OPEN ACCESS
Global Journal of Research in Dental Sciences
ISSN: 2583-2840 (Online)
Volume 05 | Issue 05 | Sept. – Oct. | 2025
Journal homepage: https://gjrpublication.com/gjrds/
Review Article

Comparative Analysis of Direct and Indirect Bonding Modalities in Orthodontics: Advances and Clinical Implications – A Review

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DOI: 10.5281/zenodo.17060182 **Submission Date: 25 July 2025 | Published Date: 05 Sept. 2025**

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Abstract
Bracket positioning is an important step in orthodontic treatment that directly influences the effectiveness of tooth movement and alignment. The advent of indirect bonding has transformed the practice of orthodontics by overcoming the shortcomings of conventional direct bonding techniques. This review discusses the advantages, limitations, and recent developments in direct and indirect bonding modalities. Direct bonding, initiated by Michael G. Buonocore's acid-etching method, is simple, economical, and versatile. It is, however, labor-intensive, prone to contamination, and subject to variable accuracy in positioning. Dr. Thomas Kalange's indirect bonding method increases precision and efficiency in bracket placement through initial positioning on a dental model and subsequent transfer to the patient's teeth with a custom designed tray. There are several indirect bonding methods, including Custom Base Technique, Double Transfer Tray Technique, and 3D-Printed Transfer Trays, which have some specific benefits. The more recent developments in indirect bonding include digital planning, robotic placement systems for brackets, advanced adhesive technologies, and bioactive bonding materials. A comparison between direct and indirect bonding shows variance in accuracy, time saving, cost-effectiveness, patient comfort, and learning curves for practitioners. The future of orthodontics is propelled by CAD/CAM technology, customized brackets, plaque-resistant materials, biodegradable polymers, and nanotechnology. Indirect bonding provides greater predictability and accuracy, but more studies are required to critically comprehend the comparative benefits and drawbacks of different bonding methods in orthodontics.

Keywords: *Direct bonding technique, Indirect bonding technique, Bracket position.*

I. Introduction
Bracket positioning during bonding is pivotal in orthodontic treatment, significantly influencing the overall success and efficiency of the process[1]. The precise placement of brackets on the teeth is paramount, as it directly impacts the direction and magnitude of the forces applied, ultimately determining the effectiveness of tooth movement and alignment. The introduction of indirect bonding in 1976 revolutionized orthodontic practices, offering numerous advantages over traditional direct bonding methods. Indirect bonding revolutionized the world of orthodontics by correcting the

shortcomings of direct bonding. Indirect bonding enables more precise positioning of brackets since the procedure is done on dental models instead of directly in the patient's mouth[2]. This method not only offers better precision in placing brackets but also brings remarkable reduction in chairside time, advantageously affecting practitioners and patients[3].Additionally, indirect bonding reduces the risk of contamination throughout the bonding process because the brackets are pre-positioned and bonded on the patient's teeth by using custom trays. The process also helps to increase patient comfort by minimizing the time spent with the mouth open during the bonding process. The combination of these factors has made indirect bonding an increasingly popular choice among orthodontists seeking to optimize treatment outcomes and enhance the patient experience.

The use of indirect bonding has resulted in more predictable treatment outcomes and greater overall efficiency in orthodontic treatment. The procedure has also promoted enhanced communication between patients and orthodontists, as treatment can be better described and visualized using dental models[4]. With ongoing technological development, further improvements in indirect bonding techniques should result in even greater precision and efficacy in orthodontic treatments.

II. Direct bonding technique

A. Description

Michael G. Buonocore's 1955 pioneering work changed the way orthodontic procedures are conducted, especially bracket bonding. His new method was based on the application of[5] 85% phosphoric acid to the enamel surface for 30 s, which greatly improved the adhesive bonding of brackets on teeth. This technique, referred to as acid etching, produces minute pores on the enamel surface so the adhesive and, in turn, the bracket are retained more mechanistically. Every technique has its drawbacks and can be chosen according to the preference of the orthodontist, case difficulty, and patient condition. His acid-etching process formed the basis of contemporary adhesive dentistry, which made it possible to create stronger and more efficient dental restorations. The concept of enamel conditioning has since been developed and applied to a number of dental treatments, such as sealant placement, composite restorations, and veneer placements. Buonocore's research not only enhanced the effectiveness of orthodontic therapy but also set the stage for minimally invasive dentistry, enabling more preservation of tooth structure in many dental treatments[6].Direct bonding method in orthodontics includes the following steps in procedure:

