Accuracy of a Dynamic Dental Implantation Navigation System in Regular Clinical Usage

Luigi V Stefanelli, DDS, DEng

ABSTRACT

Objectives: To evaluate the in-vivo accuracy of a dynamic computer-aided implantology (CAI) navigation system in regular clinical usage over a period of one year, and to assess the impact of various anatomical and usage factors on this accuracy.

Materials and methods: For a duration of one year starting in October 2015, a second-generation dynamic navigation system (Navident, ClaroNav Inc., Toronto, Canada) was incorporated into the implantation protocol, and records of the procedures were maintained, including a post-op CBCT scan. Data was obtained on 131 implants placed in a flapless approach under dynamic guidance by a single surgeon in 46 patients, 13 of whom (61 implants) were fully edentulous. An implantation accuracy assessment software program, EvaluNav, was used to precisely volumetrically register the pre-op (planning) and post-op CBCT scans, automatically fit a geometric model to the appearance of each implant in the post-op scan, and compute the distance and angular deviations between the planned and placed implant positions. The deviation data was statistically analyzed using T-tests and polynomial regressions to derive insights regarding factors that may affect the accuracy during usage, including partial vs. full edentulism, upper vs. lower jaw, dentition sextant, fully vs. partially guided implant insertion and the accumulation of usage experience (learning curve).

Results: For all implants, the mean deviations were 0.79 (range 0.02-2.78) mm at entry (lateral), 1.10 (0.32-3.05) mm at apex (3D) and the mean angle was 2.59° (0.18°-8.99°). For partially edentulous jaws, the mean deviation at the apex was smaller, 1.02mm. The apical and angular deviations for sextant 2 were significantly smaller than for the other sextants. Guiding the implant insertion resulted in improved accuracy, especially at the apex and angulation, resulting in mean values of 0.71mm, 0.94mm and 1.63° deviations for entry, apex and angle correspondingly.

The accumulation of experience has had only a minor impact on entry and apex deviations. However, angular error appears to have declined steadily, with the mean error declining to 1.6° and the maximum to 4.28° in the last quarter (33) of the placements.

Conflict of Interest statement: The author has no financial relationship with ClaroNav Inc., the supplier of the Navident system evaluated in this study.

INTRODUCTION

Computer Aided Implantology (CAI) refers to the use of computerized technology to plan and guide the placement of dental implants based on a 3D CBCT image of the jaw. This approach promises to deliver many benefits, including:

- Improved restoration quality and predictability by formulating a prosthodontically driven implantation plan and accurately transferring it to the jaw.
- Enabling flapless surgery, leading to reduced patient discomfort, reduced chair time, reduced risk of infection, and faster recovery.
- Higher safety due to reduced risk of iatrogenic damage to nearby anatomical structures.
- Increased efficiency: reduced chair time, elimination of need for plaster models, wax-ups and fabrication of scan guides, as well as improved communication between restorative team members by using a shared treatment blueprint.
- Faster and easier restorations by eliminating the need for custom abutments in most cases.
- Eliminating the need for bone augmentation in marginal cases.
- Reduced mental and ergonomic stress on the surgeon.

[Arisan 2010, Bornstein 2013, Fortin 2006, Hultin 2012, Berdougo 2010, Norkin 2013]

Two different approaches to CAI have been developed: static and dynamic. In the static approach, a custom drilling guide is digitally designed as part of the planning process and manufactured in advance of the surgery, typically by an external service facility using a stereolithographic printer. During the surgery, the custom guide is placed on the patient's jaw and metal sleeves embedded in the guide are used to guide the drilling prior to the insertion of the implant [Van Assche 2012, Block 2016]. In the dynamic approach, the computer registers the jaw with its appearance in the volumetric CT image, then provides on-screen real-time guidance to the surgeon, who operates free-hand. The guidance includes a visual feedback showing the difference between the drill tip's current position, angulation and depth and its desired position, angulation and depth in the implantation plan [Brief 2005, Widmann 2006].

