Editor

Doç. Dr. Yazgı AY

gece kitaplığı

International Research and Evaluations in the Field of Orthodontics

October 2025

Genel Yayın Yönetmeni / Editor in Chief • Eda Altunel

Kapak & İç Tasarım / Cover & Interior Design • Gece Kitaplığı

Birinci Basım / First Edition • © Ekim 2025

ISBN • 978-625-388-797-1

Gece Kitaplığı / Gece Kitaplığı
Türkiye Adres / Turkey Address: Kızılay Mah. Fevzi Çakmak 1. Sokak
Ümit Apt No: 22/A Çankaya/ANKARA
Telefon / Phone: 0312 384 80 40

web: www.gecekitapligi.com
e-mail: gecekitapligi@gmail.com

Baskı & Cilt / Printing & Volume
Sertifika / Certificate No: 42488

INTERNATIONAL RESEARCH AND EVALUATIONS IN THE FIELD OF ORTHODONTICS

EDITOR

DOÇ. DR. YAZGI AY

gece kitaplığı

CONTENTS

Chapter 4

Chapter 1

TREATMENT OPTIONS FOR CLASS III MALOCCLUSION IN GROWING PATIENTS

Alper KÜLÇÜ[1]

1 Dt, Bezmialem Vakif University Faculty of Dentistry Department of Orthodontics, kulcualper@gmail.com, 0009-0003-9588-1487

Introduction

Class III malocclusion in the growing child presents with many faces. Some children posture forward to avoid an anterior interference and show a functional, or "pseudo," Class III. Others present with true skeletal disharmony. The disharmony may reflect mandibular prognathism, maxillary retrusion, dentoalveolar compensation, or a combination . The clinical challenge begins with sorting these patterns correctly, because timing and appliance choice depend on the origin of the problem. A sizeable proportion of children show some degree of maxillary deficiency, and these are the patients in whom orthopedic protraction can help when started at the right time. Ethnicity influences prevalence and expression (Ravindra Nanda, 2015).

Diagnosis and Case Selection

Diagnosis starts by deciding whether the occlusion is being held forward by function or driven by bone. The centric relation-centric occlusion coincidence is checked; a forward shift and rapid bite closure to edge-to-edge incisor contact often signal a functional Class III. Family history helps, because strong mandibular patterns tend to run in families. Radiographic and cephalometric analysis then defines the skeleton: a reduced SNA and negative ANB suggest midface retrusion; increased SNB, an open gonial angle, and increased lower anterior facial height point toward mandibular components or vertical patterns. The incisor relationship is interpreted as compensation rather than the diagnosis itself. These steps, taken together and confirmed in a stable, deprogrammed bite, establish the baseline (Henry Fields, Brent Larson, David M. Sarver, William R. Proffit, 2025; Ravindra Nanda, 2015).

Case selection focuses on prognosis with growth. Several pretreatment variables help predict stability after early orthopedics. Larger gonial angle values, a longer mandible, and an unfavorably positioned condyle relative to the cranial base have been linked to poorer stability. Conversely, children with a short ramus (reduced posterior facial height) and a low mandibular plane angle tend to adapt better. These cephalometric signs are not the plan by themselves, but they tell us whose growth is likely to overrun an early correction and who may benefit most from protraction while the sutures are responsive (Zhou et al., 2025).

The vertical pattern is decisive. Appliances that rotate the mandible downward and backward can help a short-face child, yet the same rotation can worsen a long-face profile. The clinician should map transverse relationships as well, because constriction in the maxilla may need to be addressed before or during protraction. Finally, the stage of dental development matters: classic face-mask protocols favor early mixed dentition, whereas bone-anchored traction can be effective later, even as the permanent dentition erupts (Ngan, 2005).

Treatment Goals

Treatment aims to redirect growth and reduce dental compensation while protecting facial esthetics. In the maxillary-deficient child, the goal is anterior displacement of the nasomaxillary complex without excessive dentoalveolar side effects. A positive overjet and overbite should be achieved with controlled incisor inclination. On the mandibular side, vertical changes must be planned: many protocols produce some clockwise rotation of the mandible, and this can either aid the profile in low-angle cases or harm it in high-angle cases. Stability into adolescence is improved when skeletal correction reduces the burden on dental camouflage. Because remaining mandibular growth can bring the overjet back toward zero, retention and follow-up must be framed from the start (Rutili et al., 2024).

Treatment Options in Growing Class III

Treatment in growing Class III patients sits on a spectrum from dentoalveolar camouflage to orthopedic change. The plan depends on the relative roles of maxillary deficiency, mandibular excess, and functional shifts. In children with predominant maxillary retrusion, orthopedic protraction of the midface is the central idea, supported by transverse correction when needed and careful vertical control. In children with mild skeletal disharmony and large dental or functional components, functional appliances can improve the incisor relationship and guide the mandible. Skeletal anchorage widens the envelope by reducing dental side effects and improving vertical control. Each approach has characteristic effects, limitations, and best timing (Ravindra Nanda, 2015).

Protraction Face Mask

Face mask protraction is the most widely studied method for bringing a retrusive maxilla forward in the early mixed dentition. Classic Delaire or Petit designs use forehead and chin pads linked by a vertical bar. Elastics pull from a bonded or banded maxillary anchorage to the crossbar at an angle of about 30° to the occlusal plane. Forces in the 300-600 g range per side are typical and produce similar skeletal effects across that range, with about a 3° rise in SNA frequently reported (Cozzani, 1981). Wear is usually prolonged daily through evening and night for several months. The common response combines forward maxillary movement with a degree of backward-downward mandibular rotation, improvement in profile, labial tipping of upper incisors, and lingual tipping of lower incisors. The vertical change tends to be more favorable in brachyfacial patients and less favorable in hyperdivergent patients. Reported forward movement of the maxilla is modest, often on the order of 2-3 mm over nine to twelve months, and long-term stability is influenced by subsequent mandibular growth. Bulky size and social visibility can limit compliance (Wells et al., 2006).

A frequent question is whether maxillary expansion enhances protraction. Conventional rapid maxillary expansion (RME) can be added to open sutures and correct transverse problems. Alternate rapid expansion and constriction (Alt-RAMEC) cycles have also been proposed to "mobilize" the circummaxillary sutures without overexpansion (Liou, 2005). Yet, comparative analyses suggest that forward movement of the maxilla is similar with or without expansion, so expansion should be prescribed for transverse reasons or for anchorage design rather than on the assumption that it always increases sagittal effects (Kayafoğlu et al., 2023).

Vertical Control During Protraction

Managing the vertical dimension is central in many Class III children. Dental-anchored face masks tend to extrude molars and increase mandibular plane angle, which may flatten overbite. Bonded expanders can help limit eruption, but skeletal anchorage has become the more predictable way to reduce these side effects (Sung & Baik, 1998).

Reverse Twin Block and Double-plate Appliance

The reverse twin block and the double-plate appliance alter occlusal planes and posture to favor a positive overjet. When used alone their effects are largely dentoalveolar, with upper incisor proclination and lower incisor retroclination. When combined with a face mask, the skeletal response increases and overjet correction becomes more robust. This combined strategy can be attractive in early mixed dentition when cooperation is good and a functional shift co-exists (Gencer et al., 2015; Seehra et al., 2012).

Reverse Chin Cup and Mandibular Headgear

The reverse chin cup uses a small acrylic chin component, a high-pull headcap, and elastics to an upper plate, delivering about 500 g per side. It advances the upper jaw in a way broadly similar to a face mask, with the advantage of smaller size and less visibility. Like face mask therapy, it may tip incisors and rotate the mandible backward (Showkatbakhsh et al., 2012)respectively. The IMPA decreased by 4·1° (SD: 6·5°. Mandibular cervical headgear acts on the lower arch and mandibular growth direction, distalizing lower molars and tempering forward mandibular growth in selected patients (Baccetti et al., 2007). These approaches are useful when mandibular prognathism and short lower anterior facial height are present, but their long-term skeletal influence is variable.

Tongue Appliances

Palatal tongue appliances harness tongue pressure during swallowing and at rest. Removable designs use Adams and C-clasps with palatal cribs; fixed designs solder cribs to a Hyrax framework so that expansion loosens the sutures and the cribs direct a forward component to the nasomaxillary complex. A tongue plate places an acrylic shield behind the upper incisors to collect and redirect tongue forces. These intraoral options are more discreet and less dependent on visible wear. They tend to reduce the backward rotation observed with face masks and can be helpful in long-face patients. A tendency for lower incisor lingual tipping is expected while the tongue is constrained, and cooperation still matters for removable versions (Showkatbakhsh et al., 2013).

Functional Appliances

Frankel III, Bionator III, the Eschler "progenic" appliance, and the reverse twin block are long-standing options. They posture the mandible, influence soft tissues, and guide dentoalveolar compensation. Construction bites place the mandible in centric relation; wear is extensive. These appliances are most useful when a functional shift or dental compensation dominates and the skeletal discrepancy is mild to moderate. Their skeletal change is limited compared with face mask therapy, but they can improve incisor inclination and sagittal overjet in cooperative children (Almeida et al., 2011; G et al., 1998; Henry Fields, Brent Larson, David M. Sarver, William R. Proffit, 2025).

Skeletal Anchorage and BAMP

Skeletal anchorage has changed the balance between orthopedic and dental effects. Bone-Anchored Maxillary Protraction (BAMP) uses miniplates in the infrazygomatic crest of the maxilla and between the lower lateral incisor and canine on each side. Class III elastics are applied, often with immediate or early loading. Compared with RME plus face mask anchored to teeth, BAMP tends to produce greater sagittal advancement of the maxilla, better vertical control, less clockwise mandibular rotation, and reduced proclination of upper incisors and retroclination of lower incisors. These advantages are valuable in hyperdivergent cases and in late mixed or early permanent dentition when dental side effects would otherwise be pronounced (Creekmore & Eklund, 1983; Enacar et al., 2003). Miniplate-anchored face mask protocols show a similar trend: more protrusive skeletal effect with fewer dental side effects than tooth-anchored masks (Showkatbakhsh et al., 2011). Reported elastic forces in skeletal anchorage protocols are higher than with dental anchorage and may be in the range of several hundred grams per side, sometimes more when screws or plates are robust and soft tissue health is stable (Podda et al., 2025).

Other skeletal anchorage strategies exist. Temporary onplants and osseointegrated implants can accept 300-600 g per side and were used historically to deliver protraction forces without dental anchorage, including placement in the zygomatic buttress. Intentionally ankylosed primary canines have been used as direct anchors in very young patients, though resorption limits their lifespan to the mixed dentition (Hong et al., 2005; Singer et al., 2000). Case reports also describe titanium screws used as lag anchors to deliver around 800 g per side with favorable short-term advancement (Enacar et al., 2003).

Hybrid Hyrax

Hybrid Hyrax expanders use two palatal miniscrews with molar bands to create a mixed skeletal-dental anchorage. When used before or with face mask therapy, they can reduce molar extrusion and upper incisor proclination while still opening the midpalatal suture. This is attractive in hyperdivergent children, where preserving vertical control is important (Nienkemper et al., 2013).

Corticotomy-assisted Maxillary Advancement

In older children with low mandibular plane angles and marked maxillary retrusion, corticotomy-assisted protraction is a consideration when ordinary orthopedic traction is unlikely to succeed and surgery is not acceptable. An incomplete Le Fort I corticotomy reduces resistance at circummaxillary sutures and allows heavy early face-mask pull. Reports describe initiating traction within a week at 1700-2000 g per side and achieving 5-9 mm of advancement, with some relapse over long follow-up but preservation of dental relationships. This option carries surgical morbidity and is reserved for carefully selected cases (Nevzatoğlu & Küçükkeleş, 2014; Singer et al., 2000).

Timing and Expectations

Timing shapes outcomes. Early mixed dentition—around 6–8 years, after eruption of the maxillary first molars and incisors—is the classic window for tooth-anchored face-mask therapy because the circummaxillary sutures are more responsive at this stage. Skeletal anchorage (miniplates or miniscrews with intermaxillary elastics) extends the window into the late mixed and even early permanent dentition, since forces are delivered to bone and the approach reduces reliance on primary teeth and bulky extraoral pads; cooperation with elastic wear is still important (DiBiase et al., 2022). Skeletal anchorage also tends to reduce dental side effects and offers better vertical control when compared with tooth-anchored protocols.

Regardless of approach, the expected orthopedic advancement is modest, and subsequent mandibular growth can lessen sagittal correction over time. Families should understand that phase I aims to establish a normal incisor relationship, normalize function, and improve facial balance. A second phase with comprehensive fixed appliances is often needed in adolescence to complete alignment and detailing (Zhou et al., 2025).

Mechanics and Vertical Control

Force direction, magnitude, and where the load is applied determine the pattern of change. With tooth-anchored face mask therapy, forces of a few hundred grams per side are typically applied 30° to the occlusal plane; the result is a mix of skeletal displacement and dental compensation. The mandibular rotation that accompanies face mask therapy can be helpful in low-angle patterns. When the child is long-faced or shows weak posterior vertical control, skeletal anchorage reduces clockwise rotation and keeps the correction more orthopedic (Ngan, 2005).

Retention and Follow-up

Night-time retention after overjet and overbite correction is typically advised for months to a couple of years, but the bigger story is growth. Even after a clean early correction, long-term reviews show that a quarter to a third of children may drift back toward zero overjet by the end of mandibular growth. This relapse reflects the mandible's continued growth more than loss of maxillary gains. Children starting with a large gonial angle may be at higher risk. Regular review through adolescence is therefore part of the plan, with honest counseling about the possibility of later orthodontic camouflage or orthognathic planning if growth outpaces early correction (Baccetti et al., 2004)2004.

Adverse Effects

Bulky extraoral pads and facial bars can hinder wear, irritate skin, and complicate life for children who wear glasses; cooperation varies and should be anticipated. Tooth-anchored traction tends to procline maxillary incisors and retrocline mandibular incisors; careful bracket positioning, light forces, and anchorage planning reduce these effects. Vertical changes must be watched closely in high-angle patients. Oral hygiene demands increase with any appliance, and protocols should support children and families to keep gingival health stable during treatment (Wells et al., 2006).

Conclusion

Most growing patients with a true skeletal Class III driven by maxillary retrusion benefit from early orthopedic traction, provided the vertical pattern and prognosis favor stability. In the early mixed dentition, tooth-anchored face mask therapy remains a sound option when cooperation is good and vertical rotation is acceptable. When dental side effects or vertical control are concerns, or when the child is older, skeletal anchorage allows traction to be delivered with more orthopedic and fewer dental effects. Expansion is planned for transverse discrepancies rather than as a reflex addition to every protraction protocol. Stability rests on honest diagnosis, growth-aware goals, and follow-up into adolescence.

