Implant Locating and Placement Based on a Novel Tactile Imaging and Registration Concept: A Technical Note

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Computed-assisted surgery (CAS) has been designed to improve oral implant planning and positioning and to increase safety and operator comfort. This is especially important in the esthetic zone, at sites with bone deficiency, and when minimally invasive implant placement is the therapy of choice. Current available CAS systems are relatively large and expensive and require a lengthy learning period. This report presents a novel tactile imaging and registration concept that enables the operation of a newly developed computerized implant locating system. An intraoral bone-sounding device maps the surface of the jaw through the soft tissue. Bone contour data are registered over the computerized tomographic image. Guided by treatment preplanning software, a chairside robotic manipulator fabricates guiding sleeves that direct the drill and implant during the osteotomy and implant placement, respectively. The authors' clinical experience shows that tactile registration based the Implant Locating System is simple to use and provides accurate implant design and placement that requires only basic computer experience, minimal operational space, and low infrastructure investment. The system allows final adjustments at the time of operation, transforming each implant surgery into a fully monitored procedure. Int J Oral Maxillofac Implants 2007;22:1007–1011

Key words: *computer-assisted surgery, dental implants, flapless implant surgery, navigation, registration process*

Dental implant placement is a sensitive surgical procedure that requires special training and skills. Successful implant placement followed by proper rehabilitation depends on careful presurgical planning and precise execution of the plan. Errors in the depth or direction of the osteotomy can result in irreversible damage; for example, the drill could penetrate anatomic structures such as the inferior alveolar canal and bundle, the maxillary sinus, the lingual artery, or the buccal or lingual cortex of the jaw. Errors in implant positioning can lead to nonrestorable situations.[1–5]

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An ultimate goal of implant surgery is to allow the operator to perform optimal risk-free prosthetic oriented implant placement. A minimally invasive surgical procedure can reduce patient morbidity and postoperative swelling and discomfort[2,3] as well as prevent potential postoperative bone resorption associated with mucoperiosteal flap procedures.[6]

Computer-assisted surgery (CAS) was established more than 20 years ago. However, this treatment modality, which combines simplicity, safety, accuracy, and low cost, has only recently become an operational option in dentistry.[7–14]

The purpose of this report is to present a recently developed tactile imaging and registration concept that enables the operation of a novel computerized implant locating system (ILS).

IMAGING AND REGISTRATION—AN OVERVIEW

The main application of CAS is an image-guided navigation system that relates the position of a surgical instrument to the surgical site in real time. Accurate registration is the core technology of every comput-

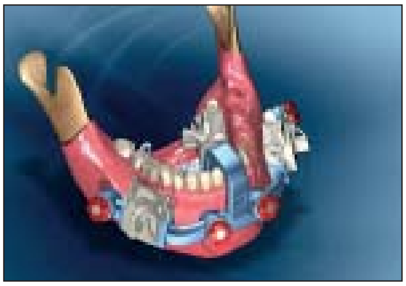


Fig 1 The intraoral device, which consists of a rigid frame *(blue)* to which affixation pins are attached *(red)*, and in which tactile sensors containing needle arrays are affixed *(gray)*.

Fig 2a Internal view of a sensor showing a needle array *(gray)*.

Fig 2b A sensor showing a needle array *(gray)* penetrating the oral mucosa. Sounding is determined when contact with the bony cortex is made.

erized tomography (CT)-guided system. *Registration* is a technical term used to describe the process of cross-correlating and adjusting different frames of reference onto a single metric coordinate system.[15] In medical applications, registration aligns the patient's anatomy with an image obtained through CT, magnetic resonance imaging (MRI), or ultrasound and relates the surgical instrument position. This provides the operator with better orientation and enables accurate location of a diagnostic or surgical device at an unseen predetermined site.

There are numerous technical approaches to registration in image-guided surgery. The most relevant concepts are

1. Fiducial markers (FM). FM, such as ceramic balls made from aluminum oxide, are well-defined geometric structures that can indicate imaging deformations and contrast. The FM are attached to an anatomic structure (eg, teeth, jaw) before preoperative imaging, such as MRI, ultrasound, or CT. The same FM, at the same positions, are used during surgery. At the beginning of the procedure, the locations and orientations of the FM are identified with a surgical instrument or probe, which is then accurately mapped within the medical image.
2. Anatomic landmark registration. An anatomic landmark is a singular anatomic geometric structure (eg, spinal vertebra, skull joints).
3. Surface-based procedures. One example is the laser surface scan.[16]

The patient's anatomy and preoperative imaging are related to each other and are identified by sounding anatomic sites using a calibrated traced instrument. Registration is made using a surface-matching algorithm that aligns the anatomic surface with an acquired 3-dimensional (3D) image. Therefore, in landmark registration, the registration procedure is more singular and accurate when the surface anatomy is more rigid and geometrically irregular.

