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RESEARCH ARTICLE

Extra-radicular Implants: Redefining the Limits of Orthodontic Anchorage

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Abstract: Achieving desired tooth movement with the fewest possible unfavourable side effects is the aim of any orthodontic therapy.8 Since the beginning of orthodontics, anchoring control techniques have been crucial to good treatment outcomes. Absolute intraoral anchoring is nearly impossible to accomplish with traditional orthodontics. Skeletal anchoring has become more and more common recently, particularly in difficult circumstances.9 There have been many significant developments in the area of orthodontics, but few can compare to the clinical impact of micro-implants and the newly developed extra-radicular bone screws. With their idea of absolute anchorage, temporary anchorage devices have completely changed the orthodontic sector. They have also shown themselves to be a useful tool for clinicians to manage difficult malocclusions and clinical problems.10 A paradigm is a widely recognised scientific viewpoint that offers the most up-to-date explanation of a natural phenomenon. A paradigm might be compared as laying brick upon brick of fresh discoveries and insights, serving as the cornerstone around which a scientific structure is built. The "truths" of the present turn into the myths of the future when each new paradigm supplants the previous one. We are currently at the cusp of a paradigm shift in orthodontics that will alter the field's basic conceptual foundations and, along with them, the conventional focus on diagnostic and treatment planning.

Keywords: Orthodontics, Skeletal Anchorage, Temporary Anchorage Devices (TADs), Micro-implants, Paradigm Shift.

INTRODUCTION

One of the most important components of orthodontic treatment planning has always been anchorage control, which is also crucial for handling the most challenging situations. One method available to orthodontists is the use of temporary anchoring devices (TADs). TAD has turned out to be a beneficial addition, minimising the potential negative effects of traditional anchorage in those treatments that call for the highest level of anchorage management.[1-7]

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There have been many significant developments in the area of orthodontics, but few can compare to the clinical impact of micro-implants and the newly developed extra-radicular bone screws. With their idea of absolute anchorage, temporary anchorage devices have completely changed the orthodontic sector. They have also shown themselves to be a useful tool for clinicians to manage difficult malocclusions and clinical problems.[10]

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BRIEF APPLICATION OF EXTRA-RADICULAR (E-A) TEMPORARY SKELETAL ANCHORAGE DEVICES

E-A bone screws are cutting-edge medical products with a distinctive past. The E-A idea was developed by Taiwanese orthodontist Chris Hwai-Nan Chang using concepts from craniofacial biology, orthodontics, bone physiology, and oral surgery.[11-16] According to his theory, TSADs inserted into the basilar bones of both arches may be able to reverse the causes of severe skeletal and dental malocclusion. However, only surgical methods using bone plates and retromolar implants have been able to provide intraoral access to the basilar bone.[17-18] For both arches, cautious access to the basilar bone required basic intraoral techniques.

To address sagittal, vertical, and intermaxillary discrepancies, E-A bone screws in the basilar bone of both arches offer stability for moving teeth in relation to the jaws. If there is little variation in the relative positions of individual teeth, such as with passive, relatively rigid aligners or a fixed device with a suitable rectangular archwire to avoid tipping, then the movement of a whole dental arch is determinate (predictable).[16] An arch is basically a big multi-rooted tooth when it is moved as a whole.[19] When arches are aligned in three dimensions before starting intermaxillary elastics, this principle is clearly understood with fixed appliances. Skeletal malocclusion can be effectively corrected without extractions or orthognathic surgery by retracting and rotating whole arches using E-A bone screws.[11,12,16]

Ankylosed teeth naturally exhibit absolute or infinite anchoring, which is defined as zero movement of the anchor unit. The same principle was used in the development of skeletal anchoring devices, or TADS, which are secured directly to the bone.[20] To meet the anchorage requirements of modern orthodontic therapy, mini implants (MIs), are commonly placed in the dentoalveolar region, especially in the gaps between tooth roots. Smaller size, lower cost, and simpler installation and removal are the benefits of interradicular miniscrews. But the thin alveolar bone between the roots restricts the use of miniscrews. The distance between molar and premolar roots is just 2 to 2.5 mm. Additionally, failure of screw anchorage may result from miniscrews being too close to the roots.[20]

The disadvantages of interradicular mini screws on the buccal and palatal sides can be addressed by using miniplates (skeletal anchorage system) and extra alveolar TADS, which are fastened away from the root apices and do not impede tooth movement.[21,22]

Types of extra-radicular Temporary skeletal anchorage devices

The following are examples of skeletal anchoring devices: Osseointegrated restorative implants, 45, Implants of the retromolar prosthetic type;[13,23] Miniscrews Inter-radicular (I-R);[24,25] Screws for extra-alveolar (E-A) bone;[11,12,26] Bone screws for the mandibular ramus,[13] Craniofacial orthopaedic bone plates and mini-plates.[27,28] At the annual convention of the American Association of Orthodontists in 1983, Roberts reported the first use of a TSAD.[29]

From inter-radicular (I-R) miniscrews and retromolar implants to extra-alveolar (EA) bone screws inserted in the basilar bone buccal to the first molars, namely the mandibular buccal shelf (MBS) and infrazygomatic crest (IZC), TSADs have evolved. To move teeth, segments, and arches, E-A anchoring uses determinate mechanics. Without the need for extractions or orthognathic surgery, severe skeletal dysplasia can be corrected by retracting and rotating the lower arch, which reverses the aetiology of Class III openbite malocclusion.