While requiring a larger upfront investment in technology and training, dynamic CAI has the potential to provide important advantages over the static approach, including:

- CT scanning, planning and surgery in a single appointment (when a CBCT is available on site).
- Increased safety and predictability due to ability to verify guidance accuracy at any time.
- Simpler and faster planning (no surface segmentation, no guide design).
- Ability to view and modify the plan during the surgery, for example to accommodate tactile feedback or unexpected complications.
- Lower per-procedure costs.
- Improved irrigation, reducing risk of bone damage due to overheating.
- Works with any implant or drill system.
- Without sleeves, guidance is provided even when interocclusal or interdental space is limited.

• Elimination of guidance failures due to fractured or badly fitting guides.

[Block 2016, Vercruyssen 2014]

Despite its inherent advantages over static guidance, early attempts to commercialize dynamic navigation technology in the mid-2000s failed, mainly due to high system price, immaturity of design and limited access to CT scanners. Since then, however, improvements in computing and optical tracking technology, and the spread of CBCT scanners in dental practices, have created an opportunity for a second generation of dynamic navigation systems to deliver on the technology's promise.

Accuracy in common clinical use is the main performance characteristic of CAI systems. Several studies have compared the accuracy of dynamic and static navigation in vitro using models [Jung 2009, Somogyi-Ganss 2014] and found them to be similar. Accuracy is, however, most usefully assessed in vivo by comparing the planned and actual positions of implants using accurately registered pre- and post-surgery CT scans. In [Vercruyssen 2014] this approach was used to compare, in a randomized prospective study, the accuracy obtained using static pilot-drill templates with that obtained by freehand ("mental navigation") placement in the fully edentulous jaws of 59 patients. Not surprisingly, the study concludes that guidance offers clear accuracy advantages.

Perhaps due to the limited use of first generation dynamic navigation systems, their in-vivo accuracy has, to the best of our knowledge, never been properly studied and documented. Our aim in the current study is to address this need by providing an in-vivo accuracy assessment of one of the new generation of dynamic navigation systems when used to place a substantial number of implants in a representative range of cases encountered in common daily practice.

We also aim to evaluate the impact on accuracy of a variety of factors: partially vs. totally edentulous patients, lower vs. upper jaw, different jaw sextants, and guided drilling only vs guided drilling and implant insertion. We further aim to assess the impact of the accumulation of user experience ("learning curve") on the placement accuracy.

MATERIALS AND METHODS

Study approach

This is a retrospective observational in vivo study. Starting in October 2015, we have incorporated a second-generation dynamic navigation system (Navident, ClaroNav Inc., Toronto, Canada) into our general dental practice. According with ethical principles and with the understanding and written consent of each patient, we collected records of implantations performed with the aid of Navident's guidance during the first usage year. The records were later processed to obtain placement accuracy data for each of the guided implants.

Navigation system design

Dynamic navigation systems track the position of the tip of the drill and map it to a pre-acquired CT scan of the jaw, kept in registration with the actual jaw, to provide real-time drilling and placement guidance. When the drill approaches a preplanned implant location, the system provides a cross-hairs display to guide the surgeon to precisely locate the drill tip at the planned entry point, adjust the drill orientation to the planned entry angle, and to drill to the planned depth. Once the osteotomy preparation is complete, the same approach can be used to guide the insertion of the implant itself.

Navident, the system used in this study, consists of five main components (Fig. 1, 2):

- **1.** A notebook computer, running the Navident software which provides integrated planning and navigation functionalities.
- 2. A handpiece attachment consisting of a universal handpiece-hugging removable metal adapter, and an optically marked plastic part ("DrillTag") which latches onto the adapter.
- **3.** A patient jaw attachment consisting, for a partially edentulous jaw, of a moldable stent part ("NaviStent", A in Fig. 3), or, for a fully edentulous jaw, of a mini-implant and a matching bracket (Fig. 4). In either case, an arm (C in Fig. 3,4) extending from the attachment is designed to connect to a "CT-Marker" part (B in Fig. 3) during the CT scan and to an optically marked plastic tag ("JawTag") during surgery (Fig. 2).
- **4.** An optical position sensor ("MicronTracker") which detects the special patterns printed on the DrillTag and JawTag and constantly reports their relative positions, to a small fraction of a millimeter, to the Navident software.
- 5. A compact mobile cart which provides a foldable boom arm that, when extended, enables positioning the laptop and optical position sensor above the patient's chest while the cart base is placed next to the patient's left or right thigh.

