

ROLE OF THE MAXILLARY TUBerosITY IN PERIODONTOLOGY AND IMPLANT DENTISTRY - A REVIEW

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Background: The maxillary tuberosity in implant dentistry presents the clinical location for clinicians with respect to the periodontal, surgical, prosthetic, implantological and mechanical aspects.

Objective: The aim of this paper was to evaluate the role of the maxillary tuberosity based on the literature and to enhance the role of tilted implants placed in the maxillary tuberosity as an anchorage to the most posterior end of prostheses in order to avoid biomechanical complications from distal cantilevers.

Data Sources: Information was obtained mainly from the PubMed and MEDLINE databases, online books managed by the National Center for Biotechnology Information, and non-indexed sources. Previous studies have demonstrated more than 94% survival rates of implants placed in the maxillary tuberosity despite the usage of varied implant designs and surgical protocols.

Data Extraction and Synthesis: The web search included the following keywords: bone, dental implant, dental implantation, maxillary osteotomy, osseointegration for period 1980 to 2017. Proper insertion of tapered implants with adequate bone condensation of the local cancellous bone is effective in generating the required primary stability and eventual osseointegration required for long-term success. In cases where implant placement in the maxillary tuberosity provides no immediate restorative benefit, various hard and soft tissues of the region can be harvested for autogenous grafting to address distant constraints. Usage of the maxillary tuberosity for implant placement or as a grafting source can provide increased options for clinicians to restore a patient's dentition to a higher quality without the requirement of more numerous, costlier and complicated surgical restorative procedures.

Keywords: Bone; Dental Implant; Dental Implantation; Maxillary Osteotomy; Osseointegration.

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1. Introduction

The maxillary tuberosity (MT) is a bony region located bilaterally on the upper jaw that is posterior to the most distal molar roots. It is often characterized by its prominent rounded appearance that bulges outward from the face of the maxillary bones around the maxillary sinus. The tuber region is comprised primarily of spongy cancellous osseous tissue – specifically categorized as a combination of type III and IV bone with abundant marrow [1,2]. It is situated along the medial side of the pyramidal process of the palatine bone and forms an articular surface at this site. The posterior superior alveolar nerves and vessels pierce through the posterior surface of the MT, and this tu-

ber region also functions as an attachment point for the medial pterygoid muscles. In the past, soft and hard tissues of the MT served as excellent donor sites when these tissues were deficient elsewhere in the maxilla. It has been shown that gingival connective tissues can be harvested and grafted successfully at recipient sites for cosmetic and functional root coverage in the anterior maxilla [3,4]. The MT can also function as a bone source as there is frequently an abundance of untapped usable bone mass, even in patients with bone recession throughout the remainder of the maxilla. Bone harvested from the maxillary tuberosity has been used in the reconstruction of compromised sockets for immediate implantation,

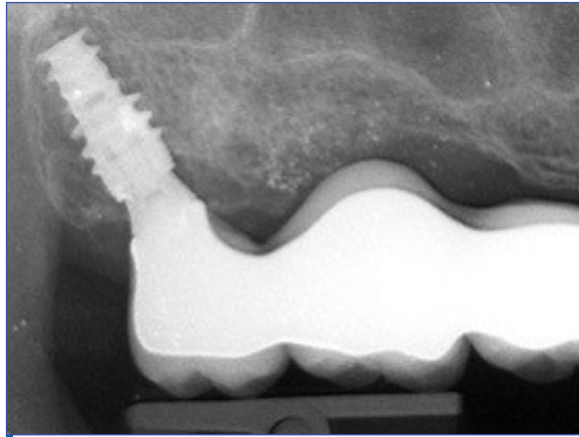


Figure 1. Maxillary tuberosity providing support for an implant-supported fixed prosthesis (courtesy: Dr. E. El-Haddad, Torino, Italy).

as well as effectively in the management of intrabony defects in mandibular molars [4,5]. Varying defects covering trauma, infection, or bone recession often result in structure changes of alveolar processes that cannot be candidates for implantation without additional grafting procedures. The usage of bone grafts harvested from the MT can provide a superb alternative source of autogenous bone to augment the alveolar ridges and sockets without the need for more invasive surgical harvesting procedures, such as when bone tissues are taken from the chin or the ramus [6]. Although the maxillary tuberosity does not naturally support teeth nor is it a traditional site for dental implants, it can provide support for some restorations in particular cases.

The MT is a more permanent structure, and even with the extraction of all maxillary teeth, the MT remains with only minor resorption. It is speculated that the pterygoid medialis muscle provides loading forces during mastication which counteract disuse atrophy [1,2]. Bone resorption in the palatal direction and narrowing of the MT is generally only seen when tooth loss is secondary to pronounced periodontal disease. As such, the convex anatomy of MT should always be taken into consideration in traditional denture design as the medial and lateral walls resist the horizontal and torquing forces which would move the denture base in the lateral or palatal directions [7-11]. In more recent times, the MT has been deemed as an acceptable site for implant placement, especially in cases where there is a need to avoid sinus grafting, thus providing increased stability for fixed (Fig. 1) or removable prostheses (Fig. 2).

