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Original Research Article

Three-Dimensional Evaluation of Ideal Zygomatic Implant Trajectory Based on the 5.5 Rule: A Retrospective Cone Beam Computed Tomography Study

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Abstract

Background:

Rehabilitation of the severely atrophic maxilla presents a persistent challenge in implant dentistry. ZI offer a predictable alternative to extensive bone grafting procedures, thereby reducing surgical morbidity and treatment duration. Nevertheless, successful outcomes depend on precise implant trajectory planning, and determining a pathway that maximizes bone–implant contact (BIC) remains a critical clinical concern.

Aim:

This study aims to evaluate the optimal trajectory for zygomatic implant placement that achieves maximum radiographic bone–implant contact (rBIC) using the proposed 5.5 rule.

Materials and Methods:

A retrospective radiographic study was conducted using cone-beam computed tomography (CBCT) scans from 10 completely edentulous patients with severely atrophic maxillae, classified as Cawood and Howell Class V or VI. Virtual ZI were planned according to the proposed 5.5 rule, which designates Point A at the second premolar region tangent to the infraorbital foramen, Point B at the center of the ZB, and Point C at the outer cortical perforation point. Implant planning and measurements were performed using Blue Sky Plan® software. Radiographic bone–implant contact was assessed separately on the temporal and facial aspects of the ZB and expressed as the percentage of implant length engaged within the zygoma.

Results:

The mean rBIC was 85.43% ± 6.43% on the temporal aspect and 88.80% ± 7.60% on the facial aspect, with an overall mean rBIC of 87%. Application of the 5.5 rule consistently guided implant placement through the central portion of the ZB, resulting in substantial bone engagement and favorable implant trajectory.

Conclusion:

The 5.5 rule offers a straightforward, reliable, and reproducible approach for planning zygomatic implant trajectories that maximize radiographic bone–implant contact. Further research involving larger patient cohorts and clinical follow-up is necessary to validate its effectiveness and long-term clinical applicability.

Keywords: Zygomatic implant; Maxilla; Cone beam computed tomography; Implant trajectory; Bone–implant contact.

Introduction

Rehabilitation of patients with a severely atrophic maxilla (AM) represents one of the most complex procedures in implant dentistry. Progressive resorption of the alveolar bone (AB) after tooth loss, together with maxillary sinus pneumatization, frequently leads to inadequate bone volume for conventional dental implant placement. Traditionally, such cases have been managed using reconstructive procedures like sinus floor augmentation (sinus lift procedures), onlay bone grafting procedures like block grafts, guided bone regeneration (GBR) procedures along with allogenic bone substitutes or autografts. Although these treatment modalities can improve bone availability, they come with complications like increased surgical morbidity, prolonged treatment duration, higher treatment costs, and unpredictable graft resorption. These factors also contribute to increased emotional and physical strain on patients, who may face multiple surgeries and extended periods without functional teeth. The need for donor sites in autogenous grafting procedures can further increase patient discomfort and risk for complications, such as infection or graft failure. Additionally, the requirement for complex surgical interventions often necessitates treatment in specialized centers, limiting patient access and increasing logistical challenges. Consequently, there has been a growing interest in alternative treatment approaches that can provide predictable outcomes while reducing patient discomfort and treatment complexity. New developments in biomaterials and digital technologies have also driven the search for less invasive yet effective solutions, aiming to improve both clinical and patient-centered outcomes.

Zygomatic Implants (ZI) have emerged as a predictable and expedited treatment option for the management of severely AM, as they eliminate the need for extensive regenerative procedures and reduce overall surgical invasiveness.[1] Since their introduction, ZI have achieved high survival rates and favorable long-term outcomes, making them a reliable alternative for patients with AM. By utilizing the dense cortical structure of the zygomatic bone (ZB) for anchorage, these implants provide stable support for fixed prosthetic rehabilitation even in situations where conventional implants are not feasible. This approach significantly reduces treatment time and allows for immediate or early loading protocols, which can be particularly advantageous for patients seeking rapid functional and esthetic restoration. Additionally, ZI can be successfully combined with conventional anterior implants in a hybrid prosthesis design, further enhancing prosthetic stability and patient satisfaction. Despite their clinical success, the placement of ZIs remains a technically demanding procedure. Successful treatment requires comprehensive evaluation of multiple clinical, anatomical, and prosthetic factors, together with meticulous preoperative planning. The implant trajectory must be carefully selected to achieve adequate anchorage within the ZB while avoiding vital anatomical structures such as the maxillary sinus, orbital floor, infraorbital nerve, and infratemporal fossa. Any deviation from the optimal implant pathway may compromise prosthetic positioning, reduce implant stability, or increase the risk of surgical complications. The learning curve associated with ZI placement is steep, and even experienced clinicians may encounter intra- or postoperative complications such as sinusitis, oroantral fistula, or periorbital hematoma. Therefore, accurate three-dimensional assessment and planning are essential for achieving predictable outcomes.[2] Advances in imaging techniques, such as cone beam computed tomography (CBCT), and the use of virtual surgical planning have greatly improved the accuracy and safety of ZI placement, allowing clinicians to visualize anatomical landmarks and plan the implant trajectory with high precision.