Tooth preparation begins with cleansing and desiccating the tooth surface, followed by isolating the area to prevent moisture contamination. Begin by applying an etchant, usually 37% phosphoric acid, for a duration of 15 to 30 seconds. Afterward, ensure the etched surface is thoroughly rinsed and dried. For the adhesive step, apply a thin layer of primer to etched enamel, light cure if required, and follow up by applying a bonding agent to the tooth surface. Bracket preparation is done by applying adhesive to the base of the bracket, keeping it evenly distributed. In bracket placement, place the bracket on the tooth surface, position according to proper alignment and angulation, and press firmly to seat the bracket. Carefully eliminate excess adhesive along the bracket margins, taking care not to leave any adhesive in contact areas or gingival margins. Polymerize the adhesive using a dental curing light according to the manufacturer's guidelines on curing time. Lastly, check position and alignment of brackets, taking care to achieve proper seating and bonding.

B. Factors influencing precision of bracket position

The precision of bracket placement in orthodontics depends on an overwhelming number of factors that can strongly affect the outcome of treatment. Accurate bracket placement is fundamental to optimal tooth alignment and occlusion. A number of key factors play a role in positioning accuracy, such as the expertise and experience of the orthodontist, the patient's morphology, and the particular bonding method employed. The orthodontist's skill is most important in deciding on the best bracket position for every tooth, considering variables like tooth anatomy, required tooth movement, and overall treatment goals. Patient-specific factors like tooth size, shape, and irregularities on the surface may create difficulties in ensuring uniform bracket placement. Additionally, the choice of the bonding mode, either direct or indirect, may impact accuracy. Direct bonding has the advantage of real-time correction but could be more prone to human error, whereas indirect bonding has potential for greater accuracy but requires careful laboratory preparation. Other considerations that can influence the accuracy of bracket positioning include the quality and [4] design of the brackets, the effectiveness of etching and bonding agents, and ambient conditions like control of moisture during bonding. Some of the factors that can affect the precision of bracket placement in orthodontics include:

1. Clinician expertise:
- Technical proficiency and level of experience
- Familiarity with optimal bracket placement for varied tooth types
- Visualization and performance of accurate angulation and height

2. Factors relating to the patient:
- Tooth morphology and crown shape variation
- Dental anomalies or restorations

- Tooth position and alignment within an arch
- Texture and quality of enamel surface
- Cooperation of the patient during the bonding process

3. Environmental factors:
- Operatory lighting
- Moisture management and isolation of the working area
- Temperature and humidity influences on adhesive quality
- Ergonomics of the clinical environment

4. Technical factors:
- Quality and accuracy of the brackets
- Accuracy of bracket placement instruments or guides
- Characteristics of the bonding agent and its application method
- Intensity and duration of the curing light

5. Methodological factors
- Direct versus indirect bonding methods
- Digital planning and 3D-printed transfer trays
- Computer-aided bracket positioning systems

6. Time limitations:
- Time pressure to bond within a set time frame
- Clinician fatigue after lengthy bonding sessions

7. Visual acuity:
- Clinician vision and the use of magnification devices
- Legibility of bracket markings and positioning guides

Correction of these factors can enhance bracket position accuracy, resulting in more effective orthodontic treatment and possibly eliminating mid-treatment adjustments or rebounding.

C. Advantages and Limitations

Orthodontic direct bonding has multiple advantages and limitations. On the advantageous side, it is an easy and inexpensive technique with minimum equipment needs and lower initial investment. It can be adjusted immediately, allowing for on-the-spot corrections of positioning. The method is versatile and can accommodate most tooth forms and clinical conditions. Direct visual control offers accurate evaluation of surface tooth and bracket position, and less laboratory dependency obviates the use of models or impressions. Direct bonding does have negatives, however. It is a slow chairside procedure and can result in longer appointment times and patient discomfort. The process is prone to greater contamination hazard from saliva and moisture. Operator fatigue can degrade accuracy and consistency, and inconsistent positioning accuracy is susceptible to human error. Limited visualization also can be problematic in accessing certain teeth, affecting the overall outcome of the procedure.

D. Recent Advances

Recent developments in direct bonding in orthodontics have greatly enhanced treatment efficiency and results. Self-etching primers blend etching and priming procedures into a single step, saving chair time. Moisture-resistant adhesives improve bond strength in difficult oral environments. Colour-change technology light-cured adhesives enable accurate bracket placement and effortless removal of excess. Bioactive bonding promoters foster remineralization and minimize white spot lesions. Digital systems for bracket positioning utilize 3D scans and CAD technology to increase accuracy. Bracket base plasma treatment increases bond strength. Adhesives with nanoparticles allow higher bond strengths and possible antibacterial activity. Fluoride-releasing products provide caries prevention. Improved base designs of ceramic brackets enhance bond strength and make treatment more efficient. These innovations together lead to more efficient, effective, and patient-friendly orthodontic treatment.

