Futuristic trends in dental Implant surgery:

Robotic assisted dental implant surgery with an autonomous dental implant Robot (ADIR)

The extensive application of robotics in the field of medicine owing to standardising new approaches for better treatment has been undertaken since last few years. The field of Dentistry has also upgraded it's techniques for better efficiency in surgery with minimal invasiveness . Ideal implant placement is the basis for long term implant survival and satisfactory restoration outcomes. Static and dynamic computer assisted guidance have been used to improve the accuracy of implant placement[1]. One of the future trends in Oral and Maxillofacial surgery in India shall certainly unveil the application of Robotic assisted implant surgery technology as the latest technique for improved accuracy while performing conventional implant surgery keeping low invasiveness at it's best interest and also for extending surgical expertise .

Guided implant therapy has become a popular method to place dental implants. However, the technologies associated with guidance have evolved over the last few years[2].

Moreover , keeping extending surgical expertise in best interest, innovative technological application is considered for overall precision and accuracy. It is essential for the practitioner to leverage the technological innovations in imaging and planning for meeting patient demands for both expeditious treatment pathways and flawless function and aesthetics. Freehand implant surgery relies on the experience of the surgeons which makes the accuracy of implant placement uncertain.

Digital Imaging

The benefits of digital imaging is highly undeniable while planning through surgical intervention for overall precision

Methods of guidance :

Static and Dynamic navigation for implant placement

Depending on your patient's needs and individualized treatment plan, DDS Labs provides three different types of surgical guides to provide the most personalized and accurate results for implant restoration surgeries. These three options include a SAFE Guide, Universal Guide, and Pilot Guide. The virtue of a static , computed tomography (CT) generated guide stent along with a coordinated system of specified drilling can result in less than 2 mm crestal and apical deviation from the plan and an angulation error of less than 5°. However, Navigation methods mostly hold more precision than Conventional methods [3].Considering, CT generated static stents have workflow time and cost considerations, Dynamic navigation uses a time effective method for maintaining overall precision while implant placement. Even though, there's an equivalent probability for implant placement error.

The major dubiety is about the choice of the practitioner to implement either of the Static system or Dynamic navigation system. Let's keep all the basics upfront [3]:

• Navigation allows minimal invasiveness by allowing limited flap elevation, which lead to limited post-operative morbidity to the patient.

• The system allows accurate spacing and angulation of implants in the contrast to freehand approaches.

• Enables control over accurate depth control while increasing the risk of damage to Inferior Alveolar nerve.

• Virtual implant planning and subsequent navigated placement makes sure that the implant placement angulation and depth for aesthetic situations are appropriate.

• By using virtual implant planning and navigation, the prosthetic and surgical teams can collaborate precisely and execute the plan accurately, achieving results that are specific to each patient.

However, to use CT generated static stents, one has to pay for the software and the fabrication of the guide stent and in case of Dynamic navigation system, one has to pay for the computer system with arrays. The only recurring cost is the patient - specific clips, which is relatively cheap. Now let’s move to the individual systems.

Static Guides :

A static system uses CT generated computer aided design and computer aided manufacturing to create stents, with metal tubes. It is a method of placing implants using a stent that is designed and manufactured based on CT images of the patient (fig 1)[3]. The metal tubes guide the instruments to insert the implant in the exact position that was planned. The implant position cannot be changed once the stent is placed(fig 2)[3]. A laboratory-made imaging guide with the prosthetic plan is needed before scanning the patient’s mouth with a cone-beam CT (CBCT) scan. This is used to create a CT-generated surgical guide for static navigation. This process can cause time delays and extra costs for the team and the patient. The imaging guide may be replaced by digital methods in the future. The CT planning software needs the CBCT Digital Imaging and Communications in Medicine (DICOM) data. The software also needs training. Some clinicians may not master the software and may hire a third party to plan the case. The team uploads the final plan to the stent maker which is followed by a model or an optical scan of the arch is needed to make a guide that fits well on the teeth. This needs impressions, stone, and model trimming which adds time and costs to the static CT-guided method. The stent maker checks the uploaded scan for quality control but the clinician may have to do it again if the guide does not fit well on the teeth or tissues. It can take 2 weeks to get the guide stent. The surgery can be performed after that. The cost for static CT-generated guides varies by maker. They need preoperative procedures and extra costs , while the clinician may not want to learn the planning software well. This makes a workflow barrier for using static CT-generated guides[3]. The surgeon needs the right surgical kit for the implant system when using a CT static guide owing to the fact that the implant choice is hard to change after making the CT guide stent. The implant position cannot be changed in surgery unless the surgeon stops using the CT guide stent. The CT-generated guide stent also makes it hard to irrigate the drill during the process. The access to the bone is limited and there may be more heat. Hence, Static guides are hard to use when the patient cannot open their mouth wide and when they need placement in the posterior region of the mouth. The drill length and the prolongation for accurate depth may be too long for the patient’s mouth opening and this problem is worse in the posterior region of the oral cavity.

