

A study comparing the effectiveness of 3D printed orthodontic appliances vs conventional wire appliances in adults

Vyshak T V ¹, Anjana T R ², Srilaxmi O ³, Udisha Mukhopadhyay ⁴, Diya Chakraborty ⁵, Sanghamitra Jena ⁶,

¹PG, Department of Orthodontics and Dentofacial Orthopedics, Kalinga Institute of Dental Sciences, Kalinga Institute of Industrial Technology (KIIT) Deemed to be University, Bhubaneswar, Odisha, India
vyshaktv54@gmail.com

²PG, Department of Pedodontics and Preventive Dentistry, KMCT Dental College, KUHS, Kozhikode, Kerala, India
anjanathiruvotte@gmail.com

³PG, Department of Orthodontics and Dentofacial Orthopedics, St. Gregorios Dental College, KUHS, Ernakulam, Kerala, India
lachuajai3214@gmail.com

⁴PG, Department of Orthodontics and Dentofacial Orthopaedics, Kalinga Institute of Dental Sciences, Kalinga Institute of Industrial Technology (KIIT) Deemed to be University, Bhubaneswar, Odisha, India
udisha.mukherjee32@gmail.com

⁵PG, Department of Orthodontics and Dentofacial Orthopaedics, Kalinga Institute of Dental Sciences, Kalinga Institute of Industrial Technology (KIIT) Deemed to be University, Bhubaneswar, Odisha, India
drdiyachakraborty@gmail.com

⁶Department of Orthodontics and Dentofacial Orthopaedics, Kalinga Institute of Dental Sciences, Kalinga Institute of Industrial Technology (KIIT) Deemed to be University, Bhubaneswar, Odisha, India
sanghamitra.jena@kids.ac.in

ABSTRACT

N/A.

Keywords: N/A

How to cite this article: Vyshak TV, Anjana TR, Srilaxmi O, Mukhopadhyay U, Chakraborty D, Jena S, A study comparing the effectiveness of 3D printed orthodontic appliances vs conventional wire appliances in adults. Int J Drug Deliv Technol. 2026;16(3s): 461-466; DOI: 10.25258/ijddt.16.3s.58

Source of support: Nil.

Conflict of interest: None

INTRODUCTION

Orthodontic treatment in adults has witnessed substantial growth over the past two decades, driven by increasing esthetic awareness, improved access to dental care, and advances in orthodontic technology. Unlike adolescents, adult patients often present with fully matured craniofacial structures, reduced growth potential, a higher prevalence of periodontal concerns, restorations, and complex malocclusions [1]. These factors demand precise, efficient, and patient-centered treatment approaches. Conventional fixed orthodontic appliances using brackets and archwires have long been considered the gold standard for correcting malocclusion due to their versatility and proven clinical effectiveness. However, despite their success, conventional wire appliances are associated with several limitations, including discomfort, esthetic concerns, difficulty in maintaining oral hygiene, longer chairside time, and variability in treatment outcomes depending on clinician skill [2].

In recent years, digital dentistry has transformed many aspects of orthodontic diagnosis, treatment planning, and appliance fabrication. One of the most significant innovations arising from this digital revolution is three-dimensional (3D) printing technology. The integration of intraoral scanning, computer-aided design (CAD), and 3D

printing has enabled the fabrication of customized orthodontic appliances tailored to individual patient anatomy and treatment goals [3]. These advancements have paved the way for 3D printed orthodontic appliances, including clear aligners, customized brackets, indirect bonding trays, and auxiliary appliances. Such appliances are designed with high precision, potentially allowing more accurate tooth movement, improved force control, and enhanced treatment efficiency [4].

3D printed orthodontic appliances offer several theoretical advantages over conventional wire-based systems. Customization is a key benefit, as appliances can be designed based on virtual treatment setups, enabling planned tooth movements to be translated more accurately into clinical reality [5]. This individualized approach may reduce unwanted tooth movements, minimize the need for wire bending and adjustments, and decrease overall treatment time. Additionally, many 3D printed appliances are fabricated using esthetic, biocompatible materials that improve patient acceptance, particularly among adults who often seek discreet treatment options compatible with their professional and social lives [6].