The DrillTag, JawTag and NaviStent are part of a single-use procedure kit. The software used in this study was Navident release 1.2 and release 1.3.



Figure 1



Figure 2



Figure 3



Figure 4

Workflow

The Navident usage workflow involves four major steps:

Jaw attachment preparation.

When a stable partial dentition is available, a hot water thermoplastic retainer is molded over the dentition, left to harden for about a minute, and then removed and trimmed to provide access to the intended implantation regions. An arm made of the same thermoplastic material is then glued to the retainer and adjusted to ensure that the CT Marker, when connected to the arm, is rigidly interlocked with the retainer. The formed appliance is called "NaviStent" (Fig. 3).

In fully edentulous jaws, or when the teeth are insufficiently stable or expected to be removed during the implantation procedure, a single mini implant is temporarily inserted in the jaw to provide a stable anchor for the arm. A special version of the arm, with a bracket designed to provide strong and stable coupling to the head of the implant, is then used to attach the CT-Marker to the jaw. While more invasive, we found this attachment approach to be faster and easier to apply than the retainer-based one (Fig. 4).

The mini-implant based jaw attachment method was made available to us only in the second half of the study period. Thus, the first 7 fully edentulous jaws were treated using a different approach, where an acrylic stent was fabricated to mate with the mucosal surface, and was anchored to the bone prior to the CT scan using small fixation screws.

Scan

The NaviStent, or the edentulous arm, with the CT Marker attached, is thoroughly disinfected, then securely mounted on the patient's jaw. The jaw is scanned using the on-site CBCT scanner (Soredex Scanora 3D, Tuusula, Finland, with a 14-bit gray density, 0.250 mm pixel size, tube voltage of 90 KV, and 0 gantry tilt).

Plan

The image data in DICOM format is imported to Navident from the scanner by a direct transfer using the local network. Virtual teeth are placed and adjusted to simulate the desired restoration, and supporting implants are placed in consideration of the restoration plan, the available bone and nearby critical structures, such as the mandibular nerve canals, the sinuses and nearby roots.

Place

The laptop is positioned over the patient's chest, and the NaviStent, or edentulous arm, with the JawTag attached, are re-attached to the jaw. The DrillTag is mounted on the handpiece. A brief drilling axis calibration is performed, followed by a brief drill tip calibration and an accuracy check. Drilling is then done, usually in a flapless approach, under aiming guidance. No interaction with the laptop is required throughout this stage unless the plan is modified. The motions of the handpiece are used as input to the software.

A unique aspect of using dynamic navigation is that, during the drilling, the surgeon is typically watching the screen, rather than the drilling site. However, unlike with static guides, access to the site for viewing,

irrigation or suction is unhindered. The drill tip calibration and the accuracy check are repeated after each change of drill. Finally, the implant tip itself may be calibrated as if it was a drill, helping to insert it using the handpiece at the correct angle to the correct depth. Alternatively, it may be inserted manually without guidance using a torque wrench.

During drilling, the operator can see on the screen different views (Fig. 5); in particular in the target view (Fig. 6), it is easy to check real time the distance (mm) between the drill tip and the central length axis of the planned osteotomy, the angle of the drill in relation to the central length axis of the planned osteotomy and the distance (mm) between the tip of the drill and the apical end of the planned osteotomy.



