

In-House Clear Aligners: Technologies, Materials, Protocols and Clinical Challenges: A Comprehensive Review

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Abstract: Clear aligner therapy has shifted from being almost exclusively outsourced to commercial laboratories toward an in-house, or “chairside,” model in which the clinician controls scanning, digital treatment planning, 3D printing, and thermoforming within the practice itself. This places material selection, manufacturing technology, and biomechanical design directly in the orthodontist’s hands, yet practical guidance on translating this control into predictable tooth movement remains scattered across the literature. This narrative review consolidates current evidence on in-house clear aligner systems, covering the advantages and disadvantages of in-house fabrication relative to outsourced systems; the three principal in-house workflows - thermoformed, direct 3D-printed, and hybrid/multilayer aligners; the manufacturing technologies used to produce them, including fused deposition modelling (FDM) and vat-polymerization printing (stereolithography, digital light processing, and masked stereolithography/LCD); the mechanical behavior of the three thermoplastics most commonly used in-house - thermoplastic polyurethane (TPU), polyethylene terephthalate glycol-modified (PETG), and crystallized/co-polyester PET (PET-C) - framed through a wire analogy familiar to orthodontists, with particular attention to stress relaxation and force decay; attachment (“engager”) design and bonding protocols used to programme specific tooth movements; and severity-based correction algorithms for crowding and for vertical, transverse, and anteroposterior discrepancies. The review also outlines the practical problems encountered in day-to-day in-house practice, including force-calibration errors, fit and marginal-adaptation issues, under-delivery of planned interproximal reduction and proclamation, and staff-training demands. Taken together, the evidence indicates that in-house aligner therapy can reduce turnaround time and increase clinician control, but that its success depends on a movement-specific approach to material selection, realistic mid-treatment monitoring, and a working understanding of how aligner materials behave mechanically after activation — knowledge that has traditionally resided with the outsourced laboratory rather than the clinician.

Keywords: Clear Aligners; In-House Aligners; Chairside Orthodontics; 3D Printing; Thermoforming; Stress Relaxation; Aligner Attachments; Malocclusion; Orthodontic Biomechanics.

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I. INTRODUCTION

Clear aligner therapy has transformed contemporary orthodontics by offering an esthetic, removable alternative to fixed appliances. For much of the last two decades, aligner fabrication was outsourced to large commercial laboratories such as Align Technology (Invisalign) and ClearCorrect. However, the convergence of affordable intraoral scanners,

open-source and proprietary treatment-planning software, and desktop 3D printers has enabled clinicians to fabricate aligners entirely within their own clinics - a model widely termed “in-house” or “chairside” aligner therapy. This shift places not only the digital treatment plan but also material selection, attachment design, and manufacturing technology directly in the orthodontist's hands, making a working

knowledge of aligner polymer science and biomechanics clinically essential rather than optional.^{1,2}

This review consolidates the advantages and disadvantages of in-house aligner systems, outlines the different types of in-house workflows and the manufacturing technologies (FDM, SLA, DLP, and MSLA) that underpin them, clarifies the mechanical behavior of the three polymers most commonly used in in-house fabrication (TPU, PETG, and PET-C), details the attachment/engager systems used to programme specific tooth movements, presents malocclusion-specific correction algorithms for crowding, vertical, transverse, and anteroposterior discrepancies, and discusses the practical problems clinicians encounter in day-to-day in-house practice.^{1,3,4}

II. WHAT CONSTITUTES AN “IN-HOUSE ALIGNER”?

An in-house aligner workflow typically involves four steps performed by the clinician or in-office technician: (1) intraoral or model scanning to generate a digital arch; (2) virtual treatment planning and staging using software (open-platform or proprietary); (3) fabrication of sequential models via 3D printing, followed by vacuum/pressure thermoforming of aligner sheets over the models; or, increasingly, (4) direct 3D printing of the aligner itself using photopolymer resins, bypassing thermoforming altogether. This gives the orthodontist control over every link of the production chain that is normally delegated to an external laboratory.^{3,4,5}

