CONTRIBUTION OF DIGITAL TECHNOLOGY TO THE SURGICAL TECHNIQUE OF MINISCREW INSERTION: A LITERATURE REVIEW

CONTRIBUIÇÃO DA TECNOLOGIA DIGITAL PARA A TÉCNICA CIRÚRGICA DE INSERÇÃO DE MINI-IMPLANTES: UMA REVISÃO DE LITERATURA

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ABSTRACT

Orthodontic miniscrews are used to achieve absolute anchorage. Their insertion technique is simple but must be precise to avoid intra- and postoperative complications. This study aimed to review the literature on the role of digital technology in the precise placement of miniscrews and to describe the different stages of the insertion guide manufacturing chain. The databases used were PubMed, Science Direct, and Google Scholar, including the following English descriptors: "Orthodontic Anchorage Procedures," "Cone Beam Computed Tomography." Digital technology improves the accuracy of miniscrew placement by using 3D imaging to assess the quantity and quality of bone and the proximity of anatomical structures in the area to be implanted. By combining 3D imaging with the new techniques of 3D printing and virtual planning, the orthodontist can obtain a personalized placement guide for the patient using computer-aided design and manufacturing techniques. A digitally-assisted miniscrew insertion system is a promising technique for precise and safe miniscrew insertion but cannot be used routinely. Therefore, large-scale studies are needed to map miniscrew insertion in different areas, considering ethnicity, gender, and different anatomical characteristics.

Keywords: Workflow, Orthodontics, Orthodontic Anchorage Procedures, Cone-Beam Computed Tomography.

RESUMO

Mini-implantes ortodônticos são usados para obter uma ancoragem segura. Sua técnica de inserção é simples, mas deve ser precisa para evitar complicações intra e pós-operatórias. Este estudo teve como objetivo revisar a literatura sobre o papel da tecnologia digital na colocação precisa de mini-implantes e descrever as diferentes etapas da cadeia de fabricação do guia de inserção. As bases de dados utilizadas foram PubMed, Science Direct e Google Scholar, incluindo os seguintes descritores em inglês: "Orthodontic Anchorage Procedures", "Cone Beam Computed Tomography". A tecnologia digital melhora a precisão da colocação dos mini-implantes usando imagens 3D para avaliar a quantidade e qualidade do osso e a proximidade das estruturas anatômicas na área a ser implantada. Ao combinar imagens 3D com as novas técnicas de impressão 3D e planejamento virtual, o ortodontista pode obter um guia de posicionamento personalizado para o paciente usando técnicas de design e fabricação auxiliadas por computador. Um sistema de inserção de mini-implantes assistido digitalmente é uma técnica promissora, mas não pode ser usado rotineiramente. Portanto, são necessários estudos em larga escala para mapear a inserção dos mini-implantes em diferentes áreas, considerando etnia, gênero e diferentes características anatômicas.

Palavras-chave: Fluxo de Trabalho, Ortodontia, Procedimentos de Ancoragem Ortodôntica, Tomografia Computadorizada de Feixe Cônico

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INTRODUCTION

Miniscrews are widely used in orthodontic practice thanks to their many advantages: simple surgical placement and removal, small size, relatively low cost, and minimal postoperative requirements (1). However, miniscrews placement can be problematic considering the lack of knowledge of the implanted site anatomy, especially in the palate and the infra-zygomatic ridge, which can sometimes lead to failure. Several methods have been described in the literature to optimise the correct placement of miniscrews and improve their success rate based on digital technology (2-4). Digital technology has revolutionised dentistry, first in implantology and now in orthodontics. Thanks to cone beam computed tomography (CBCT) analysis, it is possible to plan the position of the miniscrew, avoiding anatomical pitfalls. Then, using sophisticated software, we can choose the type of miniscrew, as well as its orientation and depth of insertion, using the same technique as for implant planning. Finally, for greater precision during miniscrews placement, 3D printing from digital impressions and CBCT produces surgical guides. This review aimed to assess the value of CBCT in improving the placement accuracy of miniscrews and to itemise the manufacturing workflow of insertion guides.