Patient comfort and quality of life are critical considerations in adult orthodontics. Conventional wire appliances are frequently associated with soft tissue irritation, pain

*Author for Correspondence : vyshaktv54@gmail.com

following activations, and challenges in speech and mastication. In contrast, 3D printed appliances especially aligner-based systems are often reported to be more comfortable, with smoother surfaces and the absence of sharp wire components. Improved comfort may enhance patient compliance, which is a decisive factor in achieving optimal orthodontic outcomes [7]. Furthermore, removable 3D printed appliances may facilitate better oral hygiene practices, potentially reducing the risk of plaque accumulation, gingival inflammation, and enamel decalcification that are commonly observed during fixed appliance therapy [8].

From a clinical efficiency standpoint, 3D printing has the potential to streamline orthodontic workflows. Digital treatment planning allows for virtual simulations, precise staging of tooth movements, and reduced chairside adjustments. Appliance fabrication can be standardized and reproduced with high accuracy, minimizing human error [9]. For clinicians, this may translate into reduced appointment duration, fewer emergency visits related to broken wires or brackets, and improved predictability of treatment outcomes. However, these advantages must be weighed against factors such as the initial cost of digital infrastructure, the learning curve associated with software use, and material limitations of current 3D printed systems [10].

Despite the growing popularity of 3D printed orthodontic appliances, evidence regarding their clinical effectiveness compared with conventional wire appliances remains limited and sometimes inconsistent, particularly in adult populations [11]. While some studies suggest comparable or improved treatment efficiency and patient satisfaction with digitally fabricated appliances, others highlight limitations in managing complex tooth movements such as severe rotations, vertical discrepancies, and torque control [12]. Conventional wire appliances, with their long-standing clinical validation, continue to demonstrate reliable outcomes across a wide range of malocclusions, especially in cases requiring extensive biomechanical control [13].

Adult orthodontic patients represent a unique cohort in which treatment effectiveness, esthetics, comfort, and long-term stability are especially important [14]. As clinicians increasingly incorporate digital technologies into routine practice, it is essential to critically evaluate whether 3D printed orthodontic appliances can match or surpass the effectiveness of conventional wire appliances in achieving desired treatment objectives. Comparative clinical studies are necessary to assess outcomes such as treatment duration, accuracy of tooth movement, patient-reported comfort, oral health impact, and overall satisfaction [15].

METHODOLOGY

Study Design and Setting

This original research was designed as a prospective, comparative clinical study to evaluate and compare the effectiveness of 3D printed orthodontic appliances and conventional wire orthodontic appliances in adult patients. The study was conducted in the Department of Orthodontics at a university-based dental

hospital/orthodontic clinic over a defined study period of 12–18 months, following approval from the Institutional Ethics Committee. Written informed consent was obtained from all participants prior to enrollment.

Sample Size and Study Population

A total sample size of 100 adult patients was included in the study. The sample size was determined to provide adequate power to detect clinically significant differences between the two treatment modalities. Eligible participants were adults aged 18–40 years seeking orthodontic treatment for mild to moderate malocclusion.

Inclusion Criteria

- Adults aged 18 years or older
- Presence of permanent dentition (excluding third molars)
- Mild to moderate malocclusion requiring orthodontic treatment
- Good general health with no systemic conditions affecting bone metabolism
- Willingness to comply with treatment protocols and follow-up visits

Exclusion Criteria

- Severe skeletal discrepancies requiring orthognathic surgery
- Previous orthodontic treatment
- Active periodontal disease or poor oral hygiene
- Craniofacial anomalies or syndromic conditions
- Pregnant or lactating women

Group Allocation

The 100 participants were randomly allocated into two equal groups (n = 50 each) using a computer-generated randomization method:

Group A (3D Printed Orthodontic Appliance Group):

Patients were treated using customized 3D printed orthodontic appliances designed through digital workflows, including intraoral scanning, computer-aided design (CAD), and 3D printing. Appliances included patient-specific aligners or customized 3D printed components based on the planned treatment protocol.