IZC

Anatomically, the infrazygomatic crest is a pillar of cortical bone situated close to the maxilla's zygomatic process. This enhances the main stability of the miniscrew and permits bicortical fixation via the sinus floor and buccal cortical plate. Thicker bones allow for more osseous contact and greater miniscrew biting depth.[30]

With an overall success percentage of 93.7%, stainless steel has long been the preferred material for applications requiring resistance to fracture. Higher implantation angles and longer mini-implants provide better pull-out strength. The placement is done at an angle of 65 to 70 degrees to the first molar's distobuccal root, 12 to 17 mm above the occlusal plane.[31] The length of the implant had no discernible effect on stress at the implant-bone interface.[32] The screw is aimed at the occlusal plane at a 90° angle. After the initial insertion in the bone is created, the bone screw driver's orientation is moved downward and towards the tooth by 55° to 70°.

The success rate for IZC mini-implants is 78.2%, which is slightly lower than the average mini-implant. Numerous parameters, including operator expertise, micro implant length, duration of usage, skeletal face pattern, oral hygiene state, mucosa versus attached gingiva, insertion angle, and loading force direction, influence the success rate.[33]

MBS

In the posterior region of the mandibular body, anterior to the oblique line of the mandibular ramus, and lateral to the molar area, the buccal shelf is a bony depression with a thick cortical plate that extends buccally with a significant amount of bone bilaterally. In the Indian population, the buccal shelf area is usually deep and thin; a 2x12 mm screw is the suggested option.[34]

The optimal location is 4 mm buccal to the mandibular second molar CEJ, typically close to the distal root and the mucogingival junction. A self-drilling screw is inserted into the bone as close to parallel to the mandibular first and second molar roots as feasible and perpendicular to the occlusal plane. Following the initial notch, the driver's orientation is moved upward and towards the tooth by 60° to 75°, assisting the screw in avoiding root contact and guiding it to the mandibular buccal shelf area.[34]

Ramal Extra-alveolar screws

In certain situations, third molars can be moved to replace lost mandibular first or second molars. These are challenging movements that require the use of Ramal Extra-alveolar screws.[35]
It is believed that 5 to 8 mm above the occlusal plane, midway between the internal and external oblique ridges of the ascending ramus, is the best place to implant ramal screws without obstructing the occlusal plane.[36] It is recommended that ramal implants be positioned 13 to 25 degrees away from the occlusal line.[37]

Retromolar Bone Screws
The tiny screws utilised in this investigation have a diameter of 2 mm and a length of 10 mm. Better stress distribution around the mini-screw, particularly at the mini-screw neck, can be guaranteed by these measurements. A line was drawn in the program to join the buccal cusp of the second molar with the cusp of the canine to calculate the angle at which the MRM should be inserted. This line, known as the occlusal reference line (ORL), serves as a standard for the MRM's insertion angle. Pure Ti exhibited the lowest Von Mises stresses, whereas the SS MRM had the greatest at 45° and 60° angles.[38]

Materials used
Stainless steel (SS), titanium (Ti), titanium alloy (TiA), titanium (Ti), and titanium (Ti) are the materials used to make bone fixtures.4 Ti is recommended for bigger root-form implants that are greater than 3 mm in diameter since it is a robust but somewhat fragile material. Usually, TiA is the material of choice for small interradicular miniscrews (less than 2 mm in diameter) due to its strength and fatigue resistance.[25,39-41] SS is a better material for dense cortical bone since it is harder.[11,12] SS is the recommended material for all non-integrated TSADs15 and orthopaedic bone plates due to its reduced cost and acceptable material qualities.[42] TiA is utilised for osseous attachment of functional equipment and bone plate anchorage in orthodontics.[28]
It was found that titanium miniscrews had a higher insertion and removal torque than stainless steel miniscrews in thicker corticals. Maximum fracture torque, a measure of fracture resistance, was higher in stainless steel mini-screws than in titanium mini-screws, indicating that using stainless steel mini-screws makes the insertion process safer.[11] Because of its increased ductility, stainless steel has superior mechanical qualities when taking bending effects into account. Stainless steel's torsional resistance reduces the chance of breakage by giving the professional more sensitivity during insertion. Professionals find it challenging to detect when the rupture is likely to happen since titanium mini-screws do not produce haptic sensation during insertion.[43]

Orthodontic forces' effects on biomarkers of bone turnover in peri-implant crevicular fluid
Bone turnover markers, or biomarkers that indicate resorption or formation activity, have been widely utilised to track changes in the osseous structure.[44] Bone turnover biomarkers in gingival crevicular fluid (GCF) and peri-implant crevicular fluid, respectively, have been proposed as promising tools for diagnosis, prognosis, and treatment in patients with osseointegrated implants or chronic periodontitis.[45,46] The value of certain bone turnover indicators as an extra criterion for the identification of periodontal and peri-implant tissue infections has been emphasised by recent evidence-based syntheses.