III. ADVANTAGES OF “IN-HOUSE ALIGNER”?

➤ *Cost-Effectiveness:*

Eliminating laboratory and courier fees substantially reduces the per-case cost, making aligner therapy accessible to a wider patient base and improving practice margins.^{3,4}

➤ *Reduced Turnaround Time:*

Models, aligners, or refinements can be produced within hours rather than the days-to-weeks required for outsourced systems, allowing same-day delivery in suitable cases.^{3,4}

➤ *Greater Clinical Control:*

The treating clinician designs the tooth-movement staging, attachment placement, and force system directly, rather than relying on a remote technician's interpretation of the prescription.^{3,4,6}

➤ *Flexibility In Refinements and Midcourse Corrections:*

Rescans and revised stages can be generated immediately in-clinic without waiting for a new laboratory cycle.^{3,4}

➤ *Material Customization:*

The clinician can select or combine materials (TPU, PETG, PET-C) according to the specific type of tooth

movement required in a given arch or stage, rather than being limited to a single proprietary material.^{1,7,8}

➤ *Patient Engagement and Transparency:*

Chairside visualization of the digital set-up strengthens patient understanding, consent, and satisfaction.^{6,9}

IV. DISADVANTAGES OF “IN-HOUSE ALIGNER”?

➤ *High Initial Capital Investment:*

Intraoral scanners, 3D printers, post-processing units, and thermoforming machines require significant upfront expenditure.^{3,4}

➤ *Steep Learning Curve:*

Treatment-planning software demands training in digital tooth movement, biomechanics, and staging that differs from conventional orthodontic education.^{3,4}

➤ *Operator-Dependent Quality:*

Unlike large laboratories with dedicated quality-control teams, in-house output quality depends heavily on the experience of the clinician or in-office technician, leading to variability between practices.^{3,4,5}

➤ *Limited Long-Term Outcome Data:*

Compared with well-established commercial systems, in-house protocols have less peer-reviewed longitudinal evidence on treatment predictability and relapse.^{3,4,9}

➤ *Material And Equipment Maintenance:*

3D printers and thermoforming units require calibration, resin/sheet inventory management, and periodic servicing, adding a logistical burden.^{3,10}

➤ *Regulatory And Liability Considerations:*

In several jurisdictions, in-house fabricated aligners fall under medical-device regulations that the clinician, not a manufacturer, becomes directly responsible for.^{3,4}

V. TYPES OF “IN-HOUSE ALIGNER SYSTEMS

➤ *Thermoformed (Indirect) Aligners*

The conventional and still most widely practised in-house method: sequential setups are 3D printed as solid resin models, over which thermoplastic sheets (TPU, PETG, or PET-C) are vacuum- or pressure-formed and trimmed. This approach benefits from decades of established thermoforming knowledge and broad material availability.^{3,5}

➤ *Direct 3D-Printed Aligners*

An emerging method in which the aligner itself — not just the model — is printed layer-by-layer from photopolymer resins with shape-memory or elastic properties at body temperature. Recent comprehensive reviews of direct-3D-printing technologies for aligners report that this approach can offer higher dimensional accuracy, better load resistance, and lower permanent

deformation than thermoformed aligners, since it eliminates the thermoforming step and its associated material thinning at cuspal and incisal edges. However, the literature also notes that approved, clinically validated resins and aligner-specific planning software remain limited, and that the technology is still comparatively young.^{3,4}

➤ Hybrid/Multilayer Aligners

Some in-house protocols combine layers — for example, a rigid outer PETG or PET-C layer with an inner TPU layer — to balance stiffness with comfort and fit, mirroring the multilayer approach used by several commercial brands.^{1,2}

VI. 3D PRINTING TECHNOLOGIES USED IN IN-HOUSE ALIGNER FABRICATION

Whether producing sequential thermoforming models or directly printing the aligner, in-house workflows depend on one of two broad 3D-printing families: extrusion-based printing (FDM) for models, and vat-photopolymerisation printing (SLA, DLP, and MSLA/LCD) for both high-accuracy models and direct aligner printing.^{3,5,10}

