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ORIGINAL RESEARCH

COST AND CLINICAL IMPACT OF DIGITAL VS. CONVENTIONAL INDIRECT BONDING IN EXTRACTION ORTHODONTIC TREATMENT OF CLASS I MALOCCLUSION

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Abstract

Background:Orthodontic treatment advancements aim to improve clinical outcomes, efficiency, and patient satisfaction. Indirect bonding techniques, both conventional (CIB) and digital (DIB), are innovations that enhance bracket placement accuracy, reduce chairside time, and potentially minimize the number of visits. However, while digital methods offer increased precision and efficiency, they incur higher laboratory costs and require advanced technology.

Methods: This prospective, randomized controlled trial included 28 patients with Class I malocclusion requiring orthodontic extraction. Participants were randomized into CIB or DIB groups. Brackets in the CIB group were manually positioned on plaster models and transferred using vacuum-formed trays, while the DIB group used digitally scanned models with 3D-printed transfer trays. Treatment outcomes were assessed using the Objective Grading System (OGS). Cost, treatment time, number of visits, and bracket failure rates were also evaluated.

Results: Both techniques yielded comparable OGS scores (CIB median: 14; DIB median: 12; P=1.000), indicating similar treatment quality. Laboratory costs were significantly higher for DIB ($100.54) than CIB ($16.30; P<0.001). However, the DIB group demonstrated significant advantages, including shorter treatment times (20 months vs. 24 months; P=0.021) and fewer visits (23 vs. 27; P=0.003). Initial bracket failure rates were lower in the DIB group (2 vs. 4; P=0.018).

Conclusion: Both techniques provide similar treatment quality, but DIB represents a promising advancement in orthodontics, balancing initial costs with improved clinical efficiency and patient satisfaction. Further research with larger, diverse populations is necessary to validate these findings and assess long-term cost-effectiveness.

Keywords: extraction orthodontic treatment, Class I malocclusion, indirect bracket positioning, conventional indirect bonding, digital indirect bonding

INTRODUCTION

Orthodontic treatment continues to evolve, with a strong focus on improving clinical outcomes, efficiency, and patient satisfaction. As demand for orthodontic care rises, optimizing treatment efficiency and reducing costs have become critical goals. Indirect bonding techniques, both conventional and digital, are key innovations in addressing these challenges by minimizing chairside time, enhancing bracket placement accuracy, and potentially reducing the number of required visits.

Conventional indirect bonding, introduced by Silverman and Cohen in the 1970s, was initially praised for its ability to reduce chairside time by allowing brackets to be positioned on a model outside the mouth and then transferred to the patient using a bonding tray[1].

This method improved visibility and precision compared to direct bonding but required time-intensive laboratory steps that increased total treatment time and costs[2]. Since then, the technique has undergone numerous refinements, as summarized in a comprehensive review by Kalange and Thomas[3]. Bozelli et al. noted that while indirect bonding could reduce clinical time, its labor-intensive nature in the laboratory limited its overall efficiency[4].

In recent years, digital technologies have transformed orthodontics, offering significant improvements in workflow precision and efficiency. Digital indirect bonding (DIB), powered by computer-aided design and manufacturing (CAD/CAM), involves virtual bracket placement on 3D models and the fabrication of bonding trays using 3D printing technology. Early adopters such as Redmond et al. and Garino and Garino highlighted how CAD/CAM workflows could enhance efficiency and reduce errors[5,6].Ciuffolo et al. demonstrated the potential of rapid prototyping to simplify tray preparation further [7].

Studies suggest that digital indirect bonding may reduce the number of visits and total treatment time due to its enhanced precision and fewer required follow-up adjustments. For example, Christensen and Cope highlighted how digital workflows using intraoral scanning and 3D printing streamline the process, potentially leading to shorter treatment durations[8]. Similarly, Rosti et al. described how digital methods improve bracket placement accuracy, reducing mid-course corrections and the overall number of visits [9].