Implant placement in this posterior region is quite comparable to that of conventional implant placement elsewhere in the maxilla with only slight alterations of drilling, bone condensation procedures, and instruments in order to protect the weaker bone in the area. Several previous studies have demonstrated excellent survival rates comparable to that of implants placed throughout the remainder of the maxilla [12-21]. Successfully placed and osseointegrated implants in the tuber region can be used as abutments for

implant-supported prostheses to avoid distal cantilevers and control bending moments in the posterior segments. Implant placement in the MT is a much more conservative option in treatment when there is insufficient bone mass throughout the rest of the maxilla. This allows for the circumvention of extensive surgical grafting or sinus lifting procedures that entail greater risk of complications. Implant placement in the MT becomes a more sensible choice for elderly patients, those with healing deficiencies, or those where cost for treatment is restricted.

2. Materials and methods

This literature review was carried out through the utilization of PubMed.gov, an online database comprised of biomedical literature from MEDLINE, life science journals, and online books managed by the National Center for Biotechnology Information. Search criteria for scientific papers in this review were confined to the role of the maxillary tuberosity and pterygoid in implant dentistry. This included anatomy, implant placement, removal of tissues, and surgical outcomes.

3. Results

The tuberosity currently serves as an underutilized region of the maxilla that has the potential to be a critical area for implant placement in patients with bone deficiencies throughout the mouth. Despite its advantages, implant placement in this region is often hindered by its own anatomy; primarily the spongy bone of the maxilla is softer and more cancellous than that of the mandible, and bone density decreases posteriorly.

The bone of the tuberosity presents a high volume of bone marrow with increased vascularization [1,2,12,22,23]. As such, any clinician planning for the placement of implants in this location must first take into consideration the relative lower density and properties of this osseous tissue to best avoid implant failure [8,9,11,18,24]. Generally, implants must be angulated to properly fit the tuberosity bone structure with sufficient length.

Angled (tilted) implants were seen as unfavorable to support large restorations in the past as they were thought to increase risk of bone resorption and implant failure, but more current studies have shown that angulated implants offer the same, if not better, long-term results when compared to their non-angulated counterparts – especially with implant lengths exceeding 13mm, regardless of angulation [25-27]. This may likely be due to greater primary stability imparted by the additional threads of longer implants, leading to more successful long-term outcomes.

This primary stability may have been a more critical factor to implant success than the spongy bone's lesser density support.

Additional considerations for implant placement in the MT include the amount of bone available and bone height issues.

Table 1. Survival rates of implants placed in the maxillary tuberosity across published studies[12-21].

Author	Number of Patients	Number of Implants in Tuberosity Region	Length of Implants (mm)	Width of Implants (mm)	Number of Implants in Other Maxillary Regions	Implant Manufacturer	Follow-ups (months)	Survival Rate In Tuberosity (failures)	Survival Rate in other regions (failures)
Shirota et al.	1	2	10.0	4.0	4	N/A	24	100%	100%
Leles et al.	1	2	11.0 & 13.0	3.75	3	N/A	24	100%	66.6% (1)
Alves and Neves	1	2	14.0	4.1 & 4.8	6	N/A	36	100%	100%
Markt	1	4	10.0 & 13.0	3.75	2	N/A	18	75% (1)	50% (1)
Nocini et al.	1	2	N/A	N/A	6	N/A	N/A	100%	100%
Park and Cho	7	7	11.5-15	3.75-4.0	10	CSM	12 to 84	100%	N/A
Ridell et al.	20	22	13.0-20.0	3.75-4.0	64	Nobel Biocare, Brånemark	12 to 144	100%	96.87% (2)
Venturelli	29	29	10.0-20.0	3.75-4.0	13	Implant Innovations	36 to 48	100%	92.3% (1)
Bahat	45	72	N/A	N/A	0	Nobel Biocare, Brånemark	21.4	93% (5)	N/A
Krämer et al.	11	19	N/A	N/A	53	Cylindrica 1 IMZ type	6 to 60	84.21% (2)	92.45% (4)
TOTAL	117	161			161		52.08 (mean)	95.03 (8)	94.41% (9)