After orthodontic loading, peri-miniscrew crevicular fluid biomarkers of bone growth or resorption responded differently. All things considered, the results pointed to adaptive changes in bone in response to physiologic force inputs.

A deeper comprehension of the biological reactions surrounding miniscrews in response to orthodontic loads may be possible with the analysis of peri-miniscrew crevicular fluid bone turnover biomarkers.[47]

According to data from the identified research, during the investigated periods, peri-miniscrew crevicular fluid levels of certain bone turnover biomarkers showed either temporary or more permanent changes as a result of orthodontic stresses. All things considered, the results pointed to an adaptive bone response to force stimuli. When physiological forces are applied, orthodontic loading could not have a significant impact on early bone remodelling and miniscrew clinical performance. Therefore, loading the mini-screws right after placement, at least with force levels comparable to those employed in the identified trials (i.e., between 50 and 200 g), would be consistent with good practice.[47]

Accuracy of 3D imaging and digital process for orthodontic TSAD placement
A digital intraoral scan registered using a cone-beam computed tomography (CBCT) or lateral cephalogram can be used to plan the insertion of guided miniscrews utilising various software programs on the market. When a thorough examination of a particular anatomical problem is necessary, CBCT should be utilised to prevent patients from needless radiation exposure.[48] Although there is a degree of error in guided clinical insertion, both approaches are accurate.[49-51]

Miniscrew insertion planning software, including that used in earlier research, is typically made specifically for orthodontic applications, can be connected with lab software, or is supplied by firms to be used only with their miniscrews. These systems' benefit is the workflow's efficiency, from planning to appliance delivery (including fully digital CAD-CAM applications). The software's expensive cost (buy or annual subscription) or the single case (planning/appliance fabrication bundle) are also drawbacks.[52]

Extra-radicular implant placements using digital guidance could result in shorter orthodontic treatment times, the elimination of laboratory and clinical procedures, improved accuracy and predictability, and increased patient comfort. However, using CAD/CAM technology in orthodontics comes with a higher price tag and requires expert training.[53]

FEA and TSADs

The use of mini-implants placed into the IZ crest for en masse maxillary dentition distalization using clear aligners had not yet been the subject of any FE research. One of the FE research on CAT that has already been done is by Bai et al., who investigated the impact of mini-implants combined with clear aligners on anterior retraction after first premolar extractions.[54]

The centre of resistance for mandibular rotation is actually an axis of rotation (CRot). For example, only 3D FEA can forecast the CRot for a lower arch retracted using bilateral MBS bone screws.[56]

For example, according to finite element analysis (FEA), the CRot in the upper third of the lower canine roots bilaterally was perpendicular to the midsagittal plane as a result of the traction of the MBS anchoring. The greater bone mass in the mandibular symphyseal region is compatible with the CRot axis's more anterior position in 3D. As the lower arch retracts, the lower molars are intruded to seal the VDO, which is a significant advantage for treating Class III openbite malocclusion.[55] The use of this mechanical engineering technology in diagnosis, treatment planning, and retrospective analysis is growing. To address skeletal Class III malocclusion, FEA also replicates occlusal plane rotation and mandibular arch retraction. FEA iterations are used to model the 3D tooth movement paths.[56]

To broaden the therapeutic horizon for aligner treatment, Align Technology investigated novel materials, techniques, and technologies, such as employing TSADs for osseous anchorage.[57-59] Conversely, aligners can reposition teeth in relation to the apical base of bone, thanks to TSAD anchoring.[59] For skeletal and dental correction, bone screws buccal to the molars work well. However, because the necessary data set is retrospective, new approaches are slow to affect web-based algorithms that project outcomes with artificial intelligence (AI).[57-59]

Clinical decision systems and AI techniques

In dentistry, artificial intelligence has grown in importance. Trained algorithms can help with decision-making because of the volume of clinical and imaging data available to researchers and clinicians, as well as the application of improved data science techniques.[60]

According to Pareek et al., there are about 4,000 dental implants available globally, each with a different shape and method of treatment.[61] Therefore, the key to success is understanding which one is more appropriate for a given patient based on their condition. In this domain, artificial intelligence (AI) can assist computer-aided design/manufacturing, panoramic radiography, and dentists in identifying and prioritising the implants to prevent issues