These innovations overcome drawbacks of conventional bonding techniques.
Adhesive-free bonding methods deliver higher strength and durability and opposition to environmental conditions[7]. Such methods do away with surface preparation and curing times, which are optimized in the manufacturing processes. In addition, such methods often result in stronger and more uniform bonds that are able to resist severe thermal cycling and mechanical stress[8].

III. Indirect bonding technique [9]

A. Description

Indirect bonding methods of orthodontics have greatly enhanced bracket placement precision and efficiency since their development during the 1970s. The technique was developed by Dr. Thomas Kalange, having started from previous attempts to make bracket positioning more precise[3].

Major clinical implications of indirect bonding are:
1. Increased precision in bracket placement
2. Minimized chair time
3. Increased patient comfort
4. Increased possibility of enhanced treatment outcomes
5. Reduced risk of contamination during bonding

The technique consists of setting brackets on a model of teeth and, with the aid of a specially fabricated tray[2], placing them on the teeth of the patient. The brackets are accurately placed in a controlled setting, which is then successfully transferred to the mouth of the patient.

Techniques have been worked out as follows:
1. Custom Base Technique
2. Double Transfer Tray Technique
3. Single Transfer Tray Technique
4. Thermoplastic and Silicone Transfer Trays
5. 3D-Printed Transfer Trays
6. Adhesive Precoating Technique
7. Light-Cured Adhesive Techniques
8. Chemical-Cure Adhesive Technique

Each method has certain benefits, enabling orthodontists to choose the most suitable approach for their practice and patient requirements[10].

C. Advantages and disadvantages:

Orthodontic indirect bonding techniques have a number of benefits compared to direct methods. There are several methods available, such as the Custom Base Technique, which fabricates individual composite bases on a stone model and transfers brackets with a transfer tray, enabling the placement of precise and adaptive positioning. The Double Transfer Tray Technique employs two trays for bracket positioning and transfer, ensuring stability and easier removal, whereas the Single Transfer Tray Technique eases the process with a single tray. Thermoplastic and Silicone Transfer Trays provide good accommodation and flexibility, respectively. 3D-Printed Transfer Trays, modeled through digital scans and CAD software, provide high precision and reproducibility. The Adhesive Precoating Technique minimizes chairside time and possible contamination by placing adhesive on brackets prior to their transfer to the transfer tray. Light-Cured Adhesive Techniques are more controlled in setting times and are adjustable prior to ultimate curing. Finally, the Chemical-Cure Adhesive Technique is another indirect bonding option for orthodontics.

Each of these techniques has its own benefits and can be used based on the orthodontist's preference, case complexity, and patient requirements[3,11].

factors influencing loss of accuracy in indirect bonding would involve the discussion of several aspects that can undermine the precision of this orthodontic procedure. Indirect bonding is a process of developing a transfer tray upon which brackets are placed on a dental model, and such a tray is utilized to position the brackets on the teeth of a patient. Precision can be influenced by defects in several phases of this procedure.

An important aspect is the accuracy of the initial impression and model formation. Any inaccuracy in the dental impression or model distortion can cause bracket misplacement. The transfer tray material is also very important; if it is too pliable, it will not fix the brackets in the precise location during transfer. In addition, the properties of the bonding agent, including viscosity and setting time, can influence accuracy if they make brackets slightly move before fully fixing on the teeth. Material stability may be influenced by environmental conditions such as temperature and humidity. In addition, the clinician's skill in preparing the transfer tray and seating it into the patient's mouth can generate variability. Impeccable isolation of the teeth, providing a dry operating site, and consistent pressure during bonding are all vital procedures that, if not performed accurately, can produce less than optimal accuracy in bracket placement[10,12]

D. Recent trends in indirect bonding

New developments in indirect bonding and bracket placement in orthodontics have made treatment much more precise and efficient. Digital planning and transfer trays printed using 3D technology use intraoral scans and CAD to virtually

position brackets, providing high accuracy and reproducibility. Individualized bracket bases, developed to fit unique tooth anatomy, improve fit and bond strength. Robotic placement of brackets mechanizes the procedure, minimizing human error and enhancing consistency. Latest adhesive technologies, such as light-cured adhesives with color-change indicators and moisture-resistant bonding agents, have improved the bonding process. Better transfer tray materials like thermoplastic and silicone-based ones provide for better adaptation and simpler removal. Hybrid bonding methods have the combination of direct and indirect bonding approaches available for adaptability in difficult situations. Better bracket designs include low-profile brackets and more advanced base designs for enhanced bonding strength and simpler debonding. Augmented reality guidance systems help in more accurate tray placement during bonding. Finally, bioactive bonding materials encourage remineralization and minimize white spot lesions, all in the interest of overall oral health when undergoing orthodontic treatment[4,13,14]