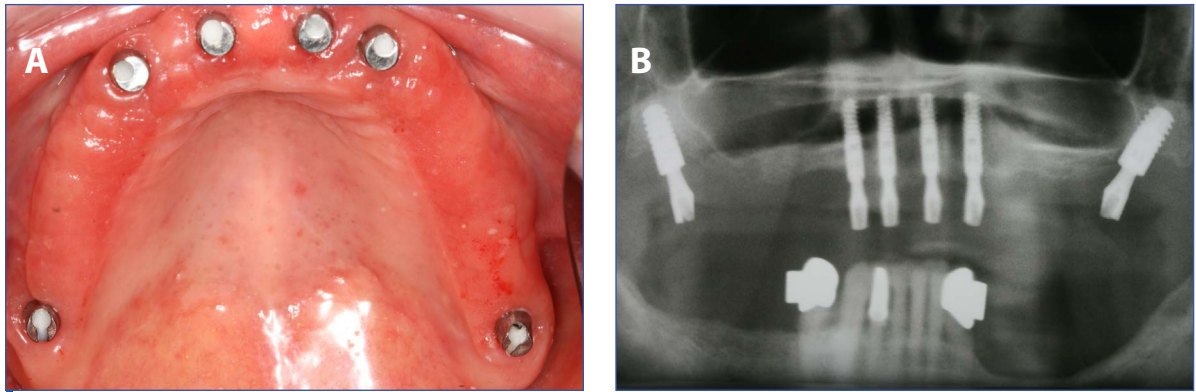


Figure 2. Clinical (A) and radiologic (B) conditions demonstrating the maxillary tuberosity providing support of tuberosity-embedded implants 10 years after functional loading of a removable implant-supported prosthesis.

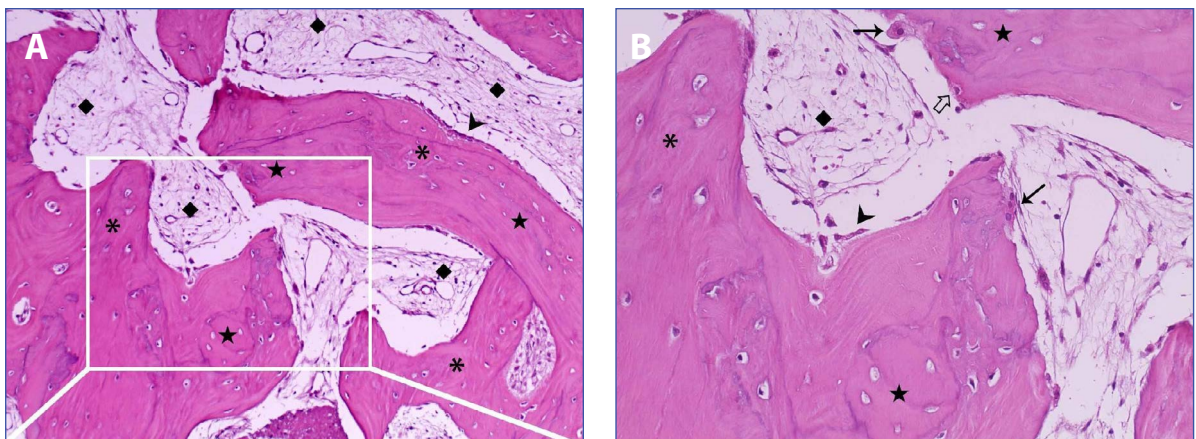


Figure 3. Representative photomicrographs of a biopsy specimens visualized by hematoxylin and eosin staining retrieved 3-months after grafting of maxillary tuberosity bone to the alveolar ridge. (A) Panoramic view (microscopic objective 10x) of well-vascularized and cell-rich marrow (◆), newly formed trabecular bone (*) with bone lining and/or osteoblast-like cells (▶), and areas of non-vital bone (★) with empty lacunae. A large number of exuberant osteocytes in lacunae are associated with non-lamellar arrangement typical of newly remodeled bone. (B) At higher magnification (microscopic objective 20x), details of marrow (◆), newly formed trabecular bone (*), bone-lining cells or osteoblast-like cells (▶), osteoblasts (◌), and osteoclasts (→) resorbing non-vital bone are evident. No signs of inflammatory reaction were observed.

As the MT is predominately lower density bone, the insufficiency of the bone tissue may inhibit a patient's candidacy for placement as ample bone volume is required for lasting results.

3.1. Implants in the Tuber Region

Pre-operative planning, implant design, superb osteotomy preparation using an optimal drilling procedure, and bone condensation are important factors to take into account in order to achieve long-term implant success. Detailed planning and bone mapping is advised on a per-patient basis to avoid surgical complications. Bone volume should be evaluated through the utilization of cone beam computed tomography (CBCT), but a combination of typical panoramic and periapical radiographs can provide adequate pre-operative bone information to substitute when CBCT is unavailable [28]. It has been suggested that a lateral window in the maxillary sinus can be made to further verify correct placement [18]. Once these considerations are taken into account, it is advised to choose a location more palatal as bone resorption is most commonly observed in the palatal direction, and distances of 35mm or greater from opposing dentition are recommended to allow for