REFERENCES

Almeida, M. R. de, Almeida, R. R. de, Oltramari-Navarro, P. V. P., Conti, A. C. de C. F., Navarro, R. de L., & Camacho, J. G. D. D. (2011). Early treatment of Class III malocclusion: 10-year clinical follow-up. *Journal of Applied Oral Science*, *19*(4), 431. https://doi.org/10.1590/S1678-77572011000400022

Baccetti, T., Franchi, L., & McNamara, J. A. (2004). Cephalometric variables predicting the long-term success or failure of combined rapid maxillary expansion and facial mask therapy. *American Journal of Orthodontics and Dentofacial Orthopedics*, *126*(1), 16–22. https://doi.org/10.1016/j.ajodo.2003.06.010

Baccetti, T., Rey, D., Angel, D., Oberti, G., & Jr, J. A. M. (2007). Mandibular Cervical Headgear vs Rapid Maxillary Expander and Facemask for Orthopedic Treatment of Class III Malocclusion. *The Angle Orthodontist*, *77*(4), 619–624. https://doi.org/10.2319/070706-281

Cozzani, G. (1981). Extraoral traction and Class III treatment. *American Journal of Orthodontics*, *80*(6), 638–650. https://doi.org/10.1016/0002-9416(81)90266-9

Creekmore, T. D., & Eklund, M. K. (1983). The possibility of skeletal anchorage. *Journal of Clinical Orthodontics: JCO*, *17*(4), 266–269.

DiBiase, A. T., Seehra, J., Papageorgiou, S. N., & Cobourne, M. T. (2022). Do we get better outcomes from early treatment of Class III discrepancies? *British Dental Journal*, *233*(3), 197–201. https://doi.org/10.1038/s41415-022-4507-0

Enacar, A., Giray, B., Pehlivanoglu, M., & Iplikcioglu, H. (2003). Facemask therapy with rigid anchorage in a patient with maxillary hypoplasia and severe oligodontia. *American Journal of Orthodontics and Dentofacial Orthopedics*, *123*(5), 571–577. https://doi.org/10.1016/S0889-5406(03)00052-0

G, G., L, L., P, C., & A, L. (1998). Skeletal and dental modifications produced by the Bionator III appliance. *American Journal of Orthodontics and Dentofacial Orthopedics : Official Publication of the American Association of Orthodontists, Its Constituent Societies, and the American Board of Orthodontics*, *114*(1). https://doi.org/10.1016/s0889-5406(98)70235-5

Gencer, D., Kaygisiz, E., Yüksel, S., & Tortop, T. (2015). Comparison of double-plate appliance/facemask combination and facemask therapy in treating Class III malocclusions. *The Angle Orthodontist*, *85*(2), 278–283. https://doi.org/10.2319/013114-83.1

Henry Fields, Brent Larson, David M. Sarver, William R. Proffit. (2025). *Contemporary Orthodontics*. Mosby.

Hong, H., Ngan, P., Li, H. G., Qi, L. G., & Wei, S. H. Y. (2005). Use of Onplants as Stable Anchorage for Facemask Treatment: A Case Report. *The Angle Orthodontist*, *75*(3), 453–460. https://doi.org/10.1043/0003-3219(2005)75%255B453:UOOASA%255D2.0.CO;2

Kayafoğlu, G. E., Esenlik, E., Kayafoğlu, G. E., & Esenlik, E. (2023). Comparison of Rapid Maxillary Expansion and Alternate Rapid Maxillary Expansion and Constriction Protocols with Face Mask Therapy. *Turkish Journal of Orthodontics*. https://doi.org/10.4274/TurkJOrthod.2023.2022.141

Liou, E. J.-W. (2005). Effective maxillary orthopedic protraction for growing Class III patients: A clinical application simulates distraction osteogenesis. *Progress in Orthodontics*, *6*(2), 154–171.

Nevzatoğlu, Ş., & Küçükkeleş, N. (2014). Long-term results of surgically assisted maxillary protraction vs regular facemask. *The Angle Orthodontist*, *84*(6), 1002–1009. https://doi.org/10.2319/120913-905.1

Ngan, P. (2005). Early Timely Treatment of Class III Malocclusion. *Seminars in Orthodontics*, *11*(3), 140–145. https://doi.org/10.1053/j.sodo.2005.04.007

Nienkemper, M., Wilmes, B., Pauls, A., & Drescher, D. (2013). Maxillary protraction using a hybrid hyrax-facemask combination. *Progress in Orthodontics*, *14*(1), 5. https://doi.org/10.1186/2196-1042-14-5

Podda, R., Imondi, F., Stefano, A. A. D., Horodynski, M., Vernucci, R. A., Galluccio, G., Podda, R., Imondi, F., Stefano, A. A. D., Horodynski, M., Vernucci, R. A., & Galluccio, G. (2025). Clinical Outcomes of Skeletal Anchorage Versus Conventional Anchorage in the Class III Orthopaedic Treatment in Growing Patients: A Systematic Review and Meta-Analysis. *Turkish Journal of Orthodontics*. https://doi.org/10.4274/TurkJOrthod.2025.2024.38

Ravindra Nanda. (2015). *Esthetics and Biomechanics in Orthodontics* (2nd ed.). Saunders. https://www.sciencedirect.com/book/9781455750856/esthetics-and-biomechanics-in-orthodontics

Rutili, V., Souki, B. Q., Nieri, M., Carlos, A. L. F. M., Pavoni, C., Cozza, P., McNamara Jr, J. A., Giuntini, V., & Franchi, L. (2024). Long-term effects produced by early treatment of Class III malocclusion with rapid maxillary expansion and facemask followed by fixed appliances: A multicentre retro-prospective controlled study. *Orthodontics & Craniofacial Research*, *27*(3), 429–438. https://doi.org/10.1111/ocr.12748

Seehra, J., Fleming, P. S., Mandall, N., & DiBiase, A. T. (2012). A comparison of two different techniques for early correction of Class III malocclusion. *The Angle Orthodontist*, *82*(1), 96–101. https://doi.org/10.2319/032011-197.1

Showkatbakhsh, R., Jamilian, A., & Behnaz, M. (2011). Treatment of Maxillary Deficiency by Miniplates: A Case Report. *ISRN Surgery*, *2011*, 854924. https://doi.org/10.5402/2011/854924

Showkatbakhsh, R., Jamilian, A., Ghassemi, M., Ghassemi, A., Taban, T., & Imani, Z. (2012). The effects of facemask and reverse chin cup on maxillary deficient patients. *Journal of Orthodontics*, *39*(2), 95–101. https://doi.org/10.1179/1465312512Z.00000000011

Showkatbakhsh, R., Toumarian, L., Jamilian, A., Sheibaninia, A., Mirkarimi, M., & Taban, T. (2013). The effects of face mask and tongue plate on maxillary deficiency in growing patients: A randomized clinical trial. *Journal of Orthodontics*, *40*(2), 130–136. https://doi.org/10.1179/1465313312Y.0000000036

Singer, S. L., Henry, P. J., & Rosenberg, I. (2000). Osseointegrated Implants as an Adjunct to Facemask Therapy: A Case Report. *The Angle Orthodontist*, *70*(3), 253–262. https://doi.org/10.1043/0003-3219(2000)070%253C0253:OIAAAT%253E2.0.CO;2

Sung, S. J., & Baik, H. S. (1998). Assessment of skeletal and dental changes by maxillary protraction. *American Journal of Orthodontics and Dentofacial Orthopedics*, *114*(5), 492–502. https://doi.org/10.1016/S0889-5406(98)70168-4

Wells, A. P., Sarver, D. M., & Proffit, W. R. (2006). Long-term Efficacy of Reverse Pull Headgear Therapy. *The Angle Orthodontist*, *76*(6), 915–922. https://doi.org/10.2319/091605-328

Zhou, X., Chen, S., Zhou, C., Jin, Z., He, H., Bai, Y., Li, W., Wang, J., Hu, M., Cao, Y., Liu, Y., Yan, B., Shi, J., Guo, J., Li, Z., Ma, W., Liu, Y., Li, H., Lu, Y., … Chen, L. (2025). Expert consensus on early orthodontic treatment of class III malocclusion. *International Journal of Oral Science*, *17*(1), 20. https://doi.org/10.1038/s41368-025-00357-9

Chapter 2

THE USE OF CLEAR ALIGNERS IN ORTHODONTICS AND THEIR EFFECTS ON MALOCCLUSIONS

Kazım Kaan YILDIZ[1] , Mücahid YILDIRIM[2],
Münire AVCI[3]

1 Necmettin Erbakan University, Faculty of Dentistry ORCID: 0009-0001-6954-0211
2 Necmettin Erbakan University, Faculty of Dentistry ORCID: 0000-0003-0939-3675
3 Necmettin Erbakan University, Faculty of Dentistry ORCID:0009-0007-7895-1198

1. WHAT ARE CLEAR ALIGNERS? THE ROLE OF CLEAR ALIGNERS IN ORTHODONTIC TREATMENT

Clear aligners are modern treatment tools that have seen significant development in the field of orthodontic treatment in recent years, prioritising aesthetics and patient comfort. These aligners are appliances developed as an alternative to traditional fixed orthodontic appliances (brackets and wires), made from clear, removable thermoplastic materials that enable controlled tooth movement (Weir, 2017). These systems are typically designed digitally using CAD/CAM technology and produced individually for each patient using three-dimensional modelling. Models obtained from digital measurements taken inside the patient's mouth (intraoral scanners) or traditional measurements are transferred to the software environment, and sequential aligners are created to achieve each tooth movement throughout the treatment process. Each aligner provides an average tooth movement of 0.25-0.30 mm and is typically worn for 7-14 days (Rossini et al., 2015). The development of transparent aligner systems has enabled orthodontic treatments to become more personalised and patient-centred. Unlike traditional fixed appliances, these aligners, which are custom-designed for each individual, allow treatment planning to progress in a more controlled and predictable manner. Furthermore, as the aligners are replaced at specific intervals throughout the treatment process, each aligner acts as a continuation of the previous one, gradually achieving the targeted tooth movement. This process allows for the changes occurring during treatment to be monitored digitally and the plan to be revised when necessary. Another important advantage is that the aligners apply controlled forces in line with biomechanical principles. Clear aligners direct the forces applied to the teeth in a limited and constant manner, enabling movement without damaging the surrounding tissues. This offers a safer treatment process in terms of periodontal health compared to traditional bracket systems. However, despite these advantages, it should be noted that clear aligners may not be sufficient on their own, particularly in complex orthodontic cases or situations involving skeletal irregularities, and may need to be combined with conventional methods. Today, transparent aligner systems have become an integral part of orthodontic practice, both for enhancing patient satisfaction and for offering clinicians the advantage of digital planning. In the future, developments in biomaterials science and artificial intelligence-based treatment planning are expected to make these systems much more functional and effective.

1.1 Advantages and Applications of Transparent Plates

One of the greatest advantages of using clear aligners in orthodontic treatment is that they meet aesthetic expectations. Clear aligners are an important choice, particularly for adult patients who are uncomfortable with the appearance of metal braces. At the same time, the removable nature of the aligners provides great convenience for patients in terms of eating and maintaining oral hygiene. The irritation of the soft tissues inside the mouth, commonly seen with traditional braces, is significantly reduced with the use of clear aligners (Joffe, 2003).

Treatment with transparent aligners is highly effective in correcting dental malocclusions. Successful results are achieved in cases of mild to moderate crowding, diastema, limited rotations, and anterior open bite (Papadimitriou et al., 2018). However, some studies indicate that transparent aligners are less effective than fixed orthodontic systems in complex movements such as vertical movements, rotations and extrusions, particularly in posterior teeth (Kriegsmann et al., 2020). Furthermore, the success of the planned tooth movements during transparent aligner treatment is directly related to the patient wearing the aligners regularly and for the recommended periods. It is recommended that the aligners be worn for an average of 20-22 hours per day. Failure to adhere to these periods may prolong the treatment time or result in outcomes that are not at the desired level (Tamer et al., 2019). In addition, clear aligners are a treatment approach that positively influences patient motivation during orthodontic treatment. The ability to simulate the treatment plan digitally allows patients to see the treatment outcome in advance, thereby increasing satisfaction. This visualisation paves the way for patients to participate in the process in a more conscious and willing manner. Furthermore, check-up appointments during clear aligner treatment are generally shorter and can be scheduled less frequently. This is a significant advantage in terms of time management, particularly for adults with busy schedules (Wong, 2002).

Another area of application for clear aligners is the retention phase. They can be used as removable retainers to maintain the new positions of the teeth after orthodontic treatment. This offers advantages in terms of both aesthetics and comfort, aiming for long-term stabilisation. They can also be used in some early orthodontic interventions for children and adolescent patients requiring mild guidance. However, as clear aligners may be insufficient for certain movements, they may need to be supported by auxiliary systems such as mini screws, elastics, and attachments in complex cases. Particular attention should be paid to the limitations of the aligner system, especially in root-controlled movements and closing large gaps caused by tooth extraction (Charalampakis et al., 2018). Therefore, appropriate case selection is one of the determining factors in the success of treatment.

1.2 Technological Developments and Digital Orthodontics

Digital technologies play a significant role in the development of clear aligner systems. Brands such as Invisalign®, ClearCorrect®, Orthero®, and Angel Align® can show patients digitally how their teeth will look at the end of treatment through advanced software at the beginning of treatment planning, thereby increasing patient motivation (Zhou et al., 2022). Thanks to three-dimensional simulations, it has also become easier to track tooth movements and revise the treatment plan when necessary.

Transparent aligner systems require fewer clinical appointments compared to traditional systems. This offers advantages in terms of time and cost for both the patient and the dentist. Furthermore, the compatibility of transparent aligner treatments with social distancing and digital monitoring during the Covid-19 pandemic has increased interest in this treatment method (Lagravère & Flores-Mir, 2005).

Advancing digital technologies enhance the effectiveness of transparent aligners not only during the treatment planning phase but also throughout the production processes. In particular, three-dimensional printers (3D printing) have made more precise and rapid production possible. Thanks to these technologies, customised aligners can be produced for each patient, enabling the treatment process to progress more efficiently and seamlessly. Furthermore, precise measurements obtained through CAD/CAM (computer-aided design and manufacturing) technologies ensure that tooth movements occur in a more controlled manner (Grünheid et al., 2017).

Using artificial intelligence algorithms in new generation software makes it possible to predict orthodontic movements more accurately and optimise treatment duration. By analysing past clinical data, this software can predict which set of aligners will yield more successful results for which patient profile. This both increases treatment success and reduces costs by preventing unnecessary aligner production (Al-Nadawi et al., 2021). Digital orthodontics has also transformed patient-dentist communication. Thanks to cloud-based software, patient monitoring can be carried out remotely, and any disruptions in the treatment process can be detected immediately, allowing corrective interventions to be planned. The widespread adoption of these systems, particularly in the post-pandemic period, has created a significant advantage in ensuring the continuity of orthodontic treatment.

1.3 Restrictions and Precautions

Although they offer many advantages, clear aligners are not suitable for all orthodontic cases. It is known that clear aligners alone are not sufficient for the treatment of skeletal malocclusions, large tooth movements, and cases requiring surgery. In such cases, aligner treatment is either used as a supplementary method or patients are referred for fixed orthodontic treatment (Papadimitriou et al., 2018). Furthermore, as patient cooperation directly affects treatment success, compliance with the treatment process should be carefully assessed, particularly in children and adolescents.