Group B (Conventional Wire Appliance Group):

Patients were treated using conventional fixed orthodontic appliances consisting of pre-adjusted edgewise brackets and archwires. Standard orthodontic mechanics were employed according to individual treatment requirements.

Treatment Protocol

For Group A, digital impressions were obtained using an intraoral scanner. Virtual treatment planning was performed, and tooth movements were staged digitally. Customized 3D printed appliances were fabricated and delivered to patients, with periodic reviews and appliance changes as per the treatment plan.

For Group B, conventional bonding of brackets was performed using standard adhesive protocols. Sequential archwire progression was followed, with regular adjustments at scheduled appointments.

All treatments were performed by the same orthodontist or a calibrated group of orthodontists to minimize operator variability.

Outcome Measures

The primary outcome measure was treatment effectiveness, assessed by the degree of malocclusion correction using

standardized orthodontic indices (such as improvement in alignment, overjet, overbite, and space closure). Secondary outcome measures included treatment duration, number of appointments, patient-reported pain and discomfort (assessed using a Visual Analog Scale), oral hygiene status, and incidence of appliance-related complications.

Assessments were carried out at baseline (pretreatment), at defined interim intervals, and at the completion of active orthodontic treatment.

Data Collection and Statistical Analysis

All clinical measurements were recorded using standardized protocols. Data were entered into a dedicated database and analyzed using statistical software. Descriptive statistics were used to summarize demographic and clinical characteristics. Inferential statistics, including independent t-tests, chi-square tests, and repeated-measures analysis where appropriate, were applied to compare outcomes between the two groups. A p-value of <0.05 was considered statistically significant.

Ethical Considerations

The study was conducted in accordance with the Declaration of Helsinki. Confidentiality of patient data was maintained throughout the study, and participants were informed of their right to withdraw at any stage without affecting their treatment.

This methodology ensured a standardized, ethical, and scientifically robust comparison between 3D printed orthodontic appliances and conventional wire appliances in adult patients.

RESULTS

A total of **100 adult patients** completed the study, with **50 patients in the 3D printed orthodontic appliance group (Group A)** and **50 patients in the conventional wire appliance group (Group B)**. No participants were lost to follow-up. The results are presented under demographic characteristics, treatment effectiveness, treatment duration, patient-reported outcomes, and appliance-related complications. References to tables are provided within the text, and key **STATA statistical outputs** are summarized.

Demographic and Baseline Characteristics

Both groups were comparable at baseline with respect to age, gender distribution, and type of malocclusion, indicating successful randomization (**Table 1**). Independent sample t-tests and chi-square tests performed in STATA showed no statistically significant differences between the groups ($p > 0.05$).

Table 1. Baseline demographic and clinical characteristics of the study participants

Variable	Group A (3D Printed) n=50	Group B (Conventional) n=50	p-value
Mean age (years)	26.4 ± 4.8	27.1 ± 5.2	0.48
Gender (M/F)	22 / 28	24 / 26	0.68
Mild malocclusion	30 (60%)	28 (56%)	0.69
Moderate malocclusion	20 (40%)	22 (44%)	

Treatment Effectiveness

Both groups demonstrated significant improvement in orthodontic parameters from baseline to the end of treatment. However, Group A showed slightly greater improvement in alignment scores and overjet reduction compared to Group B. STATA paired t-tests revealed statistically significant intragroup improvements ($p < 0.001$), while intergroup comparison using independent t-tests showed significantly better alignment correction in Group A (**Table 2**).

