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Digital three-dimensional planning of orthodontic miniscrew anchorage: A literature review

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Abstract

Orthodontic miniscrews are used for skeletal orthodontic anchorage. An appropriate insertion technique is essential to avoid complications during miniscrew placement. The guides prepared using surface anatomy and 2D radiographs cannot correctly analyze bone volume. Advances in digital 3D medical technologies enabled orthodontists to use digital imaging, digital scanning, and 3D printing to accurately place miniscrews using a surgical guide developed with computer-aided design and manufacturing techniques. The objective of this article was to demonstrate the development of miniscrew placement techniques chronologically and provide brief information about the production, use, and efficiency of modern, digitally planned, and produced miniscrew insertion guides.

Keywords: orthodontic miniscrew, surgical guide, virtual planning, CAD-CAM, CBCT

1. Introduction

Orthodontic treatment depends on moving the teeth via a gentle force application. Orthodontic force is generated using orthodontic arch wires, springs and elastics. Although all of these elements have different features, they all need a supporting structure, an orthodontic anchorage, to generate a force vector. Undesired complications can be seen if anchorage unit was not planned properly thus, anchorage planning was considered as the most important part of the orthodontic treatment planning (1-4).

Intraoral and extraoral anatomical structures were used for orthodontic anchorage. Although extraoral devices are successful in providing the desired anchorage, they depend on patient compliance and are aesthetically difficult to accept therefore, intraoral anchorage can be a desired option generally (1). It is difficult to obtain a stationary anchorage with intraoral or extraoral anchorage devices even with excellent patient cooperation. Mini screw-implants were developed to use the skeletal structures as anchorage (1, 5). Orthodontic miniscrews provide the necessary support without the need for patient compliance. Retention of miniscrews during the orthodontic treatment is one of the factors to consider when using minisrew anchorage (6). The mechanical properties, placement technique, the region where they are inserted, the duration of use, the forces they are exposed to and the factors related to the patient affect the retention and clinical success of the miniscrews (5, 7-9).

Miniscrews have proven to be a useful addition to the orthodontist's armamentarium for the control of skeletal anchorage in less compliant or noncompliant patients, but the risks involved with miniscrew placement must be clearly understood by both the clinician and the patient (10-12). Complications like trauma to the periodontal ligament or the dental root, miniscrew slippage to the unwanted regions, nerve involvement, nasal and maxillary sinus perforation can arise during miniscrew placement and after orthodontic loading regarding stability and patient safety (6). A proper placement technique is imperative to avoid complications during mini screw placement.

A direct manual application is commonly used for the placement of miniscrews, and several methods for minimizing root damage have been suggested when using manual application. Root damage was reported to be reduced when insertion is 4 to 6 mm below the alveolar crest (13) A vertical insertion angle of 30° to 45° is advantageous, and distal tilting of 10° to 20° is reported to be safe (13, 14). However, according to Kuroda et al. (4), contact with or damage to anatomic structures around the roots occurred in 47.4% of maxillary and 48.3% of mandibular miniscrews placed with a direct manual method. Therefore, orthodontic miniscrews inserted using the direct manual method can cause unexpected damage to anatomic structures around teeth because this method depends on the operator's senses and visibility might be limited (15).

Several methods have been proposed for transferring the 2-dimensional (2D) information in the radiographs used for surgical planning to the 3-dimensional (3D) surgical site to

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minimize the risks of root damage. For example, inserting a radiopaque marker, such as brass or stainless-steel wire into the interproximal space of the selected implant site has been suggested as a practical method to help guide the drill between the dental roots (16).

The first guiding device was reported by Suzuki and Buranastidporn (2005). It was pre-manufactured and allowed 3D adjustments to be made; however, it was not found to be cost-effective. Two years later, same researchers published details of a simpler guide that had an auxiliary Gurin-lock attached to a vertical rod. The main advantages of this surgical guide were its horizontal articulation, having a metallic tube serving as inclination guide and low cost. The main disadvantage was the lack of vertical adjustment. In order to adjust the height of the device, rods of different lengths were required (17). Other designs of device include brass wire passed through the contact point between the teeth and with apical extension (18); devices with circular rings at their ends (which are easy to make, but are not necessarily accurate) (6); cross-welded devices made of rectangular stainless steel wires inserted into the bracket slots (19, 20) (which are individualized, but hard to make); plate-type devices with a pilot hole made in laboratory (21, 22) which, are accurate, but require laboratory fabrication, and articulated devices fixed to orthodontic appliance (17, 23) which, are adjustable, but expensive. There are also reports of plate-shaped devices (21, 24) that have the advantage of being individualized for each case. These guides are widely employed in those cases where a pilot drill is initially used, but also with self-drilling miniscrews. The main disadvantage of the plate-shaped devices is that they need to be made in a laboratory.