However, the initial costs of CAD/CAM systems, including 3D scanners and software, remain significant, which can offset long-term savings in materials and labor[10]. Conventional indirect bonding, while more labor-intensive, involves lower upfront costs, making it more appealing in settings with limited access to advanced technologies.

Comparative studies have demonstrated the advantages of digital techniques over conventional methods. For example, Czolgosz et al. found that digital bonding significantly reduced chairside time while offering comparable bracket placement accuracy and lower failure rates[11]. Furthermore, Kono et al. reported that digital techniques, despite higher initial costs, improved overall treatment efficiency by reducing manual errors and enhancing bracket placement precision[12].

However, the higher laboratory costs of digital workflows remain a challenge. Plattner et al. highlighted that digital bonding requires significant investment in equipment, software, and materials, which may offset the time savings [13]. Sollenius et al. emphasized the need for economic evaluations to assess the cost-effectiveness of new orthodontic technologies[10].

Despite these considerations, digital indirect bonding shows immense promise. Haeger noted its potential for improving clinical metrics, particularly in achieving consistent outcomes with self-ligating brackets[14]. Additionally, Soares Ueno et al. recently demonstrated the accuracy of digital techniques, suggesting their suitability as a reliable alternative to conventional methods [15].

Despite its potential, digital indirect bonding's impact on treatment efficiency and cost requires further study. As far as we know, there have been no direct comparisons between digitally positioned brackets and the conventional manual indirect bonding technique. This study aims to address this gap by systematically evaluating both methods' clinical and financial aspects, focusing on total treatment time, laboratory costs, bracket placement accuracy, and overall efficiency. By analyzing these factors, this research seeks to guide practitioners in determining the most effective approach to indirect bonding in orthodontic treatment.

METHODS

This study was a prospective, randomized controlled trial involving 28 patients with Class I malocclusion who were scheduled for orthodontic extraction treatment. Participants were randomly assigned to either the conventional indirect bonding (CIB) group or the digital indirect bonding (DIB) group. Prior to the study, approval was obtained from the Institutional Review Board (IRB) of the Faculty of Dentistry at Suez Canal University, and all participants provided written informed consent.

To date, no studies have directly compared OGS outcomes between these specific digital and conventional indirect bonding approaches. Consequently, an a priori sample size calculation was performed using variability estimates from a previous investigation of OGS scores[16]. Assuming a standard deviation of approximately 2.5, a significance level of 0.05, and 80% statistical power, the analysis indicated that 14 participants per group (28 in total) would be necessary to detect a clinically meaningful difference.

Eligible patients were between 18 and 40 years old, had permanent dentition (excluding third molars), bilateral Angle's Class I molar relationships, no skeletal discrepancies, and no history of prior orthodontic treatment.

Dental impressions were taken to create plaster models for both groups. In the CIB group, brackets were positioned on the plaster models and transferred to the patients' teeth using a 1 mm vacuum-formed transfer tray **(Figure 1)**.

In the DIB group, digital scans of the plaster models were used to create 3D models, with the brackets positioned on the 3D models and transferred to the patients' teeth using a 3D-printed transfer tray **(Figure 2)**.