➤ Fused Deposition Modelling (FDM)

FDM printers build objects by extruding heated thermoplastic filament, layer by layer, through a moving nozzle onto a build plate, with the printer head (or bed) traversing the X, Y, and Z axes to trace each cross-section before the plate indexes down (or the head rises) for the next layer. Although inexpensive and simple to operate, FDM's comparatively coarse layer resolution and lower dimensional accuracy make it more suitable for auxiliary models, working casts, or bite blocks than for the fine-detail sequential models required for precise aligner thermoforming.^{3,10}

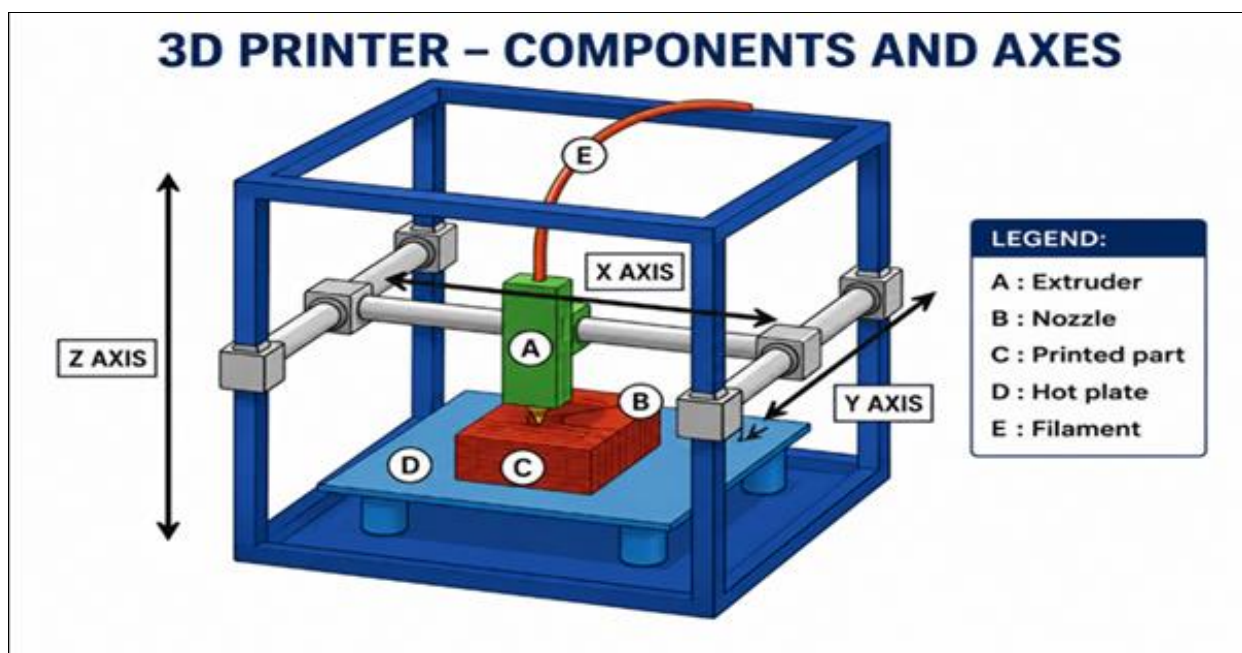


Fig 1 Fused Deposition Modelling (FDM)

➤ Vat-Polymerisation Printing: SLA and DLP

Stereolithography (SLA) and Digital Light Processing (DLP) printers both build objects through vat polymerisation: a build platform is progressively lowered into (or raised out of) a vat of liquid photosensitive resin, and each cross-sectional layer is selectively cured by light exposure before the platform indexes to expose the next layer. SLA cures each layer point-by-point using a scanning laser beam, tracing the outline and interior of the cross-section; DLP instead projects an entire cross-sectional image at once using a digital micromirror device, curing a full

layer simultaneously. Comparative studies of 3D-printed orthodontic models report that SLA systems tend to show lower trueness error than DLP or LCD-based systems, while DLP has demonstrated advantages in precision (repeatability) and, because it cures a whole layer per exposure, in build speed for larger batches. Direct clear-aligner resin systems using DLP have been reported to achieve dimensional accuracy within ± 0.1 mm, compared with roughly ± 0.2 mm for thermoformed alternatives, reflecting DLP's layer-by-layer consistency advantage.^{3,5,10}