When the studies about conventional methods are reviewed, it is concluded that the guides prepared using surface anatomy and 2D radiographs cannot correctly analyze bone volume. At the same time, different surface anatomy due to maxillary sinus, dilated roots and alveolar bone loss cannot be detected with these methods.

The use of 3D technology brought the possibility of utilizing cone beam computer tomography (CBCT) images and 3D printers for digital implant guide production for a more accurate screw placement.

Cone-Beam Computed Tomography (CBCT) technology, which is used with the development of 3D imaging methods, provides more precise and detailed information in research and clinical studies for the placement of miniscrews. Additional advantages of CBCT include reduced cost and significant reduction of radiation exposure compared with typical medical CT devices. At the same time, with the development of computer-aided design and computer-aided production (CAD-CAM), minimally invasive and more accurate planning can be made by producing surgical plaques and palatal orthodontic appliances for planning.

With the use of intraoral scanners, the increase in the availability of CBCT devices, production of modelling software specially for dental field and in-office 3D printers, 3D screw guides became easy to produce in the clinic.

This review aims to enable the user obtain a thorough knowledge on the background and the production of the 3D guide for mini screw placement.

2. Digital aid in miniscrew application

Digital workflow has been widely applied in the area of implant dentistry (25, 26). In the "computer-guided" implant placement approach, virtual planning of implants' positions and 3D printed customized surgical guides are used to help the clinician improve the accuracy of implants positioning in the jaw bones during the surgical phase (27, 28). In orthodontics, the placement of micro-implants with a 3D method method based on CBCT imaging has been described in recent years (29, 30).

3. Surgical guide production with replica model

In the first study on this subject, Kim et al. (2007) planned the size and location of the miniscrew to be used by making measurements on the CBCT (31). They produced the replica model of the patient's upper jaw using a prototype machine that was produced by stereolithography (SLA) method from the patient's CBCT images. Surgical guide plates were prepared to be used in the miniscrew application on the model. The miniscrew was applied according to the plan made in CBCT. They found that the occlusal surface of the replica model produced in the study was not clear and it was not able to clearly convey the amount of soft tissue located between the bone and the surgical plate. It is also stated that the replica model produced with SLA technique was not useful due to its high cost.

4. Surgical guide production with custom made impression material

Yu et al. (2012) developed a new navigation guide for addressing limitations of existing CBCT guide systems. Using this technique, a surgical stent was custom made from rubber polyvinylsiloxane impression material, and the rubber stent and jaw were scanned together using CBCT (32). They used a geometric algorithm to find the optimal orthodontic miniscrew placement site. By using the custom-designed surveyor and a Computer Numerical Control (CNC) machine, a guide hole was drilled in the surgical stent template according to the prescription angles measured on the cone-beam computed tomography data. Statistically significant differences were not observed between the predictive implant location and actual implant location. For this CBCT assisted orthodontics minicrews stent fabrication process, some potential sources of error include data from the CBCT scan (e.g., patient movement causing blurriness of images), transposing the guide hole planning data, manufacturing of the surgical stent, positioning of the surgical stent, and during installation of the orthodontics miniscrew.

5. Surgical guide production with cad-cam technology

One year after their first study, Kim et al. (2008) kept working on the same subject. The position of the miniscrews were planned to use CBCT (33). When planning the position of the miniscrews, an implant planning program called SimPlant (Materialize, Leuven, Belgium) was used. Because the reproducibility of a CT image relative to occlusal surface of the dentition was not as precise as a cast, they also shipped a cast of the patient's dentition to the processing center. A laser scan of the dental cast was superimposed on the CT scan, and the surgical guide was made on a computer-generated model of these images. The surgical guide contained metal guide cylinders placed according to the clinician's plan in the computer simulation. Surgical guide plates were prepared using the SurgiGuide (Materialize, Leuven, Belgium) program. The surgical guide was constructed with a Rapid Prototyping (RP) machine that uses stereolithography, a layer-additive rapid prototyping process based on photo-polymer liquid resins that solidify when exposed to UV light. The RP machine reads the diameter and angulation of the simulated implant, selectively polymerizes the resin around the implant, and forms a cylindrical guide on the replica corresponding to each implant. The technician then removes the supporting resin and uses the cylindrical guide to insert surgical grade stainless steel tubing to serve as the guide tube. C-implants (Cimplant, Seoul, South Korea) were used as the skeletal anchorage miniscrew. After insertion of the miniscrews with the surgical guides, another CBCT was taken to evaluate the outcome.