LITERATURE REVIEW

A non-systematic electronic search was performed in the PubMed, Science Direct, and Google Scholar databases using the following English descriptors: "Orthodontic Anchorage Procedures," "Cone Beam Computed Tomography." using the Boolean operator "AND." Research articles, literature reviews, randomized clinical trials, and case reports pertinent to the subject, published from January 2000 to July 2023, in English or French language were included. Exclusion criteria included articles with disparities in the proposed theme, abstracts, and letters to the editor. A total of 390 articles were found, 21 duplicates were eliminated using Zotero software, and the remaining 369 articles were examined manually. Finally, 39 articles met the selection criteria for inclusion in this study.

Current state of knowledge

Tomographic determination of miniscrews site insertion:

CBCT indication:

The use of preoperative CBCT is not systematic, it is justified in cases where (5,6):

- Retro alveolar images show real root proximity;
- The noble anatomical structures are close to the insertion site;
- Routine cephalometry has highlighted the likelihood of insufficient bone quality or quantity and the risk of complications;
- Implant sites are being mapped for a given population.

Recommended sites for miniscrew placement:

Several scientific studies have been carried out on groups of patients to determine the safe areas for inserting miniscrews, based on the interradicular spaces and the thickness of the cortical and alveolar bone with the help of CBCT (7-11). However, given anatomical variability, carrying out a personalised analysis is still necessary in some particular cases (periodontitis, anatomical variations, clefts, etc.).

Interradicular miniscrew:

In the maxilla, the most favourable vestibular interradicular sites are located mesial and distal to the first molar and between the canine and lateral incisor, all located 6 mm away from the cementoenamel junction (CEJ). The recommended sites in the palatal interradicular zone are from the mesial of the second molar to the distal of the first premolar 4 mm away from the alveolar crest (AC). In the mandible, the most favourable vestibular interradicular sites are between the first and second molar and between the first and second premolar, both 5 mm away from the CEJ. For the anterior and posterior lingual part of the mandible, the available data is limited, since these areas are rarely used for miniscrew placement (8).

A vertical insertion angle of 30 and 45 degrees (12) and a distal tipping of 10° to 20° (13) may provide better contact between the cortical bone and the miniscrew without damaging the roots.

Palatal miniscrew:

- **Posterior area**

The palatal posterior supra-alveolar area is a suitable site for posterior insertion of palatal miniscrews. Miniscrews placed in this area can aid in skeletal palatal expansion, intrusion of maxillary posterior teeth, and upper molar distalisation. The optimal insertion site is between the second premolar and the first molar with a 45° angulation to the palatal plane. This location could provide tricortical stabilisation (palatal vault cortical plate, nasal and maxillary sinus cortical plates) and application of a higher apical expansion force, thus improving biomechanical force application and potentially achieving better skeletal treatment effects (5,7) (Figure 1).

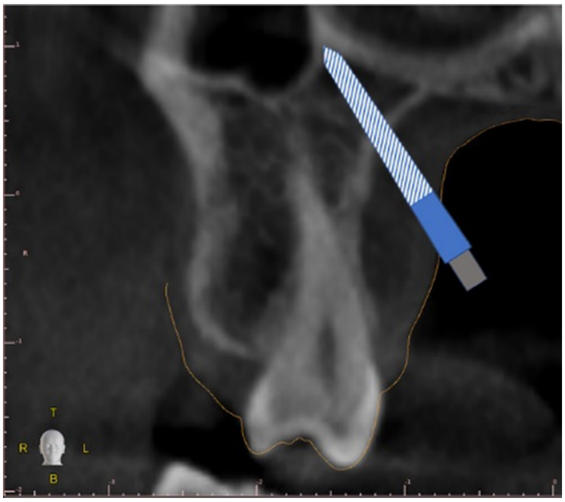

Figure 1: *Ideal miniscrew position in palatal posterior supra-alveolar insertion site to reach tricortical stabilization (7).*