Figure 5





Principle of guidance

To guide the drilling, Navident must accurately map the drill tip to the CT image of the jaw used for planning the implantation. It achieves this in three steps (Fig. 7), performed in the following order:

- 1. **Registration**: Mapping the JawTag to the CT image. This is done automatically when the image data is imported into Navident by the software, which recognizes in the images the appearance of at least a portion of a zig-zagging fiducial body embedded in the CT marker part.
- **2. Calibration**: Mapping the drill tip to the DrillTag. The drilling axis calibration is done once prior to the start of the operation by placing the handpiece chuck over a pin in the JawTag. The drill tip location is calibrated by touching a dimple on the JawTag after each drill change.
- **3. Tracking**: Mapping the DrillTag to the JawTag. This is dynamic and is done throughout the operation by the optical tracking system.



Figure 7

Sources of guidance errors

Errors in the drill-tip to CT image mapping can appear at any step in the coordinate mapping chain (Fig. 7) due to slight deviations between geometrical assumptions made by the mapping software and reality (eg, manufacturing tolerances of all parts, changes to the NaviStent shape between the scan and the placement), or due to optical tracking noise or "drift" away from perfect calibration because of mechanical, thermal or optical changes from the time the tracker was last calibrated. Furthermore, any looseness, or "play", in the rigid coupling between the components involved could further degrade accuracy. These includes, for example, patient motion during the CT scanning process, unstable seating of the jaw attachment, bending of arms or connectors during surgery, and movement of the tip of the drill relative to the handpiece's handle being tracked. These factors can all be tightly controlled when performing in-vitro experiments to produce accuracy results that are much more accurate than in actual clinical practice, especially over long periods, where a wide range of circumstances is encountered and the system sustains "wear and tear".

A major benefit of dynamic navigation systems is the ability to assess, in real time, the accuracy of drill tip mapping by touching visible rigid anatomical landmarks in proximity to the implantation sites. These include, for example, the surfaces of nearby teeth. When the indicated accuracy is insufficient, the surgeon can then troubleshoot and eliminate the source of the inaccuracy by following a step-by-step procedure shown on screen. If the issue is not resolved, they may elect to proceed without guidance, or, if guidance is critical and the problem appears to relate to the CT scanning stage, repeat the scan and the planning stages, then restarting the placement.

Of course, even if the navigation system has an extraordinary accuracy in mapping the tip to the image, the surgeon's control of the handpiece is imperfect due to hand-eye-coordination challenges and personal skills at applying fine motor control under practical time limits. Thus, manual handpiece control adds a significant amount of operator-dependent error.

Accuracy measurement

The Navident system includes an accuracy measurement software application called EvaluNav. Using EvaluNav, the planning and post-op scans are loaded and registered to each other, the exact position of each implant is automatically detected in the post-op CT, and the deviations between the actual and planned positions are automatically computed and reported. The application has been validated on models by the manufacturer.

Once the data is loaded, the processing steps involved are:

- 1. Isolate regions to register: Using 3D sculpting tools, the user isolates only the jaw regions surrounding the implants. The opposing jaw or any structures that appear in only one scan, other than the implants themselves, are masked out.
- **2. Register**: After an initial manual rough alignment of the same region in the pre and post scan images, the software iteratively refines the alignment in an attempt to achieve a perfect registration.
- 3. Evaluate registration: This is a critical step, in which the quality of the registration is visually evaluated using 3 viewing methods: (1) Checkerboard interleaving of the images (Fig. 8), (2) Magenta/green blending of the images, each in a different color. The colors were chosen such that the blended image appears gray in well matched regions (Fig. 9), and (3) flip back and forth between the two images, probably the most sensitive and reliable method, since even alight mis-registration is easily noticeable as back and forth motion of structures. With all methods, the user may scroll through the registered volumes in all three cardinal planes. If the registration is not perfect, the user may return to an earlier stage to correct the problem.





Figure 9

4. **Compute and document accuracy**: The software automatically identifies and iteratively fits an implant model to the appearance of each of the planned implants in the post-op scan. The user can step through the implants, inspect the model fit and, as needed, adjust the model position and reinitiate the fine fitting algorithm.

For each implant, EvaluNav provides a visual presentation of the geometrical relationship between planned and placed models, and three numerical deviations: Entry, Apex and Angle (Fig. 10, 11). Additional measurements may be generated and saved as well.