A key factor influencing the long-term success of implant therapy is the extent of bone–implant contact (BIC). BIC represents the interface between the surface of the implant and the bone surrounding the implant and plays a critical role in achieving primary stability and successful osseointegration. A greater extent of BIC facilitates improved biomechanical load distribution and enhances the stability of the implant during functional loading. It is well acknowledged that the length of BIC is a crucial factor in determining the success and survival rate of implants.[3] In the context of ZI, the unique anatomy of the ZB coupled with the variability in maxillary atrophy patterns, makes it particularly difficult to ensure optimal BIC. Factors such as the thickness and density of the ZB, the degree of sinus pneumatization, and individual anatomical variations all influence the achievable amount of BIC. The choice of implant length and diameter, as well as the precise entry and exit points on the residual alveolar crest and ZB, are critical for maximizing BIC and ensuring long-term clinical stability. However, in zygomatic implantology, identifying the ideal implant trajectory that maximizes engagement with the ZB remains a significant challenge. The present study proposes a novel geometric guideline known as the 5.5 rule for determining the ideal trajectory of ZI placement. This rule is intended to provide a simple and easy to reproducible method for maximizing BIC while maintaining a safe and anatomically favorable implant pathway. The 5.5 rule is based on extensive three-dimensional analysis of anatomical structures and is designed to be easily applied in clinical practice, potentially aiding both novice and experienced clinicians in achieving optimal outcomes. Hence, the aim of this study is to evaluate the ideal trajectory of ZI placement with maximum BIC using the proposed 5.5 rule.

Materials and Methods

This retrospective study was conducted in the Department of Periodontology after obtaining approval from the Institutional Review Board (IRB). All participants provided written informed consent prior to inclusion, and all study procedures followed the ethical standards which were outlined in the Declaration of Helsinki. The study specifically included CBCT scans of completely edentulous maxillae classified as Cawood and Howell Class V or VI, focusing on patients who underwent imaging between January 2021 and December 2023.[4] Patients were excluded if they exhibited anatomical abnormalities or pathology involving the zygoma or maxilla, had facial asymmetry, or displayed inadequate residual bone volume below Class V of the Cawood and Howell classification.[4]

To ensure a robust methodology, the study proposed the 5.5 rule as a standardized geometric approach for zygomatic implant planning. According to this rule, Point A corresponds to the second premolar region, tangent to the infraorbital foramen; Point B is the midpoint of the zygoma, determined by drawing a tangential line from the junction of the horizontal and vertical arms of the zygomatic arch to the orbital floor; and Point C represents the external cortical exit of the implant. The trajectory established by these points is hypothesized to pass centrally through the ZB, thereby maximizing BIC. For virtual implant placement and analysis, CBCT DICOM data (Planmeca Promax, 150 µm voxel size) were imported into Blue Sky Plan® software. Virtual ZI were positioned according to the A–B–C line defined by the 5.5 rule, with central passage through the zygoma confirmed in the axial plane (Figure 1). This comprehensive approach enhances the reproducibility and reliability of zygomatic implant placement, ensuring optimal outcomes for patients with edentulous maxillae.

