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Primary Stability of Pterygoid Implants: The Influence of Macrodesign, Bone Density, and Insertion Angle

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Abstract

Objective
To evaluate how implant design, local bone quality, and insertion direction collectively influence the initial fixation of pterygoid implants and the feasibility of early or immediate loading.

Materials and Methods
The study was conducted in the format of an analytical narrative review. Publications indexed in PubMed/PMC and other peer-reviewed sources were analyzed, focusing on pterygoid implantation, parameters of primary stability, cortical engagement, and preparation of the implant bed in low-density bone.

Results
The decisive factor is not the nominal implant length alone but rather the combination of several conditions: a tapered macrodesign, an active apical thread, an appropriate entry point, and achievement of contact with dense cortical bone of the pterygoid plate or the pyramidal process of the palatine bone. Insertion torque and implant stability quotient (ISQ) describe different aspects of mechanical stability and therefore should be interpreted jointly. In soft bone, modification of the drilling protocol is justified only when it preserves cortical support and does not lead to excessive compression.

Conclusion
Primary stability of a pterygoid implant is formed as a result of interaction between anatomy, trajectory, surgical technique, and implant macrodesign; therefore, it cannot be reliably explained by a single isolated parameter.

Keywords
Pterygoid implants; Primary stability; Implant macrodesign; Bone density; Insertion angle; Posterior maxillary atrophy; Bicortical fixation.

Introduction

Treatment of patients with posterior maxillary atrophy remains a challenging task for implantologists. The reason is evident: in this region, a deficiency of alveolar ridge volume is frequently combined with pneumatization of the maxillary sinus and low cancellous bone density. In such clinical situations, pterygoid implants are considered a practical alternative to sinus floor elevation, bone grafting procedures, short implants, extended distal cantilevers, and removable prosthetic solutions.

According to early systematic reviews and more recent meta-analyses, the technique demonstrates high functional survival rates when performed with precise surgical technique.

From a biomechanical perspective, the value of pterygoid implantation lies in the fact that the implant is inserted through relatively soft tuberosity bone toward denser cortical structures of the pterygomaxillary region. Therefore, in this anatomical area, it is not sufficient to simply select a long implant; reliable primary stability must be achieved at the time of placement. Primary stability limits micromobility in the early postoperative period, influences the feasibility of immediate or early loading, and largely determines the risk of early implant failure.

In this context, three groups of factors simultaneously influence initial fixation:

- implant geometry
- bone quality along the implant trajectory
- insertion direction, which determines which anatomical structures will be engaged.

The purpose of this work was to analyze the influence of implant macrodesign, bone density, and insertion angle on the primary stability of pterygoid implants and to demonstrate why these factors should be evaluated only in an integrated manner.

Materials and Methods

The study was performed as an analytical narrative review. The analysis included systematic reviews, anatomical and radiological studies, prospective and retrospective clinical series, as well as experimental publications devoted to primary implant stability in low-density bone conditions.

The present article is aimed at providing a clinically oriented interpretation of the mechanisms determining primary stability of pterygoid implants.

To clarify current concepts, publications from 2021–2025 were additionally reviewed, including clinical series on pterygoid and tuberosity implants, evaluation of stability based on insertion torque and resonance frequency analysis, the significance of cortical contact, and methods of implant bed preparation in soft bone.

Such selection had an analytical rather than exhaustive purpose: it was intended to identify the mechanisms that genuinely influence initial fixation of implants in the pterygomaxillary region.

Anatomical Preconditions and Distribution of Bone Density

The pterygomaxillary region is heterogeneous in both bone density and structural architecture. In a classical cone-beam computed tomography study conducted by Rodríguez et al., based on 202 examinations, bone density in the region of the pterygoid plate was found to be 139.2% higher than in the tuberosity region. Density values ranged from 285.8 to 329.1 DV in the tuberosity area, whereas values in the pterygoid plate region ranged from 602.9 to 661.2 DV.

The practical implication of these findings is that tuberosity bone alone is often insufficient for reliable mechanical fixation, and therefore the outcome of the intervention largely depends on whether the implant reaches dense cortical support distally and medially.

A three-dimensional morphometric study by Salinas-Goodier et al. demonstrated significant variability in the anatomy of the pterygomaxillary region depending on sex, age, and dental status. This leads to an important practical conclusion: there is no universal safe angle or standard implant length suitable for all patients.

