively. The most common clinical applications are femoral neck fractures, femoral shaft fractures and ruptures of the SI joint.

## *Reality enhancement*

The present navigation systems are equipped with additional features for enhancement of virtual reality. The dynamisation of conventional C-Arm-pictures in different levels at the same time, i.e. referencing through various fragment types and by dynamisation of x-rays to produce a realistic check of the positioning in the virtual x-ray is possible. Thus, it is possible to show spatial changes in the position of the bone structures as a modification in the two-dimensional pictures.

The repositioning of the fragments can be controlled radiation-free and followed in real-time.

A further step to approximate virtual fluoroscopy to the realistic is the representation of three-dimensional implants as three-dimensional in two-dimensional figures mentioned earlier. For this purpose, a virtual 3D representation based on the virtual x-ray is created. Using information from the two-dimensional level, the position of the radiation source and the image amplifier, a virtual space is created, in which the surgical object, i.e. the bone structure, is shown, and the position of the instruments and implants is determined in relation to it (2).

Instruments and implants are visualized with the help of CAD data as true to live three-dimensional structures in the graphic data of more complex pictures.

## *Measurement of the real femur antetorsion angle*

Due to the accurate mathematical relationship of the registered fluoroscopy images in three-dimensional space, geometrical analysis of this imaging information is possible. This is clinically relevant for defining angle degrees in torsion measurement. CT-based measurement has established itself as a standard method for determining the femoral torsion angle. The high radiation dose and the lack of intraoperative availability are unfavorable factors for osteosynthesis or derotating osteotomies. Using referenced, calibrated C-arm pictures makes it possible to define anatomical landmarks in bone structures. The navigation system can measure the angle between two defined lines in these pictures with a mathematical algorithm. The fluoroscopy based navigated determination of the femoral antetorsion angle is a statistically significant reproducible method of measurement. The reproducibility on models corresponds to that of conventional CT measurements. With this method it is possible to check intraoperatively both corrective osteotomies and osteosynthesis of the femur in regard to ante torsion and to compare results with the healthy side.

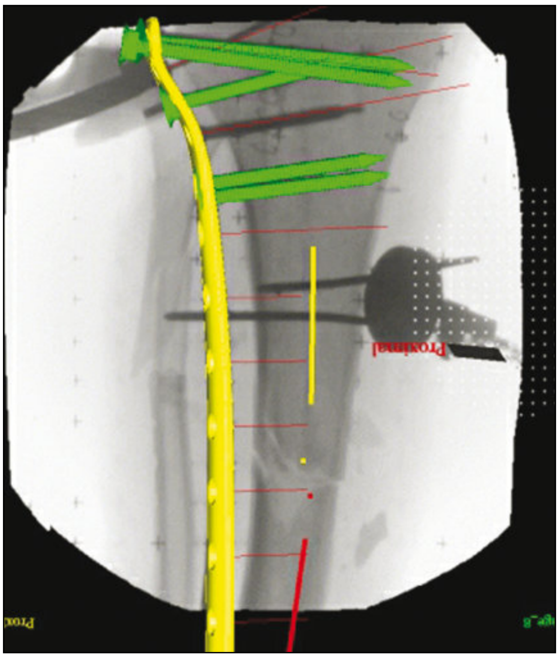


*Figure 2. Display of the implants in virtual fluoroscopy.*

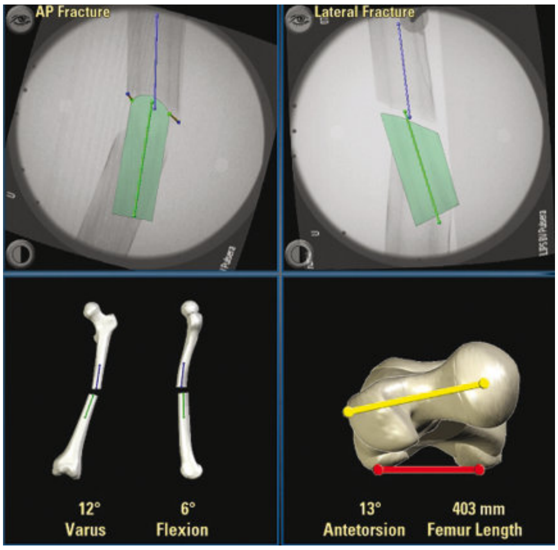



*Figure 3. Measurement of femoral anteversion, reduction and leg length.*

## *Implementation of the LISS® clinical workflow in navigation*

With LISS, we have an osteosynthesis procedure, which allows a minimally invasive stabilization of the fragments in metaphyseal problem fractures. LISS is best compared to an internal fixator. The problem lies