The success of clear aligner treatment largely depends on the patient wearing the aligners for the recommended periods and in the correct manner. When the aligners are not worn, tooth movement does not occur, which both prolongs the treatment period and makes it difficult to achieve the planned results. Treatment may fail, particularly in young individuals, due to reasons such as lack of motivation or failure to understand the seriousness of the treatment process. Therefore, before recommending clear aligner treatment, the patient's compliance with the treatment and their capacity to take responsibility must be carefully assessed (Hennessy & Al-Awadhi, 2016).

In addition, there are technical limitations to achieving certain tooth movements with clear aligners. Clear aligners may be insufficient for complex movements, particularly canine rotation and vertical tooth movement (intrusion and extrusion). In such cases, additional support such as attachments, elastics or mini screws may be required. Furthermore, clear aligners may cause unwanted side movements during treatment, necessitating a reassessment of the treatment plan (Barreda et al., 2020).

Another important consideration is the cost and duration of treatment. In some cases, clear aligner systems may be more expensive than fixed treatments, and the process may take longer if additional refinement aligners are required. Therefore, before starting treatment, all alternatives should be clearly presented to the patient, and expectations should be managed realistically.

2. THE DEVELOPMENT PROCESS OF CLEAR ALIGNERS IN ORTHODONTICS

In orthodontics, clear aligners have rapidly gained popularity as an innovative treatment option that meets aesthetic and comfort expectations in modern orthodontic practice. This development process is directly linked to significant advances in materials science, digital technology, and clinical orthodontics. The origins of clear aligners date back to the 1940s. At that time, aligners made from simple thermoplastic materials showed limited success in aligning teeth and were not widely preferredDue to the poor durability and shape memory of the materials, these early transparent aligners could only be used for short-term, simple corrections (Proffit, Fields & Sarver, 2019). However, technological advances have fundamentally changed this situation. Developed by Align Technology in 1997, the Invisalign system has cemented the place of clear aligners in modern orthodontics. Invisalign uses computer-aided design and manufacturing techniques to produce customised clear aligners by capturing the patient's intraoral data in a digital environment. This allows tooth movements to be planned in advance, treatment steps to be simulated, and control to be maintained throughout the process (Lagravère & Flores-Mir, 2005). Today, the materials used in the production of transparent aligners are polyethylene terephthalate glycol (PETG), polyurethane and similar thermoplastics. These materials have high elasticity, durability and transparency properties. Thus, the aligners are almost invisible from an aesthetic point of view, while also being able to apply the necessary force to the teeth. Furthermore, advances in materials science have improved the surface smoothness of the aligners, reducing irritation in the mouth (Simon et al., 2014). Another important development that enhances the effectiveness of clear aligners is the use of dental attachments. These small composite attachments, bonded to the tooth surface, are specifically designed to increase control over tooth movement. Attachments enable complex tooth movements such as rotation, extrusion, or intrusion, while ensuring the aligners adhere better to the teeth. This has significantly expanded the applicability of clear aligners (Krieger et al., 2012). Advances in digital technology are also critical factors affecting the success of clear aligner treatment. Intraoral scanners enable the rapid and highly accurate acquisition of digital measurements of the patient's oral cavity. This method has replaced traditional alginate impressions, increasing patient comfort and minimising measurement errors. The digital models obtained are transferred to computer-aided design (CAD) software for treatment planning. This allows the orthodontist to simulate tooth movements in a three-dimensional environment and determine the necessary adjustments in advance during the treatment process (Zhou, Guo & Tang, 2020). Additionally, high-precision plates are produced quickly and in accordance with standards using 3D printer technologies and thermoplastic material moulding techniques during the production process. This enables the treatment process to be accelerated and patient-specific plates to be used more effectively (Weir, 2017). The applications of transparent aligners have also expanded considerably. Initially preferred mainly for mild to moderate dental misalignments, this method is now used in the treatment of Class II and Class III malocclusions, for tooth intrusion and extrusion, in expansion procedures, and even for complex tooth movements (Jin et al., 2020; Lione et al., 2021). However, the effectiveness of clear aligners depends on case selection and patient compliance. In particular, combined treatment with fixed appliances may be preferred in cases of severe skeletal anomalies and very significant tooth movements. Consequently, the development of clear aligners has progressed in parallel with advances in material technologies, digital orthodontics, and production techniques, establishing them as an aesthetic, comfortable, and predictable treatment option in orthodontics. Today, these technologies continue to evolve and offer new innovations to enhance treatment success.

In recent years, thanks to artificial intelligence-based software, more accurate predictions have begun to be obtained in treatment planning. These systems can analyse past patient data and recommend the most appropriate sequence of actions for similar cases; thus, optimising the number of plates, reducing unnecessary refinements, and shortening the total treatment time. Additionally, patient compliance can be more effectively monitored through patient tracking and reminder systems via mobile applications (Hansa et al., 2021). In addition, new research in the field of biomaterials aims to develop thermoplastic plate materials that are more durable, highly elastic and possess antibacterial properties. The use of these materials aims to make plates more resistant to deformation and to preserve their biomechanical effects even with long-term use. At the same time, nanotechnological applications aimed at reducing the surface roughness of plates also have the potential to increase patient comfort (Li et al., 2023). All these developments are likely to enhance the effectiveness of clear aligner therapy not only today but also in the future. Orthodontic practice is now shaped not only by mechanical forces but also by a multidisciplinary approach based on digital analysis, software support, and biotechnological solutions. This situation ensures that clear aligners can be used safely in an increasing number of case types each year and that clinical success rates are rising.

3. TYPES AND CHARACTERISTICS OF MALOCCLUSION

Malocclusion is a disorder resulting from the deviation of teeth from their ideal positions in the jaw arch. The term is of Latin origin and means "poor closure". Malocclusion is a complex condition involving not only the teeth but also the jaw relationships, and it is one of the primary reasons for the need for orthodontic treatment. As it can lead to both functional (chewing, speaking) and aesthetic problems, it can directly affect an individual's quality of life (Proffit et al., 2019).

3.1 Classification of Malocclusion

One of the most common systems for classifying malocclusion was introduced by Edward H. Angle in 1899. This system is based on the relationship between the maxillary and mandibular first molars. However, today, a multifaceted classification is made by evaluating not only dental but also skeletal, soft tissue and functional factors (Angle, 1899; Graber et al., 2017)

3.1.1 Angle Class I Malocclusion

Class I malocclusion refers to anomalies in tooth alignment in individuals with normal molar relationships. The mesiobuccal tubercle of the maxillary first molar corresponds to the buccal groove of the mandibular first molar. However, the individual may have crowding, rotation, missing teeth, diastema, or misaligned teeth (Proffit et al., 2019). Characteristics: Normal molar relationship, crowding in anterior or posterior teeth, rotations, spacing, deep bite or open bite, aesthetic concerns are often the reason for referral.

3.1.2 Angle Class II Malocclusion

This class covers situations where the mandibular first molar is positioned more distally (backward) relative to the maxillary first molar. This is usually due to relative retrusion of the lower jaw or excessive protrusion of the upper jaw. Class II malocclusion is divided into two subgroups: In the first type, the upper incisors are protruded. This situation is characterised by increased overjet and usually causes lip closure difficulties, an open lip profile and a concave facial appearance. In the second type, the upper central incisors are retruded, while the lateral teeth are usually protruded. Overjet may not be increased, but deep bite is frequently seen (McNamara, 1981).

3.1.3 Angle Class III Malocclusion

In Class III malocclusion, the mandibular first molar is positioned more mesially (forward) than the maxillary first molar. This condition may be associated with a skeletal abnormality where the lower jaw is forward or the upper jaw is backward. Characteristics: negative overjet (anterior crossbite), mandibular prognathism, prominent chin, anterior or posterior crossbite, and skeletal problems requiring surgical intervention (Ngan et al., 1997)

3.2 Other Malocclusion Characteristics

3.2.1 Vertical Anomalies

- **Deep bite:** The upper incisors cover the lower incisors excessively. This can cause aesthetic and periodontal problems.
- **Open bite:**There is no contact between the teeth in the front or back region. This can lead to phonetic problems and swallowing disorders. It often develops in connection with parafunctional habits such as thumb sucking and tongue thrusting (Proffit et al., 2019).

3.2.2. Transverse anomalies

- **Crossbite:** It is the reverse closure of the teeth in the transverse plane. It can be seen in the anterior or posterior region. It often causes jaw misalignment.
- **Midline shift:** It is a condition where the maxillary and mandibular dental midlines do not align. It may be an indication of jaw displacement.

3.3 Functional Problems

Functional malocclusions encompass incompatibilities that arise during jaw movements. Examples include jaw deviation during closure or temporomandibular joint (TMJ) problems (Okeson, 2013).

3.4 Effects of Malocclusion

Malocclusion is not merely an aesthetic problem. Over time, it can impair chewing and speech functions, negatively affect periodontal health, cause temporomandibular joint disorders, and lead to psychosocial problems (Zhang et al., 2015). For these reasons, identifying the correct type of malocclusion and developing an effective treatment plan is of great importance.

4. THE EFFECT OF CLEAR ALIGNERS ON DIFFERENT MALOCCLUSIONS

In recent years, clear aligner systems have become increasingly popular among orthodontic treatment options, standing out for their aesthetic, comfort and hygiene advantages. Developed as an alternative to traditional fixed appliances, these systems are custom-made using 3D digital modelling and computer-aided manufacturing technologies (Weir, 2017). The planned tooth movements with clear aligners are achieved gradually with each set of aligners. However, the success of these systems depends on the patient's type of malocclusion, the degree of the problem, and patient compliance. This section will discuss in detail the effects of clear aligners on various types of malocclusion.

4.1 Class I Malocclusions

Class I malocclusions are cases where the molars have a normal relationship but there are dental irregularities such as crowding, rotation or diastema. Clear aligners yield highly successful results in such cases. Mild to moderate crowding cases can be effectively treated with interproximal stripping (IPR) and proper alignment of the teeth (Zhou et al., 2020). The predictability of tooth movement during treatment with aligners is high thanks to digital planning. Furthermore, the patient's ability to maintain oral hygiene increases the success of the treatment process (Lagravère & Flores-Mir, 2005). For this reason, Class I malocclusions constitute the most suitable group for clear aligner treatment.

4.2 Class II Malocclusions

Class II malocclusions are disorders characterised by the maxillary teeth being positioned forward relative to the mandibular teeth and are typically associated with increased overjet. Clear aligners can be used in such cases to provide dental compensation. A Class I relationship can be established through the distalisation of the upper teeth and the mesial movement of the lower teeth (Jin et al., 2020). Transparent aligner manufacturers (e.g., Invisalign) have developed attachment systems compatible with Class II elastics. These elastics can be used to reduce overjet by directing the lower jaw forward. However, this treatment approach is only effective in cases where the skeletal component is minimal. Otherwise, fixed functional appliances or orthognathic surgery may be required (Proffit et al., 2019).

4.3 Class III Malocclusions

Class III malocclusion is a condition in which the mandibular dental arch is positioned forward relative to the maxillary dental arch and is often accompanied by an anterior crossbite. The success of treatment with clear aligners varies depending on the degree of the skeletal component in the case. In mild dental Class III cases, particularly in pseudo Class III (functional) situations, positive results can be achieved by guiding the anterior teeth into their correct positions (Lione et al., 2021). In the correction of anterior crossbite, the inclination of the maxillary incisors and the retraction of the mandibular incisors can be achieved using transparent aligners. However, advanced skeletal malocclusions cannot be treated with aligners and require surgical orthodontics.

4.4 Open Bite

Anterior open bite is characterised by a vertical gap between the upper and lower incisors. This condition usually results from parafunctional habits (tongue thrusting, mouth breathing). The greatest advantage of clear aligners in these cases is that they support the closure of the anterior segment by enabling passive intrusion of the posterior teeth (Simon et al., 2014). Transparent aligners are particularly effective in treating anterior open bites, especially in young adults and in cases where habit modification is achievable. Furthermore, the continuous wearing of the aligners by the patient also contributes to preventing habits such as tongue thrusting.

4.5 Deep Bite

Deep bite is defined as the upper incisors abnormally covering the lower incisors. This condition can lead to gum trauma and aesthetic imperfections. During clear aligner treatment, the intrusion of posterior teeth and the extrusion of anterior teeth can be performed in a controlled manner (Krieger et al., 2012). However, careful planning and appropriate attachment selection are crucial in these cases.

4.6 Crossbite

Crossbite is a malocclusion in which one or more lower teeth are positioned on the labial or buccal side of the upper teeth. In cases of anterior crossbite, the success rate with clear aligners is high. It is possible to correct the teeth with appropriate torque and movement directions. However, in the correction of posterior crossbite, clear aligners alone may not be sufficient in cases where palatal expansion is required (Lagravère et al., 2017).

5. PATIENT COMPLIANCE AND TREATMENT SUCCESS

Success in orthodontic treatments is not solely dependent on the dentist's planning and the techniques they employ, but is directly related to the patient's compliance with the treatment process. Patient compliance has become a much more decisive factor in clear aligner systems than in fixed appliances. This is because clear aligners are removable, requiring the patient's active participation in the treatment process. In this context, patient compliance encompasses many variables, such as wearing the aligners for the recommended periods, using them correctly, and adhering to hygiene rules (Weir, 2017). The recommended usage time for clear aligner treatment is generally reported to be 20-22 hours per day. Aligner usage below this duration may cause delayed tooth movement, ineffective application of planned biomechanical forces, and prolongation of the overall treatment period (Lagravère & Flores-Mir, 2005). Furthermore, transparent aligners are used in a specific sequence, and the small movements in each aligner follow one another like a chain. Therefore, patient non-compliance can disrupt not only the effect of a single aligner but the entire treatment plan. Factors affecting patient compliance include age, socio-economic status, motivation for treatment, level of information about treatment, and psychological factors. Lack of motivation in young individuals and neglected usage periods in adults due to work life or social environment are among the most common compliance issues. Therefore, it is important to inform the patient, clarify their expectations and increase their motivation before starting treatment (Jin et al., 2020). The dentist's role is also a decisive factor in patient compliance. Providing feedback on progress at each check-up, reminding the patient of the seriousness of the treatment, and monitoring the correct use of transparent aligners can increase compliance. Furthermore, patient-aligner usage can now be tracked through certain digital systems, enabling both the patient and the dentist to monitor the treatment process more closely. Treatment success is not limited to simply wearing the aligners; correctly inserting and removing them, cleaning them regularly, changing them in the specified order, and attending follow-up appointments on time are also essential for successful results. Otherwise, unexpected tooth movement, poor fit of the aligners, and even the need for a new treatment plan may arise (Simon et al., 2014). Advancing technology also offers digital solutions aimed at improving patient compliance. In particular, through mobile applications and wearable devices, the duration of plate wear can be monitored, and daily notifications can be sent to the patient to ensure more disciplined participation in the treatment process. For example, sensor systems such as "SmartTrack", which measure the time braces remain in the mouth, both increase patient awareness and facilitate the feedback process for clinicians. (Buschang et al., 2021). However, low motivation during the treatment process can negatively affect patient compliance, especially in long-term cases. If the targeted tooth movements do not occur on time, additional aligner sets called refinements may be required. The refinement process can both prolong the treatment period and increase costs. This situation may further reduce patient motivation. Therefore, during treatment planning, the goal should be to achieve the most effective results in the shortest possible time, and the patient should be informed transparently about this process (Krieger et al., 2012). It has been demonstrated that treatment compliance is significantly higher in psychologically motivated patients. Involving the patient in the treatment process, demonstrating the outcome in advance using digital simulations, and providing regular positive feedback are factors that directly influence treatment success. Therefore, in orthodontic treatments, effective communication and patient education are indispensable elements for success, alongside technical competence (Papadimitriou et al., 2018).