surgical access [14]. More confined openings may negatively influence implant angulation or the ability for the surgeon to manipulate instruments. The use of a radiopaque marker integrated on a surgical guide or other acrylic guide can be employed along the edentulous ridge to assist in proper implant site location [12]. Several operatory procedures for implant placement in the MT have been suggested with mutual attributes yielding very similar results, and several studies have suggested that the utilization of an adapted drilling technique in sites of poor bone density is vastly advantageous in improving initial endosseous stability [9,14,15,25,28-33]. The highest success rates and greatest primary stability were observed after procedures that extensively employed under-sizing of the osteotomy, local bone condensation, osseodensification (Versah drills), or a combination of these methods as compared to that of traditional bone drilling techniques. By first under-drilling the bone with minimal countersinking and then minimizing the site preparation, the implant can obtain a constricted fit into the osteotomy once the fixture is eventually placed. This allows for a stronger thread engagement into the surrounding bone walls. Additionally, angulation of the implant site is criti-

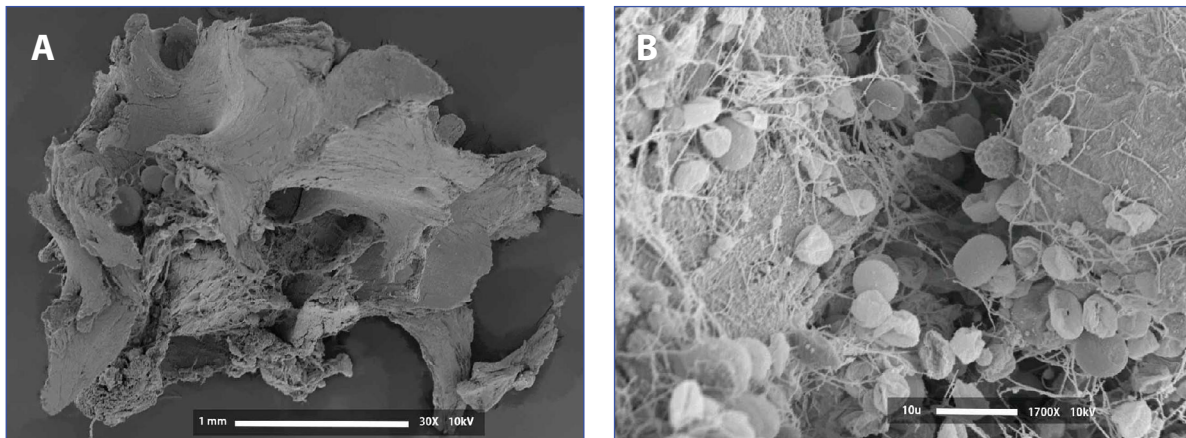


Figure 4. Representative scanning electron micrographs of a bony fragment retrieved from the maxillary tuberosity with associated particulate harvested via rongeur forcep. (A) Panoramic view of a particle with structure larger than 1mm to facilitate the osseointegration process (30x). (B) At higher magnification, details of bone matrix and fibrin network within cells are observed, which remain intact even after the particulate procedure (1,700x).

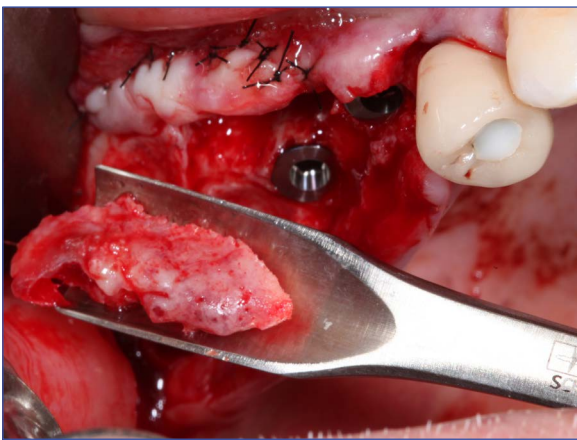


Figure 5. The bone graft was harvested from maxillary tuberosity in close proximity to the receptor site using IDR chisels. The graft was reshaped in relation to the defect configuration, and the remaining bone was crushed for use as particulate graft.

cal, as the implant should maintain a 10-20° mesial slant to mimic the natural angulation of the third molar [12,34]. A special emphasis is also placed on the bone condensation of the low quality bone. Bone condensation is obligatory in areas of reduced bone density in the posterior maxilla to attain sufficient implant stability [35]. To accomplish this condensation properly, an osteotome or modified osteotome technique or the method of osseodensification should be implemented over a conventional drilling technique [15,31,36]. Blunt surgical osteotomes are recommended as the lack of sharpened edges, such as those found on drills, reduces the chance of cutting palatine and other maxillary arteries and nerves [15]. After bone condensation, significantly higher implant stability has been recorded immediately after surgery, as well as during the following observation periods compared to solely bone drilling techniques [33]. Procedures with the highest success rates and greatest implant stabilities consistently placed tapered implants in bone once implant sites were drilled and condensed [12-21]. The soft tissues of the maxillary tuberosity should be treated with care during surgery to avoid periosteal tears that will hinder