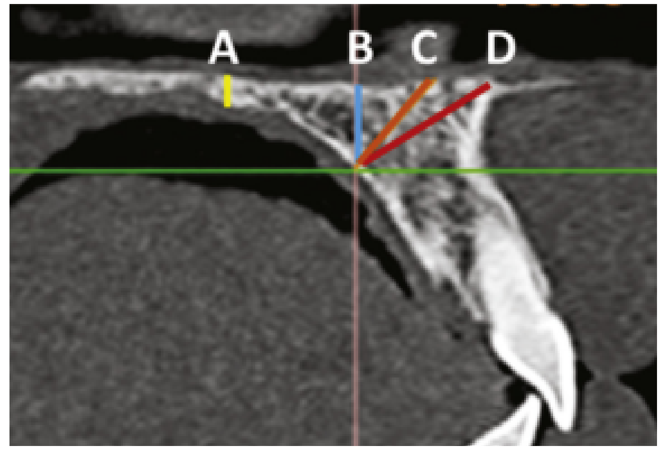

Figure 3: *Coronal slice CBCT, reference lines constructed to measure the palate thickness and the optimal mini-implant zone insertion. The D line is the measurement from the palatal cortical bone to the nasal floor cortical bone (30°) on dpmL3 point (10).*

— **Anterior area**

In the anterior region of the palate (distal surface of the first premolars), the optimal insertion site is 3 mm lateral to the midpalatal suture, from the palatal cortical to the nasal floor cortical at 30° (10). According to Nucera et al. (2022), both the third palatal ruga and 2 mm posterior to the third ruga (4 mm paramedian perpendicular to the palatal mucosa) could be the optimal insertion site for palatal miniscrew placement (14) (Figure 2, Figure 3).

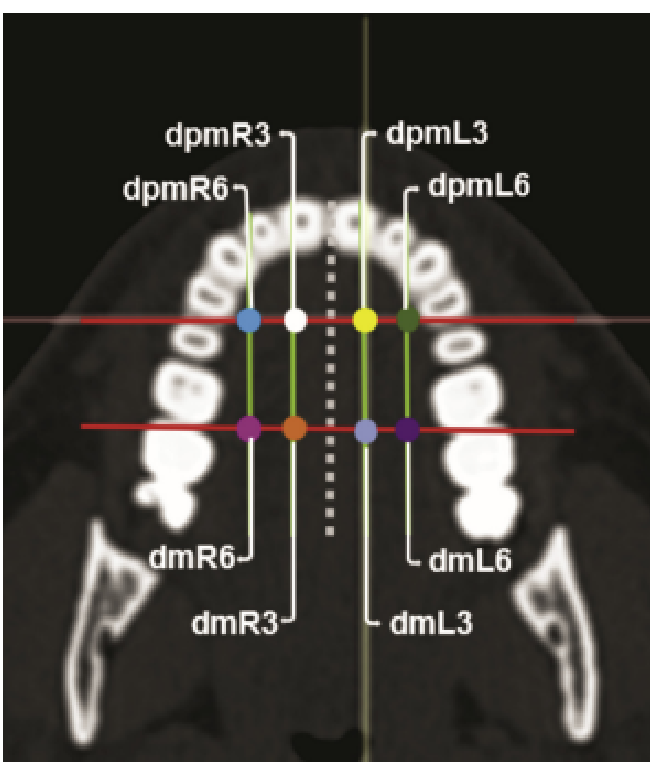

Figure 2: *Axial slice CBCT, reference points constructed to measure the palate thickness and the optimal mini-implant zone insertion, with distal face of the left first premolar at 3 mm from the midpalatal suture (dpmL3) (10).*

Mandibular Buccal shelf MBS miniscrew:

The insertion site with optimal bone quantity is located regarding the buccal aspect of the distobuccal cusp of the 2nd molar, the preferred angle of insertion of the mini-implant is 30°–45° to the long axis of the tooth to engage maximum bone thickness and have adequate clearance from the tooth roots. Maximum bone thickness can be engaged by placing the miniscrew at a depth of 8-12 mm below the CEJ (15).

Infrazygomatic miniscrew:

The preferred site for placing the miniscrew is between the first and second molars, 4 mm away from the CEJ. The miniscrew size (2.0 × 12 mm) and insertion angle (60°) should be selected to allow for a deep enough bone insertion of the miniscrew to allow for bicortical fixation (16). According to Bingran et al., the miniscrew site is located between the first and the second upper molar at a height of 15 mm above the posterior occlusal plane, a gingival tipping angle of 60°-70° and a distal tipping angle of 30°. The appropriate miniscrew for this site is characterized by the following dimensions: 9-11 mm in length and 1.6-2.3 mm in diameter. From a clinical point of view, digital palpation allows the greatest prominence of the infrazygomatic crest for miniscrew insertion (17) (Figure 4).