(1) (2)

FIGURE 1. Computed tomography-generated static guide for an edentulous patient.

FIGURE 2. Multiple implants in predetermined positions as directed by the computed tomography-generated static guide. The guide allowed for accurate implant placement; however, no changes in the plan could be performed with guidance owing to the static nature of the guide stent .

Accuracy Considerations:

CT-generated guide stents place implants more accurately than free-hand or model-based nonrestricted guides, for the apical and platform positions and depth control. CT-generated guides have some error. The deviations are 0.6 to 1.5 mm at the implant apex and 0.6 to 1.27 mm at the shoulder, depending on mucosa- or tooth-supported guides. The implant angulation deviations from the plan are 2.5 to 5. More than half will be more shallow than planned. The accuracy with static CT-generated guides varies by clinician. Some clinicians place implants more accurately with CT-guided than others. A difference was found between surgeons for the positions of the apex, depth, and angle. When experienced surgeons watched inexperienced surgeons, there was no difference between them for implant placement accuracy with CT-generated stent use. For guided surgery (mucosa and bone supported) and free-hand implant placement or a surgical template in fully edentulous jaws, the guided implant placement group had 1.4 mm deviation at the entry point, 1.6 mm at the apex, and 3.0 of angular deviation. The free-hand methods had 2.7 mm at the entry, 2.9 mm at the apex, and 9.9 of angular deviation. The CT-generated guided methods placed closer to the virtual plan [3].

Advantages[3] :

- Places implants accurately by using a flapless method.
- Moreover it is able to make fixed provisional restorations before surgery.
- Also static CT-generated stents usually need less invasive surgery which results in less patient morbidity.

Indications:

For edentulous cases, a static guide generated by CT should be used when:

- A flapless method is desired.
- The static guide generated by CT can be used to preoperatively fabricate a provisional prosthesis on models generated from the static guide itself.
- The clinician wants to use a bone reduction guide to accurately provide space for the planned prosthesis.
- Implant placement is critical for a planned full arch fixed crown and bridge type prosthesis.

Dynamic Navigation[3] :

Dynamic navigation systems for dental implant placement use visual technologies to monitor the patient and the hand piece and to show images on a screen [3].

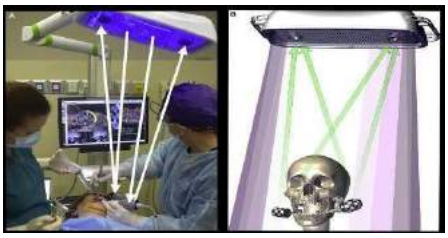
The visual systems use ***PASSIVE*** or ***ACTIVE ARRAYS*** of trackers.

Passive systems use arrays that reflect light from a source to the stereo cameras. Active system arrays send out light that the stereo cameras track. A passive visual dynamic navigation system (X-Nav Technologies, Inc, Lansdale, PA) needs fiducial markers on the patient's arch during CBCT scanning (fig-3)[3]. The device with the fiducial markers aligns the arch to the cameras, with an array attached. The array remains outside the mouth and on the clip with the fiducial markers. The implant handpiece has an array too, which with the clip's fiducial markers, makes triangulation and accurate guidance possible (fig 4)[3]. The drill and patient-mounted arrays must be in the sight of the overhead stereo cameras to be tracked right on the screen [3].

