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Review Article

Dentistry Section

Skeletal Anchorage Systems: A Narrative Review of Biomechanical Considerations for Predictable Orthodontic Tooth Movement with Maxillary and Mandibular Distalisation

RAMESH CARMEL[1], VINCY ANTONY MARGARET[2], MUHAMMED SHALOOB[3], SINJIMOL THOMAS[4], INDU NAMBIAR[5]

ABSTRACT

In recent years, skeletal anchorage systems have become an integral component of orthodontic biomechanics. They provide a reliable source of anchorage that is independent of the dentition, thereby improving the efficiency of distalisation with better control and reduced dependence on patient compliance. The present narrative review focuses on the biomechanical principles underlying skeletal anchorage-assisted distalisation. In particular, it examines the relationship between force vectors and the centre of resistance of the dental arches. Tooth movement depends largely on the point of force application relative to this centre, which determines whether the movement is primarily translational or accompanied by rotational changes, such as clockwise or counterclockwise rotation of the occlusal plane. Several skeletal anchorage options are available, including infrazygomatic crest mini-implants, buccal shelf screws, interradicular mini-implants, and palatal mini-implants. Each provides specific biomechanical advantages depending on the clinical situation. Maxillary and mandibular distalisation present distinct anatomical and biomechanical challenges, often requiring individualised force system design. Careful control of force magnitude, direction, and vector position allows predictable en masse distalisation. This approach also helps maintain incisor torque, vertical dimension, and occlusal stability. With appropriate planning, skeletal anchorage systems can be used to manage sagittal discrepancies in both camouflage and presurgical orthodontic treatment, offering better control and greater efficiency than conventional anchorage methods.

Keywords: Buccal shelf bone screw, Fixed orthodontic treatment, Infra-zygomatic crest bone screw, Orthodontic bone screws, Skeletal anchorage, Total Maxillary Distalisation

INTRODUCTION

Anchorage control is a fundamental determinant of successful orthodontic treatment outcomes, particularly in clinical situations requiring distalisation of the dentition. Conventional anchorage approaches, dependent on intraoral dental units or extraoral appliances, are inherently limited by reciprocal tooth movement, anchorage loss, and a high reliance on patient compliance [1]. These limitations become more pronounced during maxillary and mandibular distalisation, where large orthodontic forces are required to move posterior teeth against natural resistance from surrounding skeletal and soft tissue structures.

The introduction of skeletal anchorage systems (SAS) has fundamentally altered orthodontic biomechanics by enabling force application directly to bone rather than teeth. Skeletal anchorage eliminates the need for patient cooperation and allows clinicians to achieve movements that were previously considered difficult or impossible using conventional mechanics [2]. Over the past two decades, the use of temporary anchorage devices (TADs), miniplates, and palatal implants has expanded rapidly, particularly in the management of Class II and Class III malocclusions requiring distalisation without extractions or orthognathic surgery [3-5].

The present review aimed to provide a comprehensive and biomechanically focused evaluation of skeletal anchorage systems in orthodontics, with particular emphasis on maxillary and mandibular distalisation. The biomechanical principles governing force application, centre of resistance considerations, clinical protocols, limitations, and evidence-based outcomes are discussed to facilitate predictable and controlled orthodontic tooth movement. Maxillary and mandibular distalisation present distinct biomechanical challenges due to differences in bone morphology, anatomical limitations, cortical bone density, and the spatial relationship of adjacent structures. Consequently, the biomechanics of distalisation in the maxilla and mandible must be analysed independently.

Literature Search Strategy

A narrative literature search was conducted to identify relevant evidence on the biomechanics of skeletal anchorage systems used for maxillary and mandibular distalisation. Electronic databases including PubMed/MEDLINE, Scopus, Google Scholar, and the Cochrane Library were searched for articles published between January 2005 and February 2026. The search strategy combined Medical Subject Headings (MeSH) and free-text keywords, including: “skeletal anchorage”, “temporary anchorage devices”, “TADs”, “infrazygomatic crest”, “IZC”, “buccal shelf”, “palatal mini-implants”, “miniplates”, “maxillary distalisation”, “mandibular distalisation”, “orthodontic biomechanics”, “force vector”, “centre of resistance”, and “extra-alveolar miniscrews”.