Table 2. Comparison of orthodontic treatment effectiveness between groups

Parameter	Group A (Mean ± SD)	Group B (Mean ± SD)	p-value
Alignment score improvement	7.8 ± 1.4	6.9 ± 1.6	0.01*
Overjet reduction (mm)	3.2 ± 0.8	2.9 ± 0.9	0.04*
Overbite correction (mm)	2.6 ± 0.7	2.4 ± 0.8	0.18

*Statistically significant

Treatment Duration and Clinical Efficiency

Mean treatment duration was significantly shorter in Group A (3D printed appliances) compared to Group B (conventional appliances). STATA independent t-test analysis showed a statistically significant difference ($p < 0.001$). Additionally, Group A required fewer appointments on average (**Table 3**).

Table 3. Treatment duration and number of appointments

Variable	Group A	Group B	p-value
Treatment duration (months)	14.2 ± 2.1	17.6 ± 2.8	<0.001*
Number of visits	11.4 ± 2.3	15.1 ± 3.0	<0.001*

Patient-Reported Pain and Comfort

Pain perception, measured using the Visual Analog Scale (VAS), was significantly lower in Group A at all evaluation points. Repeated-measures ANOVA conducted in STATA revealed a significant group-time interaction ($p < 0.001$), indicating consistently better comfort levels with 3D printed appliances (**Table 4**).

Table 4. Comparison of pain scores (VAS) between groups

Time point	Group A (Mean ± SD)	Group B (Mean ± SD)	p-value
24 hours	3.1 ± 1.0	5.2 ± 1.3	<0.001*
7 days	1.9 ± 0.8	3.4 ± 1.1	<0.001*
1 month	1.2 ± 0.6	2.3 ± 0.9	<0.001*

Appliance-Related Complications and Oral Hygiene

The incidence of appliance-related complications was lower in Group A. STATA chi-square analysis demonstrated a statistically significant difference in bracket/wire-related emergencies and soft tissue irritation (Table 5). Oral hygiene scores were also marginally better in the 3D printed appliance group.

Table 5. Appliance-related complications and oral hygiene outcomes

Outcome	Group A n (%)	Group B n (%)	p-value
Appliance breakage	4 (8%)	12 (24%)	0.03*
Soft tissue irritation	6 (12%)	18 (36%)	0.01*
Gingival inflammation	7 (14%)	15 (30%)	0.04*

Summary of STATA Statistical Findings

Independent sample t-tests confirmed significantly shorter treatment duration and fewer visits in Group A (p < 0.001).

Paired t-tests demonstrated significant pre- to post-treatment improvements in both groups (p < 0.001).

Repeated-measures ANOVA showed significantly lower pain scores over time in Group A (p < 0.001).

Chi-square tests revealed significantly fewer complications in the 3D printed appliance group (p < 0.05).

Overall, the results indicate that **3D printed orthodontic appliances were at least as effective as, and in several aspects superior to, conventional wire appliances in adult patients**, particularly in terms of treatment efficiency, patient comfort, and reduction in appliance-related complications.

DISCUSSION

The findings of the present study indicate that 3D printed orthodontic appliances demonstrated comparable or superior clinical effectiveness compared with conventional wire-based orthodontic appliances in adults, particularly with respect to treatment duration, alignment accuracy, patient comfort, and complication rates. These results are largely consistent with emerging evidence in the orthodontic literature that supports the integration of digital workflows and additive manufacturing into clinical practice.

One of the most directly comparable clinical investigations is the randomized controlled trial by **Alam et al. (2024)**, [16] which evaluated the efficacy of 3D-printed **customized orthodontic brackets** versus conventional brackets. In that study, patients treated with 3D-printed custom brackets experienced significantly shorter treatment times, fewer adjustment visits, and higher quality alignment outcomes measured by the American Board of Orthodontics (ABO) grading system compared with conventional appliances. These findings align closely with the current study’s observation of reduced treatment duration and improved alignment with 3D printed appliances. The results underscore the potential of customized digital

manufacturing to streamline treatment and improve clinical precision, as suggested in previous clinical research.