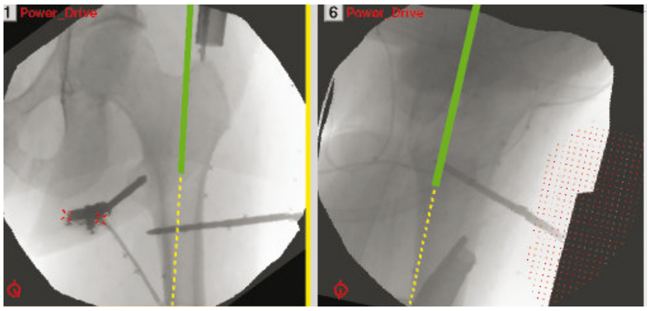



*Figure 4a. Finding of the insertion point in navigated femoral nailing*

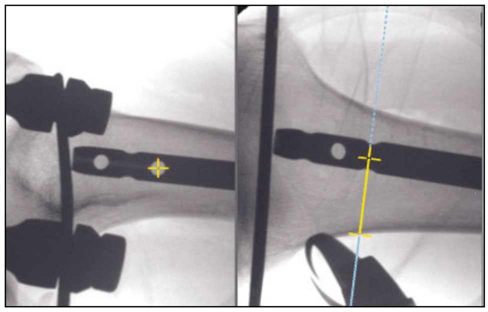


*Figure 4b. Distal locking.*

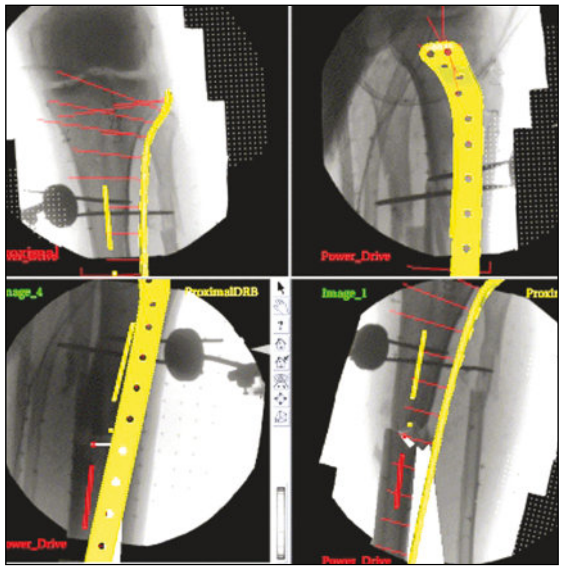



*Figure 5. Navigated LISS osteosynthesis.*

in the need for an accurate operation technique with minimal room for error and does not permit conventional 'buttressing reduction by the plate', but allows the implant to lie perfectly in the convexity of the bone. The goals of the development of the LISS navigation were on one hand the X-ray-free check of the reduction process in navigated C-arm pictures (virtual fluoroscopy), on the other hand the three-dimensional representation of instruments and implants in these pictures with a reduction in the problems specified above.

In a first step, one reference base with LED markers was affixed on both the proximal and distal main fragments. After acquisition of C-arm pictures in 2 planes each proximally, distally and within the fracture area, a reduction of the fracture and stabilization of the bone was carried out. With the help of the virtual cylinders from different x-rays, a structure with similar bone volume was created. The x-rays can be dynamized and the reduction process can thus be checked without further radiation.

The implants, including the LISS plates, screws and instruments, are compared three-dimensionally to virtual x-rays, realistically adjusted and represented in real time. Both the insertion of the plate as well as the fixation with screws including the drilling process and linear measurement could be navigated.

## *Intraoperative 3D Imaging*

Although modern tomographic diagnostics of computer tomography as the absolute standard makes excellent assessment, classification and preoperative planning possible, nonetheless conventional 2D imaging yields only limited information. An intra-operative CT is only an option in a limited number of centres, in addition to being a time- and labour-intensive and expensive option. By means of modern image intensifiers, intraoperative images can be acquired, that permit the intra-operative three-dimensional presentation of osseous structures.

In addition to conventional 2D imaging, by way of 3D imaging during a motor-driven, continuous orbital rotation of 190° one can choose 50 or 100 separate fluoroscopic images in fixed angle intervals. From the 2D fluoroscopic images obtained in this way, a 3D data cube with a marginal positioning of some 12 cm can be calculated. Within this cube any chosen number of tomographic planes (multiplanar reconstructions: MPR) can be displayed in real time in an associated workstation. The record is isotropic, that is to say each of the images thus obtained possesses, on the coronary, sagittal and transverse planes, the same resolution of 256 x 256 pixels with in each instance a pixel size of 0.46 mm 17.