During surgical planning, the clinician must evaluate not only the total length of the selected implant but also the actual bone corridor passing through:

- the maxillary tuberosity
- the pyramidal process of the palatine bone
- the pterygoid plate.

A study by Sahoo et al., analyzing bone height, width, volume, and density in dentate and edentulous patients, further confirmed the value of individualized planning based on cone-beam computed tomography. Despite differences in absolute parameters between groups, the study convincingly demonstrated that selection of implant length, diameter, and direction should rely on personalized radiological assessment rather than average anatomical schemes.

Implant Macrodesign as a Modifier of Primary Stability

Data on implant placement in low-density bone consistently demonstrate the advantages of tapered macrodesign compared with cylindrical systems in terms of primary stability.

In a prospective clinical study by Lozano-Carrascal et al., tapered implants demonstrated higher insertion torque and ISQ values.

For pterygoid implantation, this is particularly significant because the initial segment of the implant bed often passes through soft tuberosity bone, where the ability of the implant to condense surrounding tissue and generate lateral compressive resistance becomes decisive.

The study by Menini et al. showed that not only body taper but also thread profile plays a crucial role. In poor-quality bone, a more aggressive V-shaped apical thread increased mechanical stability and resistance to vertical loading.

Similar results were obtained by Stoilov et al. In bone models of varying density, insertion torque and resonance frequency analysis values were significantly influenced by:

- implant macrodesign
- implant length
- implant diameter bone density.

Tapered systems more frequently provided an optimal torque range under low-density bone conditions. However, the simplified statement that "a tapered implant is always better" is methodologically incorrect. Heitzer et al. demonstrated that implant stability depends not only on implant shape but also on:

- cortical thickness
- cancellous bone density
- thread depth
- thread pitch
- implant diameter.

Therefore, implant macrodesign should be considered not as a universal solution but as a tool that must be harmonized with the anatomy of the recipient site.

Insertion Angle: Why There Is No Fixed Ideal Value

Pterygoid implantation is traditionally associated with a pronounced posterior and medial inclination of the implant. However, specific angular values differ significantly between studies.

This variation is explained not by contradictions in data but by differences in measurement reference planes and prosthetic requirements.

Clinical and radiographic studies often report reference values of:

- 45–70° in the anteroposterior plane
- 10–15° in the buccopalatal direction.

Meanwhile, Rodríguez et al., analyzing bone corridors using CBCT data, reported mean values of:

- 74.19°
- 81.09°

relative to the Frankfurt horizontal plane.

These discrepancies reflect differences in measurement methodology rather than incompatibility of results.

Motiwala and Bathina proposed using the hamular line as an intraoral landmark and demonstrated that with this approach the average vertical angle was 49.8° relative to the Frankfurt horizontal plane, with engagement of the pterygoid plate achieved in approximately 98% of implants.

However, these values should not be interpreted as rigid templates, as they do not eliminate the need to evaluate:

- tuberosity volume
- sinus position
- desired prosthetic emergence point
- patient-specific anatomy.

Accuracy of trajectory, classification, and navigation

Modern classifications of pterygomaxillary implants emphasize that the selection of angle and depth of distal engagement depends not only on the intention to reach the pterygoid region but also on the actual relationship between bone volume and density in the tuberosity area.

Ren and Shu proposed distinguishing clinical situations in which the tuberosity region has:

- sufficient volume but insufficient density (Type IIa)
- limited bone mass (Type IIb).

Such classification facilitates transition from empirical technique to anatomically justified trajectory selection.

The importance of placement accuracy was also confirmed by Tao et al.

In a fully edentulous maxilla model, dynamic navigation demonstrated significantly smaller deviations compared with freehand placement:

- Coronal deviation:
- 0.93 ± 0.46 mm vs 2.28 ± 1.08 mm
- Apical deviation:
- 1.37 ± 0.52 mm vs 3.14 ± 1.82 mm
- Angular deviation:
- 2.41 ± 1.24° vs 10.13 ± 4.68°

For pterygoid implants, such differences are clinically significant, as even minor displacement may lead to:

- loss of cortical contact
- increased risk of complications.