BIOMECHANICAL CONSIDERATIONS IN MAXILLARY DISTALISATION USING SKELETAL ANCHORAGE

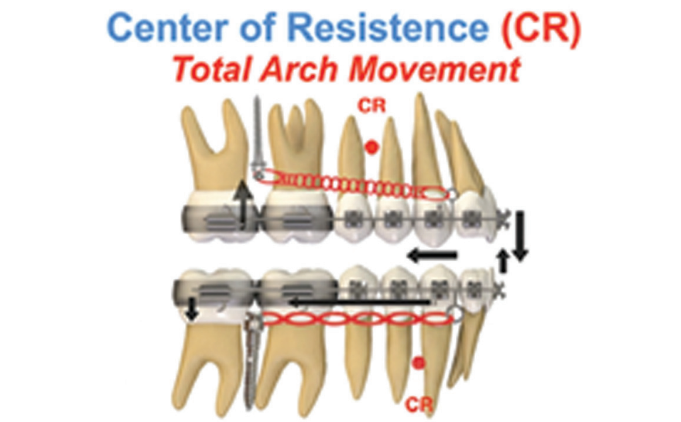
Maxillary distalisation may be achieved through anchorage placed either in the buccal alveolar region or the palatal vault. The site of anchorage placement significantly influences the biomechanics of force application, including the line of action of force, magnitude and direction of moments generated, and the resulting dental and skeletal responses. Therefore, force vector design, centre of resistance considerations, vertical side effects, and occlusal plane changes differ substantially between buccal and palatal approaches.

Buccal Skeletal Anchorage for Maxillary Distalisation

On the buccal aspect, commonly used skeletal anchorage devices include Infrazygomatic Crest (IZC) mini-implants, interradicular

Temporary Anchorage Devices (TADs), and miniplates. The vertical and anteroposterior position of the anchorage unit relative to the maxillary dentition determines the biomechanical response during distalisation.

When en masse distalisation of the entire maxillary arch is planned, understanding the location of the Centre of Resistance (CR) of the maxillary dentition is critical. The CR of the maxillary dental arch has been described as being located approximately between the first and second premolars in the sagittal plane, at a vertical level near the furcation of the first molars, assuming a consolidated arch form[6] [Table/Fig-1].



[Table/Fig-1]: Estimated location of the Centre of Resistance (CR) of maxillary and mandibular dentition. The CR of the entire dental arch was localised somewhere between the first and 2nd premolar in the maxillary arch at the level of the maxillary first molar furcation. As for the mandibular arch, CR is at the interradicular area between the 1st premolar and canine. Total arch movement will provide not only horizontal forces but also vertical forces around molars and incisors and rotation of the occlusal plane [6].

Application of distalising force through skeletal anchorage generates not only horizontal translatory forces but also vertical force components and rotational moments, depending on the line of force relative to the CR. For bodily distalisation of the entire arch, the line of action of force should ideally pass through the CR of the maxillary dentition [6].

According to Poggio PM et al., interradicular mini-implants are commonly inserted between the maxillary first molar and second premolar at a height of approximately 5-8 mm from the alveolar crest [7]. Placement in this region allows the line of force to pass close to the centre of resistance, thereby promoting more controlled tooth movement. However, distalisation with interradicular mini-implants is generally limited to approximately 2 mm because of anatomical constraints and the risk of root contact during tooth movement [8]. As a result, their effectiveness in full-arch distalisation is limited. In comparison, miniplates have demonstrated greater efficiency and stability during distalisation mechanics and cortical engagement; however, their major disadvantage is the need for a surgical procedure for placement [9]. Whereas extra-alveolar mini-implants such as IZC and buccal shelf screws are placed away from the dental roots, they allow greater distalisation and facilitate full-arch distalisation mechanics with minimal root interference. In addition, unlike miniplates, they do not require any surgical procedure for placement. So here IZC and buccal shelf mini implant for full arch distalisation are discussed.