Intra-operative 3D fluoroscopy facilitates the intra-operative three-dimensional presentation of bony structures and implants. By means of this technology it is possible to evaluate implant locations and repositioning results of articular surfaces, spine and pelvis.

Linking to navigation makes it possible to transfer the generated 3-D data directly to the navigation system. The advantages of CT-based navigation with 3-D representation of bone structures are therefore combined with the advantages of inherent navigation with intraoperative imaging. The surgical instrument is immediately displayed in the image, i.e., without any complex manual registration procedure.

The results herein for the extremities, spine, and pelvis are very encouraging and portend an advance in safety and quality in the operating room.

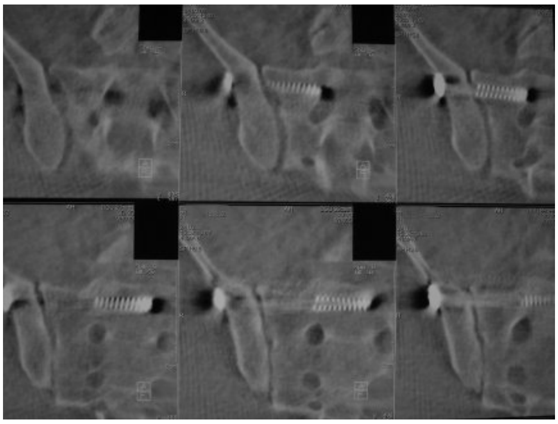


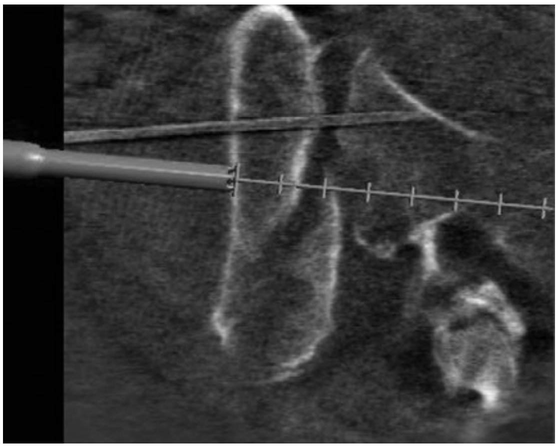
*Figure 6. Intraoperative control of SI screw placements.*

## Summary

Navigation systems are spreading rapidly in trauma and orthopedic operating rooms. This technology does not make an inexperienced surgeon an expert, but gives the experienced surgeon a helpful instrument to improve both the procedure and the quality of results and to reduce in particular the possibility of outliers. The experience in our hospital shows that only the consistent use of navigation, in complex and standard cases, leads to an increasing acceptance and a broader application of this system with increasing confidence and safety in its technical execution. Only the future will show whether a direct profit for the patient can be obtained using this technology, and also whether a socio-economic effect can be achieved by a decrease of the complication rate.

The navigation systems themselves and their software applications are subject to rapid growth with the goal of improved user interfaces, minimal changes in existing operating room flow and, of course, by the development of more economical systems, in finding a broader application.

The goals of the improvements are the simplification of the intraoperative setup, the improvement of the image quality and the adaptation of the instruments to the navigation technology. The potential of these techniques appears enormous and already proves to possess advantages such as a decrease in the intra-



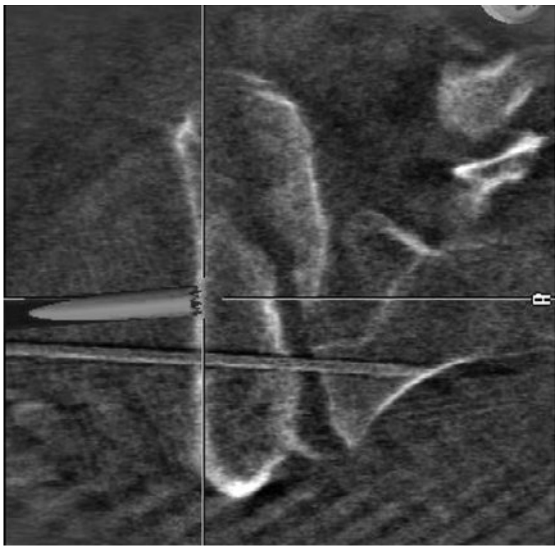


*Figure 7a and 7b. Navigated SI screw placement by means of 3D fluoro-navigation* operative radiation dose, more precise operation techniques and thus more safety for the patients.

By way of the navigated LISS osteosynthesis, the disadvantages of the minimal invasive procedure could be crucially reduced by visualization, repositioning, placement and adjustment of the implant.

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