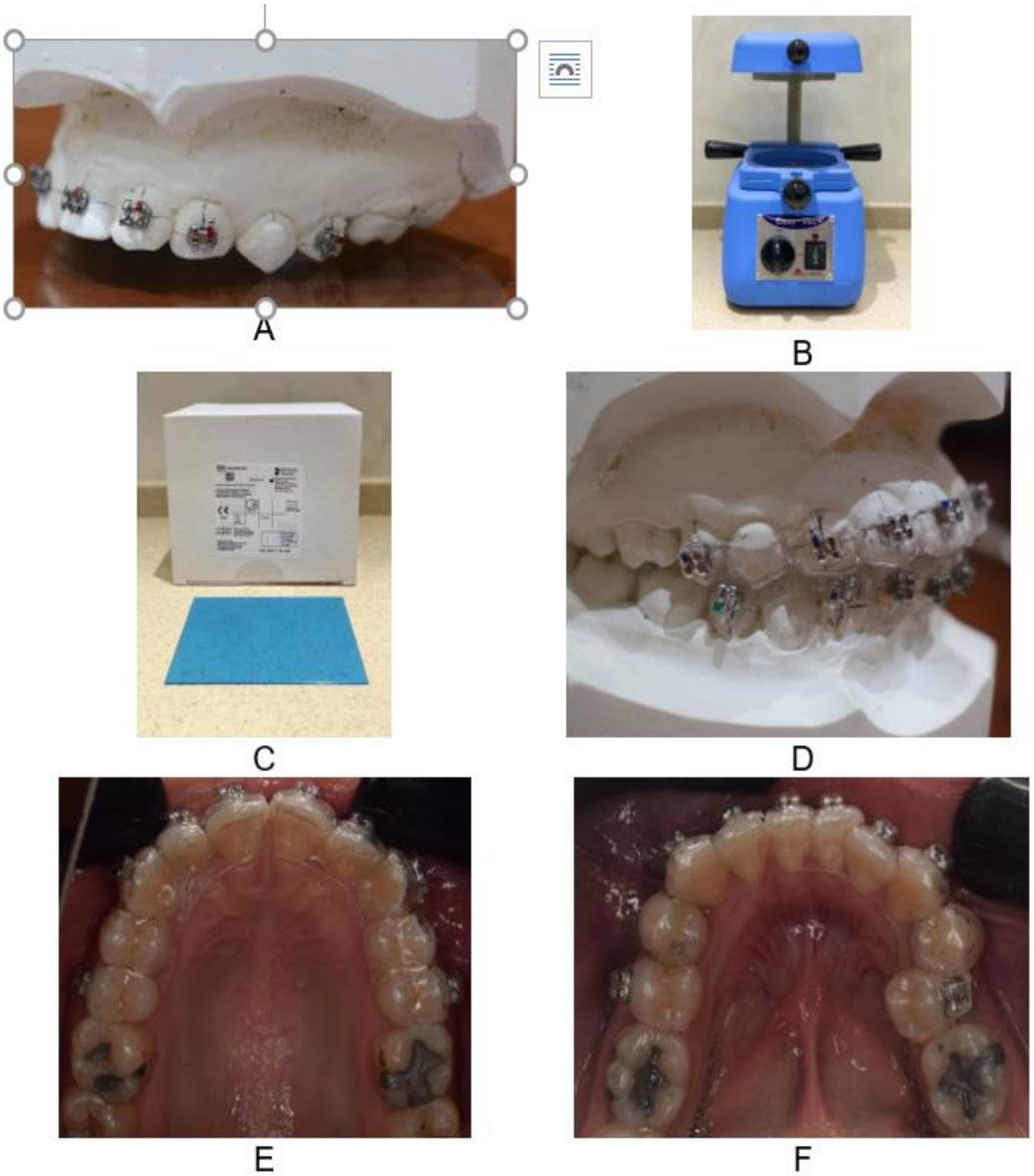

Figure 1. Conventional indirect bonding technique: A, positioning of the brackets on dental cast according to positioning guidelines; B, Vacuum former used in the study; C: Sheets used in the Conventional group; D: transfer tray after installation of the casts; Occlusal view showing trasnfer trays, upper (E) and lower (F) arches.