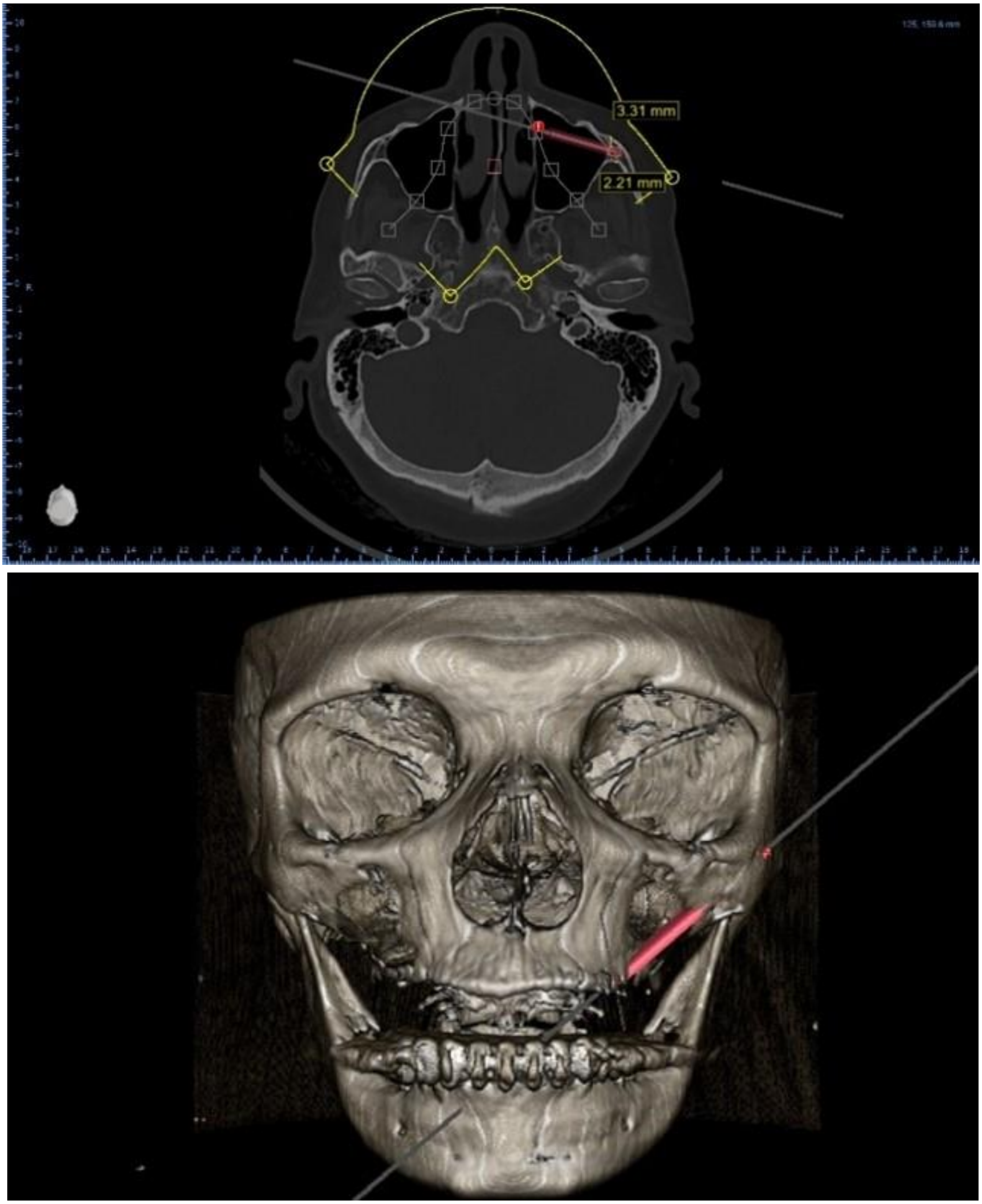

Figure 1: Virtual zygomatic implant placement in an atrophic maxilla using Blue Sky Plan® software (A). Axial section confirming central trajectory through the ZB (B).

Measurement of Radiographic BIC (Figure 2)

Using the inbuilt ruler tool, the following parameters were recorded:

- **L1:** Total bone length on the temporal side.
- **L2:** Length of implant in contact with bone on temporal side.
- **M1:** Total bone length on the facial side.
- **M2:** Length of implant in contact with bone on facial side.

