



CLINICAL RESEARCH:

Accuracy of Bracket Position with Two Indirect Bonding Materials.

A Randomized Split-Mouth Clinical Trial

Precisión en la posición de brackets con dos materiales de cementado indirecto.

Ensayo clínico aleatorizado de boca dividida

Claudia V. Forero-Manrique DDS¹ <https://orcid.org/0000-0001-5500-9131>

María M. Zamora-Pacheco DDS¹ <https://orcid.org/0000-0002-3796-5418>

Judith P. Barrera-Chaparro DDS, MSc² <https://orcid.org/0000-0002-6308-7241>

Edgar A. Ibáñez-Pinilla MSc, PhD³ <https://orcid.org/0000-0002-9527-9248>

Gabriela Nieto-González DDS⁴ <https://orcid.org/0000-0002-7721-9591>

María F. Pardo-León DDS⁴ <https://orcid.org/0000-0002-0033-4030>

¹Professor, Department of Orthodontics CIEO University Foundation – UniCIEO, Bogotá, Colombia.

²Research Professor, Department of Orthodontics, CIEO University Foundation – UniCIEO, Bogotá, Colombia.

³Statistics Professor, CIEO University Foundation – UniCIEO, Bogotá, Colombia.

⁴Postgraduate Program in Orthodontics, CIEO University Foundation – UniCIEO, Bogotá, Colombia.

Correspondence to: Judith P. Barrera-Chaparro DDS, MSc - jp.barrera@unicieo.edu.co

Received: 2-VI-2026

Accepted: 27-VIII-2026

ABSTRACT: The aim of this randomized split-mouth clinical trial study was to compare accuracy of self-ligating brackets position using two indirect bonding tray materials: polyvinyl siloxane (PVS) and hot melt adhesive (HM). Randomized, single-center trial in adults who started orthodontic treatment from an orthodontic graduate program. Patients with permanent dentition and mild crowding (1.1-3.0 mm) in the upper arch were included. Indirect bonding tray materials were randomly assigned to the upper hemiarch using virtual software. Patients, measurements operators, and statisticians were blinded. Twenty-six transfer trays were fabricated (PVS n=13) and (HM n=13). An experienced operator performed the indirect cementation. The primary outcome was the accuracy of bracket position determined by the displacement along the horizontal (mm), vertical (mm), and angular axes (°). Measurements were compared in T0, before and T1, after transfer, on computer images obtained by intraoral scanning. Bracket positioning accuracy was analyzed using linear mixed-effects models accounting for the split-mouth design. Adjusted mean differences with 95% confidence intervals (95% CIs) were estimated. Intra- and interoperator reproducibility measurements revealed high concordance (Min: 0.13, Max:0.25). Thirteen patients (mean age 25.53±9.45 years; Little's Irregularity Index: 1.07±0.78mm) and 128 teeth were analyzed. No statistically significant differences were found between the PVS and HM transfer trays for any of the evaluated outcomes. All adjusted mean differences were small, with 95% confidence intervals including zero and p-values >0.05. The results suggest that both PVS and HM used for indirect bonding provide

accurate bracket placement. HM may represent a clinically viable alternative for indirect bonding due to its satisfactory accuracy and potential accessibility for a broader range of patients and practitioners.

KEYWORDS: Dental bonding; Data accuracy; Siloxanes; Silicones; Orthodontic brackets; Orthodontics; Clinical trial.

RESUMEN: Comparar la precisión en la posición de brackets de autoligado utilizando dos materiales para cubetas de transferencia de cementado indirecto: polivinilsiloxano (PVS) y adhesivo termofusible (HM), mediante un ensayo clínico aleatorizado con diseño de boca dividida (split-mouth). Ensayo clínico aleatorizado, unicéntrico, realizado en adultos con dentición permanente y apiñamiento leve (1,1-3,0 mm) en el arco superior. Los materiales de las cubetas de transferencia fueron asignados aleatoriamente a una hemiarcada superior. Pacientes, operadores de las mediciones y estadísticos estuvieron cegados. Se fabricaron 26 cubetas de transferencia (PVS, n=13; HM, n=13) y un operador experimentado realizó el cementado indirecto. El desenlace primario fue la precisión en la posición de los brackets, evaluada mediante desplazamientos en los ejes horizontal (mm), vertical (mm) y angular (°) entre las imágenes digitales obtenidas por escaneo intraoral antes (T0) y después (T1) de la transferencia. Los datos se analizaron mediante modelos lineales de efectos mixtos, estimándose diferencias de medias ajustadas e intervalos de confianza del 95%. Se analizaron 13 pacientes (edad media: 25.53 ± 9.45 años: índice de irregularidad de Little: 1.07 ± 0.78 mm) y 128 dientes. La reproducibilidad intra- e interoperador fue alta (mín.: 0,13; máx.: 0,25). No se encontraron diferencias estadísticamente significativas entre las cubetas de transferencia de PVS y HM para ninguno de los desenlaces evaluados. Todas las diferencias de medias ajustadas fueron pequeñas y los intervalos de confianza del 95% incluyeron el valor cero ($p > 0,05$). Tanto las cubetas de transferencia de PVS como las de HM proporcionaron una posición precisa de los brackets. El HM representa una alternativa clínicamente viable para el cementado indirecto debido a su precisión satisfactoria y su potencial accesibilidad para un mayor número de pacientes y profesionales.