The surgeon can make a small flap to show the crestal bone if needed and the normal drilling protocol for implant site is used. The surgeon guides the drilling with the navigation screen, not looking much at the drill in the patient's mouth. The dynamic navigation workflow starts with putting the fiducial markers on the arch. A clip with 3 metal fiducial markers goes on the patient's teeth in an area without surgery. If an aesthetic plan is used, teeth with radiopaque can be in the mouth as an imaging guide to help with virtual implant position later. The CBCT scan is done with the clip on. The clip can come off and be stored for surgery. The navigation system's computer gets the DICOM data set. A virtual implant is placed. The software is easy and the clinician does not need much computer experience. The implants are generic and use the platform diameter, apical diameter, and length in 0.1-mm steps. The implant can be moved as needed. In surgery, the clip with the fiducial markers gets an array. The staff should register the clip with the attached array and the handpiece with similar arrays to the navigation system. The surgeon can use normal anaesthesia and small cuts, with little flap reflection. The clip array should go back on the arch securely. The drill lengths should have been registered before. The surgeon then puts the patient and arrays in sight of the overhead cameras [3].

The 3-dimensional images on the screen show how to orient the drills, including the depth. The surgical assistant should take care of the irrigation, retraction, and suctioning, as usual. The implant can be placed by hand fully or partially, depending on what the clinician likes (fig 5) [3].

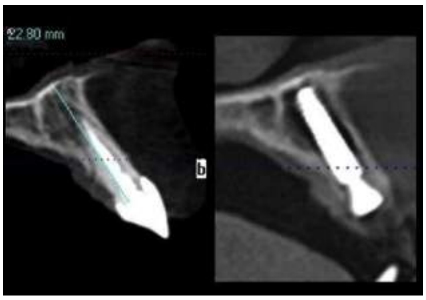
FIGURE 3- Clip with fiducials placed in the patient's mouth before cone-beam computed tomography scanning. The fiducial markers allow for registration of the patient's maxilla for triangulation during the implant placement procedure.



(4A)　　　　　　　　(4B)

FIGURE (4A), Overhead lights emitting blue lights, which are reflected back to 2 cameras by the arrays on the clip in the patient's mouth and on the handpiece .

FIGURE(4B), Line drawing depicting the emitted light from the blue lights in the overhead array, which are then reflected back to the 2 cameras in the overhead array. The 3-dimensional graphics are then displayed on the navigation screen.



(5A)　　　　　　　　(5B)

FIGURE (5A). Cross-sectional images showing the A, preoperative view.

FIGURE (5B), actual postoperative cross-section with the implant in place. The implant site was prepared using the dynamic navigation system and placed under guidance.

Accuracy Considerations:

Studies by Chiu et al, Kramer et al, Brief et al, and Casap et al have shown that dynamic navigation systems have an entry error of about 0.4 mm and an angular deviation error of about 4. Clinical studies have been few, but have said implant success rates are like conventional drilling methods.

Advantages:[3]

The dynamic navigation method has some benefits.

• It is accurate, saves time and money, and lets the clinician change the implant size, system, and location during surgery.

• It also needs less-invasive flap reflection than free-hand methods and causes less trouble for the surgeon because the surgeon's posture is better, with less bending of the back and neck.

• In a patient who has a hard time opening their mouth or needs an implant at a second molar site, which can be hard to reach, dynamic navigation helps with implant placement by using the navigation screen to guide the drills without looking directly in the patient's mouth.

• There is a learning curve for getting good at using a dynamic navigation system. The medical data have said that 15 to 125 cases can be needed, depending on the procedure and the use of surgical simulators, before clinicians can get good at new surgical procedures.

Dynamic navigation also needs a team approach. The surgeon and the first assistant must work together well to use a dynamic navigation system efficiently

Indications[3]:

Dynamic navigation is indicated for any of the following situations:

•Placing implants in patients with a limited mouth opening.

•Placing the implant on the same day as the CBCT scan.

•Placing implants in hard-to-reach locations such as the second molar.

•Placing implants when direct visualization will be difficult.

•Placing implants in narrow interdental spaces when static guides cannot be used due to tube size.

•Placing implants adjacent to natural teeth when static guide tubes will interfere with optimal implant placement

Propositions[3]:

For specific situations, the best choice of method will be clear. As the clinician gains more experience and surgical proficiency, the dynamic method might become more predominant, because of its time- and cost-efficient workflow. In dentate patients, dynamic navigation requires the presence of teeth to stabilize the registration clip and array. The registration clip and array should not be placed on provisionally cemented restorations or on mobile teeth. Also, placing implants in molar locations with difficult direct visual access occurs in patients with a limited mouth opening or crestal bone loss, resulting in the need for drill extenders. Placing adjacent implants requires accurate spacing between the implants and adjacent teeth. Static or dynamic systems can each be used; however, the selection will depend on the clinician's experience and case-specific considerations. Dynamic navigation is flexible, allowing the clinician to change the surgical plan as the clinical situation dictates. It also does not require any laboratory work, thus allowing for immediate scanning, planning, and guidance on the same day as the patient's presentation. The clinician must understand that gaining proficiency requires a learning curve.