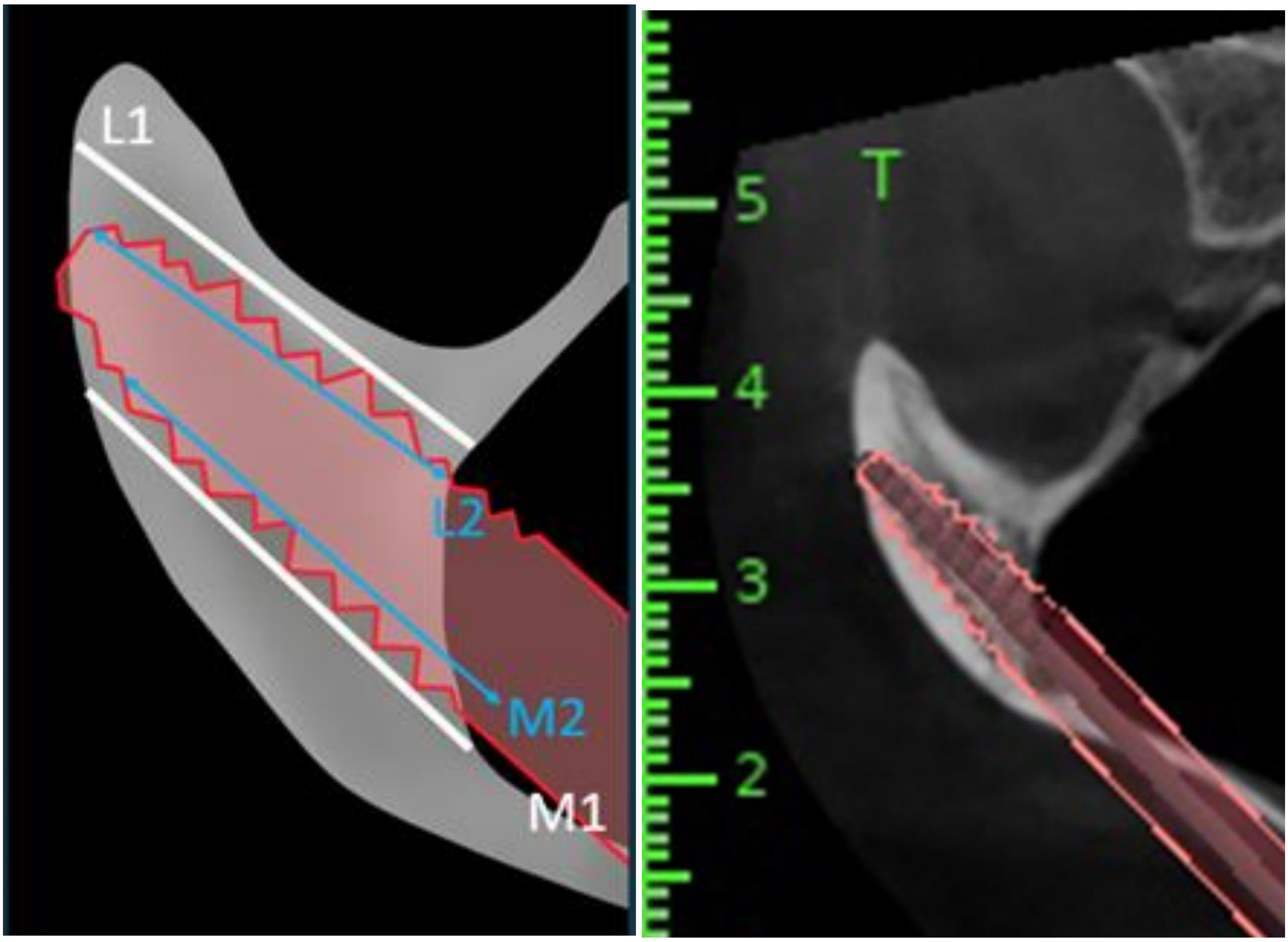

Figure 2: Measurement of total and contact bone lengths (L1, L2, M1, M2). Measurement of rBIC using the inbuilt digital ruler tool.

rBIC (%) was calculated as:

$\mathbf{rBIC}_{tempo\zeta al}$ = (L2 / L1) × 100

$\mathbf{rBIC}^{M}{}_{a}{}^{cl}{}_{al}$ = (M2 / M1) × 100

Descriptive statistics were computed using Microsoft Excel.

3. Results

CBCT scans of 10 patients (5 males cases and 5 females cases; age range: 49–79 years) were analysed. Mean measurements for temporal and facial aspects are summarized (Table 1).

Table 1: Individual and mean measurements of radiographic BIC parameters

S.No	**L1 (mm)**	**L2 (mm)**	**M1 (mm)**	**M2 (mm)**
1	14.3	12.3	12.7	12.2
2	13.5	12.6	13.1	11.6
3	14.8	11.9	13.1	11.8
4	12.9	10.8	11.2	10.9
5	14.7	11.5	12.5	11.7
6	14.0	12.9	13.5	11.8
7	14.8	11.5	13.4	11.2
8	13.6	12.5	14.5	10.7

9	14.1	11.8	13.3	11.2
10	12.8	12.2	13.1	11.1
Mean	**13.95**	**12.0**	**13.04**	**11.42**

L1 = total bone length (temporal side); L2 = bone–implant contact length (temporal side); M1 = total bone length (facial side); M2 = bone–implant contact length (facial side).