6. RESULTS

Orthodontic treatment methods have undergone a major transformation over time with the advancement of technology, and one of the most prominent examples of this transformation is clear aligner systems. Clear aligners, which have begun to partially replace traditional fixed orthodontic appliances, have increased interest in treatment, particularly among adult patients, by minimising aesthetic concerns. Clear aligners have become indispensable tools in contemporary orthodontics, both because they enable digital planning and because they offer comfortable use. Considering the types of malocclusion, high success rates have been achieved, particularly in the treatment of Class I dental crowding, diastema, and minor rotations. Furthermore, success has also increased for more complex malocclusions such as Class II and Class III, thanks to various attachments and additional appliances. However, it should be noted that clear aligners are still limited in their effectiveness for advanced skeletal cases; in such situations, hybrid approaches or surgical interventions may be necessary. One of the most important determinants of treatment success is the patient's compliance with treatment. Unlike fixed appliances, transparent aligners require the patient's active participation in the treatment process. Wearing the aligners regularly for the recommended periods, using them correctly, and maintaining oral hygiene directly affect the success of the treatment. Therefore, informing patients and maintaining their motivation is extremely important. The communication established between the dentist and the patient, the transparency of the process, and digital tracking systems are factors that increase patient compliance. In addition to patient compliance, psychological factors during the treatment process are also important elements that affect success. Particularly in adolescents, the intensity of aesthetic concerns can influence motivation for treatment. On the other hand, for adult patients, the advantage of invisibility offers a more liberated treatment process in social life, thereby supporting psychological well-being. Furthermore, the long-term stability of clear aligner treatments is another issue that needs to be considered. The permanence of tooth movements achieved with clear aligners is closely linked to the post-alignment retention protocol. Correct use of retention aligners is essential for lasting success. Otherwise, as with any orthodontic treatment, there is a risk of relapse (reversion) in the teeth.

Another important issue is cost-effectiveness analysis. Transparent aligners are generally more expensive than fixed appliances due to digital planning, customised production and laboratory processes. However, the shorter treatment duration, less time-consuming check-up appointments and high patient comfort increase the effectiveness of treatment in the long term and can offset this cost. In light of all this information, clear aligners are now not just an aesthetic choice but, when applied in a planned and systematic manner, have become an effective treatment alternative in terms of function and biomechanics. With the correct selection of patients, clinician experience, appropriate digital planning, and strong patient-clinician collaboration, the treatment spectrum of clear aligner systems is expanding. Furthermore, with innovations such as artificial intelligence-supported analyses, 3D printing technologies, and biocompatible material developments, it is expected that they will become a much more effective and accessible treatment option in the future.

In conclusion, transparent aligner therapy has established a revolutionary position in contemporary orthodontic practice in terms of clinical success, aesthetic satisfaction, patient comfort, hygienic advantages, and integration with technological innovations. With the correct indications, patient compliance, and sustainable follow-up processes, these systems continue to offer a safe and effective solution for both dentists and patients.

KAYNAKÇA

Joffe, L. (2003). Invisalign®: Early experiences. Journal of Orthodontics, 30(4), 348–352.

Kriegsmann, L., Simon, M., & Drescher, D. (2020). Impact of different auxiliaries on the efficacy of aligner therapy: A systematic review. Journal of Orofacial Orthopedics, 81, 343–356.

Lagravère, M. O., & Flores-Mir, C. (2005). The treatment effects of Invisalign orthodontic aligners: A systematic review. Journal of the American Dental Association, 136(12), 1724–1729.

Papadimitriou, A., Mousoulea, S., Gkantidis, N., & Kloukos, D. (2018). Clinical effectiveness of Invisalign® orthodontic treatment: A systematic review. Progress in Orthodontics, 19(1), 37.

Rossini, G., Parrini, S., Castroflorio, T., Deregibus, A., & Debernardi, C. L. (2015). Efficacy of clear aligners in controlling orthodontic tooth movement: Asystematic review. Angle Orthodontist, 85(5), 881–9.

Tamer, İ., Öztaş, E., & Marşan, G. (2019). Aligner sistemleri ve sabit ortodontik tedavi sistemlerinin karşılaştırılması. Türk Ortodonti Dergisi, 32(2), 95–101.

Weir, T. (2017). Clear aligners in orthodontic treatment. Australian Dental Journal, 62(1), 58–62.

Zhou, N., Guo, J., & Lin, J. (2022). Patient satisfaction and psychological responses during Invisalign® treatment. American Journal of Orthodontics and Dentofacial Orthopedics, 161(1), 97–105.

Angle, E. H. (1899). Classification of malocclusion. Dental Cosmos, 41, 248–264.

Graber, L. W., Vanarsdall, R. L., Vig, K. W. L., & Huang, G. J. (2017). Orthodontics: Current Principles and Techniques (6th ed.).

Elsevier. McNamara, J. A. (1981). Components of Class II malocclusion in children 8–10 years of age. The Angle Orthodontist, 51(3), 177–202.

Ngan, P., Hägg, U., & Yiu, C. (1997). Treatment of Class III problems in the growing child. The International Journal of Orthodontics, 8(2), 15–22.

Okeson, J. P. (2013). Management of Temporomandibular Disorders and Occlusion (7th ed.).

Mosby. Proffit, W. R., Fields, H. W., Sarver, D. M. (2019). Contemporary Orthodontics (6th ed.).

Elsevier. Zhang, M., McGrath, C., & Hägg, U. (2015). Orthodontic treatment need and oral health– related quality of life. The Angle Orthodontist, 84(3), 451–56.

Jin, S., Yoon, S. H., Kim, J. H., & Park, S. B. (2020). The effectiveness of clear aligners for Class II correction with mandibular advancement: A systematic review and meta-analysis. Orthodontics &Craniofacial Research, 23(4), 388–96.

Krieger, E., Seiferth, J., Marinello, I., Jung, B. A., & Wehrbein, H. (2012). Invisalign® treatment in the anterior region: Effectiveness of incisor torque control. Journalof Orofacial Orthopedics, 73(5), 365–76.

Lagravère, M. O., & Flores-Mir, C. (2005). The treatment effects of Invisalign orthodontic aligners: A systematic review. Journal of the American Dental Association, 136(12), 1724–9.

Lagravère, M. O., Carey, J. P., Heo, G., Toogood, R. W., & Major, P. W. (2008). Transverse, vertical, and anteroposterior changes from treatment with Invisalign appliances. The Angle Orthodontist, 78(5), 1023–1029 345.1

Lione, R., Barone, S., Pavoni, C., Galli, V., & Cozza, P. (2021). Treatment of Class III malocclusion with clear aligners: A systematic review. Progress in Orthodontics, 22(1), 10.

Proffit, W. R., Fields, H. W., & Sarver, D. M. (2019). Contemporary orthodontics (6th ed.).

Elsevier. Simon, M., Keilig, L., Schwarze, J., Jung, B. A., & Bourauel, C. (2014). Treatment outcome and efficacy of an aligner technique—Regarding incisor torque, premolar derotation and molar distalization. BMC Oral Health, 14, 68.

Weir, T. (2017). Clear aligners in orthodontic treatment. Australian Dental Journal, 62(Suppl 1), 58–62.

Zhou, N., Guo, J., & Tang, Y. (2020). The effectiveness of clear aligners in treatment of anterior crowding malocclusion: A systematic review. Journal of Orofacial Orthopedics, 81(3), 181–189.

Lagravère, M. O., & Flores-Mir, C. (2005). The treatment effects of Invisalign orthodontic aligners: A systematic review. Journal of the American Dental Association, 136(12), 1724–9.

Weir, T. (2017). Clear aligners in orthodontic treatment. Australian Dental Journal, 62(Suppl 1),58–62.

Simon, M., Keilig, L., Schwarze, J., Jung, B. A., & Bourauel, C. (2014). Treatment outcome and efficacy of an aligner technique—Regarding incisor torque, premolar derotation and molar distalization. BMC Oral Health, 14, 68.

Krieger, E., Seiferti, J., Engelke, J., & Lapatki, B. G. (2012). Evaluation of orthodontic tooth movement with clear aligners using digital superimposition. American Journal of Orthodontics and Dentofacial Orthopedics, 142(5), 617–24.

Zhou, J., Guo, J., & Tang, L. (2020). Digital orthodontics: A review of current applications. Orthodontics & Craniofacial Research, 23(3), 315–21.

Jin, S. Y., Lee, S. J., & Choi, J. W. (2020). Effectiveness of clear aligners for treating class II malocclusion: A systematic review. Korean Journal of Orthodontics, 50(5), 346–57.

Lion, R., Franchi, L., Alessandri-Bonetti, G., & Cozza, P. (2021). Clear aligners therapy for dental intrusion: A systematic review and meta-analysis. Progress in Orthodontics, 22, 9.

Proffit, W. R., Fields, H. W., & Sarver, D. M. (2019). Contemporary Orthodontics (6th ed.).

Elsevier Health Sciences. Lagravère, M. O., & Flores-Mir, C. (2005).The treatment effects of Invisalign orthodontic aligners: A systematic review. Journal of the American Dental Association, 136(12), 1724–9.

Weir, T. (2017). Clear aligners in orthodontic treatment. Australian Dental Journal, 62(Suppl 1), 58–62.

Simon, M., Keilig, L., Schwarze, J., Jung, B. A., & Bourauel, C. (2014).Treatment outcome and efficacy of an aligner technique—regarding incisor torque, premolar derotation and molar distalization. BMC Oral Health, 14, 68.

Jin, S. Y., Lee, S. J., & Choi, J. W. (2020). Effectiveness of clear aligners for treating class II malocclusion: A systematic review. Korean Journal of Orthodontics, 50(5), 346–57.

Rossini, G., Parrini, S., Castroflorio, T., Deregibus, A., & Debernardi, C. L. (2015). Efficacy of clear aligners in controlling orthodontic tooth movement: Asystematic review. The Angle Orthodontist, 85(5), 881–9.

Weir, T. (2017). Clear aligners in orthodontic treatment. Australian Dental Journal, 62(S1), 58–62.

Zhou, N., Guo, J., & He, S. (2020). Efficiency of clear aligner therapy compared to fixed appliance therapy: A systematic review and meta-analysis. Orthodontics & Craniofacial Research, 23(1), 26–34.

Charalampakis, O., Iliadi, A., Ueno, H., Oliver, D. R., & Kim, K. B. (2018). Accuracy of clear aligners: A retrospective study of patients who needed refinement. American Journal of Orthodontics and Dentofacial Orthopedics, 154(1), 47–54.

Papadimitriou, A., Mousoulea, S., Gkantidis, N., & Kloukos, D. (2018). Clinical effectiveness of Invisalign® orthodontic treatment: A systematic review. Progress in Orthodontics, 19(1), 37.

Tamer, İ., Öztaş, E., & Marşan, G. (2019). Evaluation of tooth movement with clear aligners: A retrospective clinical study. Journal of Istanbul University Faculty of Dentistry, 53(2), 20–8.

Wong, B. H. (2002). Clear aligners: An innovation in orthodontic treatment. Hong Kong Dental Journal, 1(1), 28–34.

Kriegsmann, J., Ahlers, M. O., & Klages, U. (2020). Efficacy of clear aligner therapy: A review of the literature. Journal of Orofacial Orthopedics, 81(6), 447–55.

Al-Nadawi, M., Kravitz, N. D., Hansa, I., Makki, L., Ferguson, D. J., Vaid, N. R., & Makki, L. (2021). Effect of clear aligner therapy on oral health-related quality of life: A systematic review. The Angle Orthodontist, 91(3), 353–60.

Grünheid, T., Loh, C., & Larson, B. E. (2017). How accurate is Invisalign® in nonextraction cases? Are predicted tooth positions achieved?. The Angle Orthodontist, 87(6), 809–15.

Zhou, N., Guo, J., & He, S. (2022). Technological advances in clear aligner systems: Current status and future directions. Orthodontics & Craniofacial Research, 25(1), 12–21.

Lagravère, M. O., & Flores-Mir, C. (2005). The treatment effects of Invisalign orthodontic aligners: A systematic review. Journal of the American Dental Association, 136(12), 1724–1729.

Barreda, G. J., D'Apuzzo, F., & Perillo, L. (2020). Clear aligners: A review of efficacy and limitations. Orthodontics & Craniofacial Research, 23(4), 451–459.

Hennessy, J., & Al-Awadhi, E. A. (2016). Clear aligners generation and efficacy: A literature review. Journal of Orthodontics, 43(1), 1–8.

Papadimitriou, A., Mousoulea, S., Gkantidis, N., & Kloukos, D. (2018). Clinical effectiveness of Invisalign® orthodontic treatment: A systematic review. Progress in Orthodontics, 19(1), 37.

Hansa, I., Katyal, V., Ferguson, D. J., & Vaid, N. R. (2021). Artificial intelligence driven clear aligner therapy: Enhancing treatment predictability and patient compliance. Seminars in Orthodontics, 27(1), 12–8.

Li, Z., Zhang, J., Zhou, X., & Chen, Y. (2023). Development of antibacterial and high- transparency thermoplastic materials for orthodontic aligners: A review of current progress and future prospects. Journal of Biomedical Materials Research Part B: Applied Biomaterials, 111(2), 387–97.

Weir, T. (2017). Clear aligners in orthodontic treatment. Australian Dental Journal, 62(Suppl 1), 58–62.

Zhou, N., Guo, J., & Tang, J. (2020). The evolution of clear aligners in orthodontics: A review of clinical applications and material advancements. Orthodontics & Craniofacial Research, 23(4), 432–440.

Proffit, W. R., Fields, H. W., & Sarver, D. M. (2019). Contemporary Orthodontics (6th ed.).

Elsevier Health Sciences. Jin, Y., Yang, Y., & Zhang, J. (2020). Application and efficacy of clear aligners in complex malocclusion cases: A review. Journal of Clinical Orthodontics, 54(8), 476–84.

Lione, R., Franchi, L., & Cozza, P. (2021). Management of Class II and Class III malocclusions with clear aligners: Current evidence and future challenges. Progress in Orthodontics, 22(1), 1–9.

Buschang, P. H., Sankey, W., Campbell, P. M., & Sharma, P. (2021). Monitoring clear aligner therapy: The role of technology and patient engagement. Seminars in Orthodontics, 27(1), 32–9.

Krieger, E., Seiferth, J., Saric, I., Jung, B. A., Wehrbein, H. (2012). Accuracy of Invisalign® treatments in the anterior tooth region. The Angle Orthodontist, 82(5), 770–7.

