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Basic research and 12 years of clinical experience in computer-assisted navigation technology: a review

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Abstract. Computer-aided surgical navigation technology is commonly used in craniomaxillofacial surgery. It offers substantial improvement regarding esthetic and functional aspects in a range of surgical procedures. Based on augmented reality principles, where the real operative site is merged with computer generated graphic information, computer-aided navigation systems were employed, among other procedures, in dental implantology, arthroscopy of the temporomandibular joint, osteotomies, distraction osteogenesis, image guided biopsies and removals of foreign bodies.

The decision to perform a procedure with or without computer-aided intraoperative navigation depends on the expected benefit to the procedure as well as on the technical expenditure necessary to achieve that goal. This paper comprises the experience gained in 12 years of research, development and routine clinical application.

One hundred and fifty-eight operations with successful application of surgical navigation technology—divided into five groups—are evaluated regarding the criteria ''medical benefit'' and ''technical expenditure'' necessary to perform these procedures. Our results indicate that the medical benefit is likely to outweight the expenditure of technology with few exceptions (calvaria transplant, resection of the temporal bone, reconstruction of the orbital floor). Especially in dental implantology, specialized software reduces time and additional costs necessary to plan and perform procedures with computer-aided surgical navigation.

Key words: computer-assisted navigation; augmented reality; arthroscopy; dental implantology; biopsies; distraction osteogenesis.

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Nineteenth-century surgery is primarily based on the knowledge of the anatomy of the region of interest. The discovery and application of X-rays marks the beginning of medical imaging, a revolutionary development still continuing. The use of imaging techniques allows preoperative evaluation of pathology and anatomy, but it is required that the surgeon transfers this visual information to the actual operation site just in imagination. Consequently the wish to have a ''glasslike patient'' arises, where relevant information from preoperative imaging is directly available to the surgeon's perception.

This can be achieved with the application of ''augmented reality''[3,4,7,25]. This technique allows to merge information as computer generated overlay-graphics (the mathematical term could be

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''information-space'') into the surgeons field of view. In contrast to ''virtual reality''-technology, ''augmented reality'' does not rely solely on artificially generated environments but expands the real world with additional elements (information content)[5,22]. Spatial and temporal linking of the operation-site with computer-generated additional information can be achieved by using tracking-technology, which continuously registers the position of patient and surgical tools by means of special sensors (''computer-aided navigation'').

Navigation technology is already tested and established by many research groups and clinical physicians in numerous applications. VERSTREKEN et al. state that computer-assisted planning in oral implant surgery ''... largely outperforms the manual planning practice based on two-dimensional dental computerized tomographic images printed or on film ...''[19] and that ''... the improvements often avoid complications such as mandibular nerve damage, sinus perforations, fenestrations, or dehiscences''[20]. SIESSEGGER et al. report on successful navigation in dental implantology and conclude that ''the use of an image-guided navigation system provides a valuable tool in implant dentistry and proved superior to conventional implant surgery especially in difficult anatomical regions''[18]. CAVALCANTI et al. have investigated the precision and accuracy of three-dimensional multislice spiral CT imaging for implant planning and find that it ''... allows highly accurate measurements for dental implant placement...''[4]. ISHIMARU et al. describe computer-based simulations of arthroscopies of the temporomandibular joint (TMJ) ''... to observe the presence of a partial defect in the articular disc and an osteophyte on the condyle ...''[10], WAGNER et al. have published the initial report on intraoperative navigation during TMJ arthroscopies, also in combination with interactive teleconsultation[28,29]. The wide range of CAS (computer-assisted surgery)-applications furthermore covers skull-base surgery and osteotomies[8,13], removal of foreign bodies[12,17], and the treatment of cranio-maxillofacial tumors. SCHRAMM et al. conclude that ''... intraoperative navigation makes radical tumor surgery more reliable ...''[16].