Researchers have also concentrated on applying AI techniques to identify fractures and implant failures. Three deep convolutional neural networks (VGGNet-19, GoogLeNet Inception-v3, and automated DCNN) were assessed by Lee et al. in 2020 for the classification of broken dental implants in panoramic and periapical rays.[62] Using a database containing 21,398 fractured implants, they discovered that the AI methods performed well in identifying and classifying fractured implants. The best results were obtained when periapical radiography images were used alone (automated DCNN with an area under the curve of 0.984).[63]

Osseointegration and TSADs

Retromolar osseointegrated implants were the first TSADs, and they were utilised to treat acquired intermaxillary malocclusion brought on by the early loss of a lower first molar (L6).[13,23]

More common TSADs that were less costly and simpler to use but less dependable and adaptable were small nonintegrated inter-radicular (I-R) miniscrews.[24,26] To offer basilar bone anchorage for conservative correction of skeletal malocclusion, extra-alveolar (E-A) bone screws expanded upon the advantages of earlier ideas.4 Direct or 2-4 indirect TSAD anchoring is possible.[13,23-26] The mechanical stabilisation of a tooth to act as an anchor for moving other teeth is known as indirect anchorage.[13,23] Static abutments, like those used for sutural expansion, are made to move complete bones.[64]

In 1959, Brånemark[65] called this process "osseointegration." Osteointegration is accomplished by a persistent bone remodelling response within 1 mm of the implant surface for Ti screws larger than 3.2 mm in diameter with conditioned (cleaned) surfaces.[13,14,64]

Even when a root impinges, osseous flexure creates a slip plane at the bone contact that promotes healing and remodelling since titanium is ten times stiffer than cortical bone. Small Ti and TiA miniscrews (less than 2 mm in diameter) do not osseointegrate, even after several surface treatments to improve bone bonding.[25,26,66,67] Slender miniscrews' increased interface flexure is incompatible with the severe bone remodelling necessary for osseointegration; yet, laminar bone growth keeps miniscrews stiff.

When loaded, osseointegrated implants remain stationary, whereas clinically rigid nonintegrated devices could stray by at least 4 mm.[68-73] Miniscrews that are not integrated (less than 1.6 mm) are far less dependable than osseointegrated fixings and have a higher failure rate.[24,13,64] The mandibular buccal shelf (MBS),[11,12] maxillary infrazygomatic crest (IZC),[11,27,] and mandibular ramus are the three locations where nonintegrated 2mm SS bone screws have a success rate of almost 95%.[11,12] The failure rate for TiA and SS did not differ in a clinically significant way.[14] When PDL and roots impinge, small I-R devices run the danger of failing, in contrast to big osseointegrated fixtures.[74]

Although they offer superior anchoring, osseointegrated implants have drawbacks. They are costly, there is a several-month lag between placement and loading, Moreover, in contrast to traditional dental implants, the varying bone morphology in different regions places some limitations on implant geometry, and removal could be challenging.[75-77] According to histological research, titanium miniscrews osseointegrate less than half as well as traditional dental implants.[78]

Clear Aligners and TSADs

For the first alignment, orthodontists must rely on the materials' compliance and durability (aligners and archwires). The "large multirooted teeth" that stabilised segments and arches are, however, be moved with specific mechanics with the use of temporary skeletal anchoring devices (TSADs).

Chang et al.[79,80] Although fixed appliances have been used for a long time, routine aligner treatment has only lately begun to use IZC and MBS bone screws.[81-85]

Indeterminate (unpredictable) mechanics govern the initial orthodontic alignment of several teeth using fixed equipment or aligners. To resolve sagittal, vertical, asymmetric, and intermaxillary discrepancies, the E-A anchoring with IZC and MBS bone screws allows for the precise movement of complete arches in three dimensions. Carefully planned slits, bonded buttons, and strong aligner retention are necessary for attaching TSAD-anchored elastics to aligners. Algorithms for automated AI treatment need a large database that keeps up with the latest developments. To effectively use TSAD anchoring to address dental and skeletal malocclusion, an orthodontist with proper training is needed.

At first, simple orthodontic cases were treated with clear aligner therapy (CAT). More recent developments have investigated how well CAT works to treat more complicated malocclusions. Nevertheless, unintentional tooth movements have been linked to aligners' natural flexibility.[25,26] Intermaxillary forces or auxiliary devices, like mini-implants, are required to offer a high degree of skeletal anchoring to attenuate reactions related to intramaxillary forces, especially for en masse distalization of anterior teeth.[11] Mini-implants have made it easier to manage mild to severe malocclusions, which has decreased the need for premolar extractions.[13]

CONCLUSION

Due to a paradigm shift, extra-alveolar skeletal anchoring is now frequently utilised in orthodontic therapy. We can better prevent any injuries or issues associated with it and help to fully benefit from it if we have the correct knowledge on screw placement, indications, and particular considerations. Indeterminate (unpredictable) mechanics govern the initial orthodontic alignment of several teeth using fixed equipment or aligners. To resolve sagittal, vertical, asymmetric, and intermaxillary discrepancies, the E-A anchoring with IZC and MBS bone screws allows for the precise movement of complete arches in three dimensions. Algorithms for automated AI treatment need a large database that keeps up with the latest developments. To effectively use TSAD anchoring to address dental and skeletal malocclusion, an orthodontist with proper training is needed.