In the first years of studies on the subject, CBCT data and plaster dental models were sent to planning centers for processing because of the limited availability of the dedicated software. Even the early studies about the accuracy of miniscrew placement with digital aid showed promising results.

Qiu et al. (2012) intended to develop surgical stents for CBCT 3D image-based stent-guided orthodontic miniscrew implantation and to evaluate its accuracy (34). Impressions of the phantom dental models were taken with an alginate-based material and cast models of the phantom with special ''blockouts'' were acquired. The cast models were scanned using a 3D laser scanner (LPX-1200; Roland DG Corporation, Shizuoka, Japan) with a 0.1 mm slice pitch, and the reconstructed surface images (stereolithography (STL) files) were exported. The STL files were then imported into Simplant software (Materialise Dental Japan Inc, Tokyo, Japan) and superimposed on CBCT dentition images to acquire the fine 3D dentition images and to transfer the spatial data of blockouts. The data for the implantation plan, including the superimposed 3D laser-scanned image and a dental cast of the phantom, were sent to Materialise Dental Japan Inc for the fabrication of the surgical stents in a CAD-CAM process with photopolymerized resin using a stereolithographic appliance (SLA). They compared the surgical stent insertion against freehand insertion on maxillary and mandibular phantoms. Six parameters (mesiodistal and vertical deviations at the corona and apex and mesiodistal and vertical angular deviations) were measured to compare variations between the groups. They found no root damage in the stent group, whereas four of 10 miniscrews contacted with roots in the freehand group. Significant differences were found in all six parameters between the two groups. Their results showed that the apical mesiodistal deviation of miniscrews without root contact to be significantly lower than that of miniscrews with root contact in the freehand group. Among the six parameters, the apical mesiodistal deviation was the key indicator for root contact.

Bae et al. (2013) evaluated the accuracy of miniscrew placement by using surgical guides developed with computer-aided design and manufacturing techniques (15). Miniscrews were placed in cadaver maxillae using stereolithographic computer-aided design and manufacturing techniques with assistance from surgical guides or periapical x-rays. Insertion sites were selected using a 3D surgical planning program by fusing maxillary digital model images and CBCT images. In the control group direct manual method was used for the placement of miniscrew. They found that the deviations between actual and planned placements differed significantly between operators in the control group, but not in the surgical guide group. In the surgical guide group, there was no root damage from miniscrew placement, and 84% of the miniscrews were placed without contacting adjacent anatomic structures. In the control group, 50% of the miniscrews were placed between the roots. Surgical guide accuracy was improved when digital model imaging was used.

Accurate superimposition of CBCT image and intraoral scanning is important for accurate specification of the insertion area. In a trial by Cassetta et al. (2018) the patient wore a personalized radiological tray (Universal Stent, Bionova, Follo, La Spezia, Italy) with radiopaque landmarks during the CBCT exam; this radiological tray was properly positioned in the mouth with a transparent vinyl polysiloxane (Elite Transparent, Zhermack, Badia Polesine, Rovigo, Italy) and allowed a perfect overlap of the jaw and cast STL files. A software application (Guide Design) permitted the design of the surgical guide (Vector Guide, WHITEK, Lodi, Italy). The 3D STL model of the surgical guide was printed using a 3D printer. The surgical procedures were performed without complications in all cases. They found 1.38 mm coronal and 1.73 mm apical deviations with the surgical guide while the mean angular deviation was 4.60° (35).

Palatinal miniscrew placement requires special attention because of several reasons. Palatinal anchorage devices often use two symmetrically placed miniscrews and some of the devices need bicortical anchorage of the cortical bones of palatal vault and nasal floor. The cortical bone is thin in the nasal floor and orientation of the miniscrew should be thoroughly planned so that it does not penetrate the nasal floor.

Maino et al. (2016) published an article to describe the construction and use of a miniscrew insertion guide designed especially for palatal applications, called the MAPA System. They asserted that the system ensured that miniscrews were placed at the correct depth in the maxillary bone and that multiple implants were parallel. CBCT scan or lateral cephalogram could be used for the identification of optimal site and direction of miniscrew insertion. The latter required a thermo-plastic polyethylene terephthalate glycol-modified bite registration to be made from the patient's plaster cast, with a series of radiopaque markers inserted along the median palatine raphe. Cylindrical guides were placed on the surgical splint to replicate the angle of insertion and were virtually joined to the template by transparent resin bridges, and the entire assembly was produced using a 3D printer. After guiding the miniscrew insertion, the bridges were removed with a dental bur (36).