Force Vector Relative to the Centre of Resistance

When the line of force passes precisely through the CR, translation of the maxillary dentition occurs with minimal rotational side effects. However, deviations from this ideal force vector generate rotational moments [Table/Fig-2].

Clinical Selection of Distalisation Force Systems in Class II Malocclusion

The biomechanics of total maxillary distalisation can be deliberately adjusted to suit different Class II phenotypes by modifying the vertical

Force position	Rotation	Maxillary arch effects	Mandibular arch effects
Above CR CCW rotation	↺	Anterior intrusion· posterior extrusion· proclination of incisors· counter-clockwise rotation of occlusal plane [6,10] [Table/Fig-3]. Useful: Class II Div 2, deep bite, gummy smile correction	Molar intrusion· incisor extrusion· reduction in mandibular plane angle· counterclockwise occlusal plane rotation [Table/Fig-4]. Useful: Class III hyperdivergent, anterior open bite
Through CR translation	→	Bodily arch movement · minimal rotational side effects · incisor torque preserved · vertical dimension maintained Useful: Class II with normal overbite, acceptable inclination	Bodily arch movement · minimal rotational side effects · incisor torque preserved · occlusal plane unchanged Useful: Presurgical Class II — creating overjet for surgery
Below CR CW rotation	↺	Anterior extrusion · posterior intrusion · molar distal tipping tendency · clockwise occlusal plane rotation [6]. Useful: Class II with anterior open bite, hyperdivergent	Lingual root torque of incisors · relative incisor intrusion · mild molar extrusion · clockwiseocclusal plane rotation Useful: Class III hypodivergent, deep bite, camouflage

[Table/Fig-2]: Force vector relative to the centre of resistance

relationship between the force vector and the anterior dentition. Rather than applying a uniform distalisation protocol to all patients, the clinician should select a force configuration that complements the existing vertical and incisor characteristics.

Class II with anterior open bite or hyperdivergent pattern: In Class II patients presenting with anterior open bite tendency or increased vertical facial proportions, distalisation mechanics that produce a mild clockwise rotational effect on the maxillary dentition may be advantageous.

When the force vector is designed to act inferior to the anterior segment's centre of resistance, the resulting biomechanics can contribute to:

- Controlled anterior extrusion
- Improvement in incisal overlap
- Favourable vertical settling
- Sagittal correction combined with bite closure

When the force vector is designed to act inferior to the anterior segment's centre of resistance, the resulting biomechanics can contribute to controlled extrusion of maxillary anteriors, improvement in incisal overlap, favourable vertical settling, and simultaneous sagittal correction with bite closure. In these patients, the vertical side effect of clockwise rotation is not necessarily detrimental; instead, it may assist in achieving both sagittal and vertical correction simultaneously. Therefore, positioning the force vector slightly inferior to the centre of resistance may be strategically utilised rather than avoided [6].

Class II with normal overbite and acceptable incisor inclination: In patients who present with a Class II sagittal discrepancy but exhibit satisfactory incisor inclination and vertical proportions, the treatment objective is often pure translatory distalisation without alteration of torque or vertical dimension.

In such cases, the force system should be designed to minimise rotational moments. This can be achieved clinically by coordinating implant height and power arm length so that the distalising force approximates the anterior CR. The objective is biomechanical neutrality:

- Preservation of incisor torque
- Minimal vertical alteration
- Maintenance of occlusal plane orientation

This configuration allows sagittal correction while maintaining pre-existing vertical harmony.