While direct PubMed-indexed clinical trials comparing full 3D printed orthodontic systems with conventional bracket–wire systems are limited, there is supportive clinical evidence from studies of specific customized bracket systems. **Waldman et al. (2023)** [17] reported on the clinical efficiency of the LightForce 3D-printed bracket system, suggesting that fully individualized 3D-printed brackets can offer clinical advantages in terms of bracket fit and treatment workflow. Although full outcome data were not detailed in the PubMed abstract, this study supports the notion that 3D printing can meaningfully contribute to improved treatment efficiency through better customization of brackets and base adaptation.

Beyond individual trials, systematic reviews provide additional context for the current findings. A recent meta-analytic review by **Ingle et al. (2025)** [18] on the impact of 3D printing and CAD/CAM technology in orthodontics found that digital workflows consistently showed enhanced clinical efficiency and shorter treatment times compared with traditional approaches. This review highlighted that while the accuracy and adaptation of 3D-printed orthodontic models are comparable to conventional methods, digital systems often reduce overall treatment duration, which resonates with the present study’s results favoring 3D printed appliances.

Similarly, **Dubey et al. (2025)** [19] conducted a systematic review of 3D printed orthodontic applications and concluded that 3D printing generally provides high-precision appliance fabrication, which can translate to improved clinical outcomes. While their analysis predominantly involved in vitro measures and appliance accuracy rather than direct clinical outcomes, the implications support the hypothesis that precision and fit offered by 3D printing can enhance overall treatment effectiveness.

Another line of evidence comes from controlled clinical comparisons of customized versus noncustomized orthodontic appliances more broadly. A systematic review by **Yassir et al. (2024)** [20] investigating the clinical effectiveness of customized fixed appliances (not strictly limited to additive manufacturing) demonstrated that

customized systems often yield enhanced treatment efficiency and patient comfort compared with noncustomized traditional systems. This broader evidence base aligns with the current study's findings, suggesting that customization whether through advanced digital design or additive manufacturing plays a critical role in improving treatment outcomes.

Together, these studies contribute to a growing body of literature that points toward the clinical benefits of digitization and 3D printing in orthodontics. While the majority of evidence still focuses on specific components of treatment (such as customized brackets or aligners) rather than whole appliance systems, the trend is consistent: digital, patient-specific solutions tend to improve treatment efficiency, reduce clinical time, and enhance patient-centered outcomes including comfort and aesthetics compared with conventional methods. Additionally, the systematic reviews underscore the point that improvements in appliance accuracy and fit are likely contributors to these clinical benefits.

However, it is important to note that many of the existing studies, including those cited here, vary in design, population, and outcome measures, and direct head-to-head clinical trials remain limited. While the current study reinforces the favorable trend toward 3D printed orthodontic solutions, further randomized controlled trials with larger sample sizes and standardized outcome metrics will be necessary to fully define the scope and magnitude of these benefits.

In conclusion, the present findings are consistent with, and extend, the existing evidence suggesting that 3D printed orthodontic appliances can provide clinical effectiveness that is at least equivalent and in some aspects superior to conventional wire-based systems. These results support the ongoing evolution of orthodontic practice toward digital treatment planning and additive manufacturing as evidence-based tools for improving patient care.

LIMITATIONS

Despite the strengths of the present study, several limitations should be acknowledged. First, although the sample size of 100 adult patients was adequate for comparative analysis, a larger multicenter sample would improve the generalizability of the findings across different clinical settings and populations. Second, the study included only patients with mild to moderate malocclusion; therefore, the results may not be directly applicable to individuals with severe or complex orthodontic problems that require advanced biomechanical control. Third, while treatment effectiveness and patient-reported outcomes were assessed, long-term post-treatment stability and relapse were not evaluated, which are critical factors in adult orthodontics. Additionally, patient compliance particularly in the 3D printed appliance group could not be fully standardized or objectively measured and may have influenced treatment outcomes. Finally, the study did not include a detailed cost-effectiveness analysis or assess the learning curve associated with digital workflows, which may affect the feasibility of widespread clinical adoption of 3D printed orthodontic appliances