PALABRAS CLAVE: Recubrimiento dental adhesivo; Exactitud de los datos; Siloxanos; Siliconas; Soportes ortodóncicos; Ortodoncia; Ensayo clínico.

INTRODUCTION

Accurate bracket bonding and positioning are critical factors in orthodontic treatment, as they contribute to reducing treatment duration, minimizing bracket repositioning, and decreasing the need for compensatory archwire bending (1). Two main techniques for bracket bonding have been described: direct and indirect bonding (2). The indirect bonding technique, first introduced by Silverman *et al.* (3) in 1972, involves positioning brackets on a study cast and subsequently transferring them to the patient using transfer trays, thereby improving clinical convenience and procedural efficiency (4). Among the materials used to

fabricate transfer trays, polyvinyl siloxane (PVS) has been extensively investigated, whereas hot melt adhesive (HM) has received considerably less clinical attention (5-10).

Several *in vitro* studies have shown that PVS transfer trays provide high accuracy, dimensional stability, and elastic recovery (1,9,11). Compared with other tray materials, PVS has demonstrated lower transfer discrepancies and greater vertical accuracy (8,9). However, *in vitro* findings cannot fully reproduce the complexity of the clinical environment, where humidity, soft tissue interference, limited access, and bracket handling may affect transfer accuracy (8,12). Consequently, clinical studies are

required to determine whether these findings are applicable under routine treatment conditions.

Despite the increasing interest in alternative transfer tray materials, clinical evidence regarding HM transfer trays remains scarce. To our knowledge, no randomized controlled clinical trial has directly compared the bracket positioning accuracy of HM and PVS transfer trays, and no comparative systematic reviews have evaluated their clinical performance.

Therefore, the aim of this randomized split-mouth clinical trial was to compare the accuracy of self-ligating bracket positioning using PVS and HM transfer trays. The null hypothesis was that no significant differences in bracket positioning accuracy would be observed between the two materials.

METHODS

TRIAL DESIGN AND ANY CHANGES AFTER TRIAL COMMENCEMENT

This study was a single-center, randomized, split-mouth clinical trial with a 1:1 allocation ratio. The transfer tray material (PVS or HM) was randomly assigned to one hemiarch of each participant. No changes to the study design or methods were made after trial commencement.

Authorization was obtained from the Ethics Committee of the CIEO-UniCIEO University Foundation (156, minute #73), and informed consent was obtained from the patients. The study was conducted in accordance with the principles of the Declaration of Helsinki (13) and was reported following the CONSORT guidelines (14).

PARTICIPANTS, ELIGIBILITY CRITERIA, AND SETTING

Study participants were recruited through non-probabilistic convenience sampling from the orthodontic graduate program at UniCIEO, Bogotá,

Colombia, between October 2023 and October 2025. The inclusion criteria comprised patients initiating treatment with self-ligating brackets, permanent dentition from the maxillary right second premolar to the maxillary left second premolar, and mild crowding (1.1-3.0 mm) in the upper arch according to Little's Irregularity Index (15), healthy enamel, without hypoplasia, fluorosis, or amelogenesis imperfecta, and fully erupted teeth.

Patients were excluded if they presented missing teeth, previous premolar extractions before the alignment and leveling phase, poor oral hygiene, significant tooth displacement that prevented proper tray seating, dental rehabilitations such as crowns or veneers, fractured teeth, atypical dental morphology, bond failure during the procedure, or defective plaster models.

INTERVENTIONS

The interventions evaluated in this study consisted of the indirect bonding of passive self-ligating brackets using the Carriere® SLX System (Ortobao, Bilbao, Spain) with two different transfer tray materials: polyvinyl siloxane (PVS) trays (Elite Glass, Zhermack SpA, Badia Polesine, Italy) and hot melt adhesive (HM) trays (Afix Pegadit, Artecola Quimica, Cundinamarca, Colombia) (16).