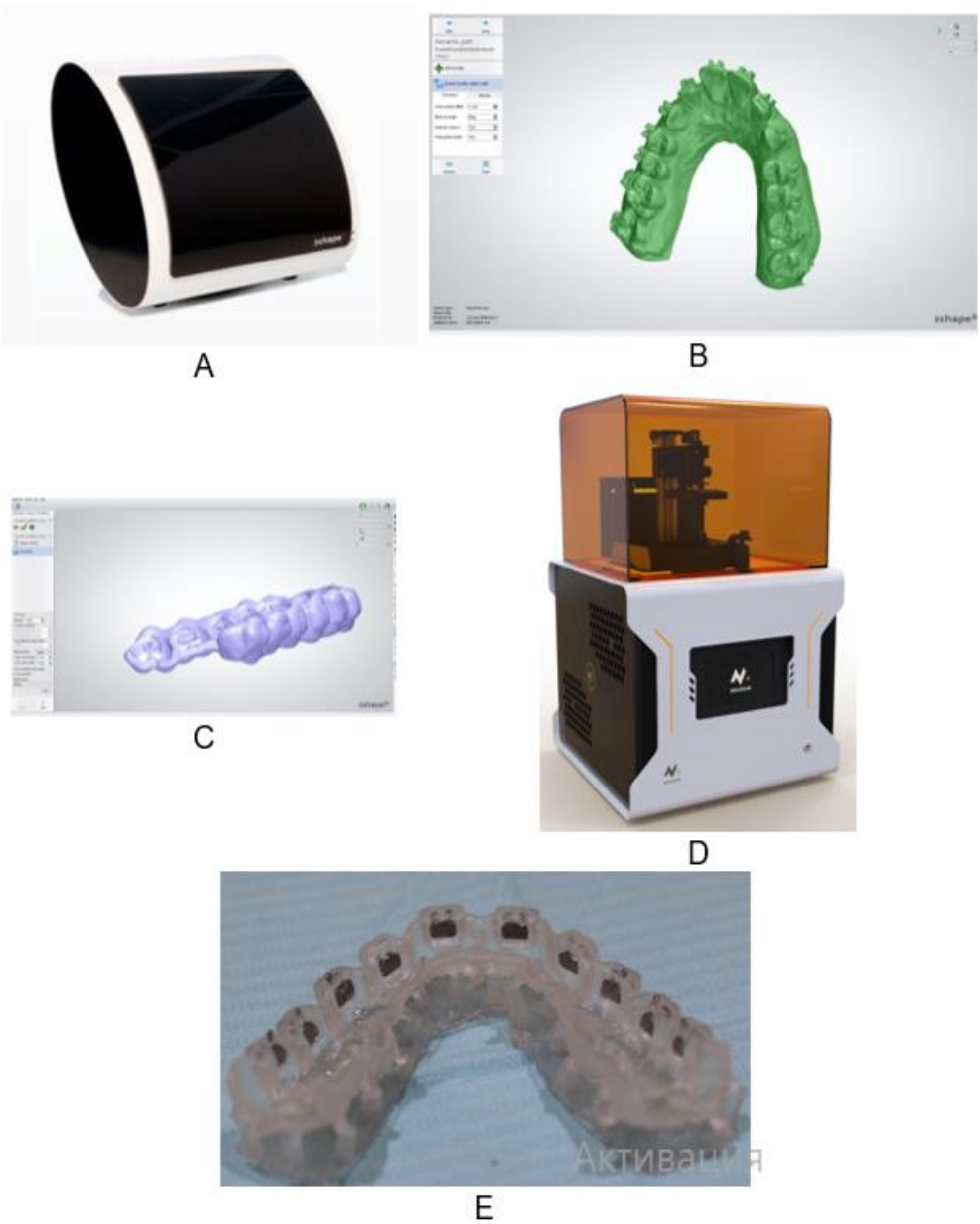

Figure 2. Digital indirect bonding technique: A, Lab scanner 3Shape R500; B, 3Shape OrthoAnalyzer software defining digital bracket adjustment; C, Constructed virtual transfer tray ready for printing; D, DLP printer Mogassam Dent 2; E, transfer tray loaded with brackets.

Treatment outcomes were evaluated using the Objective Grading System (OGS), which assesses factors such as alignment, marginal ridges, buccolingual inclination, occlusal contacts, occlusal relationships, overjet, interproximal contacts, and root angulation [17]. A total OGS score of less than 20 points was considered to meet the ABO's standard for orthodontic treatment. All patients were bonded by a single operator to ensure consistency, and a single evaluator assessed the OGS scores and was blinded to group assignments to minimize the risk of detection bias.