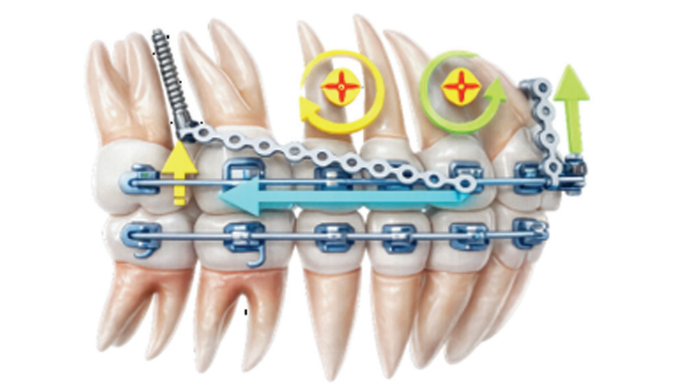
Class II division 2 or deep bite pattern: Patients with retroclined incisors and increased overbite require a fundamentally different biomechanical approach. In these cases, distalisation should not merely reposition the arch posteriorly but should also improve incisor torque and vertical balance.

Designing the force vector superior to the anterior centre of resistance generates a counterclockwise moment on the incisors. Clinically, this facilitates:

- Lingual root movement
- Torque correction of retroclined incisors
- Controlled reduction of deep bite
- Improved incisor display and smile arc

Here, distalisation becomes a combined sagittal and torque-corrective procedure rather than a purely posterior movement [6].

In certain cases, placing long hooks on the anterior segment may be limited by anatomical constraints, making it difficult to generate a counterclockwise moment for gummy smile correction. During Class II distalisation with IZC TADs, the line of force passes below the centre of resistance of the anterior teeth, which can lead to clockwise rotation of the maxillary occlusal plane, loss of anterior torque, and extrusion. This effect may be unfavourable in patients with a deep bite and a gummy smile. To counteract this, interradicular TADs placed between the maxillary incisors can provide vertical control, balancing the clockwise rotation, facilitating gummy smile correction, and maintaining anchorage during anterior retraction while IZC TADs drive posterior distalisation [Table/Fig-3].



[Table/Fig-3]: Mechanics for distalising the entire maxillary dentition with two mini-implants in the IZC, located between the first and second maxillary molars, and associated anterior intrusion with I-R miniscrews.

Rosa WGN et al., [11] investigated the clinical outcomes of maxillary distalisation using IZC mini-screws. All patients achieved Class II molar correction within an average duration of 7.7±2.5 months. The authors reported approximately 4 mm of molar distalisation, which was accompanied by a combination of intrusion (around 1.2 mm) and distal tipping (approximately 11.2°) of the first molars. In addition to molar movement, the maxillary incisors showed significant retraction (about 4.7 mm) with associated lingual tipping (13.4°), contributing to a reduction in both overjet (3.6 mm) and overbite (2.4 mm). A mild clockwise rotation of the occlusal plane (2.8°) was also observed, along with modest soft tissue changes, including 1 mm of upper lip retraction and an increase in the nasolabial angle by 5.1°. These findings indicate that IZC-supported distalisation produces not only sagittal correction but also vertical, transverse, and soft tissue changes, reflecting its broader biomechanical effects.

Palatal skeletal anchorage for maxillary distalisation: Palatal mini-implants provide effective skeletal anchorage for maxillary distalisation due to the favourable anatomical characteristics of the anterior palate, which include thick cortical bone, ample interradicular space, and minimal risk of dental root contact [12]. This superior positioning allows the applied distalising force to act closer to the centre of resistance of the posterior segment, often resulting in efficient molar distal movement with greater control of vertical and sagittal components and less unwanted anterior displacement compared with buccal anchorage alone. Sar C et al., evaluated the Miniscrew Implant Supported Distalisation System (MISDS) and the Bone-Anchored Pendulum Appliance (BAPA) in patients with Class II malocclusion [13]. Both appliances achieved molar distalisation, but the pattern of movement differed. MISDS showed near-bodily movement, while BAPA was associated with noticeable distal tipping of the maxillary first molars. These findings suggest that the design of skeletal anchorage plays an important role in controlling how teeth move during distalisation.