REFERENCES

1. Su L, Song H, Huang X. Accuracy of two orthodontic mini-implant templates in the infrazygomatic crest zone: A prospective cohort study. BMC Oral Health 2022;22:252.
2. Kravitz ND, Kusnoto B. Risks and complications of orthodontic miniscrews. Am J Orthod Dentofacial Orthop 2007;131:S43-51.
3. Chang CH, Lin JH, Roberts WE. Success of infrazygomatic crest bone screws: Patient age, insertion angle, sinus penetration, and terminal insertion torque. Am J Orthod Dentofacial Orthop 2022;161:783-90.
4. Matias M, Flores-Mir C, Almeida MR, da Silva Vieira B, de Freitas KM, Nunes DC, et al. Miniscrew insertion sites of infrazygomatic crest and mandibular buccal shelf in different vertical craniofacial patterns: A cone-beam computed tomography study. Korean J Orthod 2021;51:387-96.
5. Jia X, Chen X, Huang X. Influence of orthodontic mini-implant penetration of the maxillary sinus in the infrazygomatic crest region. Am J Orthod Dentofacial Orthop 2018;153:656-61.
6. Bae MJ, Kim JY, Park JT, Cha JY, Kim HJ, Yu HS, et al. Accuracy of miniscrew surgical guides assessed from cone-beam computed tomography and digital models. Am J Orthod Dentofacial Orthop 2013;143:893-901.
7. Liou EJ, Chen PH, Wang YC, Lin JC. A computed tomographic image study on the thickness of the infrazygomatic crest of the maxilla and its clinical implications for miniscrew insertion. Am J Orthod Dentofacial Orthop 2007;131:352-6.
8. Proffit WR. Contemporary Orthodontics. 6th ed. St. Louis: Mosby Yearbook; 1993. p. 307.
9. Jong Lin JL. Text Book of Creative Orthodontics: Blending the Damon System and TADs to Manage Difficult Malocclusions. Yong Chieh: Taipei,Taiwan; 2007.
10. Chandrasekaran, Agharsh & Deepti, H.P. & Kidiyoor, Harshavardhan. (2022). Understanding