Over the past 12 years our department has been conducting extensive basic research and computer-aided navigation-technology was employed intraoperatively in a wide range of indications. This paper gives an overview of computer-aided navigation technology in craniomaxillofacial surgery, summarizes the most important applications and assesses technical expenditure as well as clinical relevance. It also presents perspectives of future developments in computer-aided navigation-technology (teleconsultation, open-source-software).

Material and methods

Imaging systems

The basic principle for application of augmented reality and computer-aided navigation in craniomaxillofacial surgery is the visualization of two- and three-dimensional views of the surgical site superposed on the real image of interest. In most cases computertomographic images are used (CT), but conventional X-rays, magnetic resonance imaging (MRI) or fusion of CT and MRT images are also available for special indications.

The two- and three-dimensional images of the real anatomical situation are complemented with graphical structures like points, lines and planes made during the course of preoperative planning, helping to define the optimal entrance and direction of arthroscopes and other surgical tools. These landmarks can also be used to visualize the planes of symmetry, osteotomy-lines, contours of tumors or positions of dental implants[15,23,30,33–36] (''overlay-graphics'', Figs 1 and 2).

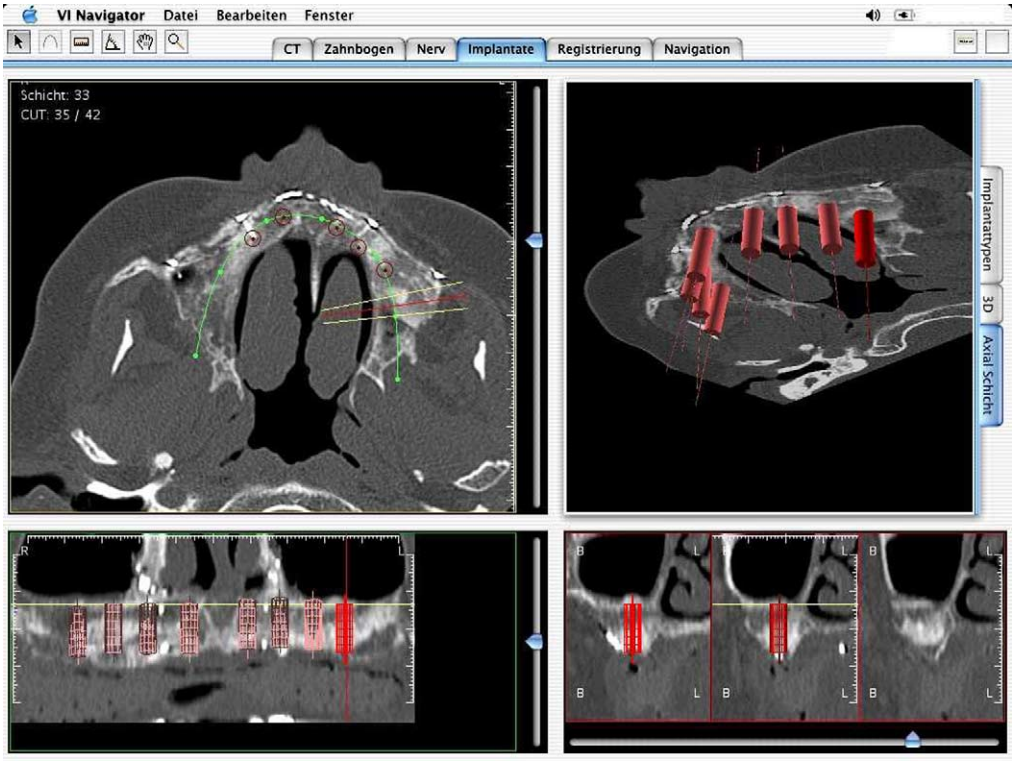

Fig. 1. Preoperative planning in computer-assisted dental implantology. Figure shows two- and three-dimensional visualization of planned implant positions. (Software: Artma Virtual Implant™.)