Digital workflow for the production of miniscrew guides:

Digital workflow is a process of acquiring digital images of the patient's dental arches, viewing and manipulating these images in specific computer-aided design (CAD) software and printing the files in 3D. In orthodontics, the placement of miniscrews can be planned, based on 3D digital models and radiographs. The conception of a digital printed insertion guide is made following this protocol (18):

Digital selection of the miniscrew insertion site:

Acquisition of clinical data:
The first step is to obtain 3D CBCT data of the area of interest. Then, information on the intraoral situation, including teeth, alveolar ridge, and soft tissues, can be acquired with an intraoral scanner or by using conventional digitized plaster casts (18). According to TOMITA et al. (2018) (19), intraoral scans can be more accurate than conventional impression/mold scans. File data from dental arch scans and from DICOM CBCT (Digital Imaging and Communications in Medicine) are exported as a universal STL files (stereolithography) (20, 21).

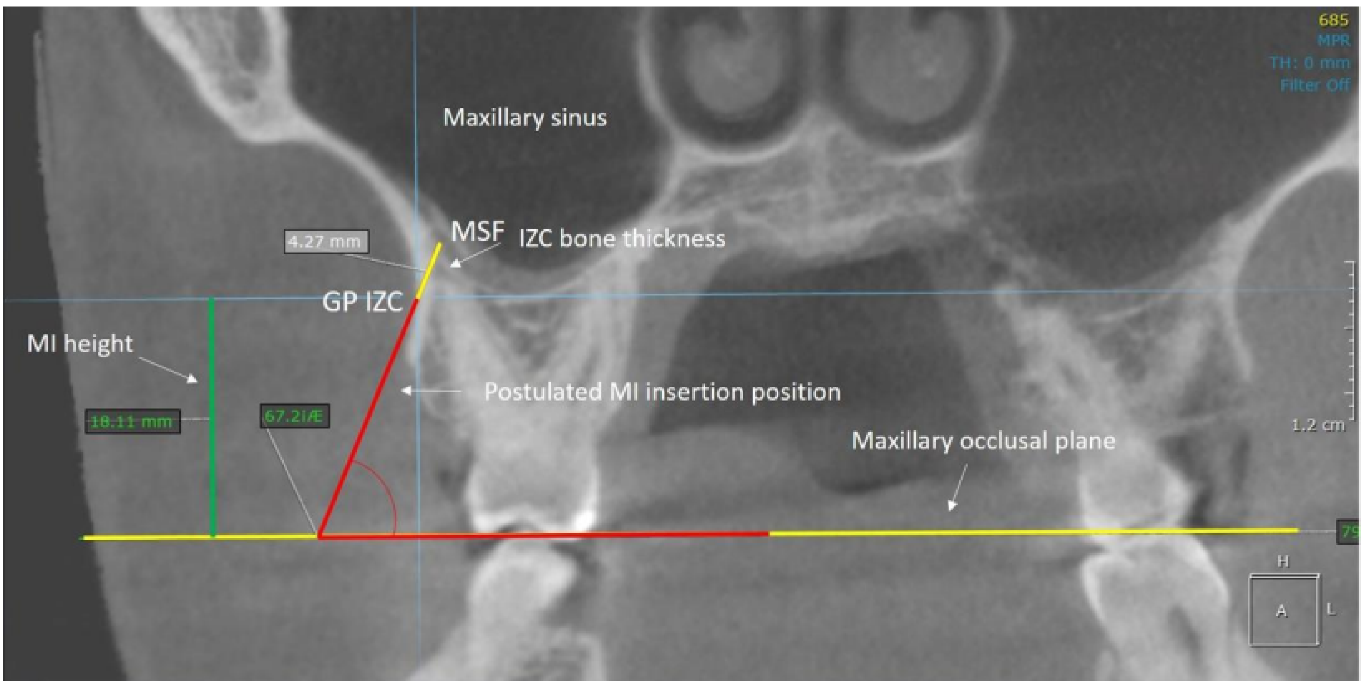

Figure 4: *Coronal slice, reference lines constructed to measure the infrazygomatic crest thickness and the mini-implant insertion angle and height according to Antelo et al. (2022) (17)*

Using surgical planning CAD program software:
Software tools for digital planning range from open source to proprietary solutions. The chosen software superimposes dental arches on the CBCT with intraoral scan. The CBCT provides alveolar and facial bone structures and dental roots data whereas the intraoral scan provides a high-quality dental arch surface data in the same 3D structure (18, 21).