proper blood flow and slow the healing process, and intimate wound approximation is required for optimal results. Complications at this site are minimal as there are no major vital structures in the immediate surgical area. Excess soft tissue over the surgical site should be trimmed to be no more than 3mm, allowing for adequate space for proper hygiene once the initial wound has healed [12]. Any implants placed in the tuber region should be allowed to heal for 6 months or more without loading in most cases. Premature loading would cause unwarranted stress on the surrounding low-density bone, increasing risk of failure before proper osseointegration [37]. In cases of severely weakened bone, progressive or early moderate loading protocols of the bone with implant prostheses may be used to strengthen the bone over the healing period [38,39]. Posterior occlusal forces can reach nearly ten times that of those in the anterior jaw, and these forces must be eliminated or adjusted to reach the desired load [12]. Loading forces can be decreased through the reduction of prosthesis occlusive contacts or through the adjustment of opposing dentition in contact with the prosthesis.

Shorter healing times (4-6 months) and more prompt integration may be plausible with implant surface modification [40]. Upon adequate healing of the implant site, fixed permanent prostheses can be fabricated and placed in a similar fashion as fixed dentures supported by implants placed in traditional maxillary positions. In fully or partially edentulous patients, posterior implants can be splinted together with anterior implants to reduce stresses in the supporting bone, as well as provide the framework for bridge or hybrid restorations that span larger proportions of the maxillary arch [41]. High survival rates of implants placed in the tuber region have been consistently shown in multiple studies [12-21,28]. Across these studies, 161 implants were placed in the maxillary tuberosity with a 95.03% survival rate over an average follow-up period of 52.08 months (Table 1). All studies demonstrated high success rates. Comparatively, 161 implants were placed in traditional regions in the