Beyond palatal mini-implants, the modified C-palatal plate (MCPP) offers effective skeletal anchorage for full-arch maxillary distalisation with minimal surgical exposure. Lee SK et al., [14] reported that palatally placed MCPPs produced greater molar distalisation and intrusion with less tipping compared with buccal TADs, highlighting the biomechanical advantage of palatal anchorage for controlled sagittal and vertical tooth movement.

Despite their clinical effectiveness, palatal mini-implant systems are not without limitations. While survival rates are generally favourable, placement and stability may vary based on individual palatal morphology, and direct control of anterior torque often still requires auxiliary mechanics or careful force vector design [15]. Additionally, comparison studies indicate that palatal systems may produce more intrusion and less distal tipping than some buccal mechanics [14,16], but rigid appliance design and proper insertion technique are critical to optimise outcomes.

Conceptual Framework

These clinical variations demonstrate that skeletal anchorage-supported distalisation is not a single mechanical entity but a customisable three-dimensional force system. The same anchorage source—such as an IZC bone screw or mini-implants—can produce different treatment effects depending on how the force vector is engineered.

Thus, successful Class II correction with skeletal anchorage depends less on the presence of the anchorage device itself and more on thoughtful biomechanical design tailored to the patient's vertical pattern and incisor morphology.

BIOMECHANICAL CONSIDERATIONS IN MANDIBULAR DISTALISATION USING SKELETAL ANCHORAGE

Mandibular distalisation exhibits biomechanical characteristics distinct from those observed in the maxilla, largely due to limitations imposed by the anterior alveolar bone housing and posterior anatomical boundaries. In contrast to the maxilla, where both buccal and palatal anchorage sites may be utilised, mandibular distalisation is predominantly performed using buccal skeletal anchorage, particularly in the buccal shelf region. Consequently, treatment planning and force system design must carefully consider the confines of the anterior alveolar envelope, posterior anatomical restrictions, and the potential influence on the temporomandibular joint (TMJ), to minimise the risk of periodontal complications, occlusal malfunction, and TMJ breakdown [17].

For the mandibular arch, the CR of the consolidated dentition has been described in the interradicular region between the canine and first premolar [10] [Table/Fig-1].

When en masse distalisation is performed, force application rarely coincides perfectly with this biomechanical centre. Therefore, total arch distalisation produces not only horizontal displacement but also vertical force components affecting incisors and molars, along with rotation of the mandibular occlusal plane. The final clinical outcome is largely determined by the vertical relationship between the force vector and this CR [6].

Buccal Shelf Skeletal Anchorage for Mandibular Distalisation

The mandibular buccal shelf provides a favourable site for placement of extra-alveolar Temporary Skeletal Anchorage Devices (TSADs) due to its substantial cortical bone thickness and distance from dental roots. Its posterior and inferior location allows the application of distalising forces without interfering with root movement, thereby enabling true en masse distalisation of the mandibular dentition [18].

Because the buccal shelf is typically positioned apical and posterior to the dental arch, the vertical vector of force is highly sensitive to the height of the power arm and the relative position of the archwire hook. Consequently, mandibular distalisation must be conceptualised as a three-dimensional force system rather than a purely sagittal correction.

Clinical Selection of Mandibular Distalisation Force Systems

The biomechanics of mandibular distalisation should not be applied uniformly across all malocclusions. Rather, the vertical skeletal pattern, incisor inclination, and overall facial proportions must guide the selection of the force vector relative to the centre of resistance (CR). Because buccal shelf anchorage allows significant flexibility in vertical vector control through modification of power arm height and implant position, the clinician can deliberately engineer distinct rotational patterns to complement the patient's morphology.

Class III with hyperdivergent pattern or anterior open bite: In Class III patients presenting with increased lower anterior facial height or anterior open bite tendency, vertical control becomes as critical as sagittal correction. In such cases, directing the distalising force occlusal to the CR produces a counterclockwise rotation of the mandibular dentition. Clinically, this contributes to molar intrusion and relative anterior extrusion, facilitating bite closure while achieving posterior repositioning of the arch.