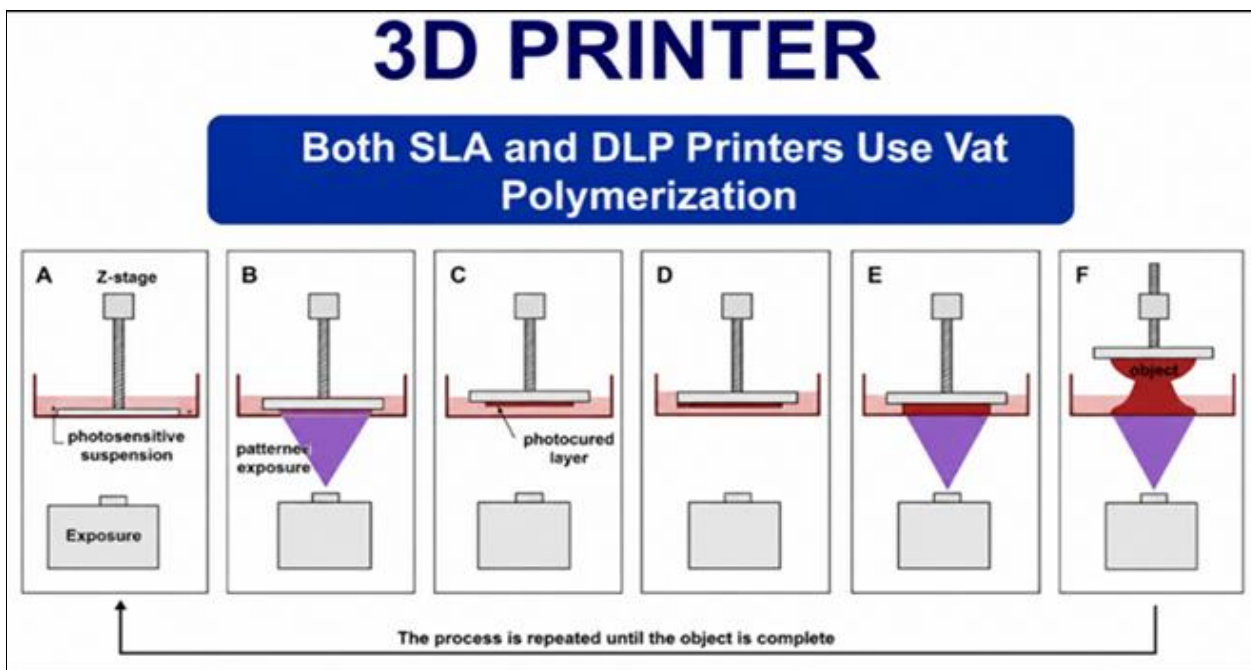


Fig 2 Vat-Polymerisation Printing: SLA and DLP

➤ *Masked SLA (MSLA) / LCD Technology*

Masked SLA — also marketed as MSLA or LCD printing — is a variant of vat polymerisation in which an LCD photomask, backlit by an LED array, replaces the laser (SLA) or digital micromirror projector (DLP) as the light-patterning source. Because the LCD panel can mask and cure an entire layer at once across the full build area, MSLA systems can print multiple aligner-stage models side by side

in a single layer exposure, improving throughput for the batch production of sequential in-house models. MSLA has become popular in entry-level and mid-range dental 3D printers because it combines much of the whole-layer speed advantage of DLP with lower hardware cost, although industrial SLA and DLP systems generally retain an edge in fine positional accuracy.¹⁰