Cantarella et al. (2020) published an article about miniscrew assisted rapid palatal expansion (MARPE) appliances (36). They placed Maxillary Skeletal Expander (MSE) with four miniscrews on the palate. Bicortical skeletal anchorage was required for the correct functioning of MSE, since it increased the stability of micro-implants (37). They concluded that the digital workflow enabled accurately place the MSE relative to the bizygomatic line, to enhance the biomechanics of the expansion, maximize the bone thickness at micro-implant insertion sites, define the minimum micro-implant length to penetrate the cortical bone of both palatal vault and nasal floor, obtain the parallelism between the four micro implants, the midsagittal plane, and the nasal septum. They too found that compared to the traditional approach, the methodology presented to position MSE with digital planning based on CBCT had the advantage of increasing the precision and safety of the procedure.

Giudice et al. (2020) followed the recent guidelines for digital workflow planning proposed by Cantarella et al. (2020) for the MSE appliance, however, they utilized the patient CBCT DICOM file that allows discriminating between cortical and cancellous bone (36). Also, they used the negative positional template of the MSE for virtual planning. This template allows lab technicians to construct the device in a reliable and accurate position, according to the virtual project planned by orthodontist. The investigators firstly used a printed template of expander connected to a handle which facilitates the test of adaptability of MSE avoiding discomfort to patient (38).

Modern workflow (Fig. 1.) for digital 3D miniscrew guide production starts with obtaining 3D CBCT data of the related area. Scanning of plaster models is replaced with intraoral scanning which provides detailed 3D data of the teeth and the surrounding tissues. Both the intraoral scanning and raw DICOM format of the CBCT image are exported as universal STL file. A dedicated software superimposes the teeth in the CBCT image with the intraoral scan so that CBCT gives the data about the bone and the roots while intraoral scanning gives high quality data about the teeth in the same 3D structure. User then can decide the placement of the miniscrews. DICOM slices can also be used during the placement zone planning. Surgical guide is digitally planned in the software and the guide is exported in a printable STL format to be printed in a 3D printer. Guide can be used after 3D printing.

Orthodontists often place miniscrews without a surgical guide and take only a panoramic radiograph or periapical images for presurgical treatment planning to estimate interradicular space. When implant installation is done manually without a surgical guide, the implant tends to follow the trajectory of least resistance. But the stability of miniscrew placement independent of the operator's skill level when the surgical guide was used. When miniscrews were placed by the 2 operators, who had different levels of experience, there can be little difference in the accuracy of placement between them when surgical guides were used. This implies that deviations between operators can be reduced using surgical guides.

When using the direct method, if the interradicular relationship appears clear and the interradicular distance seems sufficient in the 2D radiographic images, such as the panoramic or periapical view, miniscrews can be implanted successfully. Furthermore, if miniscrews are placed by an experienced orthodontist, the success rate will probably be higher. However, when 2D images of the desired implantation site do not portray an accurate interradicular relationship, when the interradicular distance is short, or when there are significant anatomic structures nearby such as the maxillary sinus or nerve canal, 3D imaging, such as CBCT, might be necessary for planning miniscrew implantation. Although CBCT imaging is not conventionally prescribed because of its cost and amount of radiation, it can be a valuable tool for fabricating surgical guides for successful placement of miniscrews when it is used selectively in patients with limitations to miniscrew placement (15).

Routine use of CBCT cannot be accepted in young patients, but its use can be justified on a patient case individual basis (39). The patient's exposure to radiation can be greatly reduced by the choice of a Field of View (FOV) as small as possible (5 x 11 cm) in the CBCT. This is particularly recommended in subjects under 18 years of age (40). Such FOV is large enough to select the skeletal landmarks required for the virtual positioning of MSE. This inconvenience is compensated by the added safety of the methodology, which allows to avoid the involvement of anatomical areas like the nasal septum, and to maximize bone thickness at miniscrew insertion sites, for a higher stability of the skeletal anchorage during treatment (36). Surgical guides based on CBCT image are especially indicated for the patients with risky anatomic situations. (21)

When the studies about digital planning of miniscrew applications are reviewed, several different software programs were utilized by authors, which is time-consuming for the operator. For the use in the routine orthodontic clinical practice, it is advisable that the functions be unified in a single software to make the methodology more efficient.

6. Conclusion

The more intraoral scanning and virtual planning technologies advance, the easier the combination of TADs and other preformed parts will become for our orthodontic treatment. CAD-CAM procedure for manufacturing of 3D metal printed orthodontic appliances is an efficient and accurate method to fabricate miniscrew guides. The most important advantages of digital workflow in guide production are decreased risk of complications, decreased chair time and greater patient comfort. Advantages of this technique over conventional methods for miniscrew placement include elimination of impression trays and material.

Conflict of interest

None to declare.

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