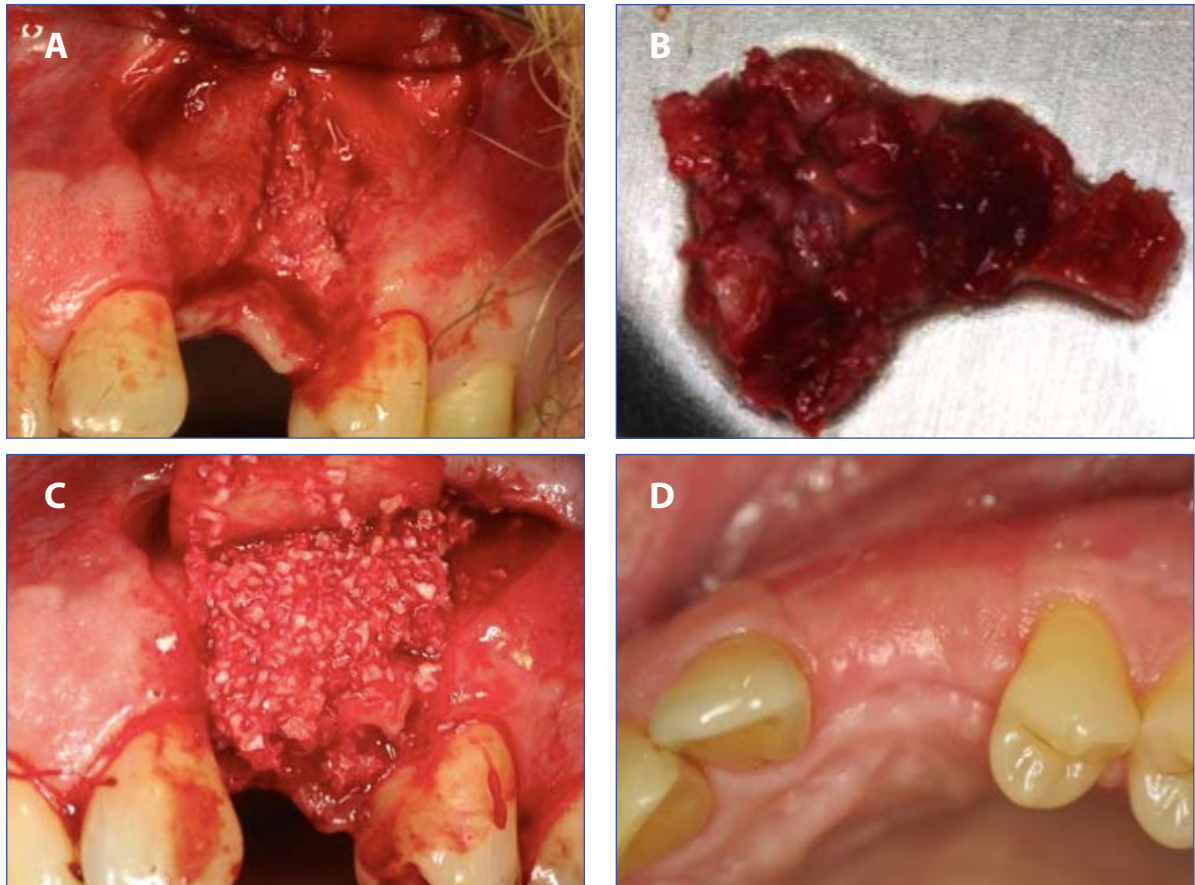


Figure 6. (A) Maxillary alveolar ridge deficiency prior to site grafting. Adequate graft material was obtained through the harvest of tuberosity bone (B) in combination with bovine osseous particulate as a composite graft (C). (D) The surgical site presented with excellent ridge contour after 3-months of healing post-operatively.

maxilla with a 94.41% survival rate in the same patients over the same time interval (Table 1). Survival rates of implants in the MT and that of other maxillary implants were not significantly different from one another ($p>0.05$). Marginal bone resorption across all studies was analogous to that of conventional implants placed throughout the maxilla despite different surgical modalities [28]. Similarities in survival rates amongst implants placed throughout the maxilla suggest tuberosity-based implants can provide a stable and predictable alternative to the traditional major grafting procedures that would otherwise be required to stabilize implants in maxillary areas with bone deficiencies further anterior to the tuberosity. This provides a much more conservative option for patients restricted financially or by medical conditions that hinder or delay healing processes. Survival rates over longer time intervals (>15 years) are required to further validate this conclusion as an effective conservative alternative to major grafting or lifting procedures and to make accurate comparisons to established long-term studies of fixed prostheses. Often times, the bone volume of the maxillary tuberosity alone is insufficient for implant fixture placement. In these cases, implants have also been placed into the pterygoid plate area to overcome anatomical constraints similar to the way implants in the MT have been used in partially or completely edentulous patients [10,42-46]. The consideration of pterygoid

implants was first proposed as a means of anchoring the posterior ends of fixed prostheses into as dense bone as possible in the posterior maxilla with implants longer than 15mm [42]. This involves drilling through the pterygoid processes of the sphenoid, the pyramidal process of the palatine bone, as well within the MT in close proximity to the posterior wall of the sinus at approximately 35-55° angulation [10]. The occlusal forces generated in the posterior maxilla far exceed those generated in anterior areas, and the bone quality of the MT is often inadequate to support fixed prostheses alone [12]. In these situations, compensation by means of fixture engagement of the pyramidal process of the cortical plate and associated pterygomaxillary regions may be required [44]. Increased implant length in the pterygomaxillary region was found to lead to superior rates of osseointegration [46]. This may be a result of better implant apex engagement of the cortical bone between the medial and lateral pterygoid plates, thereby increasing stability after placement. It is important to note that although pterygoid implants utilize parts of the MT, not all MT-implants engage the area encompassing the pterygoid region. In this way, pterygoid implants and the implant restorations associated with them most frequently involve or incorporate a combination or direct connection of the pterygoid with the MT. Dental implants incorporating the pterygoid plate and accompanying areas have been shown to