Data analysis was performed using IBM SPSS Statistics for Macintosh, Version 26.0. Qualitative data were expressed as frequencies and percentages, while quantitative data were presented as medians and interquartile ranges (IQR).

The Mann-Whitney U test (Wilcoxon rank-sum test) was used to compare the distribution of variables between the CIB and DIB groups. Associations between categorical variables were examined using the chi-square test, and Fisher's exact test was applied when observed or expected values were less than five. A two-sided p-value of less than 0.05 was considered statistically significant.

RESULTS

The study compares conventional and digital indirect bonding techniques in orthodontics, examining both patient characteristics and treatment outcomes. Table 1 presents the baseline characteristics of the studied patients, showing a balanced distribution between the two groups. Each group consisted of 14 patients, with no statistically significant differences in gender distribution, age, or discrepancy index. The conventional group had a slightly higher proportion of males (71.4% vs 57.1% in the digital group), but this difference was not significant (P=0.695). The median ages were similar (20 years for conventional, 21 years for digital) with a narrow interquartile range. The discrepancy index showed a higher median in the DIB compared to the CIB (22 vs 30, respectively), though this difference was not statistically significant (P=0.653).

Table 1. Baseline characteristics of the studied groups

	Conventional	Digital	P
Gender			
Males, n (%)	10 (71.4)	8 (57.1)	0.695
Females, n (%)	4 (28.6)	6 (42.9)	
Age, median (IQR)	20 (3.5)	21 (4)	1.000
Discrepancy index, median (IQR)	22 (5.5)	30 (15.5)	0.653

IQR, interquartile range.

Table 2 presents the detailed cost breakdown. The total bonding cost for the conventional group was calculated at $16.30, comprising $10.00 in materials and approximately $6.30 in estimated labor costs. In contrast, the digital indirect bonding incurred a significantly higher total cost of $100.54, which consisted primarily of the fixed laboratory service fee (P < 0.001).

Table 2. Direct cost analysis of both techniques

	Time (Average)	Unit Cost (USD)	Total Cost (USD)
A. Conventional indirect bonding			
1. Clinical steps (bonding)			
Orthodontist (clinic time)	16 min 47 s	6.00 / hr	1.68
Dental assistant (assisting)	16 min 47 s	1.60 / hr	0.45
2. Laboratory steps (manual)			
Materials (alginate, stone, sheets)	N/A	Flat rate	10.00
Laboratory technician (pouring/trimming)	20 min	2.00 / hr	0.67
Orthodontist (bracket positioning)	30 min	6.00 / hr	3.00
Laboratory technician (tray fabrication)	15 min	2.00 / hr	0.50
Total cost			16.30
B. Digital indirect bonding			
1. Clinical steps (bonding)			
Dental assistant (bonding/assisting)	12 min 52 s	1.60 / hr	0.34
Orthodontist (supervision/check)	2 min	6.00 / hr	0.20
2. Laboratory steps (digital)			
3D Laboratory service fee (scan/design/print)	N/A	Flat rate	100.00
Total cost			100.54

The treatment outcomes are presented in Table 3. The total OGS scores were similar between the two groups (14 for conventional, 12 for digital; P=1.000), suggesting comparable overall treatment quality. Although the laboratory costs were significantly higher for the digital technique ($100.54 compared to $16.30 for conventional; P<0.001), the digital technique demonstrated several advantages in other metrics. Treatment time was significantly reduced with the digital technique (20 months vs 24 months; P=0.021), as was the number of required visits (23 vs 27; P=0.003). Additionally, the digital technique showed a significantly lower rate of initial bracket failure (2 vs 4; P=0.018).