Figure 10



Figure 11

Results

Accuracy data was obtained for 131 implants placed under dynamic guidance by a single surgeon (LVS) in 46 patients, 13 of whom (61 implants) were fully edentulous. The arm (C in Fig. 3) was attached to the jaw using a stent and bone fixation screws in the first 7 fully edentulous jaws (31 implants), while a mini-implant based attachment (Fig 4) was used in the other 7 edentulous jaws (30 implants). All the implants were planned to be inserted with a flapless protocol. In 13 implant osteotomies (11 in lower jaw and 2 in upper jaw for a total of 10%) a small flap was made when it was discovered that the planned implant was in mobile mucosa. No unacceptable placement deviations or adverse events associated with the use of Navident were encountered.

The case distribution is tabulated in table 1. The accuracy statistics for all the implants, as obtained using EvaluNav, are shown in table 2. The statistics for different sub-sets of the implants are shown in tables 3-9. The T-test analysis was performed using the software SPSS (Statistical Package for Social Science, IBM Corporation, NY, USA). The difference between the means of two groups is generally considered statistically significant when their 2-tailed T-test probability p is smaller than 0.05.

Overall, the mean deviations were 0.79 (range 0.02-2.78) mm at entry, 1.10 (0.32-3.05) mm at apex and the mean angle deviation was 2.59° (0.18°-8.99°). For partially edentulous jaws, the mean deviation at the apex was significantly smaller, 1.02mm, than for fully edentulous case, 1.83mm. For the fully edentulous jaws, the mini-implant based attachment was significantly more accurate than the earlier stent/screws attachment used. For the 30 implants where the mini-implant approach was used, mean deviations were 0.78 (0.21-1.48) mm at entry, 1.22 (0.45-2.15) mm at apex and 1.91° (0.18°-4.38°) angular, similar to the partially edentulous deviations.

The apical and angular deviations for sextant 2 were significantly smaller than for the other sextants. Guiding the implant insertion resulted in a significant further reduction in deviation, especially at the apex and angulation.

	Number of patients	Number of implants
All patients	46	131
Partial edentulism	33	70
Total edentulism	13	61
Upper Jaw	23	72
Lower Jaw	23	59
Sextant 1 (1.7 – 1.4)	20	24
Sextant 2 (1.3 – 2.3)	15	23
Sextant 3 (2.4 – 2.7)	18	25
Sextant 4 (4.7 – 4.4)	17	21
Sextant 5 (4.3 – 3.3)	10	20
Sextant 6 (3.4 – 3.7)	13	18

Table 1: Case characteristics

Deviation	Mean	Minimum	Maximum	STD
Entry (mm)	0.79	0.02	2.78	0.44
Apex (mm)	1.10	0.32	3.05	0.54
Angle (°)	2.59	0.18	8.99	1.75

Table 2: Mean, maximum, minimum of the entry, apex and angular deviations of all implants inserted (n=131).

Deviation \ attachment method	NaviStent	Mini implant
Entry (mm)	0.76	0.78
Apex (mm)	1.02	1.22
Angle (°)	2.43	1.91

 Table 3 Comparison between the deviation means for implants inserted using different jaw attachment methods:

 NaviStent (suitable only in partial edentulism, Fig 3) vs. mini-implant with a bracket (fully edentulous, Fig. 4).

Deviation	Upper Jaw	Lower Jaw	T-test probability (p)
Entry (mm)	0.81	0.76	0.53
Apex (mm)	1.09	1.1	0.95
Angle (°)	2.73	2.37	0.24

 Table 5 Comparison between the means for implant inserted in the lower vs upper jaw.

Deviation \Sextant	S 1	S 2	S 3	S 4	S5	S6
Entry (mm)	0.78	0.65	0.98	0.71	0.83	0.74
Apex (mm)	1.26	0.84	1.16	0.99	1.04	1.28
Angle (°)	2.92	1.98	3.29	2.54	2.26	2.28

 Table 6: Mean deviations in sextants S1-S6.