Tactile Imaging and Registration Concept

A newly developed concept of tactile imaging and registration has been developed based on a variation of the landmark registration approach. The registration process involves simultaneous sounding of the jaw surface at preselected sites using a tactile sensor that contains a needle array (Figs 1 and 2). The needles emerge from the sensor and penetrate the soft tissue until contact is made with the bone surface (Figs 2a and 2b). The sounding data of the bone surface are retrieved by the needles and transferred to the computer, where they are translated to a 3D image. A surface search is carried out over a segmented CT scan until the CT scan and the translated 3D image are matched, overlapped, and registered (Fig 3). The use of a special algorithm enables alignment of the jaw anatomy and the 3D CT scan. At this stage, the position of the instrument (drill, implant) relative to the jaw can be ascertained visually on the CT image. Following registration the position of the implant is determined virtually using planning soft-

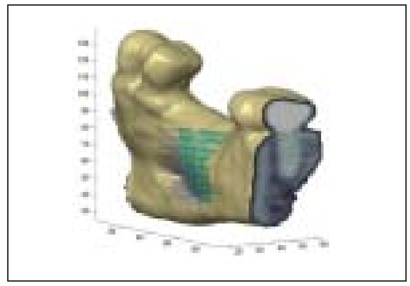


Fig 3 *(left)* The jaw surface is outlined by digitally measuring the needles' movement and the locations of the needle tips. A surface search is carried out over the segmented CT scan until the 2 images are matched, overlapped, and registered.

Fig 4 *(right)* Software presentation of the position of an implant. Positioning is determined based on the recorded data using implant-planning software.

Fig 5 *(left)* Software demonstration of a manipulator producing the guiding sleeves, 1 for each implant. Photographed during the procedure directly from the computer screen.

Fig 6 *(right)* Software demonstration of 2 sleeves placed on a platform attached to the intraoral frame, replacing the needle arrays. One to three sleeves may be placed on a single platform. Photographed directly from the computer screen.

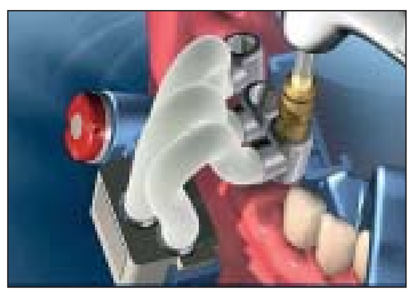


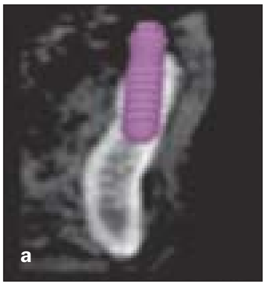
Fig 7a *(left)* Illustration of a guiding sleeve serving as a drill guide to direct 1 implant into its precise location.

Fig 7b *(right)* Clinical view of a guiding sleeve serving as a drill guide to direct 1 drill into its precise location. Handpiece was removed for photograph.

ware. Planning may be carried out before registration based on 2D and 3D scans (without the presence of the patient) or after registration in the presence of the patient (Fig 4).

To begin the sounding and registration process, an intraoral rigid frame is placed over the jaw. This frame serves as a carrier and reference platform on which the tactile sensors are seated and stabilized by precision attachments (Fig 1). Upon activation, as previously described, the sensors release the needle arrays, which are moved by hydraulic pressure. The needles penetrate the soft tissue and sound the bone surface (Fig 2).

At this stage, any preliminary planning of the implant position may be reviewed and finalized. Once the planned implant positions have been finalized, guiding drilling sleeves, 1 for each implant, are manufactured by a chairside, table-mounted, steady-hand robotic arm manipulator fed by data produced by the computer (Fig 5). The sleeves are made from a special high-plasticity fiberglass composite material. Once the material has been manipulated into its final shape, it is hardened by 2-second exposure to ultraviolet illumination. The tactile sensors are removed from the frame, and the guiding sleeves are snapped onto the frame using the same precision attachment. The guiding sleeves replace the tactile sensors, which are snapped onto the frame using the same precision attachment (Fig 6). Once the guiding sleeves are in position, drilling can begin (Figs 7a and 7b). However, even at that stage, just before drilling, the operator is still able to reassess the virtual implant location or implant dimensions (Fig 8a), change the software plan, and produce a new sleeve (Fig 8b). Upon completion of the osteotomy, the guiding sleeve may be used for guidance during implant placement. A pilot clinical study[17] using a Tactile ILS System (Tactile Technologies, Rehovot, Israel) has shown that the maximal error between the virtual and actual implant location was 0.2 mm horizontally (Fig 8c), and 0.15 mm vertically. It has further been shown that the mean registration error for all measurements was 0.4 ± 0.2 mm and that there was a significant correlation between metric values for postconvergence and registration accuracy (Rv = 0.223; $P < .004$).