Clinical outcomes and their relationship to primary stability

Recent systematic reviews generally indicate high survival rates of pterygoid implants.

- A meta-analysis by Araujo et al., including:
  1893 implants
  634 patients
- reported a mean survival rate of:
- 94.87%
- A later systematic review by Raouf and Chrcanovic reported a:
- 10-year cumulative survival rate of 92.5%
- D'Amario et al. in 2024 reported:

- 97.43% overall survival rate
  based on 768 implants.

However, these figures should not be interpreted as guaranteed outcomes in every clinical case, as systematic reviews combine heterogeneous:

- protocols
- operator experience levels
- success criteria.

A prospective study by Mirdah et al. provided an important practical observation:

- after one year, success was achieved in:
- 88.57% of implants
- Failures occurred more frequently in:
- D3 bone compared with D2 bone.

The study also demonstrated a statistical association between:

- implant failure
- complications
- marginal bone loss.

Assessment of Primary Stability Insertion Torque, ISQ, and Cortical Contact

For clinicians, it is important to understand that insertion torque (IT) and implant stability quotient (ISQ) do not describe the same parameter.

Insertion torque primarily reflects:

- mechanical resistance during implant placement.

ISQ reflects:

- stiffness of the implant-bone complex during microvibration.

Therefore, clinical decision-making regarding early or immediate loading should not be based on a single numerical threshold.

For pterygoid implants, a combined evaluation is more informative, including:

- CBCT-based planning
- confirmation of apical cortical engagement
- tactile assessment of bone density
- insertion torque value
- ISQ measurement
- prosthetic splinting strategy.

Modification of the surgical protocol in soft bone

Publications on implant placement in the posterior maxilla demonstrate that in low-density bone primary stability can be enhanced by:

- moderate under-preparation
- bicortical fixation

- adapted drilling techniques

However, these methods are effective only when they preserve or enhance cortical contact rather than simply increasing mechanical friction along the implant length.

Excessive expansion of the trans-tuberosity portion of the implant bed reduces the implant's ability to stabilize before reaching apical cortical support.

Conversely, overly aggressive under-preparation increases the risk of:

- compression injury
- trajectory deviation
- thermal damage.

Therefore, modified protocols must be individualized based on:

- CBCT anatomy
- implant macrodesign
- cortical thickness.

Practical implications for surgical strategy

From a clinical perspective, primary stability of a pterygoid implant is not achieved by a single isolated maneuver but rather results from coordination of three key decisions:

- Selection of macrodesign suitable for soft bone
- Achievement of apical cortical contact
- Prosthetically driven implant trajectory

The reverse conclusion is equally important:
Attempting to assess primary stability solely based on insertion torque or implant length inevitably oversimplifies clinical reality.
A high insertion torque with incorrect trajectory may lead to:

- overheating
- compression
- subsequent bone resorption.

In contrast, moderate torque combined with proper bicortical engagement and correct prosthetic alignment may represent a more reliable strategy.

Limitations of available evidence

Despite the increasing number of publications, the evidence base on pterygoid implants remains heterogeneous.
Many clinical studies:

- have retrospective design
- involve small sample sizes
- use different success criteria.

Additional variability arises from differences in:

- implant systems
- drilling protocols
- loading protocols
- surgical experience.

Therefore, direct transfer of specific numerical thresholds to any clinical situation is inappropriate.

Conclusion

Primary stability of pterygoid implants is largely determined by the ability to achieve apical cortical engagement within dense structures of the pterygomaxillary complex while maintaining prosthetically appropriate implant orientation.

Implant macrodesign plays an important role, particularly in soft tuberosity bone. Tapered systems with active apical threads generally improve initial mechanical fixation.

However, the key factor is not implant design alone but the degree to which it corresponds to the anatomy of the recipient site.

Bone density in the pterygoid plate region significantly exceeds that of the maxillary tuberosity, and engagement of this region largely explains the clinical success of pterygoid implants in posterior maxillary atrophy.

The most rational clinical strategy combines:

- individualized CBCT-based planning
- macrodesign adapted to soft bone
- accurate trajectory
- navigation support when necessary.

From a clinical standpoint, reliable treatment planning should focus not on achieving maximal insertion torque but on obtaining reproducible apical cortical engagement with prosthetically correct implant positioning.

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