Papadimitriou, A., Mousoulea, S., Gkantidis, N., & Kloukos, D. (2018). Clinical effectiveness of Invisalign® orthodontic treatment: A systematic review. Progress in Orthodontics, 19(1), 37.

Weir, T. (2017). Clear aligners in orthodontic treatment. Australian Dental Journal, 62(Suppl 1), 58–62.

Lagravère, M. O., & Flores-Mir, C. (2005). The treatment effects of Invisalign orthodontic aligners: A systematic review. Journal of the American Dental

Association, 136(12), 1724–29.

Jin, Y., Yang, Y., & Zhang, J. (2020). Application and efficacy of clear aligners in complex malocclusion cases: A review. Journal of Clinical Orthodontics, 54(8), 476–84.

Simon, M., Keilig, L., Schwarze, J., Jung, B. A., & Bourauel, C. (2014). Treatment outcome and efficacy of an aligner technique—Regarding incisor torque, premolar derotation and molar distalization. BMC Oral Health, 14(1), 68.

Chapter 3

SURGICALLY ASSISTED RAPID MAXILLARY EXPANSION (SARME)

Ferit DADAŞLI[1], Mehmet Sait ŞİMŞEK[2]

1 Uzm.Dt, Private Practice, fdadasli@gmail.com, 0009-0009-0803-1905
2 Uzm. Dt. Inonu University Faculty of Dentistry, Oral and Maxillofacial Surgery, sait.simsek@inonu.edu.tr, 0009-0003-4177-140X

Introduction

Transverse maxillary deficiency is a frequent component of malocclusion and a driver of esthetic and functional concerns. In growing patients, orthopedic expansion can separate the midpalatal suture and remodel circummaxillary articulations, allowing clinically meaningful basal widening (Haas, 1980). With skeletal maturation, however, the response to similar force systems shifts: resistance localizes to maxillary buttresses and the pterygomaxillary junction, and expansion efforts without surgery tend to produce buccal tipping and alveolar bending rather than basal change (Melsen, 1975). Surgically assisted rapid maxillary expansion (SARME)-also termed surgically assisted rapid palatal expansion (SARPE)-addresses this biological impasse by reducing bony resistance through selective osteotomies and then distracting the mobilized segments with an expansion device (Pogrel et al., 1992).

The contemporary rationale for SARME is therefore straightforward: when the clinical goal is skeletal transverse gain in the skeletally mature patient, surgical assistance restores a distractionlike environment that orthodontic forces alone can no longer create. This simple framing guides the entire treatment pathway, from case selection to retention.

Orthodontic correction across growth and maturity

Orthopedic expansion during growth is predictable because sutural patency allows force systems to express as skeletal widening (Silverstein & Quinn, 1997). With advancing age, interdigitation and increasing stiffness of the circummaxillary articulations reduce this skeletal response. Attempts to expand a mature maxilla without surgery increasingly yield dental side effects-buccal tipping, cortical thinning, fenestrations, and relapse-because forces are transmitted through teeth and alveolus rather than through sutural separation (Capelozza Filho et al., 1996).

This agedependent change does not imply that nonsurgical approaches have no role in late adolescence or adulthood. Miniscrewassisted expansion and carefully selected orthodontic camouflage can be effective for modest discrepancies, acknowledging that the expansion vector becomes more rotational and dental in nature (Lee et al., 2010). The practical question is not whether any width can be gained, but whether the desired change is basal, stable, and periodontally safe (Choi et al., 2016). When those are the objectives, SARME usually becomes the preferred modality.

SARME Concepts

SARME combines limited osteotomies with jackscrewdriven distraction. The intent is not to destabilize the entire midface but to reduce resistance selectively so the expansion device can separate the maxillary halves along a favorable vector (Shetty et al., 1994).

Sites of resistance

Four regions dominate resistance to transverse separation: the piriform rim and adjacent nasal walls (anterior), the zygomaticomaxillary (ZM) buttresses (lateral), the pterygomaxillary junction (posterior), and the midpalatal suture (median). In the mature maxilla, posterior tethering at the pterygomaxillary junction often determines whether expansion opens in a Vshaped pattern (anteriorly predominant) or more parallel from canine to molar (Bell & Epker, 1976).

How surgical release shapes the expansion pattern

Releasing posterior resistance-most notably with pterygomaxillary disjunction (PMD)-tends to convert an anteriorhinge opening into a nearparallel split and lowers global craniofacial stress during distraction. Omitting PMD often yields greater anterior displacement and may require deliberate overcorrection to compensate for the gradient of opening. In contrast, wellexecuted posterior release reduces the need for overcorrection and improves the symmetry and stability of the result (Chen et al., n.d.).

Indications and case selection

The primary indication for SARME is clinically meaningful transverse deficiency in skeletally mature patients when a stable, predominantly skeletal correction is desired. Typical presentations include unilateral or bilateral posterior crossbite, narrow apical base with crowding, and excessive buccal corridors on smile. Additional contexts include adults with relapse after prior expansion, cases in which orthodontic camouflage would jeopardize periodontal health, and situations where maxillary widening simplifies or enables comprehensive treatment (Silverstein & Quinn, 1997).

Integrating periodontal phenotype and imaging

Assessment of central incisor root proximity on anterior occlusal imaging or CBCT is fundamental when a midline split is contemplated. The presence of thin buccal plates over canines and premolars is associated with a higher risk of dentoalveolar side effects with toothborne anchorage; in such phenotypes, boneborne designs provide a more favorable load distribution. Appraisal of the mandibular arch clarifies whether the transverse problem reflects true maxillary deficiency or compensation from lingually inclined lower posterior teeth; subsequent decompensation of the mandibular buccal segments frequently recalibrates the maxillary expansion target (Garib et al., 2006).

Choosing between MARPE and SARME

Miniscrewassisted rapid palatal expansion (MARPE) offers a less invasive alternative for selected young adults. Its expansion pattern, however, is more rotational and often anteriorbiased when posterior resistance is high. When several millimeters of basal width are required across the caninetomolar segment-or when periodontal reserve is limited-SARME with appropriate posterior release provides a more predictable, parallel widening (Hernández-Alfaro & Valls-Ontañón, 2021)assessing the midpalatal suture maturation stage through CBCT is essential for treatment choice between RPE, MARPE, and SARPE, although it is not without risk of clinical error. In young adults with a potential suture opening, MARPE can be attempted unless in the following situations, where SARPE is advisable: large expansions (>5 mm.

The orthodontist's role in SARME

Planning the vector and selecting anchorage

Orthodontist and surgeon should agree on the desired expansion pattern and how the osteotomy design and anchorage will support it. Toothborne and boneborne expanders can achieve comparable transverse gains when paired with equivalent releases. The practical distinctions are load sharing and periodontal risk. Boneborne devices are often preferred in phenotypes with thin buccal plates or limited periodontal reserve and can be positioned to bias anterior or posterior widening as required.

Communication on surgical design

From the orthodontic perspective, the critical surgical questions are: (1) Will there be a midpalatal split between the central incisors, and has interradicular clearance been confirmed? (2) Will the surgeon perform PMD to mitigate posterior tethering? (3) Will the nasal septum be freed to limit septal deviation during distraction? The answers directly inform activation rate, expected opening pattern, and the amount of overcorrection required.

Monitoring

Early activation is commonly accompanied by verification of symmetric diastema formation and a centered maxillary midline. Observation of the interdental papillae for blanching or recession functions as a practical marker of softtissue strain; in such circumstances, modification of the activation rhythm is frequently adopted. With toothborne anchorage, transient mobility and buccal tipping at anchor teeth are monitored, whereas with boneborne designs, stability of plates and hygiene access are reviewed.

Activation protocol, consolidation, and retention

Early activation is commonly accompanied by verification of symmetric diastema formation and a centered maxillary midline. Observation of the interdental papillae for blanching or recession functions as a practical marker of soft tissue strain; in such circumstances, modification of the activation rhythm is frequently adopted. With tooth borne anchorage, transient mobility and buccal tipping at anchor teeth are monitored, whereas with bone borne designs, stability of plates and hygiene access are reviewed.

Latency

A latency of approximately five to seven days after surgery allows early callus formation while preserving tissue vitality. Immediate activation can be appropriate in selected cases if surgical mobility is excellent and softtissue response is favorable; conversely, prolonged latency risks premature consolidation and offaxis loading.

Rate and rhythm of activation

A typical daily rate is about 0.5 mm, commonly achieved as two quarterturns per day with standard screws. Consistency is more important than speed; irregular or very slow activation increases the risk of early consolidation, asymmetric opening, and device strain. Some car-jack style distractors produce less linear separation per equal turn as the screw extends; in such designs the number of turns per day may need to increase slightly to maintain a constant distraction length.

Consolidation and staged retention

An initial consolidation phase with the expander retained in situ is commonly employed; three months is a frequently cited benchmark before conversion to lighter retention, such as a transpalatal arch, while comprehensive orthodontic treatment proceeds. Total retention time often approximates six months, individualized by patient age, magnitude of expansion, surgical pattern (including performance of PMD), and periodontal phenotype. The rationale is to permit progressive mineralization of the distraction regenerate and softtissue adaptation before withdrawal of transverse control (Sokucu et al., 2009).

Complications and risk mitigation

Most complications after SARME are minor and clinicmanageable, such as transient epistaxis or postoperative discomfort. The events with the greatest impact on treatment are orthodontic: asymmetric or inadequate expansion that necessitates reoperation or compromises finishing. These failures are closely linked to two modifiable factors-posterior release and activation rhythm (Nowak et al., 2024).

Dental and periodontal considerations

Toothborne expanders can produce temporary mobility, buccal tipping, cortical thinning, or fenestration at anchor teeth, particularly in thin bone. Selecting boneborne anchorage in vulnerable phenotypes, keeping a conservative daily rate, and monitoring papillae and incisor vitality during a midline split reduce these risks. Careful preoperative imaging to confirm interradicular clearance at the midline is essential (Jensen et al., 2015; Loriato & Ferreira, 2020).

Devicerelated events

Loosening of modules, stripped screws, and hygiene difficulties may interrupt distraction. Early boneborne designs in extremely narrow or syndromic palates showed higher device complication rates, prompting improvements in abutment design and fixation. Precise placement to avoid roots and sinus floors remains the best prevention.

Serious events

Major hemorrhage, skullbase injury, or orbital sequelae are rare in experienced hands but underscore the need for controlled osteotomies and vascular awareness around the pterygomaxillary region. When PMD is indicated, a deliberate, wellvisualized technique is the best safeguard.

Outcomes, stability, and finishing

When posterior resistance is appropriately released, the expansion pattern approaches parallel across the dental arch, reducing the need for overcorrection and facilitating finishing mechanics. Both toothborne and boneborne anchorage can produce similar skeletal gains when paired with equivalent osteotomies, although the dental sideeffect profile favors boneborne devices in thinbone phenotypes. Shortterm maintenance of transverse dental widths is generally good; the commonest relapse pattern is modest dentoalveolar narrowing rather than loss of basal width, particularly if consolidation and staged retention have been abbreviated (Gogna et al., 2020)the effect of distractor type (tooth-borne vs. bone-borne.

Beyond occlusion, several studies document improvements in nasal airflow and patientreported breathing after maxillary expansion. Speech outcomes are typically stable, with no consistent worsening in nasalance when distraction proceeds along a midline split and the septum is respected (Seeberger et al., 2011; Wriedt et al., 2001).

From a finishing standpoint, the key to predictability is early recognition of the expansion pattern. If PMD was omitted and the opening proves anteriorheavy, plan for controlled overcorrection and vigilant retention in the canine region. If PMD was performed and a nearparallel split achieved, finishing is usually straightforward with minimal transverse detailing (Berger et al., 1998).

Conclusion

SARME occupies a welldefined niche in the management of transverse maxillary deficiency in skeletally mature patients. Its strength lies in biologically sensible mechanics: reduce resistance where it matters, distract along a favorable vector, and protect the regenerate with adequate consolidation and retention. When the orthodontist plans the vector with the surgeon, verifies early symmetry, selects anchorage that respects periodontal realities, and maintains a steady activation rhythm, outcomes are predictable and durable, and complications are uncommon.

Keywords: Surgically Assisted Rapid Maxillary Expansion, Transverse maxillary deficiency

KAYNAKÇA

Bell, W. H., & Epker, B. N. (1976). Surgical-orthodontic expansion of the maxilla. *American Journal of Orthodontics*, *70*(5), 517–528. https://doi.org/10.1016/0002-9416(76)90276-1

Berger, J. L., Pangrazio-Kulbersh, V., Borgula, T., & Kaczynski, R. (1998). Stability of orthopedic and surgically assisted rapid palatal expansion over time. *American Journal of Orthodontics and Dentofacial Orthopedics*, *114*(6), 638–645. https://doi.org/10.1016/S0889-5406(98)70195-7

Betts, N. J., Vanarsdall, R. L., Barber, H. D., Higgins-Barber, K., & Fonseca, R. J. (1995). Diagnosis and treatment of transverse maxillary deficiency. *The International Journal of Adult Orthodontics and Orthognathic Surgery*, *10*(2), 75–96.

Capelozza Filho, L., Cardoso Neto, J., da Silva Filho, O. G., & Ursi, W. J. (1996). Non-surgically assisted rapid maxillary expansion in adults. *The International Journal of Adult Orthodontics and Orthognathic Surgery*, *11*(1), 57–66; discussion 67-70.