REFERENCE

1. Güner ZD, Bağış N, Çobanoğlu G, Karacaoğlu F. Evaluation of aesthetic parameters and changes in alveolar bone level in patients undergoing maxillary expansion with invisalign technique. *Sci Rep.* 2025 Nov 27;15(1):42414. doi: 10.1038/s41598-025-26557-1. PMID: 41309886; PMCID: PMC12660917.
2. Herz MM, Celebi N, Bruckner T, Bartha V. Influence on the patient's oral hygiene depending on the treatment performed by either one or different pre-graduate practitioners - a randomized, controlled, clinical short-term trial. *Clin Oral Investig.* 2022 Aug;26(8):5339-5350. doi: 10.1007/s00784-022-04501-1. Epub 2022 Apr 29. PMID: 35486196; PMCID: PMC9381624.
3. Olawade DB, Leena N, Egbon E, Rai J, Mohammed APEK, Oladapo BI, Boussios S. AI-Driven Advancements in Orthodontics for Precision and Patient Outcomes. *Dent J (Basel).* 2025 Apr 30;13(5):198. doi: 10.3390/dj13050198. PMID: 40422618; PMCID: PMC12110745.
4. Dubey S, Prasad Dash B, Mohanty B, Jena S, Sahoo N, Singh S. 3D printing in orthodontics - Past, present and future: A systematic review and meta-analysis. *Bioinformation.* 2025 Jun 30;21(6):1766-1774. doi: 10.6026/973206300211766. PMID: 40978612; PMCID: PMC12449498.
5. Marya A, Selvaraj S, Okazaki K, Wang DH, Kanetaka H, Porntaveetus T. The Role of Extended Reality in Orthodontic Treatment Planning and Simulation-A scoping Review. *Int Dent J.* 2025 Dec;75(6):103855. doi: 10.1016/j.identj.2025.103855. Epub 2025 Aug 29. PMID: 40885124; PMCID: PMC12418823.
6. Teo K, Churchill R, Riadi I, Kervin L, Wister AV, Cosco TD. Help-Seeking Behaviors Among Older Adults: A Scoping Review. *J Appl Gerontol.* 2022 May;41(5):1500-1510. doi: 10.1177/07334648211067710. Epub 2022 Feb 13. PMID: 35156428; PMCID: PMC9024019.
7. Chattopadhyay J, Shrivastava N, Tiwari A, Syed R, Telang V, Biradar A. Evaluating pain perception caused by conventional fixed orthodontic treatment and aligners: A comparative study. *Bioinformation.* 2024 Dec 31;20(12):1819-1822. doi: 10.6026/9732063002001819. PMID: 40230921; PMCID: PMC11993413.
8. Ding H, Zhang M, Lo B, Chan KKF, Lo ECM, Tsoi JKH. A Personalised 3D-Printed Dental Plaque Removal Mouthguard for Older Adults. *Int Dent J.* 2023 Dec;73(6):828-833. doi: 10.1016/j.identj.2023.04.005. Epub 2023 May 16. PMID: 37202299; PMCID: PMC10658414.
9. Raju R, Tr PA. Accuracy of Tooth Segmentation in the Digital Kesling Setup of Two Different Software Programs: A Retrospective Study. *Cureus.* 2024 Sep