Limitations of the above systems and the Advantages of ADIR technology for implant placement:-

Static guides and dynamic navigation are two methods that have been used fo dental implant surgery and have shown to improve the accuracy of implant placement compared to freehand. However, static guide technology has some limitations, such as the inability to adjust the position and angle of the implant intraoperatively, and the possible interference of the guide plate with the cooling efficiency of the surgery. Moreover, the accuracy of dental implant surgery using a template depends on the surgeon's experience. Dynamic navigation technology, on the other hand, can provide real-time feedback on the position, angle, and depth of the drill during the surgery, but it also has some drawbacks, such as requiring the surgeon to constantly look at a screen instead of the operation area, which may affect their confidence and performance. Furthermore, dynamic navigation does not have physical boundaries, and the implant surgery is performed by a hand-held handpiece, which may compromise the operator's surgical precision[1].

Robots have also been employed to assist in implant placement. An autonomous dental implant robot (ADIR) was developed and its feasibility and safety were verified with an animal experiment in China by Bai ,Ren and Feng et al. In 2021 .

About the ADIR technology:

The technology works by a Robotic assisted dental implant surgery assisting the ARCHPOINT surgeons in guiding implant post into the correct spot while allowing same day surgery avoiding invasiveness for traditional implant surgery.

The ***virtues*** of this technology concerning the ARCHPOINT surgeon throughout the process include[1]-

1. Control with precision :

For obtaining better accuracy while maintaining trajectory, the Robotic assistant helps guide the surgeon's hand with precise controlled angles, including tracking patient's motion for overall decisiveness.

2. Perform Complex procedures:

Cases that do require efficiency and accuracy for their procedures with complex tooth problems adjure robotic assisted surgery.

3. Obtain Visual and Audio Data:

The enormous aspect of using Robotic assisted surgery include recuperating visual and audio clues during the treatment to counter the possibility of unintended movement.

4. Faster Recovery times:

Better decisiveness of the technique promotes the surgeon to make smaller incisions into the gum line to promote rapid recovery time overall.

5. Provide successful treatment:

Safe investment of Robotic implant with Robotic assisted aid and the cases which is indicated for minimally invasive surgeries is highly intended.

6. Extending surgical expertise[4].

7. Technologically Augmented Workflow[4]:

Repeatable surgical precision is provided by Robotic guidance during surgical procedure which is moving the practice closer to truly digital workflow.

The following flowchart demonstrates the Clinical workflow of Implant placement by ADIR (Autonomous Dental Implant Robot) system[1] : ----

Preoperative procedure:

Data acquisition

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Preoperative planning

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Accessories Fabrication

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Intraoperative Procedure:

↓

Registration

↓

Path Recording

↓

Osteotomies and implant placement

↓

Accuracy Assessment

↓

Immediate Restoration

↓

Definitive Restoration

↓

Postoperative procedure

Explanation of the procedure:

The process starts by obtaining Jaw information from a Cone beam computed Tomography (CBCT) scan and it's storage in digital imaging and communications in Medicine (DICOM) format. The teeth and soft tissues are scanned with an (IOS) intraoral scanner (CEREC Primescan, Trios 4, Medit i500, iTero Element 5D, CS 3600) and exported in (STL) Standard tessellation language format.

The DICOM and STL data are then imported into the preoperative planning software program (Yomi robotic guidance platform , DentalNavi) for 3- dimensional reconstruction and alignment. The height and width of the alveolar ridge is assessed if it is sufficient or not. Then an interim prosthesis is designed, and the drill sequence of osteotomies are determined following the surgical guidelines while assessing the bone quality of the edentulous area (fig 6A)[1]. Each drill has got a separate rotational speed and feed rate depending on the bone quality (fig 6B)[1].

Meanwhile the designs of surgical accessories are already made before the surgery which includes holder, prop, suction tray and registration holes (fig 7A)[1] for intraoperative registration by 3-dimensional printing devices. And then the surgery is performed under local anaesthesia.

The surgical marker is assembled into the holder and the intraoral registration is completed by inserting the registration probe into the registration holes subsequently (fig 7B)[1].

The surgeon then positions the handpiece manually in patient's mouth who remains seated (fig 8)[1] that is connected to the robot's end effector which reaches the planned starting position of the drill.