Table 3. Outcomes and associated costs of the studied groups

	Conventional	Digital	P
Total OGS	14 (6.5)	12 (3)	1.000
Total bonding cost ($)	16.30 (2.06)	100.54 (0.61)	0.001
Treatment time (months)	24 (2)	20 (2)	0.021
Number of visits	27 (2)	23 (1.5)	0.003
Initial bracket failure	4 (1)	2 (1)	0.018

Data are median (IQR).
OGS, Objective Grading System.

DISCUSSION

The results of this study comparing conventional indirect bonding and digital indirect bonding techniques in orthodontics provide valuable insights into both treatment efficiency and patient outcomes. The baseline characteristics of the two groups, as shown in Table 1, indicate a balanced distribution between the CIB and DIB groups, with no significant differences in gender, age, or discrepancy index. This balance ensures that patient characteristics were unlikely to have influenced the outcomes.

In terms of treatment quality, the overall OGS scores were comparable between the groups, with no significant difference between the conventional and digital methods (medians of 14 and 12, respectively, P=1.000). This suggests that both techniques can achieve similar clinical outcomes in terms of the precision of bracket placement and treatment effectiveness. This is consistent with the findings of Yıldırım and Saglam-Aydinatay, who compared direct and indirect bonding techniques in non-extraction orthodontic treatment for Class I malocclusion patients, reporting median OGS scores of 14 for indirect bonding and 17 for direct bonding [18].

The laboratory cost of DIB was significantly higher ($100.54) compared to CIB ($16.30, P<0.001). The cost of the digital technique in our study aligns with the findings of Czolgosz *et al.*,[11] who reported that the direct cost of digital indirect bonding trays was approximately 84 euros, closely matching our observed cost. However, our analysis highlights a distinct economic reality compared to such studies conducted in Europe or North America. While previous research often employs cost-minimization analyses where high clinician salaries narrow the gap between digital and conventional methods, our findings reflect the Egyptian economic context. Due to significantly lower local labor rates, the time-intensive manual steps of conventional indirect bonding—relying on affordable plaster and thermoplastic materials—added only a minimal financial burden (~$6.30). Consequently, the conventional method remained approximately six times cheaper than the digital alternative, as the latter is driven by fixed hardware and software costs that are less sensitive to local economic variations.

However, the digital technique offered distinct advantages. The DIB group experienced significantly shorter treatment times (20 months vs. 24 months; P=0.021) and fewer required visits (23 vs. 27; P=0.003). These findings are consistent with Brown et al. study[19], as treatment times for the 3 groups were significantly different; the CAD/CAM group was the shortest at 13.8 ± 3.4 months, compared with 21.9 ± 5.0 and 16.9 ± 4.1 months for the direct bonded and indirect bonded groups, respectively. The distinction is made between class 1 and class 2 malocclusions. In the case of class 1 malocclusions, traditional indirect bonding required less time on average (15 months) than direct bonding (17 months), while in class 2 malocclusions, direct bonding took less time (22 months) than indirect bonding (22.5 months). The number of treatment appointments for the CAD/CAM group was significantly fewer than for the direct bonded group.

Similarly, the findings of Yıldırım and Saglam-Aydinatay align with our results, demonstrating no significant difference in total treatment time between direct bonding (12.0 ± 3.1 months) and conventional indirect bonding (11.4 ± 2.4 months)[18].

It should be highlighted that most of the total working time for indirect bonding is spent in the laboratory stage, resulting in time savings for the clinician such a reduction in chair-side time could be advantageous in busy clinics and make the treatment more comfortable for the patient[4]. To the best of our knowledge, no other studies have specifically included patients requiring extractions, as was done in our study.

This reduction in treatment duration and appointments directly benefits both patients and practitioners. Shorter treatment times reduce the burden on patients, improving their overall experience, while fewer visits lower the clinic's workload, increasing operational efficiency. The time savings associated with the digital technique are likely due to the increased precision in bracket placement, leading to fewer adjustments and corrections throughout the treatment.