Fig 3 Masked SLA (MSLA) / LCD Technology

Selecting among FDM, SLA, DLP, and MSLA in an in-house setting is therefore a trade-off between accuracy, speed, batch capacity, and cost: SLA is often favoured

where maximum trueness is the priority; DLP suits higher-volume workflows and direct aligner printing; and MSLA

offers a pragmatic balance for practices producing multiple sequential models per case at lower capital cost.^{3,5,10}

VII. MATERIAL BEHAVIOUR: THE WIRE ANALOGY THE ORTHODONTIST ALREADY UNDERSTOOD

Most orthodontists intuitively grasp the mechanical difference between a flexible nickel-titanium (NiTi) wire and a rigid stainless-steel (SS) wire (Table 1). The same conceptual framework can, and should, be applied to aligner sheet selection — yet this analogy remains poorly disseminated in clinical practice, and many clinicians default to a single “all-purpose” material for every stage of treatment regardless of the movement being attempted.^{1,7}

➤ TPU – the “NiTi” of Aligner Materials

TPU is an elastomeric polymer with a comparatively low modulus of elasticity and high elongation-at-break. Clinically, this translates into gentle, low-magnitude forces that are released gradually as the material recovers toward its original shape — conceptually parallel to the superelastic, light continuous force delivery of a NiTi wire during initial alignment and levelling. TPU is therefore well suited to derotation and mild-to-moderate crowding correction, where light, sustained force over a longer activation range is desirable and where excessive force could risk root resorption or patient discomfort.^{1,7,8}

➤ PETG – the “Stainless-Steel” of Aligner Materials

PETG is a relatively stiff aligner polymer and can initially deliver a firm corrective force. Its viscoelastic nature, however, means that the force associated with a fixed deformation does not remain constant during wear. In practical terms, a PETG tray may feel mechanically strong at insertion but progressively lose part of that stored force as the material relaxes. This behaviour makes PETG useful when a comparatively firm force system is desired, but it also means that force decay should be considered when staging space closure, bodily translation, and other movements that depend on sustained activation.^{1,7,11,12}

Stress relaxation represents the time-dependent reduction in stress exhibited by a polymer when maintained under constant strain and is of particular relevance to clear aligner biomechanics. In thermoplastic aligner materials, the initial force generated during activation progressively decreases as molecular rearrangement occurs, with the most pronounced reduction occurring during the early loading period, followed by a slower decline.^{11–13} Studies using Duran® PET-G demonstrated substantial reductions in residual force with repeated loading and unloading, with longer loading durations and repeated recovery cycles further influencing force retention. After one week, the longest loading protocol retained only approximately 5% of the initially applied force, highlighting the viscoelastic and time-dependent nature of PET-G force delivery.¹²