The rBIC percentages were calculated as follows:

Average rBIC (temporal side) = Mean L2 / Mean L1 × 100 = 12.0 / 13.95 × 100 = **85.43%** ± 6.43%

Average rBIC (facial side) = Mean M2 / Mean M1 × 100 = 11.42 / 13.04 × 100 = **87.57%** ± 7.60%

The mean rBIC values were: Temporal side: 85.43% ± 6.43%; Facial side: 88.8% ± 7.60%; Overall average: 87%. The 5.5 rule consistently guided implant positioning through the central ZB, optimizing BIC.

Discussion

Conventional dental implant treatment is frequently not feasible in edentulous maxillary patients due to severe alveolar bone resorption or extensive the maxillary sinuses pneumatization, which results in deficient bone volume for predictable implant anchorage. In these scenarios, augmentation procedures such as onlay bone grafting, elevation of the sinus floor, and GBR have traditionally been used to increase bone volume and facilitate implant placement. While these interventions can improve treatment outcomes, they are commonly associated with notable disadvantages, including donor-site morbidity, requires surgical complexity, multiple operative interventions, prolonged healing periods, higher treatment costs, and the risk of graft resorption. These challenges impose a significant burden on both clinicians and patients, prompting the development of alternative treatment modalities.(4,5) In the early 1990s, Brånemark introduced ZI, which utilize the dense ZB as anchorage for long implants in patients with severely AM. Since their introduction, ZI have become a reliable, graft-free alternative to extensive reconstructive procedures, providing predictable support for fixed prosthetic rehabilitation even in cases of advanced maxillary resorption. Multiple studies have demonstrated favorable survival rates and long-term clinical success with ZI therapy. (2)

The successful placement of ZI necessitates meticulous preoperative planning due to the proximity of critical anatomical structures, including the orbital cavity, infratemporal fossa, and maxillary sinus. Comprehensive radiographic evaluation using computed tomography (CT) or CBCT is essential to determine a safe implant pathway and minimize the risk of surgical complications. (1) A primary challenge in zygomatic implantology is identifying an optimal implant trajectory that maximizes BIC while ensuring prosthetic feasibility and anatomical safety. In this study, virtual ZI were placed according to the proposed 5.5 rule using CT scans from 10 patients with severely atrophic maxillae, and the radiographic BIC was evaluated. BIC refers to the extent of the implant surface directly engaged with bone and is a critical determinant of primary stability, osseointegration, implant success, and long-term survival.(6) Traditionally, BIC has been assessed histomorphometrically as the proportion of mineralized bone directly contacting the implant surface.(7) However, this method requires retrieval of the implant and surrounding bone tissue for microscopic examination, making it impractical and invasive in clinical settings. As a result, many researchers have adopted radiographic methods using CT or CBCT imaging to estimate BIC. In these studies, the distance between the implant apex and the most coronal point of direct bone engagement is measured and reported as radiographic BIC.(8) Despite the increasing use of ZI, few studies have specifically evaluated BIC using virtual planning techniques.

Hung et al. reported mean BIC values of 16.70 ± 4.18 mm, 13.88 ± 3.50 mm, and 13.44 ± 3.40 mm in the superior, middle, and inferior regions of the zygoma, respectively. (9) Similarly, Balshi et al. found average malar BIC lengths of 15.5 ± 6.0 mm.(10) Wang et al. reported a mean BIC length of 14.9 ± 3.7 mm in four patients with eight ZI.(11) In the present study, the mean radiographic BIC was 13.95 mm on the temporal aspect and 11.42 mm on the facial aspect of the zygoma, which are comparable to previously reported values. Notably, this study is the first to express radiographic BIC as a percentage of the implant length within the ZB. Using this metric, implants planned according to the proposed 5.5 rule demonstrated a mean radiographic BIC of 87%, indicating substantial engagement of the ZB. The trajectory generated by this rule appears to position the implant centrally within the zygomatic body, thereby maximizing bone contact while maintaining a safe and predictable pathway. The 5.5 rule provides a straightforward, repeatable, and clinically relevant technique for determining an optimal ZI trajectory with maximal bone engagement. However, the study is limited by its sample size and reliance on virtual simulation without clinical outcome assessment. Further research involving larger patient populations and long-term clinical follow-up is necessary to validate the effectiveness and reliability of the 5.5 rule in clinical practice.

Conclusion

The 5.5 rule represents a novel and reproducible approach for determining the ideal trajectory of zygomatic implant placement. By maintaining the implant within the central portion of the ZB, this method maximizes bone–implant contact and may enhance primary stability and clinical predictability. Future clinical studies are warranted to substantiate these findings.

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