Orthodontic Bone Screws. 10.5772/intechopen.100276.
11. Upadhyay, M · Yadav, S · Nanda, R. Biomechanics of incisor retraction with mini-implant anchorage J Orthod. 2014; 41:S15-S23.
12. Chang, C · Liu, SS-Y · Roberts, WE. Primary failure rate for 1680 extra-alveolar mandibular buccal shelf mini-screws placed in movable mucosa or attached gingiva. Angle Orthod. 2015; 85:905-910
13. Chang, CH · Lin, JS · Eugene Roberts, WE Ramus screws: the ultimate solution for lower impacted molars Semin Orthod. 2018; 24:135-154
14. Chang, CH · Lin, JS · Roberts, WE. Failure rates for stainless steel versus titanium alloy infrazygomatic crest bone screws: a single-center, randomized double-blind clinical trial Angle Orthod. 2019; 89:40-46.
15. Tseng, L · Chang, CH · Roberts, WE. Simplified removal of an osseointegrated implant for space closure to correct anterior crossbite J Digit Orthod. 2020; 58:68-90.
16. Arbuckle, GR · Kanomi Roberts, WE. Osseointegrated implants and orthodontics Oral Maxillofac Surg Clin North Am. 1991; 3:903-919.
17. Sugawara, J. Orthodontic reduction of lower facial height in open bite patients with skeletal anchorage system: beyond traditional orthodontics World J Orthod. 2005; 6:24-26.
18. Peck, S. A biographical portrait of Edward Hartley Angle, the first specialist in orthodontics, part 1. Angle Orthod. 2009; 79:1021-1027.
19. Peck, S.The contributions of Edward H. Angle to dental public health Community Dent Health. 2009; 26:130-131.
20. Gray, JB · Steen, ME · King, GJ. Studies on the efficacy of implants as orthodontic anchorage Am J Orthod. 1983; 83:311-317
21. Kuroda S, Sugawara Y, Deguchi T, Kyung HM, Takano-Yamamoto T. Clinical use of miniscrew implants as orthodontic anchorage: success rates and postoperative discomfort. Am J Orthod Dentofacial Orthop. 2007 Jan;131(1):9-15.
22. Cornelis MA, De Clerck HJ. Maxillary molar distalization with miniplates assessed on digital models: a prospective clinical trial. Am J Orthod Dentofacial Orthop. 2007 Sep;132(3):373-7.
23. Tamanna Hoque, Dilip Srinivasan, Sangeetha morekonda gnaneswar,sushil chakravarthi, krishnaraj rajaram.Microimplant Assisted Rapid Palatal Expansion: A Comprehensive Review.Journal of Clinical and Diagnostic Research. 2021 Aug, Vol-15(8): ZE11-ZE15.
24. Roberts, WE · Marshall, KJ · Mozsary, PG. Rigid endosseous implant utilized as anchorage to protract molars and close an atrophic extraction site. Angle Orthod. 1990; 60:135-152.
25. Roberts, WE · Nelson, CL · Goodacre, CJ. Rigid implant anchorage to close a mandibular first molar extraction site. J Clin Orthod. 1994; 28:693-704.
26. Kanomi, R. Mini-implant for orthodontic anchorage. J Clin Orthod. 1997; 31:763-767.
27. Chang, CH · Lin, JH · Roberts, WE. Success of infrazygomatic crest bone screws: patient age, insertion angle, sinus penetration, and terminal insertion torque. Am J Orthod Dentofacial Orthop. 2022; S0889–5406:00834–9.
28. Suresh, S · Sundareswaran, S · Sathyanadhan, S. Effect of microimplant assisted rapid palatal expansion on bone-anchored maxillary protraction: a finite element analysis Am J Orthod Dentofacial Orthop. 2021; 160:523-532.
29. Duggal, I · Sidhu, MS · Chawla, A .Effects of miniplate anchored Herbst appliance on skeletal, dental and masticatory structures of the craniomandibular apparatus: a finite element study. Int Orthod. 2021; 19:301-309.
30. Roberts, WE. Endosseous implants as anchorage. Presented at Am. Assoc. of Orthodontics (AAO) annual meeting, Boston. Am J Orthod. 1983; 83:163.
31. Liou EJ, Chen PH, Wang YC, Lin JC. A computed tomographic image study on the thickness of the infrazygomatic crest of the maxilla and its clinical implications for miniscrew insertion. Am J Orthod Dentofacial Orthop. 2007 Mar;131(3):352-6.
32. Mohan S, Srinivasan D, Arumugam E. Devasahayam D, Kannan R. Effect of placement angle, diameter, length and bone density on the pull-out strength of orthodontic mini-implants: An in vitro study. Journal of Orthodontics. 2022;49(2):143-150.
33. Bharath Ramesh, Dilip Srinivasan, Sangeetha Duraiswamy.Analysis of stress in bone with orthodontic mini-implants during en-masse retraction of maxillary and mandibular anterior teeth: a finite element analysis. J. Pharm. Sci. & Res. Vol. 13(5), 2021, 302-312.
34. Uribe F, Mehr R, Mathur A, Janakiraman N, Allareddy V. Failure rates of mini-implants placed in the infrazygomatic region. Prog Orthod. 2015;16:31.
35. Ghosh A. Infra-zygomatic crest and buccal shelf - Orthodontic bone screws: A leap ahead of micro-implants – Clinical perspectives. J Indian Orthod Soc 2018;52:S127-41.
36. Nikita Kala1, Rakesh Thukral2, Jaya Singh3, Sakina Pata4, Sheetal Kanthali5. 2025 IJNRD | Volume 10, Issue 6 June 2025 | ISSN: 2456-4184.
37. Musilli M, Marsico M, Romanucci A, Grampone F. Molar uprighting with mini screws: comparison among different systems and relative biomechanical analysis. Prog Orthod. 2010;11:166–173.
38. Vickram, A. S., Samad, H. A., Latheef, S. K., Chakraborty, S., Dhama, K., Sridharan, T. B., ... & Gulothungan, G. Human prostasomes an extracellular vesicle– Biomarkers for male infertility and prostrate cancer: The journey from identification to current knowledge. International