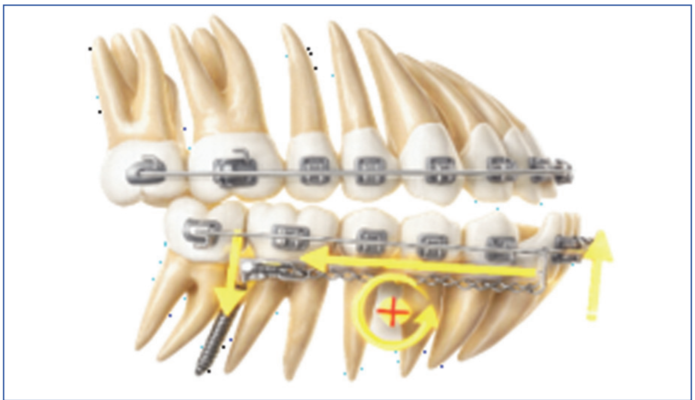
This biomechanical configuration can reduce mandibular plane angle and improve lower facial proportions when carefully controlled. However, because counterclockwise rotation may promote distal molar tipping, rigid archwire engagement and torque control are essential to prevent excessive crown movement and ensure controlled bodily displacement.

In a case report by Nguyen VA et al., a female patient with skeletal Class III malocclusion and a 2 mm anterior open bite was treated using buccal shelf mini-implant-supported distalisation. The force vector was directed above the centre of resistance, which resulted in a reduction in the mandibular plane angle and suggested an anticlockwise rotation of the mandible. Correction of the open bite was achieved along with distalisation and extrusion of the mandibular anterior teeth, resulting in improved interdigitation [19].

Thus, in hyperdivergent phenotypes, a slightly superior force vector should not be viewed as a side effect but rather as a deliberate vertical corrective strategy [6] [Table/Fig-4].

Class III with hypodivergent (Short-Face) pattern: In hypodivergent Class III patients, excessive molar intrusion or reduction of vertical dimension may compromise facial harmony. In such individuals, directing the force apical to the CR generates a clockwise rotational effect. This produces lingual root torque of the incisors and mild molar extrusion, which may help maintain or slightly increase lower facial height.

From a compensatory treatment perspective, this approach enhances incisor torque control while avoiding further flattening of the mandibular plane. Clockwise rotation in this context may improve soft



[Table/Fig-4]: Counterclockwise rotation of the mandibular occlusal plane can be seen, due to the force action line being placed occlusal to the mandibular centre of resistance (see yellow straight and curved arrows).

tissue profile balance by reducing excessive chin prominence that could otherwise be accentuated by counterclockwise mechanics.

Care must be taken, however, to avoid overexpression of clockwise rotation, which may deepen the bite in patients already predisposed to increased overbite.

Presurgical class II cases requiring mandibular advancement: In surgical Class II cases where mandibular advancement is indicated but overjet is insufficient to permit adequate advancement, mandibular distalisation may be performed to create space. In this scenario, the treatment objective is not vertical modification but pure sagittal repositioning of the dentition.

Therefore, the force vector should be designed to pass as close as possible to the CR, minimising rotational moments. Achieving near-translatory distalisation preserves incisor torque and avoids unwanted changes in occlusal plane inclination. This biomechanical neutrality ensures that the orthodontic phase prepares the dentition optimally for surgical correction without introducing secondary vertical discrepancies [6].

Borderline camouflage cases: In borderline skeletal Class III patients undergoing orthodontic camouflage, mandibular distalisation must be strategically integrated with incisor decompensation. The force vector can be adjusted according to whether torque correction, vertical control, or pure distalisation is the primary objective.

For example:

- If mandibular incisors are excessively proclined, a force slightly apical to the CR can assist in achieving lingual root torque during retraction.
- If vertical control is needed simultaneously, the vector can be modified superiorly to generate controlled molar intrusion.