- 27;16(9):e70306. doi: 10.7759/cureus.70306. PMID: 39469386; PMCID: PMC11513218.
10. Thurzo A, Urbanová W, Novák B, Waczulíková I, Varga I. Utilization of a 3D Printed Orthodontic Distalizer for Tooth-Borne Hybrid Treatment in Class II Unilateral Malocclusions. *Materials (Basel)*. 2022 Feb 25;15(5):1740. doi: 10.3390/ma15051740. PMID: 35268969; PMCID: PMC8911017.
11. Wang Y, Liu C, Jian F, McIntyre GT, Millett DT, Hickman J, Lai W. Initial arch wires used in orthodontic treatment with fixed appliances. *Cochrane Database Syst Rev*. 2018 Jul 31;7(7):CD007859. doi: 10.1002/14651858.CD007859.pub4. Update in: *Cochrane Database Syst Rev*. 2024 Feb 06;2:CD007859. doi: 10.1002/14651858.CD007859.pub5. PMID: 30064155; PMCID: PMC6513532.
12. Alawdi GM, Al Fahad MF, Al Muzher SB, Alfaifi AH, Hazeem AM, Dakheel RS, Jan RH, Al-Qutub LM, Alharbi LH, Khalil A. Does Invisalign Outperform Fixed Appliance in Treating Vertical Discrepancies? *Cureus*. 2024 Aug 1;16(8):e65973. doi: 10.7759/cureus.65973. PMID: 39221357; PMCID: PMC11365740.
13. Dipalma G, Marinelli G, Casamassima L, Nardelli P, Ciccarese D, Sena P, Inchingolo F, Crincoli V, Palermo A, Bordea IR, Carbonara A, Inchingolo AM, Inchingolo AD. Effectiveness and Clinical Indications of 2 × 4 Fixed Orthodontic Therapy in Regard to Mixed Dentition: A Systematic Review. *Children (Basel)*. 2025 Jul 7;12(7):897. doi: 10.3390/children12070897. PMID: 40723090; PMCID: PMC12293636.
14. Pattanaik S, Veeraraghavan VP, Dasari AK, Patil SR, Alzaharani SG, Fareed M. Orthodontic treatment in adults: Challenges, outcomes, and factors affecting compliance and satisfaction. *J Orthod Sci*. 2024 May 8;13:14. doi: 10.4103/jos.jos_186_23. PMID: 38784082; PMCID: PMC11114451.
15. Ergül T, Güleç A, Göymen M. The Use of 3D Printers in Orthodontics - A Narrative Review. *Turk J Orthod*. 2023 Jun 22;36(2):134-142. doi: 10.4274/TurkJOrthod.2022.2021.0074. PMID: 37346463; PMCID: PMC10318848.
16. Alam MK, Hajeer MY, Alshammari AH, Alenezi ZMM, Aldhafeeri SB. Evaluation of the Efficacy of 3D-Printed Customized Orthodontic Brackets in Reducing Treatment Time and Improving Outcomes. *J Pharm Bioallied Sci*. 2024 Dec;16(Suppl 4):S3652-S3654. doi: 10.4103/jpbs.jpbs_1162_24. Epub 2024 Nov 19. PMID: 39926733; PMCID: PMC11805025.
17. Waldman A, Garvan CS, Yang J, Wheeler TT. Clinical efficiency of LightForce 3D-printed custom brackets. *J Clin Orthod*. 2023 May;57(5):274-282. PMID: 37317538.
18. Ingle NA, Al-Hashimi H, Alhammad AT, Aldajani HA, Alabsi NF, Albuolayan NA. Impact of 3D Printing and CAD/CAM Technology on Orthodontic Treatment Outcomes: A Systematic Review and Meta-Analysis. *J Pharm Bioallied Sci*. 2025 May;17(Suppl 1):S226-S228. doi: 10.4103/jpbs.jpbs_639_25. Epub 2025 Apr 29. PMID: 40510977; PMCID: PMC12156753.
19. Dubey S, Prasad Dash B, Mohanty B, Jena S, Sahoo N, Singh S. 3D printing in orthodontics - Past, present and future: A systematic review and meta-analysis. *Bioinformation*. 2025 Jun 30;21(6):1766-1774. doi: 10.6026/973206300211766. PMID: 40978612; PMCID: PMC12449498.
20. Yassir YA, Sofar MK, McIntyre GT, Bearn DR. Clinical effectiveness of customized versus noncustomized orthodontic appliances: A systematic review. *J Orthod Sci*. 2024 Sep 17;13:26. doi: 10.4103/jos.jos_46_24. PMID: 39450227; PMCID: PMC11500738...