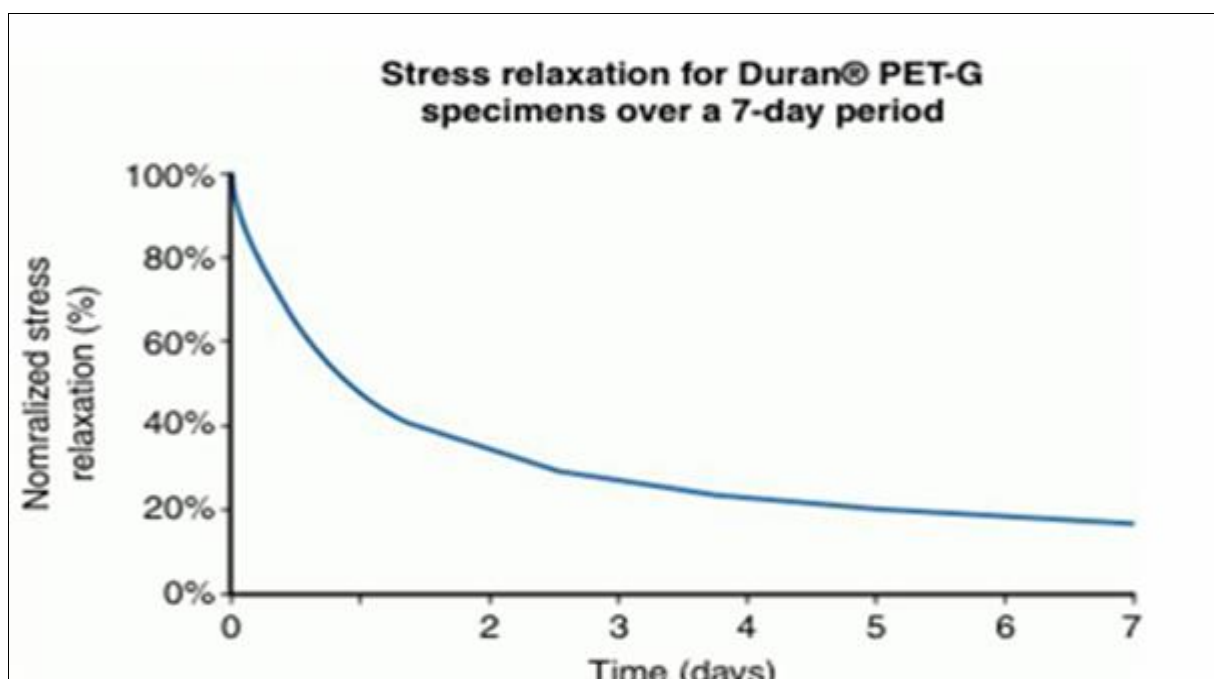


Fig 4 Stress Relaxation Represents the Time-Dependent Reduction in Stress Exhibited

➤ PET-C – the Underused Hybrid Material

PET-C and PCTG-type copolyesters occupy an increasingly important middle ground among aligner materials. Their behaviour should not be assumed to be identical across commercial formulations, because composition, thickness, processing, and test conditions all influence force retention. Recent comparative evidence suggests that PCTG can provide relatively light, sustained

forces over longer periods, whereas TPU may show faster force decay. For clinical selection, the more useful principle is therefore to match the measured mechanical behaviour of the specific material to the intended movement rather than assigning a universal label of “soft” or “stiff.”^{2,8}

VIII. ATTACHMENTS OF “IN-HOUSE ALIGNER”

Because aligners transmit force through a thin plastic shell rather than a bracket-and-wire system, composite attachments — also called “engagers” — are bonded to the tooth surface to give the aligner mechanical purchase for specific movements. Engagers are broadly classified by the direction of movement they are designed to control.^{17,18,19}

➤ Vertical Engagers

Vertical (rectangular) engagers are typically oriented with their long axis running gingivo-incisally on the tooth surface. Depending on their exact geometry — upright rectangular, tipped rectangular, or bevelled — they are used to control angulation, derotation, bodily (translational) movement, or extrusion, with recommended lengths of 2–4 mm and depths of 1–2 mm depending on the specific movement being programmed.^{17,18,19}

Type	Movement	Size/length	Size/depth
Rectangular vertical	Angulation, Derotation, Bodily movement	2, 3, or 4 mm	1–1.5 mm
Rectangular vertical tipped	Derotation	2, 3, or 4 mm	1–2 mm
Bevelled	Extrusion	2 or 3 mm	1–2 mm

Fig 5 Vertical Engagers

➤ Horizontal Engagers

Horizontal engagers are oriented with their long axis running mesio-distally. Rectangular horizontal, semilunar, and torque-element (negative) attachments are used

respectively for vertical anchorage/extrusion, extrusion, and root torque control, with the torque element characteristically designed as a negative (recessed) attachment rather than a raised composite bump.^{17,18,19}

Type	Movement	Size/length	Size/depth
Rectangular horizontal	Vertical movement: Anchorage (eg, on neighbouring teeth of desired intrusion) Extrusion	2 or 3 mm	1–1.5 mm
Semilunar	Extrusion	2 mm	1–1.5 mm
Torque element (negative attachment)	Torque	2 mm	–0.7 mm