Thus, buccal shelf-supported distalisation becomes a versatile three-dimensional tool rather than a single-direction movement.

Clinical Implication

These variations demonstrate that mandibular distalisation with skeletal anchorage is not merely a posterior displacement of teeth but a controlled manipulation of sagittal, vertical, and rotational forces. The clinician must intentionally design the force vector according to the skeletal pattern and treatment objectives. Proper biomechanical planning transforms potential side effects into therapeutic advantages.

BIOMECHANICAL CONSIDERATIONS OF FORCE MAGNITUDE IN EXTRA-ALVEOLAR SKELETAL ANCHORAGE

The magnitude of force applied during extra-alveolar (E-A) miniscrew mechanics plays a decisive role in treatment efficiency and anchorage stability [19]. Because these devices engage thick cortical bone, they are capable of tolerating relatively higher force levels compared to interradicular anchorage systems. For IZC mini-implants, a force range of approximately 220-340 g is generally recommended to achieve effective distalisation. In contrast, Buccal Shelf (BS) mini-implants typically require slightly greater force levels, commonly in the range of 340-450 g, to facilitate en masse distal movement of the mandibular dentition [20].

These magnitudes are intended for total arch distalisation, where simultaneous posterior displacement of the entire dental arch is desired. When the objective is limited tooth movement—such as segmental retraction of canines and premolars—the applied force should be reduced accordingly, generally to a range of 150-200 g, to ensure controlled tooth movement while preserving anchorage stability [20,21].

Limitation(s)

As a narrative review, this article did not include a formal assessment of study quality or risk of bias. The evidence was limited to English-language publications and included studies with heterogeneous designs and outcome measures. Additionally, much of the available evidence is based on observational studies rather than high-quality randomized clinical trials. Therefore, the conclusions should be interpreted cautiously, and further well-designed prospective studies are needed.

CONCLUSION(S)

Skeletal anchorage-assisted distalisation has transformed contemporary orthodontic biomechanics by enabling controlled en masse movement of the dental arches with minimal dependence on dental anchorage. However, successful application requires more than implant placement; it demands precise three-dimensional control of force magnitude, direction, and vector position relative to the centre of resistance.

In both maxillary and mandibular arches, the vertical relationship between the line of force and the centre of resistance determines whether distalisation results in translation, clockwise rotation, or counterclockwise rotation of the occlusal plane. These rotational effects influence incisor torque, molar vertical position, and overall facial proportions. Therefore, skeletal anchorage should be viewed as a customisable biomechanical system rather than a uniform distalisation protocol.

Furthermore, anatomical limitations—including alveolar bone boundaries, posterior clearance, and functional considerations—must be carefully respected to ensure periodontal health, occlusal stability, and long-term treatment success. When biomechanically planned and biologically controlled, extra-alveolar skeletal anchorage provides a predictable and versatile approach for sagittal correction in both camouflage and presurgical orthodontic treatment.

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PARTICULARS OF CONTRIBUTORS:
1. Postgraduate Student, Department of Orthodontics and Dentofacial Orthopaedics, MES Dental College, Perinthalmanna, Kerala, India.
2. Professor and Head, Department of Orthodontics and Dentofacial Orthopaedics, MES Dental College, Perinthalmanna, Kerala, India.
3. Professor, Department of Orthodontics and Dentofacial Orthopaedics, MES Dental College, Perinthalmanna, Kerala, India.
4. Senior Lecturer, Department of Orthodontics and Dentofacial Orthopaedics, MES Dental College, Perinthalmanna, Kerala, India.
5. Senior Lecturer, Department of Orthodontics and Dentofacial Orthopaedics, MES Dental College, Perinthalmanna, Kerala, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Dr. Ramesh Carmel,
Postgraduate Student, Five Brothers Home, Naduthura, Poonthura, Trivandrum,
MES Medical College and Hospital, Perinthalmanna, Trivandrum-679322,
Kerala, India.
E-mail: rameshcarmel067@gmail.com

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