Deviation	Total Implants	S2	T-test probability (p)
Entry (mm)	0.79	0.65	0.15
Apex (mm)	1.10	0.84	0.02
Angle (°)	2.59	1.98	0.04

Table 7.: Mean deviations of Implants inserted in the second sextant vs all implants inserted.

Deviation	Implant insertion unguided	Implant insertion guided	T-test probability (p)
Entry (mm)	0.84	0.71	0.11
Apex (mm)	1.20	0.94	0.01
Angle (°)	3.18	1.63	<0.01

 Table 8: Mean deviations of implants inserted in an unguided vs guided manner.

Deviation	First 50 implants	Last 50 implants	T-test probability (p)
Entry (mm)	0.94	0.69	< 0.01
Apex (mm)	1.17	1.07	0.35
Angle (°)	3.44	1.96	<0.01

 Table 9: Comparison between the means of the first and last 50 implants inserted.

The accuracy data was collected starting with the 3rd patient treated by the surgeon with the aid of Navident. In charts 1, 2 and 3, we plotted the values of the three types of deviations for each implant sorted by order of implantation. For each plot, we illustrate the impact of experience on the deviation magnitude using a 4th-degree regression polynomial. It appears that experience has had only a minor impact on apex deviations. However, entry and angular errors have declined steadily with experience. In particular, the mean angular error declined to only 1.6° (maximum 4.28°) in the last quarter of the samples (N=33).



Chart 1: Plot of entry deviations as a function of experience, with a 4th degree regression polynomial.



Chart 2: Plot of apex deviations as a function of experience, with a 4th degree regression polynomial.





Discussion

The golden standard in in-vivo implantation accuracy assessment is registration of pre- and postoperative CBCT and model fitting to the appearance of implants in the post-op image volume, the method we used in this study. In [Vercruyssen 2014] this technique was used to compare, in a randomized prospective study, the accuracy obtained with static pilot-drill templates with that obtained by freehand ("mental navigation") placement in the fully edentulous jaws of 59 patients. Unlike in our study, where volumetric registration and automatic model fitting algorithms were used, Vercruyssen et al used a more labor intensive and operator dependent approach in which bone surfaces are extracted, edited and registered, and in which the model fitting to the implant was done manually. They measured deviations at the entry point (1.4 mm, range: 0.3–3.7), at the apex (1.6 mm, range: 0.2–3.7) and angular deviation (3.0°, range: 0.2–16°). These were much smaller than for freehand placement, with corresponding averages of 2.7mm, 2.9mm and 9.9°) and the authors conclude that guidance offers clear accuracy advantages.

Currently, digitally designed static drill guides are the most widely used approach to placement guidance. [Tahmaseb 2014] provides a systematic review of publications on their accuracy. It finds that deviations measured in clinical studies are significantly higher than when models are used. The data showed an inaccuracy at the implant entry point of 1.12 mm with a maximum of 4.5 mmm and 1.39 mm at the apex with a maximum of 7.1 mm. Angular error averaged 4° and was as high as 21°. As the authors note, the maximal deviations were far from acceptable, and demonstrate the risks associated with guide usage, where it is not possible to evaluate the accuracy of the guidance prior to drilling. In comparison,

dynamic guidance systems reduce such risks by providing the ability to assess the accuracy at any time during the operation.

A limited number of studies regarding accuracy of dynamic navigation systems has been published. Most of them are in vitro studies. [Gunkel 2000], [Siesseger 2001], [Eggers 2005] and [Wanschitz 2002] reported an accuracy of 1 to 2mm by using different dynamic navigation systems of the first generation. [Wagner 2003] inserted 32 implants in 5 patients and reported an accuracy of 6.4°, with a range of 0.4° to 13.3°. [Somogyi-Ganss 2014] used a prototype of the system used in this study to make 80 in vitro osteotomies and reported an accuracy of 2.99°, 1.14mm and 1.71 mm for angular, entry and apical deviations correspondingly.