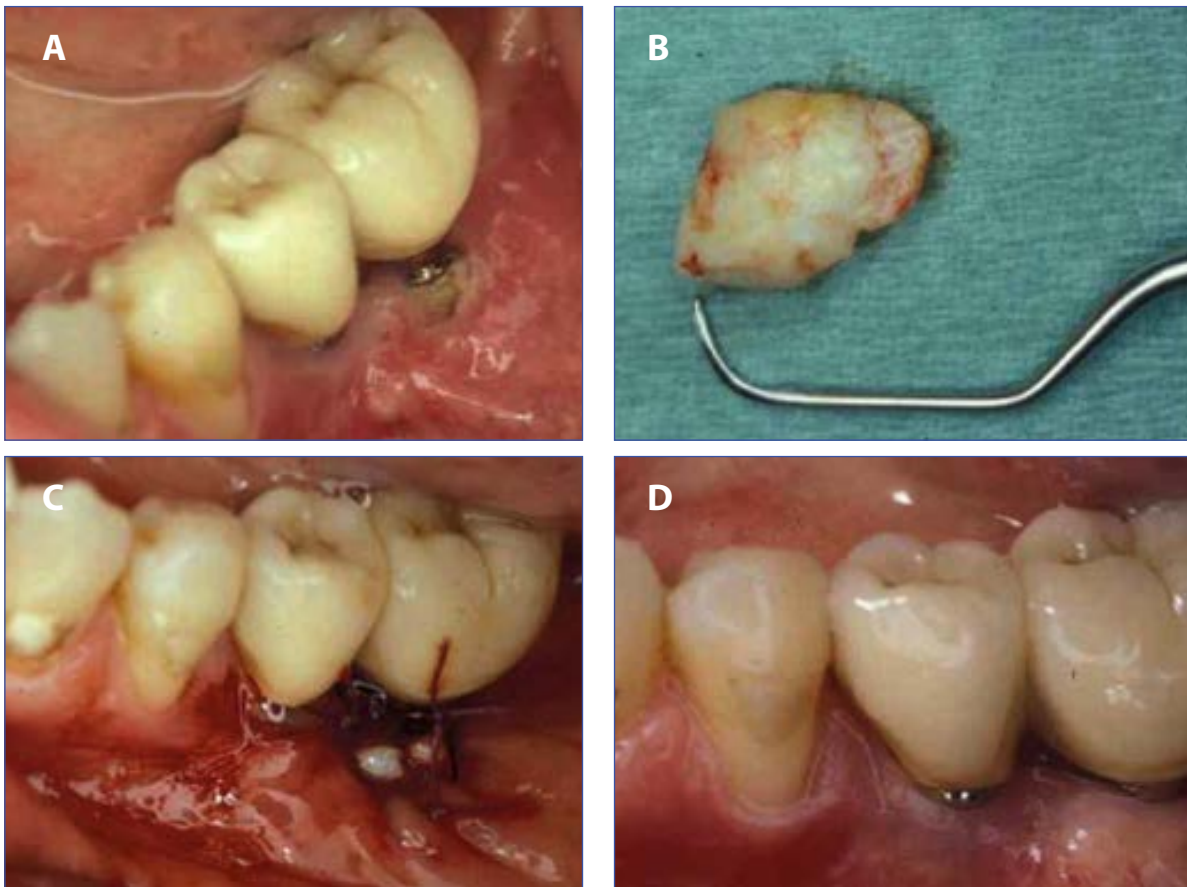


Figure 7. Peri-implant dehiscence (A) before placement of a soft tissue graft harvested from the maxillary tuberosity (B). The graft was immobilized within a pouch (C), and healing at the 2-years surgery demonstrated an outstanding soft tissue condition (D).

have high cumulative survival rates in edentulous maxillary arches ranging from 88.2% to 97.7% with similar expected bone loss as conventional implants in reported studies [10,47-50]. Implant placement into the pterygoid region poses similar difficulties as tuberosity implants: high operator learning curves, limited surgical access, and high risk of complication if arteries or their major branches are disrupted [49,51]. Regardless of inclusion of pterygoid engagement, these posterior maxillary implants function to support distal ends of fixed prostheses to alleviate bending and cantilever forces, as well as to provide overall denture stability. Their usage to restore missing dentition is highly viable as both a standalone procedure or in situations where they are combined with implants in the MT that serve to decrease non-axial loads of permanent restorations.

3.2 Bone Grafting and Harvesting from the Tuberosity

Loss of osseous tissue from trauma, infection, or genetic resorption leads to low bone density that cannot support implants, and consequently, implant-supported restorations. Traditionally, intraoral sites of autogenous bone block grafts, such as the symphysis and ramus have been used to supplement alveolar ridges with deficiencies prior to implant placement [6]. Although the tuberosity serves as a candidate for direct implant fixation, when bone volume is abundant, this maxillary region can be manipulated with the use of various instruments to serve as an addition-

al bone harvesting site to alleviate these deficiencies in cases of subpar bone mass for implant support. This is particularly critical as the MT frequently fails to be recognized as a bone graft source during implantation assessment. Typical CBCT scans and panoramic imaging can provide enough pre-operative assessment of the MT to determine if bone volume is appropriate for grafting [5,52]. Removal of bone from the MT is the least invasive alternative for intraoral grafting and would not require any extensive repair at the donor site while providing more than adequate bone volume to be used anteriorly to correct ridge deficiencies. This site has become a strong candidate as a grafting source in Immediate Dento-alveolar Restoration (IDR) of compromised sockets, where the cortico-cancellous graft can be shaped to the size of the distant defect and inserted to bolster bone mass [4,53]. Amongst autogenous bone sources, the greatest vertical gains are frequently seen from MT blocks compared to composite grafts in localized bone deficiencies [7,54,55].

The biological properties of a patient's own bone are enhanced when used as a grafting material, as the autogenous bone contains a wealth of bone marrow with great potential for angiogenesis (Figs. 3, 4). Autogenous bone is the optimal choice in larger block grafts due to its osseoinductive and osteogenic properties compared to that of xenografts, allogeneic, or alloplastic (synthetic) options [6,56-58]. Bone harvested from the MT (Fig. 5) can also be combined

with other grafting materials to form composite grafts. In situations where only minimal amounts of hard tissue can be harvested from the MT, biomaterials may be used to supplement (Fig. 6). Bone substitutes, when embedded in osteoprogenitor cells of the MT, provide adequate bone formation in vivo [59]. Employment of composite grafts using biomaterials and autogenous tuber bone expands patient candidacy by reducing the total amount of patient bone required for grafting procedures, while still retaining the benefits of utilizing autogenous tissue. In this respect, the hard tissue of the MT can be manipulated in a plethora of ways to overcome the problems of bone deficiency throughout the maxilla.