Miniscrews 3D files, are available on some CAD software libraries, or can be digitally customized in the software using the “customize implant” function, dimensions are obtained from the manufacturer or by measuring or scanning the miniscrew to be used, the created miniscrew can be saved in the software library for future case planning (2, 23).

With virtual placement, the clinician can adjust the position and orientation of the screws in the axial, coronal, and sagittal views, as well as in the 3D reconstruction. The aim is ensuring sufficient bone support and a safety margin with the surrounding anatomical structures (2).

The CBCT-based digital planning of miniscrew-supported devices such as the maxillary skeletal expander (MSE) has the advantage of increasing the precision and safety of the procedure, considering both anatomical and biomechanical factors. In fact, this planning concerns both the body of the expander and the miniscrew that supports it. It allows choosing the orientation of the expander so that the force vector of the expansion is as close as possible to the centre of maxillary resistance, to allow parallel opening of the suture. It also allows choosing the length and the orientation of the miniscrews to ensure bicortical fixation (fixation in the cortical bone layers of both the palatal vault and the nasal floor), which optimises the stability of the miniscrews during the application of an orthopaedic force (2, 23, 24).

Fabrication of the surgical guide:

The surgical guide is digitally designed in the software and exported in a STL format to a professional 3D printer. When the device supported by miniscrews already exists, the device itself can be scanned, imported on the software, and used as a guide (20).

However, first inserting the mini-implants in a good bone sites according to digital planning using guides and then proceed with clinical data acquisition to design the intraoral device is more accurate (18, 25).

According to several studies that have evaluated the accuracy of surgical placement guides (4, 23, 26, 27) (Table 1) to reduce placement deviation, the design must meet certain criteria:

— The materials used should be non-flexible.
— The surgical guide should have adequate retention and stability so that the miniscrews are not dislodged by the insertion force during placement.
— Tooth-supported insertion guides, which rest on the edges of the teeth, ensure greater accuracy of insertion than mucosa-supported guides.

Miniscrew placement

A clinical test to check the stability of the guide is necessary. After sterilisation the guide is stabilized by the occlusal force of the patient if it is a tooth-borne guide. The miniscrew is slowly inserted through the hole in the surgical guide until the body of the miniscrew is embedded in the alveolar bone as indicated by a marker on the tip of the screwdriver (23).

DISCUSSION

Thanks to digital planning, we can reduce the failure rate of miniscrews and improve the accuracy of their placement (28) (Table 1). However, due to the amount of radiation exposure and the high cost with 3D techniques, using two-dimensional radiographs with a surgical guide for routine mini-implant placement is recommended (29).

TABLE 1: RELEVANCE OF DIGITAL TECHNOLOGY IN THE ACCURACY OF MINISCREW PLACEMENT

Miniscrew area	Author	Study design	Sample size	Objective	Intervention description	Digital method relevance
Infrazygomatic crest	Prajak Jariyapongpaiboon et al., 2020 (23)	Retrospective study	20 subjects	Evaluate the accuracy of IZC miniscrew placement using a computer-aided design and manufacturing (CAD/CAM) surgical guide.	**Group DI** Direct insertion **Group SG** Insertion using CAD/CAM surgical guides	Most accurate miniscrew placement
	Li Su et al., 2022 (37)	Prospective cohort study	17 subjects	Evaluate clinical effects of two kinds of templates, type A and type B	**Group C** Direct placement **Group A–B** Miniscrew placement is designed by type A or type B template EXOCAD software.	Better depth control in the insertion Avoiding injury to the maxillary sinus
Anterior palate area	Giorgio Iodice et al., 2022 (38)	Retrospective study	35 subjects	Evaluate the differences between a planned insertion versus a direct method insertion.	**One group:** Comparison of direct insertion method planned insertion method by superimposing lateral cephalograms and plaster models of each patient.	Operating aid for clinicians with less experience
Interradicular area	Mi-Ju Bae et al., 2013 (39)	Prospective study	12 cadaver maxillae	Evaluate the accuracy of miniscrew placement by using surgical guides developed with computer-aided design and manufacturing techniques	**control group** Direct insertion using 2D periapical radiographs **surgical guide group,** Placement with surgical guides based on cone-beam computed tomography (CBCT)	More accurate miniscrew placement