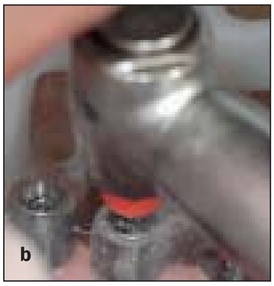


Fig 8a Software presentation of virtual placement of an implant relative to the CT segment used to plant treatment.

Fig 8b Clinical view of a guiding sleeve serving as a drill guide to direct the drill into its precise location during flapless implant placement.

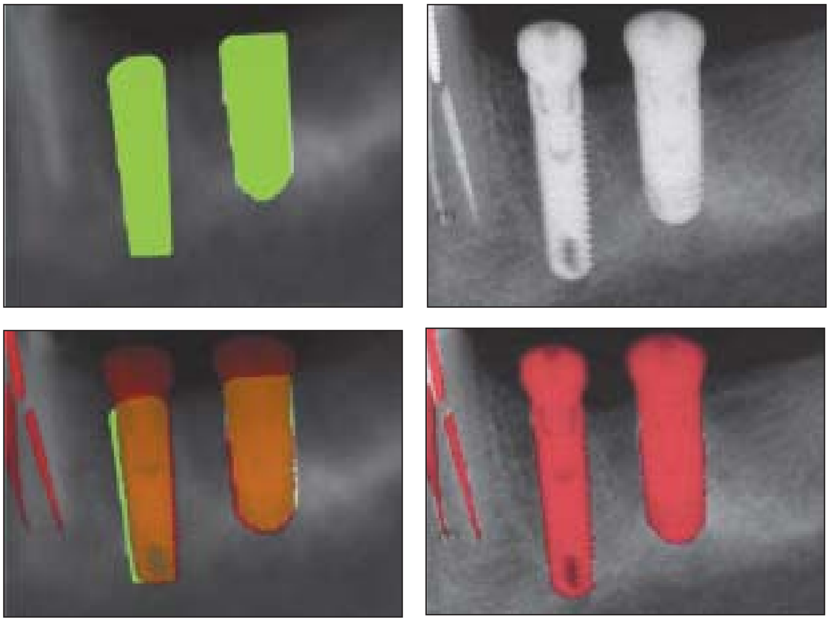


Fig 8c Virtual placement of 2 implants (*upper left*; same case as Fig 8b) compared with their actual radiograph (*upper right*), which was then colorized (*lower righ*t) and finally superimposed on the virtual placement image (*lower left*), showing a 0.2 mm deviation between the 2.

DISCUSSION

Implant surgery is a sensitive procedure requiring special training and skills. Implant placement carries some risks. The most common are incorrect implant placement, injury to the inferior alveolar bundle, injury of the lingual artery, impairment of the maxillary sinus, perforation of the cortical bone plates, and damage to adjacent teeth.[1,4] Recently, minimally invasive flapless implant placement has become popular; it is not only easier to perform but also reduces postoperative swelling, bleeding, and discomfort.[2,3] While open-flap implant placement procedures rely mainly on the surgeon's interpretation of the visible surgical field and the available imaging tools, flapless implant placement is a "blind procedure" that requires additional imaging tools and guiding assistance; experience, intuition, and skills in predicting the location of the drill relative to the unseen anatomical landmarks at the surgical site cannot replace objective accurate means.

Computer-assisted surgery has evolved to facilitate minimally invasive procedures, the gold standard of modern surgery. In dental implant placement, CAS accurately transfers the presurgical implant plan to the operation site and enhances its implementation with minimal risk. The predrilling image of the drill/implant transforms the surgery into a predetermined procedure that can be constantly re-evaluated and modified.

The novel implant locating system is an image-guided system that enables simple CT-based implant placement using a unique registration approach. These qualities combined with accurate and safe performance would enable safer and more comfortable implant placement in more complicated cases.

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