Different surgical alternatives for bone augmentation in post-extraction compromised sockets have been described [60]. However, some of these techniques require longer periods for rehabilitation and are usually expensive [61]. The Immediate Dento-alveolar Restoration (IDR), a one-stage technique, allows dental extraction, implantation, and provisionalization to occur in the same procedure as the flapless bone reconstruction using cortico-cancellous bone graft harvested from the maxillary tuberosity [62].

The IDR technique, aside from presenting lower overall costs and treatment time, has been shown clinically and radiographically to be effective with respect to soft and hard tissue stability in compromised sockets [63].

The advantages of IDR include: ease of tuberosity harvest, the malleability of bone fragment which allows adequate adaptation to the receptor region, and the biological membranous properties of the cortico-cancellous graft that promote effective bone and gingival healing. Furthermore, the trabecular nature of grafts harvested from the maxillary tuberosity contribute to increase revascularization capacity and to release growth factors to the receptor site [64]. Bone density at the buccal, palatal, and basal cortical maxillary tuberosity is less compared to other maxillary and mandibular bone locations.

Due to the decreased thickness of its cortical bone, maxillary tuberosity grafts are easily shaped, yet its cortical structure can act as a biological barrier stabilizing the soft tissue and particulate bone graft around the implant [65]. The total porosity and porous volume of these grafts indicate that the cortico-cancellous structure can act as a scaffold structure for cellular and vascular growth.

Additionally, the maxillary tuberosity is a source of osteoprogenitor cells and growth factors [66]. Taken together, the cortical and cancellous bone from the maxillary tuberosity can be considered as an ideal structure for bone regeneration, as it is a natural scaffold filled with osteoblastic cells and growth factors [67].

3.3. Soft Tissue Grafting and Harvesting from the Tuber Region

The palatal area most commonly serves as the primary donor site for soft tissue grafts in cases of root coverage. This is not always the case with patients with diminished size, thickness, or rate of blood flow of the greater palatal artery which can lead to limited quantities of connective tissue available for harvest. The MT has been associated with connective tissue that can be used as an autogenous graft for soft tissue augmentation around implants (Fig. 7) simultaneously or secondarily with implant placement [4]. The gingival cuff of the MT has been shown as an excellent source of soft tissue to provide full, lasting coverage in more anterior regions of both the maxilla and mandible [3]. Transplantation of tuberosity connective tissue onto the aesthetic anterior gingival cuff demonstrated an improvement of the tissue biotype over a healing period to match the surrounding gingival tissue in texture and color [3].

Additionally, soft tissue grafting from the MT has been shown to be easier than grafting from the palatal masticatory mucosa [3,68]. Subepithelial connective tissue can simply be harvested from the MT and sutured within a pouch in areas of localized gingival recession with little to no complications to treat buccal soft tissue dehiscence around single implants [69-70]. This can fully or partially alleviate aesthetic exposure of implant threads due to bone loss around the fixture. Soft tissues of the MT can be employed throughout the oral cavity in a similar way as other traditional gingival grafts with similar success rates.

4. Conclusions

There are high success rates of dental implants placed in the MT, which can provide a stable and predictable alternative to the traditional major grafting procedures required to stabilize implants in bone-deficient maxillary areas anterior to the tuberosity. Proper placement of implants in this region with the correct surgical techniques, especially local bone condensing, can provide support of the prostheses in patients without complex grafting procedures. Bone and soft tissue harvested from the maxillary tuberosity provides many advantages and serves as an outstanding reservoir of tissue with excellent regeneration capacity.

Author Contributions

NM and GR: wrote and edited the manuscript. JMR and LAP: provided the information about the Immediate Dento-alveolar Restoration (IDR) and supported with photographic documentation.

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Questions

1. Can maxillary tuberosity be used for implant placement?

- a. After panoramic radiographic evaluation?
- b. After occlusal radiograph?
- c. After CBCT?
- d. After periapical radiograph of the region?

2. Tilted implants are associated with more failures and crestal bone loss:

- a. The statement is not correct in case of supracrestal placement
- b. The statement is not correct in case of subcrestal placement
- c. The statement is not correct in bruxers
- d. The statement is not correct

3. An autogenous graft can be harvested from the

- a. Tuberosity
- b. Chin region
- c. Ramus
- d. All of the above

4. Soft tissue augmentation as a free gingival graft from the tuberosity is recommended compared to the area of hard palate

- a. For improvement of aesthetics
- b. To eliminate risks of bleeding
- c. To increase thickness volume
- d. All of the above

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