Chen, K.-Y., Yang, C.-Y., Fan, C.-N., Kuo, C.-S., Fan, S.-Z., & Chen, Y.-W. (n.d.). *The effects of pterygomaxillary disjunction in surgically assisted rapid maxillary expansion: A systematic review and meta-analysis*. https://doi.org/10.1111/ocr.12797

Choi, S.-H., Shi, K.-K., Cha, J.-Y., Park, Y.-C., & Lee, K.-J. (2016). Nonsurgical miniscrew-assisted rapid maxillary expansion results in acceptable stability in young adults. *The Angle Orthodontist*, *86*(5), 713–720. https://doi.org/10.2319/101415-689.1

Garib, D. G., Henriques, J. F. C., Janson, G., Freitas, M. R. de, & Fernandes, A. Y. (2006). Periodontal effects of rapid maxillary expansion with tooth-tissue-borne and tooth-borne expanders: A computed tomography evaluation. *American Journal of Orthodontics and Dentofacial Orthopedics*, *129*(6), 749–758. https://doi.org/10.1016/j.ajodo.2006.02.021

Gogna, N., Johal, A. S., & Sharma, P. k. (2020). The stability of surgically assisted rapid maxillary expansion (SARME): A systematic review. *Journal of Cranio-Maxillofacial Surgery*, *48*(9), 845–852. https://doi.org/10.1016/j.jcms.2020.07.003

Haas, A. J. (1980). Long-Term Posttreatment Evaluation of Rapid Palatal Expansion. *The Angle Orthodontist*, *50*(3), 189–217. https://doi.org/10.1043/0003-3219(1980)050%253C0189:LPEORP%253E2.0.CO;2

Hernández-Alfaro, F., & Valls-Ontañón, A. (2021). SARPE and MARPE. In M. R. Stevens, S. Ghasemi, & R. Tabrizi (Eds.), *Innovative Perspectives in Oral and Maxillofacial Surgery* (pp. 321–325). Springer International Publishing. https://doi.org/10.1007/978-3-030-75750-2_35

Jensen, T., Johannesen, L. H., & Rodrigo-Domingo, M. (2015). Periodontal changes after surgically assisted rapid maxillary expansion (SARME). *Oral and Maxillofacial Surgery*, *19*(4), 381–386. https://doi.org/10.1007/s10006-015-0506-5

Lee, K.-J., Park, Y.-C., Park, J.-Y., & Hwang, W.-S. (2010). Miniscrew-assisted nonsurgical palatal expansion before orthognathic surgery for a patient with severe mandibular prognathism. *American Journal of Orthodontics and Dentofacial Orthopedics*, *137*(6), 830–839. https://doi.org/10.1016/j.ajodo.2007.10.065

Loriato, L., & Ferreira, C. E. (2020). Surgically-assisted rapid maxillary expansion (SARME): Indications, planning and treatment of severe maxillary deficiency in an adult patient. *Dental Press Journal of Orthodontics*, *25*, 73–84. https://doi.org/10.1590/2177-6709.25.3.073-084.bbo

Melsen, B. (1975). Palatal growth studied on human autopsy material: A histologic microradiographic study. *American Journal of Orthodontics*, *68*(1), 42–54. https://doi.org/10.1016/0002-9416(75)90158-X

Nowak, R., Przywitowski, S., Golusiński, P., Olejnik, A., & Zawiślak, E. (2024). Complications of Surgically Assisted Rapid Maxillary/Palatal Expansion (SARME/SARPE)—A Retrospective Analysis of 185 Cases Treated at a Single Center. *Journal of Clinical Medicine*, *13*(7), 2053. https://doi.org/10.3390/jcm13072053

Pogrel, M. A., Kaban, L. B., Vargervik, K., & Baumrind, S. (1992). Surgically assisted rapid maxillary expansion in adults. *The International Journal of Adult Orthodontics and Orthognathic Surgery*, *7*(1), 37–41.

Seeberger, R., Kater, W., Schulte-Geers, M., Davids, R., Freier, K., & Thiele, O. (2011). Changes after surgically-assisted maxillary expansion (SARME) to the dentoalveolar, palatal and nasal structures by using tooth-borne distraction devices. *British Journal of Oral and Maxillofacial Surgery*, *49*(5), 381–385. https://doi.org/10.1016/j.bjoms.2010.05.015

Shetty, V., Caridad, J., Caputo, A. A., & Chaconas, S. J. (1994). Biomechanical rationale for surgical-orthodontic expansion of the adult maxilla. *Journal of Oral and Maxillofacial Surgery*, *52*(7), 742–749. https://doi.org/10.1016/0278-2391(94)90492-8

Silverstein, K., & Quinn, P. D. (1997). Surgically-assisted rapid palatal expansion for management of transverse maxillary deficiency. *Journal of Oral and Maxillofacial Surgery*, *55*(7), 725–727. https://doi.org/10.1016/S0278-2391(97)90587-5

Sokucu, O., Kosger, H. H., Bıcakci, A. A., & Babacan, H. (2009). Stability in Dental Changes in RME and SARME: A 2-Year Follow-up. *The Angle Orthodontist*, *79*(2), 207–213. https://doi.org/10.2319/031808-155.1

Wriedt, S., Kunkel, M., Zentner, A., & Wahlmann, Ulrich.-W. (2001). Surgically Assisted Rapid Palatal ExpansionAn Acoustic Rhinometric, Morphometric and Sonographic Investigation. *Journal of Orofacial Orthopedics / Fortschritte Der Kieferorthopädie*, *62*(2), 107–115. https://doi.org/10.1007/PL00001921

Chapter 4

TYPES AND HISTORICAL EVOLUTION OF ORTHODONTIC BRACKETS

Yasin AKBULUT[1], Zeynep Aybike YELMER[2]

1 Asst. Prof., Kocaeli Health and Technology University

yasin.akbulut@kocaelisaglik.edu.tr, ORCID ID: 0000-0002-3828-2483
2 Asst. Prof., Kocaeli Health and Technology University,

zeynepaybike.yelmer@kocaelisaglik.edu.tr, ORCID ID: 0000-0002-2120-9941

Brackets are devices bonded to the crowns of teeth to transmit forces generated by archwires in order to align and correct the teeth (1, 2). Considered the founder of modern orthodontics, Angle (3) laid the foundations of today's bracket systems through his extensive studies. He first attempted to define the fundamental characteristics of an ideal orthodontic appliance and established the following five principles:

1. It should be simple, capable of producing tooth rotation, and allow for both traction and pushing movements.
2. It should be firmly attachable to the tooth surface and remain stable.
3. It should be biocompatible with surrounding tissues, cause no irritation, and be as small as possible.
4. It should function efficiently according to Newton's laws of physics and the principles of anchorage.
5. It should not be bulky and must be as aesthetic as possible.

In line with these principles, Angle improved upon Dwinelle's gold screw by fabricating it from a silver–nickel alloy, making it easier to apply and smaller in size. Using screws and the bands he cemented around the teeth—onto which he soldered precision tubes—Angle developed the first fixed orthodontic attachment capable of applying rotational forces to teeth. He introduced this efficient, simple, inexpensive, and relatively aesthetic system—composed of standardized, prefabricated parts—as a comprehensive set known as the Angle System. This appliance marked the beginning of a fundamental transformation in the science of orthodontics (3).

In the following years, Angle (4) abandoned the use of screws for tooth movement and introduced the E-arch, a device based on the principle of three-dimensional expansion. (Figure 1) The E-arch consisted of a thick and rigid archwire passing buccally across the teeth, ligated with copper wires to the bands fixed on the molars. Subsequently, he enhanced the E-arch—that had been insufficient in producing axial tooth movement and only allowed tipping—by banding all teeth with the Pin and Tube Appliance. (Figure 2) Later, he advanced this system further by introducing the Ribbon Arch Appliance, which provided greater flexibility but limited control over root movement. (Figure 3)

During the 1920s, he developed the Edgewise System, in which the first brackets made of gold were attached to the bands. However, in the Edgewise technique, deformation of brackets and bands was observed during the use of thicker archwires, and decalcification occurred on the tooth surfaces. Additional wire bends were required to achieve three-dimensional tooth control, which demanded extra time and skill. Nevertheless, this system represented a turning point in the history of orthodontics and became the origin of the modern fixed orthodontic brackets used today (5). (Figure 4)

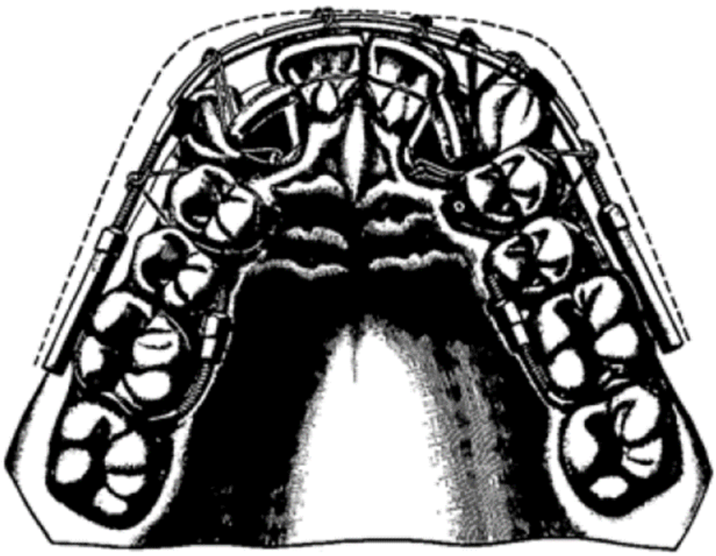

Figure 1. *Angle's Expansion E-Arch (6)*

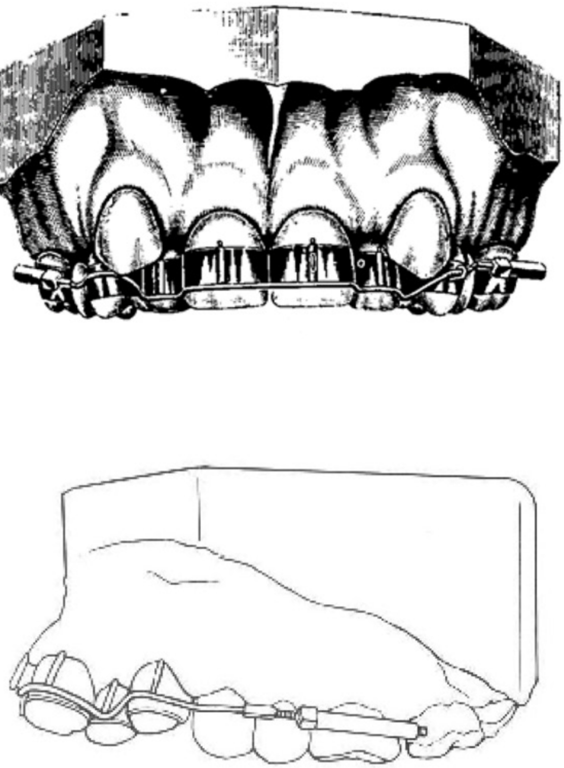

Figure 2. *Pin and Tube Appliance (6)*

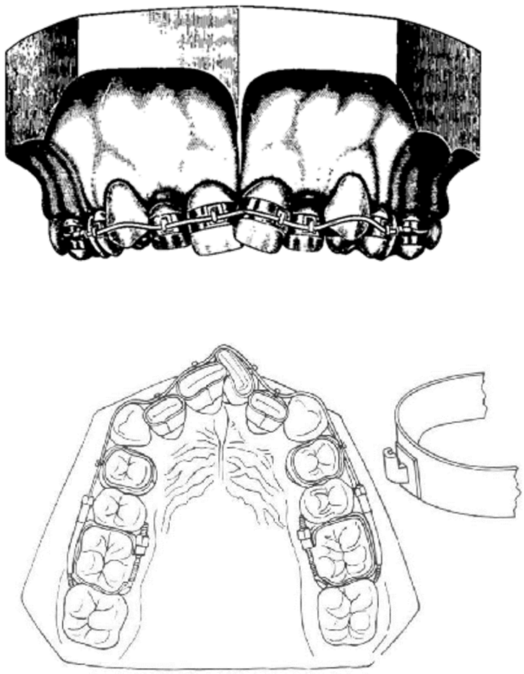

Figure 3. *Ribbon Arch Appliance (6)*

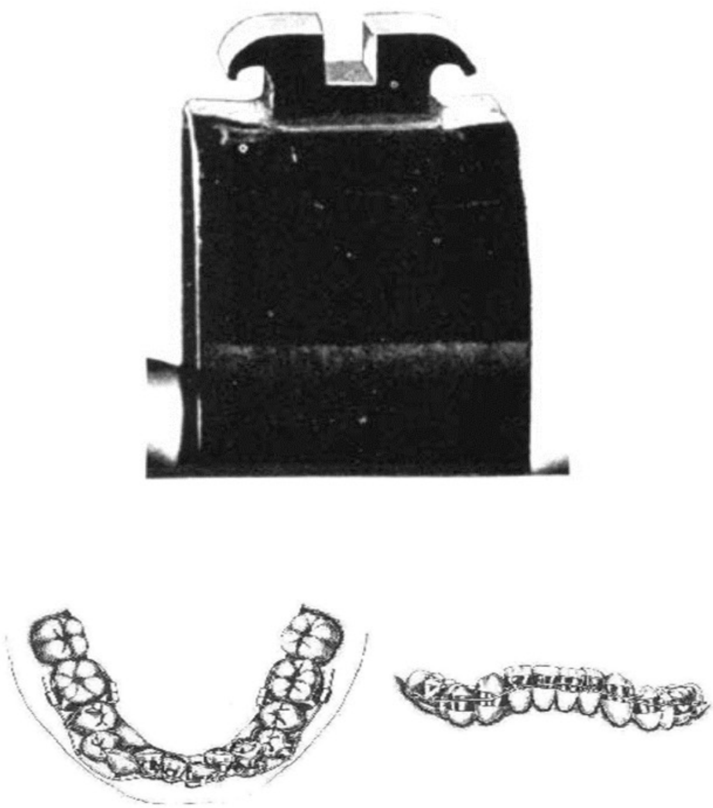

Figure 4. *Edgewise Appliance and the First Edgewise System (6)*

With the aim of enhancing control over tipping and rotational movements, a more modern version of these brackets, known as the Lewis bracket, was introduced (7). In 1952, Swain (8) launched the twin-wing brackets, which were found to be more effective than single-wing brackets in controlling root movement.

Following Buonocore's (9) introduction of the acid-etching technique in the early 1950s, Newman (10) demonstrated in 1965 that orthodontic brackets could be directly bonded to the tooth surface, leading to an increased clinical use of resin-based adhesives. This innovation marked the beginning of the direct bonding era, which eliminated the need for the separation process required during banding. The technique provided easier application, greater patient comfort, improved aesthetics, more accurate bracket positioning, and the ability to bond brackets even to unerupted teeth. Moreover, it facilitated easier cleaning and minimized the risk of demineralization under the bands (11).

In 1975, Andrews (12) introduced the pre-adjusted brackets, designed to simplify treatment by customizing factors such as the base thickness and the long-axis angulation for each tooth, thereby significantly reducing the need for archwire bending. This system, still widely used today, is also known as the Straight-Wire Technique.

Considering that orthodontic brackets remain in the oral cavity for extended periods, they must possess certain essential characteristics. Brackets should be biocompatible, provide adequate bonding strength to the tooth, and efficiently transmit the applied force to the tooth. They should have a high modulus of elasticity, low frictional resistance, and sufficient rigidity and durability. Additionally, they must not damage the tooth upon debonding, should be resistant to corrosion, stain-free, color-stable, hygienic, and not promote plaque accumulation. Furthermore, brackets should be non-toxic, non-magnetic, meet aesthetic expectations, and be cost-effective (5, 13).

METAL BRACKETS

Metal brackets are currently the most commonly preferred type of brackets (14–19). Over time, they have been manufactured from various materials, including stainless steel, titanium, cobalt–chromium, and noble metals. Initially, metal brackets were made of an austenitic stainless steel alloy containing 18% chromium and 8% nickel. Later, to enhance corrosion resistance and improve mechanical properties, martensitic stainless steel was used (20, 21). However, the nickel content in these alloys can cause allergic reactions and biocompatibility issues (22). For this reason, nickel-free metal brackets have also been developed (23).

Stainless Steel Brackets

Before the introduction of titanium and ceramic brackets, stainless steel was the standard material used in orthodontic appliances (13). Most brackets are produced from Type 304 stainless steel, which contains approximately 18–20% chromium, 8–10% nickel, and small amounts of manganese and carbon. Additionally, Type 317 stainless steel, which includes around 2–3% molybdenum and lower carbon content, can be preferred for its superior corrosion resistance and weldability (24).