***In the interradicular site:**
The two-dimensional intraoral radiograph of the interradicular area provides sufficient information for miniscrew placement. However, if miniscrew placement is difficult due to complex anatomy such as an expanded sinus or alveolar bone loss, using CBCT data for planning may be considered (29).

When placing miniscrew in the palatal or infrazygomatic site, using a surgical guide from the CBCT is interesting for more safety (Table 1).

***In the anterior palatal and paramedian area:**
The study by Jung B et al. (2011) found that 98% of bone assessments were reliable and sufficient with lateral radiography and the amount of bone was confirmed during the procedure of placing the miniscrew. The authors concluded that the bone volume in this site is favourable and the vertical bone dimension, as displayed on lateral cephalometry, reflects the minimum rather than the maximum bone height in the medial plane. Therefore, preoperative CT or CBCT is only indicated when lateral cephalometry reveals insufficient bone (30).

***In the mandibular buccal shelf zone (MBS)**
According to Natalia Escobar-Correa et al. (2021), MBS provides an optimal bone surface for miniscrew insertion, with optimal osseous characteristics for class III patients and patients with a low angle who exhibit the most favourable osseous characteristics in the MBS area (31). According to ETOO et al. (2023)the ideal site for BS miniscrew insertion is the distal root area of the second molars, regardless of facial pattern, gender, and age. In women, the buccal shelf has less bone thickness and height and less bone thickness and height than the inferior alveolar nerve canal (32). The buccal area of the first molar does not appear to show reduced values for appropriate bone width, according to Kolge et al. (2019). Nevertheless, insertion in this area can be achieved for an individual after assessing by 3D imaging or at least digital palpation showing that the patient has adequate bone (33). Arvind's trans mandibular (ATM) is a newly described radiographic technique that relies on the use of an intraoral radiographic film or radiovisiography (RVG), placed outside the patient's mouth along the lower mandibular border. The resulting radiograph shows the image in axial view along the first molar. This radiographic incidence allows to assess the postoperative buccolingual positioning of the buccal shelf implants in relation to the adjacent molars (34).

***In the infrazygomatic crest:**
The size of the miniscrew and the site of insertion depend on the bone thickness of the infrazygomatic ridge area, the morphology and thickness which vary according to the ethnicity of the patients. Tavares et al. (2020) found in their study that individual parameters (side, gender, vertical, and sagittal skeletal patterns) do not significantly influence the thickness of the infrazygomatic ridge (16), thus, mastering basic anatomical knowledge is also required. A 3D radiological evaluation would be useful to avoid perforation of the maxillary sinus during screw placement and to ensure its bicortical fixation (vestibular cortical plates and lateral wall of the maxillary sinus) (34).

***Limitations and implications for clinical practice and for further research**
Note that whereas CBCT provides accurate information for assessing alveolar bone height, it shows substantial errors assessing fenestrations and dehiscences. Caution must therefore be exercised when assessing these defects (36). Hence the need for large-scale studies to map miniscrew insertion in different regions, considering ethnic, gender and various anatomical characteristics.

CONCLUSION

The digitally-assisted miniscrew insertion system is clinically proven and offers several advantages: it ensures reliable and precise miniscrew placement, avoiding contact with roots or delicate anatomical structures. However, digital workflows require collaboration with a specialized laboratory that has mastered this technology to minimize sources of error in the manufacturing process. This technique also requires the use of CBCT, which exposes the patient to additional radiation. Therefore, these techniques should be reserved for the most complex cases and will not be used routinely.

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