The accuracy results reported in this study were significantly better than the ones reported in [Tahmaseb 2014], Wagner [2003] and [Somogyi-Ganss 2014], especially when the implant itself was guided as well (means of 0.71mm, 0.94mm and 1.63° deviations for entry, apex and angle correspondingly). This is very encouraging, especially given the many potential advantages of the dynamic navigation approach over the static one detailed in the introduction.

Navident performs fully automatic registration between the CT image data and the patient jaw. In addition to reducing surgical preparation time, this feature reduces operator variability and should, therefore, improve accuracy and predictability in clinical practice. However, drilling under dynamic guidance requires operator skill in hand-eye coordination and fine motor movement. It is reasonable to expect that accuracy will be significantly impacted by operator skill level, which is a function of innate ability, training and the accumulation of experience. A limitation of the current study is that all implantations were performed by a single surgeon, so it is uncertain whether the results for other surgeons will be similar. However, it was useful to observe that acceptably accurate results were obtained from the first case measured (3rd patient), and that entry and angular accuracy improved gradually with experience.

Using the mini-implant based jaw attachment approach, reported here for the first time, we have been able to obtain placement accuracy in edentulous cases similar to that in partially edentulous cases. While more invasive, we found the mini-implant based attachment approach to be faster and easier to apply than the NaviStent one used for partial edentulism.

We measured a significantly smaller deviation in the 2nd (upper front) sextant than in other sextants. The reasons are unclear. It could, perhaps, be the results of better drilling ergonomics. For right-handed surgeons, the 4th (lower left) sextant (or 3rd quadrant) is ergonomically the most challenging. However, we have not found that accuracy was negatively impacted in that sextant.

Conclusions

Computer aided implantology (CAI), when practiced in a flapless approach, has been demonstrated to provide many clear advantages over the free-hand unguided approach. Of the two known guidance methods, static and dynamic, only the static one has so far gained significant usage due to the commercial failure of early dynamic navigation systems. As a new generation of navigation systems is now appearing on the market, so it has become very important to assess their usability and accuracy in clinical practice.

We have successfully integrated one such new dynamic navigation system, Navident, into our daily practice, and recorded data related to its use in a wide range of implant-based restorations, including both partially and fully edentulous jaws, typically in a flapless approach. We used the data we collected to assess placement accuracy using a novel method based on precise volumetric registration and automated model fitting. The results we obtained demonstrated accuracy which is significantly better than, or equal to, the accuracy reported in the literature for static guides. Combined with the many other advantages of the technology, our evidence suggests that the usage of such systems may increase in the future, gradually replacing the imprecise free-hand placement and, in part or in whole, the use of static guides.

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FIGURE LEGENDS

Figure 1. The Navident system consists of a notebook computer (1), and an optical position sensor (4) carried by the foldable boom arm of a compact mobile cart (5).

Figure 2. The stereoscopic optical position sensor (4) detects and triangulates checkerboard targets marked on the DrillTag (2) and JawTag (3).

Figure 3. NaviStent and CT marker for partially edentulous jaw.

Figure 4. Mini temporarily implant with special arm for totally edentulous jaw.

Figure 5. The several views that the operator can see on the screen during the osteotomy: (1) Tracker video stream, (2) Panoramic view, (3) Target view, (4) Depth indicator, (5) Bucco-lingual section view, (6) Mesio-distal section view.

Figure 6. Target view that contains all the information that the clinician needs to guide the osteotomy and the implant.

Figure 7. The three coordinate mapping steps that, when chained together, map the drill tip to the planning CBCT image volume.

Figure 8. Evaluation of the overlapping between the pre-operative CBCT and the post-operative CBCT by using the viewing option checkerboard.

Figure 9. Evaluation of the overlapping between the pre-operative CBCT and the post-operative CBCT by using the viewing option MagentaGreen.

Figure 10. Legend showing how the entry and apex deviations between the planned and inserted implants are measured.

Figure 11. Visual presentation of the deviations in one of six implants inserted in an edentolous patient.