The corrosion resistance of stainless steel increases with higher chromium, nickel, and molybdenum levels, and decreases with higher sulfur and carbon content (25). Advantages of stainless steel brackets include their hygienic nature, low production cost, and high mechanical strength. On the other hand, disadvantages include the release of free nickel ions in the oral cavity and their lack of esthetics (21, 26).

In passive configuration (27), stainless steel brackets exhibit lower frictional forces compared to ceramic brackets (28–32). However, in active configuration, due to the generation of frictional resistance and binding against sliding, stainless steel brackets demonstrate higher frictional forces than ceramic brackets (31, 33).

Cobalt–Chromium Brackets

Introduced as an alternative to stainless steel brackets, cobalt–chromium brackets contain lower levels of nickel and are therefore preferred for patients with nickel sensitivity (5). Nickel released from stainless steel brackets (34) can lead to adverse reactions ranging from allergies to cytotoxic responses (35). For individuals allergic to nickel, cobalt–chromium alloys—that are highly biocompatible and nickel-free—can be safely used instead of stainless steel brackets (36).

In terms of frictional behavior, cobalt–chromium brackets can generate less friction when used with stainless steel archwires (37, 38), but higher frictional forces may occur when used with both beta-titanium and stainless steel wires (38). Moreover, increasing the chromium content in these alloys improves their resistance to corrosion (39).

Titanium Brackets

The presence of nickel in orthodontic materials has raised concerns regarding their biocompatibility and encouraged the search for alternative materials (40). Manufacturers seeking substitutes have introduced brackets made of titanium alloys and commercially pure titanium, which are easy to fabricate, durable, corrosion-resistant, and possess a low modulus of elasticity along with sufficient mechanical strength. Titanium's proven biocompatibility—demonstrated by its long-standing use in surgical and dental implants—has further supported its adoption (41–46).

Titanium's major advantages include its safety for individuals with chromium or nickel allergies and its superior bonding ability (42, 47). However, due to its intrinsic surface roughness compared to stainless steel, titanium exhibits higher resistance to sliding forces during orthodontic tooth movement (13).

Noble Metal Brackets (Gold, Palladium, Platinum)

The first Edgewise brackets were made of gold; however, due to the high cost, gold was later replaced by stainless steel (5). Today, noble metal brackets are especially preferred in lingual orthodontics (5). Rather than manufacturing the entire bracket from precious metals, stainless steel brackets are often coated with gold, palladium, or platinum to improve surface characteristics and aesthetics (34).

AESTHETIC BRACKETS

To achieve a more aesthetically acceptable appearance of orthodontic brackets and thereby enhance patient motivation, various aesthetic materials have been developed over time as alternatives to stainless steel (48). The main purpose of studies focusing on different bonding methods for orthodontic brackets has been to eliminate metal bands, which adversely affect the aesthetic appearance. With the introduction of direct bonding systems, tooth-colored or transparent brackets became available (13).

Plastic Brackets

Introduced in 1969 by Newman et al. (49), plastic brackets made of polycarbonate were presented as an aesthetic alternative to metal brackets (1). Although these brackets provided superior esthetics, they exhibited significant drawbacks such as rapid deformation, susceptibility to wear, and poor dimensional stability, which prevented the fabrication of precise bracket slots. To overcome these deficiencies, metal inserts were incorporated into the slot area.

Despite their initial esthetic appeal, discoloration due to water absorption could not be prevented. Although they initially generated high expectations, their clinical popularity quickly declined because of inadequate durability, odor and staining issues, color instability, low dimensional stability, increased friction during the use of metal archwires, and adhesion that hindered tooth movement (1, 13, 50–53).

Ceramic Brackets

Introduced in 1986 (54), ceramic brackets—a type of glass material—overcame the esthetic deficiencies observed in plastic brackets due to their resistance to discoloration. Their high resistance to wear and excellent mechanical strength also made them a more favorable orthodontic material (13, 50). The manufacturing process of ceramic brackets plays a crucial role in their clinical performance (55).

In first-generation ceramic brackets, a silane-coupling layer was applied between the bracket base and the adhesive to create a strong chemical bond. However, this high bond strength led to bracket fractures and enamel damage during debonding, prompting the development of new bonding methods and the eventual discontinuation of first-generation designs (5, 50, 54, 56–58).

To address these drawbacks, second-generation ceramic brackets were developed with mechanical retention features such as pits, mushroom shapes, dovetail grooves, and other undercuts on their bases, allowing mechanical interlocking with the adhesive (50, 54, 59–63). Some ceramic bracket types provide both mechanical and chemical bonding (63).

As an alternative, systems using a polymer interface layer on the enamel surface were also introduced. This technique aimed to create bonding between the enamel and polymer layer instead of directly between enamel and ceramic, thereby reducing the risk of enamel damage (60, 63–65).

Ceramic brackets are manufactured using alumina (aluminum oxide), either as monocrystalline (single-crystal) or polycrystalline (multi-crystal) forms. Monocrystalline brackets are produced by milling sapphire crystals, whereas polycrystalline brackets are formed by sintering alumina particles with special binders at high temperatures. The advantages of alumina include excellent esthetics, high hardness, and superior chemical resistance; however, disadvantages include brittleness, high cost, and complex manufacturing processes (66).

Due to their higher light transmittance, monocrystalline ceramic brackets are preferred over polycrystalline ones (50). Ceramic brackets are often selected by patients with high esthetic demands (57, 67), as well as by individuals allergic to nickel or chromium (5, 68, 69). They are also considered safe for patients undergoing Magnetic Resonance Imaging (MRI), as removal prior to scanning is unnecessary (1, 60, 70, 71).

Despite their advantages, ceramic brackets present several disadvantages. They are relatively brittle, possess a rougher surface leading to higher frictional resistance within the slot, and may cause cracks or enamel fractures during debonding. Their greater hardness compared to natural enamel can also result in abrasion of opposing teeth (13, 60, 67, 72–74).

Additionally, because ceramic brackets appear radiolucent on radiographs, detecting fractured fragments can be challenging, and the potential for soft tissue injury from broken pieces poses another clinical concern (75). Compared with stainless steel brackets, ceramic brackets exhibit higher frictional resistance (76) and a higher coefficient of friction

(77), while also being more porous in structure (78–80).

Some studies attribute this high friction to the rough surface texture of ceramic brackets (27, 81), while others suggest it results from their chemical composition (77). To reduce friction, metal-slot ceramic brackets have been developed (30). However, all these frictional characteristics can lead to undesirable or delayed tooth movement, ultimately increasing treatment duration (50).

Recently, zirconia brackets have been introduced as an alternative to ceramic brackets (82), though studies have reported no significant advantage in terms of frictional resistance compared to ceramics (83). Furthermore, due to their opacity, zirconia brackets are considered less esthetic (84).

SELF-LIGATING BRACKETS

Self-ligating brackets are brackets equipped with a built-in clip or slide mechanism on their outer surface that can be opened and closed (85). These ligature-free systems have a smoother design, offering greater comfort for patients and easier cleaning (86). Traditionally, archwires are tied into brackets using elastic ligatures or stainless-steel wire ligatures (87). Although steel ligatures are more hygienic and produce less friction than elastic ones, they require more clinical time during application (29).

Elastic ligatures, on the other hand, are more time-efficient but tend to exhibit higher frictional values and deteriorate in the moist oral environment, which compromises both oral hygiene and clinical effectiveness (29, 88). The primary advantage of self-ligating systems is their ability to reduce friction while also decreasing chair time in clinical practice (87, 89). Over the years, many types of self-ligating brackets (SLBs) have been developed—some have become obsolete, while others are still in clinical use today (85, 87, 90).

Despite being marketed with claims of increased treatment efficiency and improved clinical performance, the concept of directly placing the archwire into a bracket slot via a built-in mechanism dates back much earlier. The first patent related to this concept was filed in 1933 by Charles E. Boyd under the name Boyd Band Bracket (91). (Figure 5b) However, due to its high production cost, manufacturing was discontinued shortly thereafter.

In 1935, J. Stolzenberg (92) introduced another self-ligating bracket system known as the Russell attachment, which also failed to gain significant commercial success. Nevertheless, interest in self-ligating designs persisted, and several patents for alternative SLB mechanisms were filed even if they never reached the market.

In 1971, A. J. Wildman developed the Edgelok system, which achieved a degree of commercial success compared to its predecessors (93). (Figure 5a) This was followed by the introduction of the Mobillock (Figure 5c) and Speed (Figure 5d) systems a year later. The Speed System, designed by G. H. Hanson, became the first active self-ligating bracket system, as it incorporated a mechanism capable of actively seating the archwire within the bracket slot (94). Subsequently, the Time system (1995) (95) (Figure 5e) and the Damon SL1 system (1996) (96) (Figure 5g) were introduced to the market.

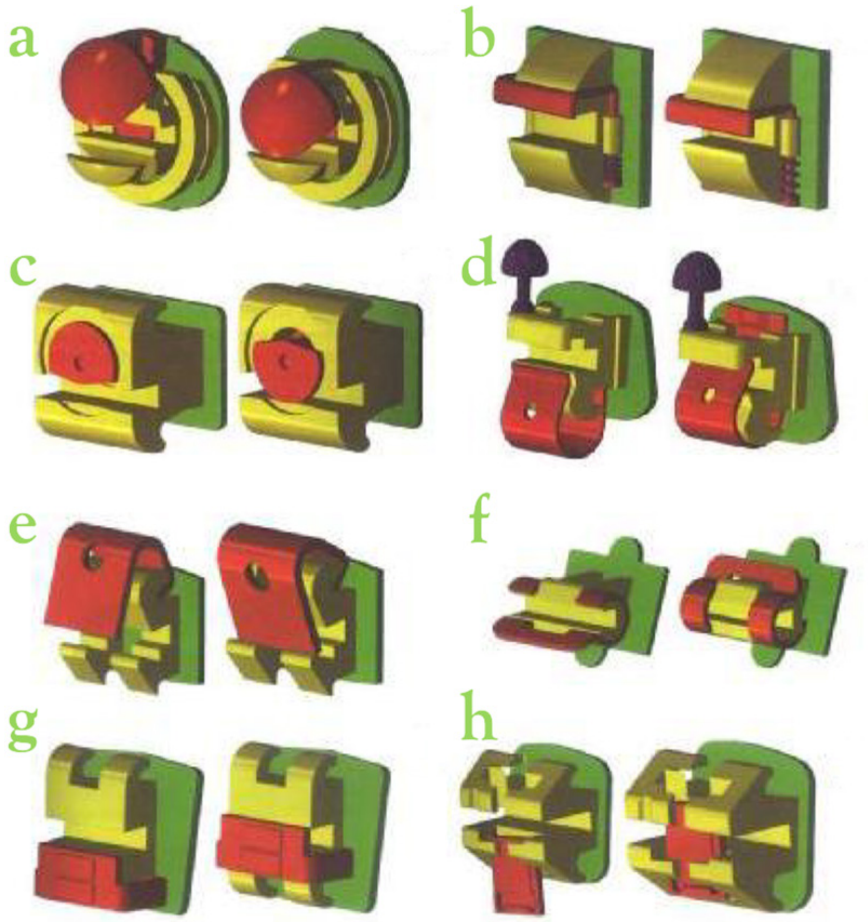

Figure 5. *Various Self-Ligating Bracket (SLB) Systems (91, 95, 96)* **a.** *Edgelok* **b.** *Boyd Band* **c.** *Mobillock* **d.** *Speed* **e.** *Time* **f.** *Activia* **g.** *Damon SL1* **h.** *Twin-Lock*

After this period, the growing interest in self-ligating brackets (SLBs) led nearly all manufacturers to include SLBs in their product lines. Existing designs evolved rapidly, and new models were introduced in quick succession. The claim that these bracket systems could provide treatments that are more efficient soon became one of the most prominent topics in the modern orthodontic market (97).

One of the most frequently cited advantages of self-ligating brackets is the reduction in chairside time. In a study comparing SLBs with conventional brackets ligated using stainless-steel ligatures, it was reported that

SLBs saved approximately 7 minutes per archwire change (89). Another study comparing SLBs with elastic ligatures found that self-ligating systems provided an average time advantage of 2–3 minutes per appointment (98).

In their investigation of archwire replacement time, Turnbull and Birnie (99) reported that SLBs saved approximately 1 second per bracket during opening and 2 seconds per bracket during closing when compared with elastomeric ligatures. Similarly, Harradine (100) observed that self-ligating systems reduced the time required for archwire insertion by approximately 9 seconds, and for removal by approximately 16 seconds.

Nevertheless, despite the measurable timesaving benefits of SLB systems, it remains debatable whether the clinical efficiency gained justifies their higher cost, considering the marginal difference in overall treatment outcomes.

REFERENCES

1. Brantley WA, Eliades T. Orthodontic materials: scientific and clinical aspects. American Journal of Orthodontics and dentofacial orthopedics. 2001;119(6):672-3.
2. Zanon G, Contardo L, Reda B. The impact of orthodontic treatment on masticatory performance: a literature review. Cureus. 2022;14(10).
3. JL V. The Tweed-Merrifield edgewise appliance: philosophy, diagnosis and treatment. Orthodontics: current principles and techniques. 1994:627-84.
4. Angle EH. The latest and best in orthodontic mechanism. Dent Cos. 1928;12:1143-58.
5. Khan H. Orthodontic Brackets Selection. Placement and Debonding. 2015.
6. Stoner M, Lindquist J. Evaluation and development of the edgewise appliance. Current Orthodontic Concepts And Techniques. 1975:453-664.
7. Lewis PD. Space closure in extraction cases. American Journal of Orthodontics. 1950;36(3):172-91.
8. Swain B, editor Clinical demonstration of the Bull technique. Charles H Tweed Foundation Meeting, Chicago; 1952.
9. Buonocore MG. A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces. Journal of dental research. 1955;34(6):849-53.
10. Newman GV. Epoxy adhesives for orthodontic attachments: progress report. American journal of orthodontics. 1965;51(12):901-12.
11. Zachrisson BU. Bonding in orthodontics. Orthodontics. 1994:542-626.
12. Andrews LF. The straight-wire appliance: syllabus of philosophy and techniques: LF Andrews; 1975.
13. Proffit WR, Fields H, Larson B, Sarver DM. Contemporary Orthodontics-E-Book: Contemporary Orthodontics-E-Book: Elsevier Health Sciences; 2018.
14. Cozza P, Martucci L, De Toffol L, Penco SI. Shear bond strength of metal brackets on enamel. The Angle Orthodontist. 2006;76(5):851-6.
15. Mitchell D, Norton T, Grenfell R, Woodgate P. Barriers to implementation of natural resource management at the landholding level in the intensive agricultural zones of Southern Australia. Australasian Journal of Environmental Management. 2007;14(2):103-10.
16. Graber T. The bandless bracket attachment. American journal of orthodontics and dentofacial orthopedics: official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 1990;98(6):18A.
17. Mundhada VV, Jadhav VV, Reche A. A Review on Orthodontic Brackets and Their Application in Clinical Orthodontics. Cureus. 2023;15(10):e46615.