FIGURE 6- Preoperative planning. A, Prosthesis and implant position. 6 B, Osteotomy steps.

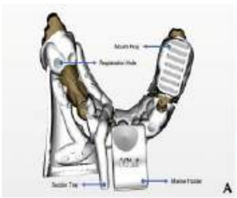


FIGURE (7A)- Design of surgical accessories with registration holes.

FIGURE (7B)- intraoral registration with probe

FIGURE 8- Surgical scenario of dental implant placement surgery with autonomous dental implant robot.

Then the handpiece is removed from the mouth and the path is recorded into the robot's computer by identifying the marker of the robot's end effector by using an active optical pose tracking system (fig 9A[5],B [4]).

The ADIR Autonomously follows the path to safely exit the mouth without touching teeth or soft tissues.

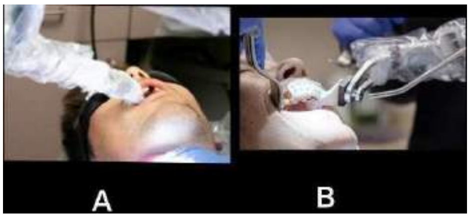
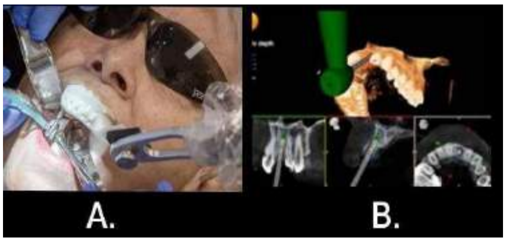


FIGURE (9A)- Yomi tracker arm attached to treatment guide to register the robot to patient's anatomy.

(9B)- Picture illustrating Yomi patient tracker connected to splint .

Thereafter, the ADIR autonomously performs osteotomies stepwise (fig 10A[4],B[5]) and implant insertion without lifting a flap along the recorded paths (fig 11 A[4],B[5]). The screen shows the depth and angle of the drill while comparing with the planned position of the implant instantaneously (fig 12A)[5] while the surgeon supervises and controls all robot movements with a pedal.



FIGURE(10A)- Osteotomies drilled under Yomi Robotic guidance while the surgeon's hand retains and controls the handpiece and the patient tracker allows real time updates in response to patient motion .

(10B)- Picture depicting Yomi guidance software providing physical, visual and audio guidance during osteotomy.

FIGURE(11A)- A- Implant placement procedure carried out with Yomi Robotic guidance.

(11B)- Picture illustrating Yomi guidance software subsequently providing physical, visual and audio guidance during implantation process.

FIGURE(12A)- Final implant placement

(12B)- Radiograph of final implant placement

In fact the surgical plan can be modified with respect to the convenience of the surgical procedure during the surgery.

Finally an immediate post operative radiograph is taken(fig 12B)[5].

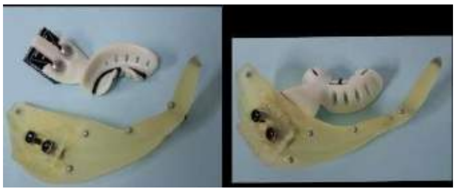
The implant stability is checked and interim abutments are connected to the implants and seated.

Robotic guidance platform :

Yomi Robotic Guidance platform (Neocis , Miami FL)

The name stands for " YomiPlan Implant Surgery Software Suite " . It is developed and released by Neocis, a company that specialises in dental robotics. It is a software suite that helps clinical teams create precise treatment plans, accomplish cases with precision and perfection. The Yomi Robotic guidance platform increases implant placement predictability over freehand surgery, avoids static guide drawbacks, enhancing patient's experience throughout, by increasing restorative sublimity overall. There are several techniques to acquire high quality digital data including facial scans, IOS and CBCT and the use of software programs within a full digital workflow for planning and implementation with robotics.

Yomi process involves 3- dimensional orientation target called Fiducial Array (fig 13A,B)[4]. It is splint-affixed to the patient in the preoperative scan (fig 14)[5]. Certain images are formed by relating the patient relative to the robotic system. Now, these images are processed with the planning software that creates a 360° view of the oral structures, while developing a "map" for surgery (fig 15A,B)[5]. Implant accuracy and restorative predictability is increased by linking " map" with Yomi Robotic guidance. It also provides visual and audio confirmations which allows assistants to closely follow the Workflow and anticipate the following steps .