Moreover, the digital method showed a significantly lower rate of initial bracket failure (2 in the DIB group vs. 4 in the CIB group; P= 0.018). Multiple studies assessed the bracket failure following different bonding techniques. However, we could not find any direct comparisons between the digital indirect bonding and conventional indirect bonding using hard splint transfer tray. Nevertheless, our numbers are comparable to that of the literature regarding the DIB method, as shown by Pottier et al., who observed a 2.5% bracket failure rate [20]. Regarding, bracket failure following conventional indirect bonding, the meta-analysis by Li et al. showed a pooled bracket failure rate of 7.5% which again aligns with our findings[21].

The significantly lower initial bracket failure rate associated with the DIB highlights the potential reliability of digital methods in improving treatment stability early on, which may further contribute to the reduction in treatment time and visits. Fewer bracket failures translate into fewer emergency visits and less need for re-bonding, adding to the efficiency of the digital workflow.

While the results are promising for the digital technique, further research with larger and more diverse patient populations would be beneficial to confirm these findings and explore their applicability across different orthodontic scenarios. Long-term follow-up studies would also be valuable to assess the stability of treatment outcomes and any differences in relapse rates between the two techniques.

Adopting digital indirect bonding in orthodontics faces barriers, including high laboratory costs for 3D scanners, CAD/CAM software, and 3D printers, which can be prohibitive for smaller practices [13,22]. The workflow's complexity and learning curve for virtual bracket positioning and tray design further hinder adoption8.

However, while the upfront laboratory costs of digital bonding are higher, they must be evaluated in the broader context of overall treatment efficiency. Digital methods can reduce chairside time, improve precision in bracket placement, and lower the risk of bracket failures or errors, potentially leading to fewer adjustments and follow-up visits. Over time, these efficiencies might offset the higher initial laboratory costs, particularly in high-volume practices where streamlined workflows and reduced treatment times can translate into cost savings and improved patient throughput.

Future research should focus on a comprehensive cost-effectiveness analysis, considering not just laboratory costs but also long-term savings in clinical time and improved outcomes associated with digital methods.

The technique's sensitivity demands precise scanning, tray production, and adhesive application, with errors potentially compromising outcomes6,2. Additionally, the setup, including scanning and 3D printing, is more time-consuming than traditional methods, deterring adoption[9,21].

Discrepancies in bracket placement during transfer raise concerns about digital systems' ability to replicate virtual setups clinically [23,24].

Addressing these barriers through technological advancements, clinician training, and additional research could facilitate broader adoption of digital indirect bonding in orthodontic practice. Finally, it is important to acknowledge the limitations of this study. First, although the sample size was adequate to detect significant differences in key metrics, it remains relatively small, which may reduce the power to identify more subtle distinctions between the bonding techniques. Additionally, the single-center design might limit the generalizability of the findings, as the results may not fully represent diverse clinical settings or patient populations. Furthermore, the study focused exclusively on patients with Class I malocclusion undergoing extraction, meaning the outcomes may not directly translate to other types of malocclusion or non-extraction cases. Despite these constraints, this research provides valuable insights into the potential benefits of digital indirect bonding techniques, highlighting their role in improving efficiency and precision in orthodontic practice. In summary, while both the conventional and digital indirect bonding techniques produce similar treatment quality, the digital approach offers several significant advantages, particularly in terms of reduced treatment time, fewer visits, and lower bracket failure rates. These findings suggest that digital indirect bonding could be an attractive alternative to conventional techniques for both orthodontists and patients. As digital technologies continue to evolve, further improvements in orthodontic care may be possible.

CONCLUSION

Both techniques provide similar treatment quality, but DIB represents a promising advancement in orthodontics, balancing initial costs with improved clinical efficiency and patient satisfaction. Further research with larger, diverse populations is necessary to validate these findings and assess long-term cost-effectiveness.

DECLARATIOM

Conflict of interest:
Authors declare that there is no conflict of interest
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