Fig 6 Horizontal Engagers

IX. MALOCCLUSION-SPECIFIC CORRECTION PROTOCOLS WITH ALIGNERS

➤ Crowding

Contemporary literature on clear aligner therapy and expert consensus recommendations advocate a severity-based approach to the management of dental crowding, broadly categorising cases as mild, moderate, or severe. The correction of crowding primarily relies on a combination of arch expansion, controlled incisor proclination, and interproximal reduction (IPR), with extraction-based treatment considered progressively as the severity of the space deficiency increases.^{6, 21, 22}

- Mild crowding: managed conservatively with expansion, controlled proclination, and IPR; published estimates suggest IPR alone can safely resolve several millimetres of crowding within enamel-thickness safety limits.^{20,21,22}
- Moderate crowding: the same expansion/proclination/IPR is used first; if space remains insufficient, lower incisor extraction and sequential distalisation are added to the plan.^{9,21,22}
- Severe crowding: follows the moderate pathway but frequently progresses to premolar extraction when the arch-length discrepancy exceeds what expansion, proclination, and IPR can safely provide.^{9,21,22}

➤ Vertical Problems: Deep Bite and Anterior Open Bite

In the management of deep bite, treatment planning should initially assess the extent of spontaneous overbite reduction expected from resolution of anterior crowding and leveling of the curve of Spee. Active maxillary and/or mandibular anterior intrusion may subsequently be incorporated when required, whereas more pronounced deep-bite discrepancies may necessitate a combination of anterior intrusion and reciprocal posterior extrusion.

For anterior open bite, mild or uncomplicated cases may often be corrected primarily through anterior extrusion. In more advanced skeletal open-bite presentations, a combination of anterior extrusion and TAD-assisted posterior intrusion may be employed to facilitate bite closure while minimizing dependence on extensive posterior tooth movement alone.^{6,9}

➤ Transverse Problems: Crossbite

A critical diagnostic consideration in the management of transverse discrepancies is the distinction between dental and skeletal aetiology. Dental crossbites involving a single or multiple teeth, whether localized or generalized, can generally be managed through tooth expansion and controlled proclination using sequential aligner therapy. In contrast, skeletal transverse discrepancies require a preliminary orthopaedic expansion phase, with rapid maxillary expansion (RME) indicated in growing patients with an unfused midpalatal suture and miniscrew-assisted rapid palatal expansion (MARPE) considered in non-growing patients with a more mature or fused maxilla. Clear aligners are subsequently used primarily for post-expansion dental alignment and finishing rather than correction of the underlying skeletal transverse deficiency.^{6,9}

➤ Anteroposterior (Sagittal) Problems – Dental Component

- Less than 2 mm AP discrepancy: posterior IPR combined with Class II or III elastics.^{6,9}
- 2–4 mm AP discrepancy: posterior IPR and Class II/III elastics, combined with sequential distalisation of the buccal segments.^{6,9}
- Greater than 4 mm AP discrepancy: the existing buccal occlusion is generally maintained rather than fully corrected with aligners alone, and extraction-based mechanics are considered.^{9,22}

➤ Anteroposterior (Sagittal) Problems – Skeletal Component

The management of skeletal anteroposterior discrepancies is primarily determined by the patient's growth status. In growing individuals, Class II discrepancies may be managed through growth modification using functional appliances or fixed Class II correctors, whereas Class III discrepancies may be addressed with maxillary protraction using a facemask. Clear aligner therapy can subsequently be employed to establish and refine a Class I dental relationship.

In non-growing patients, treatment planning generally involves a choice between dental camouflage and orthognathic correction, depending on the severity and skeletal nature of the discrepancy. Camouflage may involve non-extraction Class II or Class III elastics in conjunction with clear aligners, with extraction-based camouflage considered when the discrepancy cannot be adequately addressed through dental movements alone. Where the skeletal discrepancy is beyond the limits of orthodontic camouflage, orthognathic surgery is indicated, followed by clear aligner therapy for postoperative alignment and finishing.^{6,9}