IV. Direct vs. Indirect Bonding Comparative Analysis:

Accuracy in various types of teeth and locations:

Direct bonding tends to be precise for anterior teeth but can be difficult for posterior teeth, particularly molars. There can be bracket placement errors in hard-to-reach locations. Indirect bonding has better accuracy for all tooth types, including posterior teeth. It provides more control and precision in bracket placement, particularly in complicated cases, and provides greater accuracy in angulation and torque.[12,15]

Time efficiency:

Direct bonding takes more initial chairside time since the brackets are all individually placed. It might need more adjustments throughout the course of treatment. Indirect bonding, in contrast, provides less chairside time because several brackets can be placed at one time. But it necessitates laboratory preparation time.

Cost-effectiveness:

Direct bonding is less expensive initially with no laboratory charges but can be more expensive because of longer chairside time and possible repositioning. Indirect bonding is more expensive initially, including laboratory charges and costs for custom trays. It does provide potential long-term cost savings through shorter chairside time and fewer adjustments.

Patient comfort and chair time

Direct bonding has a longer first visit and possibility of multiple visits for adjustments. It can be less comfortable for anxious or gag-sensitive patients. Indirect bonding has a shorter first visit and less required for adjustments. It tends to be more comfortable for most patients, particularly anxious or gag-sensitive patients.

Practitioner learning curve:

Direct bonding has a higher initial learning curve and demands skill development for precise bracket placement. Indirect bonding might have a lower learning curve for the placement of brackets but demands expertise in lab skills and tray construction.[3,16]

V. Future direction and emerging technologies

Orthodontic introduction of CAD/CAM technology has been a game changer and provides the patient with very customized brackets based on individual dental anatomy. This customization maximizes treatment effectiveness while also enhancing patient comfort and decreasing total treatment time. In addition, the creation of plaque-resistant brackets deals with one of the major issues in orthodontic treatment: the maintenance of oral hygiene during the process. These cutting-edge brackets employ cutting-edge materials and surface treatments to reduce bacterial adhesion to their surfaces, thus minimizing dental caries and gingivitis risk.[17]

Aside from these advances in technology, orthodontics is also moving toward more biocompatible materials and minimally invasive procedures. Scientists are also investigating the potential to utilize biodegradable polymers and shape-memory alloys as orthodontic appliances, so that bracket removal would be avoided at the conclusion of treatment. Furthermore, the application of nanotechnology in orthodontic materials is improving their mechanical properties and antimicrobial activities16. These innovations, combined with the increasing success of clear aligner systems, are making orthodontics a more patient-centered and visually appealing specialty of dentistry, fitting into the overall trend of individualized medicine in health care.

VI. Conclusion:

Indirect bonding provides greater precision and predictability over direct bonding in orthodontic treatment [3,18]. Indirect bonding enables more precise bracket positioning with less chance of bonding errors during the treatment process. The reason for its increased accuracy is that one has the option of planning and preparing bracket positions on a dental model prior to their transfer to the teeth of the patient. This level of precision eliminates the chances of misplacement and enhances overall treatment outcome.

While it offers benefits, indirect bonding does have some disadvantages. The process usually takes more time to do than conventional direct bonding techniques. This longer time commitment is mainly because of the extra steps taken in making the transfer tray and preparing the brackets in advance. Nevertheless, most orthodontists discover that the advantages of enhanced accuracy and less chair time spent in the actual bonding process outweigh the upfront time commitment. As orthodontics advances, additional research will be required to better identify the comparative advantages and disadvantages of direct, indirect, and newer digital bonding methods. Such research will guide best practice and facilitate further innovation in orthodontic treatment approaches.

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CITATION
M. Hariis, Deepak C., Deenadayalan P., Akshay T., Nidhi A., Katepogu P., & Reshma M. (2025). Comparative Analysis of Direct and Indirect Bonding Modalities in Orthodontics: Advances and Clinical Implications – A Review. In Global Journal of Research in Dental Sciences (Vol. 5, Number 5, pp. 5–10).
https://doi.org/10.5281/zenodo.17060182