A B

FIGURE (13A)- Yomi patient splint, shown with contrasting insert and fiducial array.
(13B)- Yomi fiducial array, connected to patient splint.

FIGURE 14- Placement of treatment guide with fiducial array.

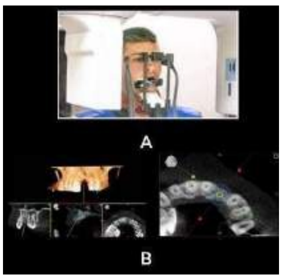


FIGURE (15A)- 3D CBCT scanning with tooth mounted treatment guide and Fiducial array in place.

(15B) - Preoperative plan "map" showing planned implant placement.

The Yomi Robotic arm stabilises the handpiece that responds to the ARCHPOINT surgeon's hand movements to improve efficiency and ergonomics. This in turn provides physical feedback normally referred to as 'haptic boundaries' (fig 16)[4] which is based on drill location with respect to surgical plan and also prevent deviations from the surgical plan along with allowing continuous direct visualisation of the surgical site throughout the process. Although surgical guides may block visual access to the operative site while navigation but can be managed by visual cues on a monitor precise location of the patient relative to the robotic arm is done by Yomi's patient tracking by tracking the fiducial on the affixed splint.

FIGURE16- Yomi Robotic operatory setup: Robotic guidance is delivered to the handpiece as haptic boundaries allows surgeon to maintain direct visualisation of surgical site. Note that the monitor provides visual confirmation as needed, while robotic haptics stabilize handpiece.

Point to be considered*: Yomi guides the entire surgical process, but it does not control it. The plan may be updated for reasons dictated by clinical circumstances at any time.

General Considerations[1]:

Dynamic real-time clinical support is a potential enhancement of the established benefits of guided implant placement with static resin guides, which can be achieved by emerging digital protocols. By overcoming the limitations of both static guides and dynamic navigation, implant placement with an ADIR offers several advantages. The surgeon can adjust the implant position according to the surgical situation, while only looking at the screen that shows the drill position and angle in real-time. The robotic arm controls and restricts the handpiece, so the surgeon does not need to hold it. This improves accuracy, reduces fatigue, and eliminates the effect of the surgeon’s skill level. This is also what distinguishes an autonomous robot from other robots that assist in dental implant placement. Unlike guided implant surgery, there is no guide plate at the surgical site, which allows better cooling of drills. Moreover, the prop helps the patient keep their mouth open for a long time, and the suction tray prevents liquid aspiration in the sitting position. The procedure does not require an assistant for cheek retraction and saliva evacuation, which makes the osteotomies more efficient. Implant placement with the ADIR system is supervised by the surgeon, which ensures safety. The robot moves according to the instructions from the pedal. The surgeon has the ability to stop the robot fast in case of emergencies, such as the patient shifting suddenly. The implant avoids vital structures and the feed rate is low, which allows the surgeon to respond. The path is saved, so the patient’s soft tissues and teeth are safe from the surgical instruments when the handpiece moves in and out of the mouth on its own.

Disadvantages of ADIR[1]:

The procedure has some drawbacks, such as:

• The need to design several customized surgical accessories before surgery, which lowers the planning efficiency. This problem might be solved by using general accessories in the future.

• The robot devices occupy a lot of space in the operating room.

• Robot calibration and spatial registration before surgery should be made easier.

• The accuracy of implant placement with ADIR was acceptable for the current patient.

But it is not clear if ADIR is more accurate than static guides and dynamic navigation. More clinical studies and case reports are required to evaluate the accuracy of ADIR.

Conclusion:

ADIR is a fresh form of dynamic surgical guidance that blends the advantages of both static and dynamic guidance technologies for dental implant placement, which is still not yet put into widespread or usual clinical practice although, It delivers high accuracy, flexibility, efficiency, and safety for implant treatment planning, osteotomy preparation, and implant placement. It also reduces the demand for surgical accessories, assistants, and radiation exposure. However, ADIR faces some challenges, such as the need for high-quality digital data acquisition, robot calibration and spatial registration, and the space occupied by the robot devices in the operating room. Additionally, the accuracy of ADIR in relation to other methods of implant placement is still vague and requires more clinical studies and case reports. Therefore, ADIR is a potential technology that may improve the outcomes of implant therapy, but it also needs more development and evaluation to verify its clinical efficacy and reliability.

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