journal of biological macromolecules 2020; 146:946-958.
39. Al-Hafidh, Nada Nashee & Alsamak, Saeed & Al-Abbood, Mohammed & Al-Khatib, Ali. Effect of Change Angulation and Material of Mini-screw inserted in Retro Molar Pad Area on Stress Distribution: A Finite Element Simulation Study. Archives of Orofacial Sciences 2024;19:173–186.
40. Umemori, M · Sugawara, J · Mitani, H . Skeletal anchorage system for open-bite correction Am J Orthod Dentofacial Orthop. 1999; 115:166-174.
41. Huang, GY · Jiang, HB · Cha, JY .The effect of fluoride-containing oral rinses on the corrosion resistance of titanium alloy (Ti-6Al-4V) Korean J Orthod. 2017; 47:306-312.
42. Yadav, S · Upadhyay, M · Roberts, WE. Biomechanical and histomorphometric properties of four different mini-implant surfaces Eur J Orthod. 2015; 37:627-635.
43. Ganesh, VK · Ramakrishna, K · Ghista, DN. Biomechanics of bone-fracture fixation by stiffness-graded plates in comparison with stainless-steel plates Biomed Eng OnLine. 2005; 4:46.
44. Yao CC, Chang HH, Chang JZ, Lai HH, Lu SC, Chen YJ. Revisiting the stability of mini-implants used for orthodontic anchorage. J Formos Med Assoc 2015;114:1122-1128.
45. Chapurlat RD, Confavreux CB. Novel biological markers of bone: from bone metabolism to bone physiology. Rheumatology (Oxford) 2016;55:1714–25.
46. Shazam H, Shaikh F, Hussain Z. Bone Turn-over Markers in Chronic Periodontitis: A Literature Review. Cureus 2020;12:e6699.
47. Kaklamanos EG, Tsalikis L. A review on periimplant crevicular fluid assays potential in monitoring and predicting peri-implant tissue responses. J Int Acad Periodontol 2002;4:49–59.
48. Kaklamanos EG, Gousopoulou E, Tsalikis L. Effects of orthodontic forces on bone turnover biomarkers in peri-miniscrew crevicular fluid: A systematic review. Int Orthod. 2020 Sep;18(3):403-411.
49. Hodges RJ, Atchison KA, White SC. Impact of cone-beam computed tomography on orthodontic diagnosis and treatment planning. Am J Orthod Dentofacial Orthop. 2013;143(5):665–74.
50. Iodice G, Nanda R, Drago S, Repetto L, Tonoli G, Silvestrini-Biavati A, Migliorati M. Accuracy of direct insertion of TADs in the anterior palate with respect to a 3D-assisted digital insertion virtual planning. Orthod Craniofac Res. 2022;25(2):192–8
51. Pozzan L, Migliorati M, Dinelli L, Riatti R, Torelli L, Di Lenarda R, Contardo L. Accuracy of the digital workflow for guided insertion of orthodontic palatal TADs: a step-by-step 3D analysis. Prog Orthod. 2022;23(1):27.
52. Möhlhenrich SC, Brandt M, Kniha K, Prescher A, Hölzle F, Modabber A, Wolf M, Peters F. Accuracy of orthodontic mini-implants placed at the anterior palate by tooth-borne or gingiva-borne guide support: a cadaveric study. Clin Oral Investig. 2019;23(12):4425–31.
53. Ronsivalle V, Venezia P, Bennici O, D'Antò V, Leonardi R, Giudice AL. Accuracy of digital workflow for placing orthodontic miniscrews using generic and licensed open systems. A 3d imaging analysis of non-native .stl files for guided protocols. BMC Oral Health. 2023 Jul 17;23(1):494.
54. Cunha TMAD, Barbosa IDS, Palma KK. Orthodontic digital workflow: devices and clinical applications. Dental Press J Orthod. 2021 Dec 15;26(6):e21spe6. doi: 10.1590/2177-6709.26.6.e21spe6.
55. Bai Y, Feng X, Liu D, Li P, Feng Y. Combined use of miniscrews and clear aligner for en-mass retraction of maxillary anterior teeth: a finite element analysis. J Pract Stomatol 2019;35:71-6.
56. Chen, J · Esterle, M · Roberts, WE. Mechanical response to functional loading around the threads of retromolar endosseous implants used for orthodontic anchorage: coordinated histomorphometric and finite element analysis Int J Oral Maxillofac Implants. 1999; 14:282-289.
57. Roberts WE, Chang CH, Chen J, Brezniak N, Yadav S. Integrating skeletal anchorage into fixed and aligner biomechanics. J World Fed Orthod. 2022 Aug;11(4):95-106. doi: 10.1016/j.ejwf.2022.04.001.
58. Bustati, N · Rajeh, N. The impact of COVID-19 pandemic on patients receiving orthodontic treatment: an online questionnaire cross-sectional study. J World Fed Orthod. 2020; 9:159-163
59. García-Camba, P · Marcianes, M · Varela Morales, M Changes in orthodontics during the COVID-19 pandemic that have come to stay. Am J Orthod Dentofacial Orthop. 2020; 158:e1-e3
60. Yassir, YA · Nabbat, SA · McIntyre, GT .Clinical effectiveness of clear aligner treatment compared to fixed appliance treatment: an overview of systematic reviews Clin Oral Investig. 2022; 26:2353-2370.
61. Bianchi J, Mendonca G, Gillot M, Oh H, Park J, Turkestani NA, Gurgel M, Cevidanes L. Three-dimensional digital applications for implant space planning in orthodontics: A narrative review. J World Fed Orthod. 2022 Dec;11(6):207-215.
62. Pareek, Mitali & Kaushik, Brahmansh. (2022). Artificial intelligence in prosthodontics: a scoping review on current applications and future possibilities. International Journal of Advances in Medicine. 9. 367. 10.18203/2349-3933.ijam20220444.
63. Lee DW, Kim SY, Jeong SN, Lee JH. Artificial Intelligence in Fractured Dental Implant Detection and Classification: Evaluation Using Dataset from Two Dental Hospitals. Diagnostics (Basel). 2021 Feb 3;11(2):233.
64. Parr, JA · Garetto, LP · Wohlford, ME. Sutural expansion using rigidly integrated endosseous