18. Iijima M, Zinelis S, Papageorgiou SN, Brantley W, Eliades T. Orthodontic brackets. Orthodontic Applications of Biomaterials: Elsevier; 2017. p. 75-96.

19. Keim RG. 2021 JCO orthodontic practice study. J Clin Orthod. 2021;55(10):589.

20. Huang TH, Yen CC, Kao CT. Comparison of ion release from new and recycled orthodontic brackets. Am J Orthod Dentofacial Orthop. 2001;120(1):68-75.

21. Tosun Y. Sabit ortodontik apareylerin biyomekanik prensipleri.: İzmir Ege Üniversitesi Basımevi; 1996.

22. Espinoza-Montero PJ, Montero-Jiménez M, Fernández L, Paz JL, Piñeiros JL, Ceballos SM. In vitro wearing away of orthodontic brackets and wires in different conditions: A review. Heliyon. 2022;8(9).

23. Green J. Orthodontic appliances for patients with a nickel allergy. Dental Nursing. 2013;9(9):504-8.

24. Maijer R, Smith D. Corrosion of orthodontic bracket bases. American Journal of Orthodontics. 1982;81(1):43-8.

25. Matasa CG. Attachment corrosion and its testing. J Clin Orthod. 1995;29(1):16-23.

26. Minagi S, Sato T, Suzuki K, Nishigawa G. In situ microsampling technique for identification of elements of a restoration with exposed metal to identify potential allergens. The Journal of prosthetic dentistry. 1999;82(2):221-5.

27. Articolo LC, Kusy K, Saunders CR, Kusy RP. Influence of ceramic and stainless steel brackets on the notching of archwires during clinical treatment. The European Journal of Orthodontics. 2000;22(4):409-25.

28. Angolkar PV, Kapila S, Duncanson Jr MG, Nanda RS. Evaluation of friction between ceramic brackets and orthodontic wires of four alloys. American Journal of Orthodontics and Dentofacial Orthopedics. 1990;98(6):499-506.

29. Bednar JR, Gruendeman GW, Sandrik JL. A comparative study of frictional forces between orthodontic brackets and archwires. American Journal of Orthodontics and Dentofacial Orthopedics. 1991;100(6):513-22.

30. Loftus BP, Ârtun J, Nicholls JI, Alonzo TA, Stoner JA. Evaluation of friction during sliding tooth movement in various bracket-archwire combinations. American journal of orthodontics and dentofacial orthopedics. 1999;116(3):336-45.

31. Smith DV, Rossouw PE, Watson P, editors. Quantified simulation of canine retraction: evaluation of frictional resistance. Seminars in Orthodontics; 2003: Elsevier.

32. Tselepis M, Brockhurst P, West VC. The dynamnic frictional resistance between orthodontic brackets and archwires. American Journal of Orthodontics and Dentofacial Orthopedics. 1994;106(2):131-8.

33. Articolo LC, Kusy RP. Influence of angulation on the resistance to sliding in fixed appliances. American Journal of Orthodontics and Dentofacial

Orthopedics. 1999;115(1):39-51.

34. Eliades T, Athanasiou AE. In vivo aging of orthodontic alloys: implications for corrosion potential, nickel release, and biocompatibility. The Angle Orthodontist. 2002;72(3):222-37.
35. Shintcovsk RL, Knop LAH, Gandini Jr LG, Martins LP, Pires AS. Comparison surface characteristics and chemical composition of conventional metallic and nickel-free brackets. Brazilian Oral Research. 2015;29(1):1-8.
36. Malinowski S, Moutaabbib L. [Metal brackets]. Orthod Fr. 2009;80(1):23-6.
37. Moore M, Harrington E, Rock W. Factors affecting friction in the pre-adjusted appliance. The European Journal of Orthodontics. 2004;26(6):579-83.
38. Nair SV, Padmanabhan R, Janardhanam P. Evaluation of the effect of bracket and archwire composition on frictional forces in the buccal segments. Indian Journal of Dental Research. 2012;23(2):203-8.
39. Schiff N, Dalard F, Lissac M, Morgon L, Grosgogeat B. Corrosion resistance of three orthodontic brackets: a comparative study of three fluoride mouthwashes. The European Journal of Orthodontics. 2005;27(6):541-9.
40. Marcusson JA, Lindh G, Evengard B. Chronic fatigue syndrome and nickel allergy. Contact Dermatitis. 1999;40(5):269-72.
41. Eliades T, Zinelis S, Bourauel C, Eliades G. Manufacturing of orthodontic brackets: a review of metallurgical perspectives and applications. Recent Patents on Materials Science. 2008;1(2):135-9.
42. Hamula DW, Hamula W, Sernetz F. Pure titanium orthodontic brackets. Journal of clinical orthodontics: JCO. 1996;30(3):140-4.
43. Kusy R, Whitley J, Ambrose W, Newman J. Evaluation of titanium brackets for orthodontic treatment: Part I. The passive configuration. American journal of orthodontics and dentofacial orthopedics. 1998;114(5):558-72.
44. Zinelis S, Annousaki O, Eliades T, Makou M. Metallographic structure and hardness of titanium orthodontic brackets. Journal of Orofacial Orthopedics/Fortschritte der Kieferorthopädie. 2003;64(6):426-33.
45. Parr GR, Gardner LK, Toth RW. Titanium: the mystery metal of implant dentistry. Dental materials aspects. The Journal of Prosthetic Dentistry. 1985;54(3):410-4.
46. Lakshmi SG, Arivuoli D, Ganguli B. Surface modification and characterisation of Ti–Al–V alloys. Materials Chemistry and Physics. 2002;76(2):187-90.
47. Wendl B, Wiltsche H, Lankmayr E, Winsauer H, Walter A, Muchitsch A, et al. Metal release profiles of orthodontic bands, brackets, and wires: An in vitro study. Journal of Orofacial Orthopedics/Fortschritte der Kieferorthopädie. 2017;78(6):494-503.
48. Arici S, Regan D. Alternatives to ceramic brackets: the tensile bond strengths of two aesthetic brackets compared ex vivo with stainless steel

foil-mesh bracket bases. British journal of orthodontics. 1997;24(2):133-7.

49. Newman GV. Adhesion and orthodontic plastic attachments. American journal of orthodontics. 1969;56(6):573-88.

50. Russell J. Current products and practice: aesthetic orthodontic brackets. Journal of Orthodontics. 2005;32(2):146-63.

51. Faltermeier A, Behr M, Müßig D. In vitro colour stability of aesthetic brackets. The European Journal of Orthodontics. 2007;29(4):354-8.

52. Hershey HG. The orthodontic appliance: esthetic considerations. The Journal of the American Dental Association. 1988;117(4):29E-34E.

53. Haynie AS, English JD, Paravina RD, Moon A, Hanigan J, Abu Al Tamn MA, et al. Colour stability of 3D-printed resin orthodontic brackets. Journal of Orthodontics. 2021;48(3):241-9.

54. Karamouzos A, Athanasiou AE, Papadopoulos MA. Clinical characteristics and properties of ceramic brackets: a comprehensive review. American journal of orthodontics and dentofacial orthopedics. 1997;112(1):34-40.

55. Theodorakopoulou LP, Sadowsky PL, Jacobson A, Lacefield W, Jr. Evaluation of the debonding characteristics of 2 ceramic brackets: an in vitro study. Am J Orthod Dentofacial Orthop. 2004;125(3):329-36.

56. Suliman SN, Trojan TM, Tantbirojn D, Versluis A. Enamel loss following ceramic bracket debonding: A quantitative analysis in vitro. The Angle Orthodontist. 2015;85(4):651-6.

57. Bishara SE, Fehr DE, editors. Ceramic brackets: something old, something new, a review. Seminars in orthodontics; 1997: Elsevier.

58. Kitahara-Céia FMF, Mucha JN, dos Santos PAM. Assessment of enamel damage after removal of ceramic brackets. American journal of orthodontics and dentofacial orthopedics. 2008;134(4):548-55.

59. Forsberg C-M, Hagberg C. Shear bond strength of ceramic brackets with chemical or mechanical retention. British journal of orthodontics. 1992;19(3):183-9.

60. Bordeaux JM, Moore RN, Bagby MD. Comparative evaluation of ceramic bracket base designs. American Journal of Orthodontics and Dentofacial Orthopedics. 1994;105(6):552-60.

61. Kukiattrakoon B, Samruajbenjakul B. Shear bond strength of ceramic brackets with various base designs bonded to aluminous and fluorapatite ceramics. The European Journal of Orthodontics. 2010;32(1):87-93.

62. Ansari MY, Agarwal DK, Gupta A, Bhattacharya P, Ansar J, Bhandari R. Shear bond strength of ceramic brackets with different base designs: Comparative in-vitro study. Journal of clinical and diagnostic research: JCDR. 2016;10(11):ZC64.

63. Elekdag-Türk S. In vitro evaluation of a ceramic bracket with a laser-structured base. BMC Oral Health. 2020;20(1):17.

64. Franklin S. Shear bond strengths and effects on enamel of two ceramic brackets. J Clin Orthod. 1993;27:83-8.

65. Olsen ME, Bishara SE, Jakobsen JR. Evaluation of the shear bond strength of different ceramic bracket base designs. The Angle Orthodontist. 1997;67(3):179-82.

66. Saunders C, Kusy RP. Surface topography and frictional characteristics of ceramic brackets. American Journal of Orthodontics and Dentofacial Orthopedics. 1994;106(1):76-87.

67. Reimann S, Bourauel C, Weber A, Dirk C, Lietz T. Friction behavior of ceramic injection-molded (CIM) brackets. Journal of Orofacial Orthopedics/Fortschritte der Kieferorthopädie. 2016;77(4):262-71.

68. Liu J-K, Chung C-H, Chang C-Y, Shieh D-B. Bond strength and debonding characteristics of a new ceramic bracket. American Journal of Orthodontics and Dentofacial Orthopedics. 2005;128(6):761-5.

69. Gautam P, Valiathan A. Ceramic brackets: in search of an ideal! Trends in Biomaterials and Artificial Organs. 2007;20(2):122-7.

70. Jena AK, Duggal R, Mehrotra A. Physical properties and clinical characteristics of ceramic brackets: a comprehensive review. Trends Biomater Artif Organs. 2007;20(2):101-15.

71. ML S. Ceramic brackets. J Clin Orthod. 1988;22:82-9.

72. Elekdag-Türk S, Yilmaz H. Ceramic brackets revisited. Current Approaches in Orthodontics. 2018.

73. Omana HM. Frictional properties of metal and ceramic brackets. JCO. 1992;17:425-33.

74. Zielinski V, Reimann S, Jäger A, Bourauel C. Comparison of shear bond strength of plastic and ceramic brackets. Springer; 2014.

75. Birnie D. Ceramic brackets. Br J Orthod. 1990;17(1):71-4.

76. Keith O, Jones S, Davies E. The influence of bracket material, ligation force and wear on frictional resistance of orthodontic brackets. British journal of orthodontics. 1993;20(2):109-15.

77. Kusy RP, Whitley JQ, Prewitt MJ. Comparison of the frictional coefficients for selected archwire-bracket slot combinations in the dry and wet states. The Angle Orthodontist. 1991;61(4):293-302.

78. Downing A, McCabe J, Gordon P. A study of frictional forces between orthodontic brackets and archwires. British Journal of Orthodontics. 1994;21(4):349-57.

79. Pratten DH, Popli K, Germane N, Gunsolley JC. Frictional resistance of ceramic and stainless steel orthodontic brackets. American Journal of Orthodontics and Dentofacial Orthopedics. 1990;98(5):398-403.

80. Tanne K, Matsubara S, Shibaguchi T, Sakuda M. Wire friction from ceramic brackets during simulated canine retraction. The Angle Orthodontist. 1991;61(4):285-90.

81. Rose CM. Reduced resistance to sliding in ceramic brackets. J Clin Orthod. 1996;30:78-84.

82. Kusy RP. Orthodontic biomaterials: from the past to the present. The

Angle Orthodontist. 2002;72(6):501-12.

83. Keith O, Kusy RP, Whitley JQ. Zirconia brackets: an evaluation of morphology and coefficients of friction. American Journal of Orthodontics and Dentofacial Orthopedics. 1994;106(6):605-14.

84. Springate S, Winchester L. An evaluation of zirconium oxide brackets: a preliminary laboratory and clinical report. British journal of orthodontics. 1991;18(3):203-9.

85. Harradine N. Self-ligating brackets: where are we now? Journal of orthodontics. 2003;30(3):262-73.

86. Shivapuja PK, Berger J. A comparative study of conventional ligation and self-ligation bracket systems. American Journal of Orthodontics and Dentofacial Orthopedics. 1994;106(5):472-80.

87. Thomas S, Sherriff M, Birnie D. A comparative in vitro study of the frictional characteristics of two types of self-ligating brackets and two types of pre-adjusted edgewise brackets tied with elastomeric ligatures. The European Journal of Orthodontics. 1998;20(5):589-96.

88. Graber LW, Vanarsdall RL, Vig KW, Huang GJ. Orthodontics: current principles and techniques. (No Title). 1994.

89. Maijer R, Smith DC. Time savings with self-ligating brackets. Journal of clinical orthodontics: JCO. 1990;24(1):29-31.

90. Read-Ward G, Jones S, Davies E. A comparison of self-ligating and conventional orthodontic bracket systems. British journal of orthodontics. 1997;24(4):309-17.

91. Woodside D, Berger J, Hanson G. Self-ligation orthodontics with the SPEED appliance. Orthodontics: current principles and techniques St Louis, MO, Elsevier Mosby. 2005:717-52.

92. Stolzenberg J. The Russell attachment and its improved advantages. International Journal of Orthodontia and Dentistry for Children. 1935;21(9):837-40.

93. Wildman A, Hice T, Lang H, Lee I, Strauch Jr E. Round table—the Edgelok bracket. J Clin Orthod. 1972;6(11):613-23.

94. Berger JL. The SPEED appliance: a 14-year update on this unique self-ligating orthodontic mechanism. American Journal of Orthodontics and Dentofacial Orthopedics. 1994;105(3):217-23.

95. Heiser W. Time: a new orthodontic philosophy. Journal of Clinical Orthodontics: JCO. 1998;32(1):44-53.

96. Dh D. The Damon low-friction bracket; a biologically compatible straight-wire system. J Clin Orthod. 1998;32:670-80.

97. Rinchuse DJ, Miles PG. Self-ligating brackets: present and future. American Journal of Orthodontics and Dentofacial Orthopedics. 2007;132(2):216-22.

98. Berger J, Byloff FK. The clinical efficiency of self-ligated brackets. Journal of clinical orthodontics: JCO. 2001;35(5):304-8.

99. Turnbull NR, Birnie DJ. Treatment efficiency of conventional vs self-

ligating brackets: effects of archwire size and material. American Journal of Orthodontics and Dentofacial Orthopedics. 2007;131(3):395-9.

100. Harradine NW. Self-ligating brackets and treatment efficiency. Clinical orthodontics and research. 2001;4(4):220-7.