X. PROBLEMS FACED IN “IN-HOUSE ALIGNERS”

- Force calibration errors: without laboratory-standardised protocols, over- or under-activation per stage is common when clinicians are inexperienced in digital staging.^{3,4}
- Fit and marginal adaptation issues: variability in printer calibration, resin shrinkage, and thermoforming pressure can produce aligners with poor cervical adaptation or excess flash requiring manual trimming.^{5,10}
- Material stress relaxation is an important practical limitation because the force generated by an aligner can fall substantially during the first hours of loading and can continue to decline with repeated loading and unloading. PETG is particularly relevant in this context: published laboratory studies show marked early force decay, followed by a slower decline toward a residual-force plateau. The magnitude of this effect depends on material composition, thickness, temperature, hydration, activation, and the daily loading/unloading pattern.^{11,12,14}
- Attachment bonding inconsistency: composite attachment shape and position, critical for engaging

aligner material appropriately, are harder to standardise without laboratory templates.^{17,18,19}

- Under-delivery of planned IPR and proclination: published outcome data show that digitally planned IPR and proclination are often only partially realised clinically, which can leave residual crowding if not monitored and corrected mid-treatment.^{20,21}
- Sterilisation and infection-control workflow: incorporating scanning, printing, and thermoforming into clinical space requires dedicated infection-control protocols not traditionally part of chairside dentistry.^{3,4}
- Staff training and turnover: in-house systems are labour-intensive, and loss of a trained technician can disrupt production continuity.^{3,4}
- Limited case selection guidance for complex movements: extraction cases, severe skeletal discrepancies, and multi-rooted bodily movement remain harder to plan and execute reliably with aligners alone, whether in-house or outsourced, and often require adjunctive elastics, TADs, or combination with fixed appliances.^{6,9}

XI. DISCUSSION

Taken together, current evidence supports in-house clear aligner fabrication as a practical extension of digital orthodontics, while emphasizing that its clinical performance depends on the integration of digital planning, material science, manufacturing technology, and biomechanics.^{1,3} In-house fabrication offers advantages such as greater control over treatment staging, rapid modifications, reduced dependence on external laboratories, and individualized appliance design. However, these benefits are accompanied by challenges including equipment requirements, operator expertise, manufacturing variability, and the need for stringent quality control.

The manufacturing technique and material properties directly influence aligner fit, force delivery, and durability. Thermoformed and directly 3D-printed aligners may differ in mechanical behaviour because of variations in polymer composition, thickness, printing parameters, post-processing, and thermoforming conditions.¹⁻³ Furthermore, aligner polymers exhibit viscoelastic behaviour, including stress relaxation and force decay, making clinical force delivery dependent on loading duration, material characteristics, appliance geometry, and intraoral conditions.

Clinical effectiveness is also movement- and malocclusion-dependent. Mild to moderate crowding, selected transverse discrepancies, and certain vertical or anteroposterior corrections may be managed using staged aligner movements with appropriate attachments, IPR, or elastics. More complex movements and significant skeletal discrepancies may require adjunctive approaches such as TADs, orthopedic appliances, or orthognathic surgery.^{6,9} Therefore, in-house aligner therapy should be regarded not simply as a manufacturing technique but as a movement-specific, digitally integrated treatment system, in which material selection, manufacturing parameters, and

biomechanical design are tailored to the individual clinical requirement

XII. CONCLUSION

In-house clear aligner therapy offers greater clinician control, reduced fabrication time, and opportunities for individualized treatment planning; however, predictable outcomes depend on appropriate case selection, accurate digital planning, standardized manufacturing, and adequate quality control.^{1,3} The viscoelastic behavior and stress relaxation of aligner polymers are particularly important, as the force generated at insertion may progressively decline during intraoral use.^{8,12} Clinical application should therefore be guided by the specific malocclusion, required tooth movement, material properties, and appropriate biomechanical adjuncts. Future research should evaluate aligner materials under standardized 37°C, wet, cyclic-loading conditions and correlate laboratory force-retention characteristics with clinically observed tooth movement to establish more predictable material- and movement-specific protocols.^{1,3,8,12}

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