implants: an experimental study in rabbits Angle Orthod. 1997; 67:283-290.

65. Brånemark, PI. Vital microscopy of bone marrow in rabbits Scand J Clin Lab Investig. 1959; 11:1-82
66. Moon, W · Wu, KW · MacGinnis, M. The efficacy of maxillary protraction protocols with the micro-implant-assisted rapid palatal expander (MARPE) and the novel N2 mini-implant-a finite element study. Prog Orthod. 2015; 16:16.
67. Mecenas, P · Espinosa, DG · Cardoso, PC. Stainless steel or titanium mini-implants? Angle Orthod. 2020; 90:587-597.
68. Deguchi, T · Takano-Yamamoto, T · Kanomi, R. The use of small titanium screws for orthodontic anchorage. J Dent Res. 2003; 82:377-381
69. Saito, S · Sugimoto, N · Morohashi, T . Endosseous titanium implants as anchors for mesiodistal tooth movement in the beagle dog. Am J Orthod Dentofacial Orthop. 2000; 118:601-607.
70. Melsen, B · Costa, A. Immediate loading of implants used for orthodontic anchorage Clin Orthod Res. 2000; 3:23-28
71. Melsen, B · Lang, NP. Biological reactions of alveolar bone to orthodontic loading of oral implants. Clin Oral Implants Res. 2001; 12:144-152.
72. Luzi, C · Verna, C · Melsen, B. Immediate loading of orthodontic mini-implants: a histomorphometric evaluation of tissue reaction. Eur J Orthod. 2009; 31:21-29
73. Liou, EJ · Pai, BC · Lin, JC. Do miniscrews remain stationary under orthodontic forces?. Am J Orthod Dentofacial Orthop. 2004; 126:42-47.
74. Mohammed, H · Wafaie, K · Rizk, MZ. Role of anatomical sites and correlated risk factors on the survival of orthodontic miniscrew implants: a systematic review and meta-analysis. Prog Orthod. 2018; 19:36,
75. Turley P K et al. 1988 Orthodontic force application to titanium endosseous implants . Angle Orthodontist 58 : 151 – 162.
76. Bernhart T , Dörtbubak O , Wehrbein H , Baier C , Bantleon H-P , Kucher G. 2000 Das Gaumenimplantat . Informationen aus Orthodontie und Kieferorthopädie 32 : 209 – 229.
77. Fritz U , Ehmer A , Diedrich P 2004 Clinical suitability of titanium microscrews for orthodontic anchorage—preliminary experiences. Journal of Orofacial Orthopedics 65 : 410 – 418.
78. Costa A , Raffaini M , Melsen B 1998 Miniscrews as orthodontic anchorage: a preliminary report . International Journal of Adult Orthodontics and Orthognathic Surgery 13 : 201 – 209.
79. Hsu, Y · Chang, CH · Roberts, WE. Non-extraction treatment for Class II open bite using the combination of aligners and IZC screws Digit Orthod. 2021; 63:4-16
80. Chang, CH · Chen, C-H · Roberts, WE. Excessive overjet, steep mandibular plane, and posterior scissors-bite treated with aligners, IZC screws, and Class II elastics Am J Orthod Dentofacial Orthop Clin. Comp. 2022;
81. Tseng, L · Chang, CH · Roberts, WE. Simplified removal of an osseointegrated implant for space closure to correct anterior crossbite. J Digit Orthod. 2020; 58:68-90.
82. Arbuckle, GR · Nelson, CL · Roberts, WE. Osseointegrated implants and orthodontics. Oral Maxillofac Surg Clin North Am. 1991; 3:903-919.
83. Tseng, LL · Chang, CH · Roberts, WE. Diagnosis and conservative treatment of skeletal Class III malocclusion with anterior crossbite and asymmetric maxillary crowding. Am J Orthod Dentofacial Orthop. 2016; 149:555-566.
84. Viecilli, RF · Budiman, A · Burstone, CJ. Axes of resistance for tooth movement: does the center of resistance exist in 3-dimensional space? Am J Orthod Dentofacial Orthop. 2013; 143:163-172
85. Almeida, MR. Biomechanics of extra-alveolar mini-implants Dent Press J Orthod. 2019; 24:93-109.