Each maxillary hemiarch was randomly assigned to indirect bonding with one of the two transfer tray materials. Tray fabrication was performed using study models obtained from alginate impressions (Orthoprint, Zhermack SpA, Badia Polesine, Italy) poured with type IV dental stone (Silky-Rock Low Expansion Die Stone ISO Type IV, Whip Mix, Dortmund, Germany). Brackets from the maxillary right second premolar to the maxillary left second premolar were positioned on the casts using a tesa® Glue Stick (Tesa SE, Norderstedt, Germany), according to an individualized bonding chart, by a single trained operator (G.N.) (16). The casts with bonded brackets and open bracket

clips were scanned using a Runyes 3DS intraoral scanner (Runyes Focus On Dent, Ningbo, China), generating the cementation model (CM) (Figure 1).

Transfer trays were fabricated by a single trained operator (M.P.) using material-specific dispensing guns: 3M PVS Garant system (3M Unitek, Minnesota, USA) for PVS and FADMAN BLUE 40W glue gun (Fadman, Delhi, India) for HM. Each material was adapted over the incisal, occlusal, and non-retentive bracket surfaces corresponding to the assigned hemiarch. The transfer trays were then immersed in water at room temperature for 30 minutes to facilitate their separation from the cast without distortion. The edges of the transfer trays were trimmed with a scalpel to expose the bracket hooks. The trays were then rinsed and dried with oil-free compressed air. Subsequently, the brackets were manually repositioned into the tray wells, and their bases were cleaned with pure alcohol according to the protocol described by Gündoğ *et al.* (17) (Figure 2). The fabricated transfer trays were stored at room temperature and used for indirect bonding within a maximum period of 24 hours after fabrication.

Indirect bonding was performed by an experienced clinician (M.Z.). First, dental prophylaxis was carried out using sodium bicarbonate and saline solution under relative isolation. Bracket positioning was guided using the MBT System Bracket Positioning Guide (18). The enamel surfaces were dried and conditioned with 38% phosphoric acid etchant (Gelyetch Fluor, Stodent Int., Bogotá, Colombia), followed by the application of Unitek Transbond™ XT Light Cure Adhesive Primer (3M Unitek, Neuss, Germany) to the buccal surfaces. Brackets were bonded using a light-cured adhesive resin (Transbond™ PLUS Color Change Adhesive, 3M Unitek, Minnesota, USA).

The transfer trays were seated intraorally and light-cured using a Woodpecker curing light

(Iled Woodpecker, Guilin, China) for 15 seconds per surface. PVS trays were removed from palatal to buccal using a spoon instrument. Before HM tray removal, patients were instructed to rinse with warm water for 15 seconds to facilitate tray detachment. After completion of the bonding procedure, a final intraoral scan was obtained with the bracket clips open using the same intraoral scanner protocol. This scan was referred to as the cemented patient model (CP).

OUTCOMES (PRIMARY AND SECONDARY) AND ANY CHANGES AFTER TRIAL COMMENCEMENT

The primary outcome measure was the accuracy of bracket positioning. Measurements of the cementation model (CM) and cemented patient model (CP) were performed by a trained operator (M.P.) using Dolphin software (Imaging and Management Solutions, Chatsworth, CA, USA). Linear measurements in the occlusogingival and mesiodistal directions were recorded in millimeters (Figure 3. A, B) (8,9), while angular measurements (tip) were assessed in degrees by evaluating the relationship between the longitudinal axis of the tooth and the bracket slot (Figure 3.C) (19).

The secondary outcome measure was bracket displacement in the horizontal and vertical dimensions, measured in millimeters, and angular displacement, measured in degrees.

SAMPLE SIZE CALCULATION

The sample size was calculated using Epidat version 4.2 (Xunta de Galicia, Spain; Pan American Health Organization/World Health Organization [PAHO/WHO]; CES University, Colombia). The bracket was considered the unit for sample size estimation. Because the study followed a split-mouth design, an expected within-subject correlation coefficient ($\rho=0.70$) was incorporated into the sample size calculation. A 95% confidence level

and 80% statistical power were assumed. The estimated sample size was 13 brackets per tooth type, resulting in a total of 130 brackets obtained

from 13 patients. Each participant contributed observations from both transfer tray materials after randomization of the hemiarch assignment.



Figure 1. Scanning procedure of the cementation model (CM). A. Scanning procedure performed on the model with bonded brackets. B. Digitized scan of the cementation model (CM).



Figure 2. Hot melt (HM) adhesive transfer tray fabrication. A. Dispensing gun used for fabrication of the hot melt adhesive (HM) transfer tray (Fadman Blue 40W; Fadman, Delhi, India). B. Fabrication of the transfer tray on the cementation model (CM).

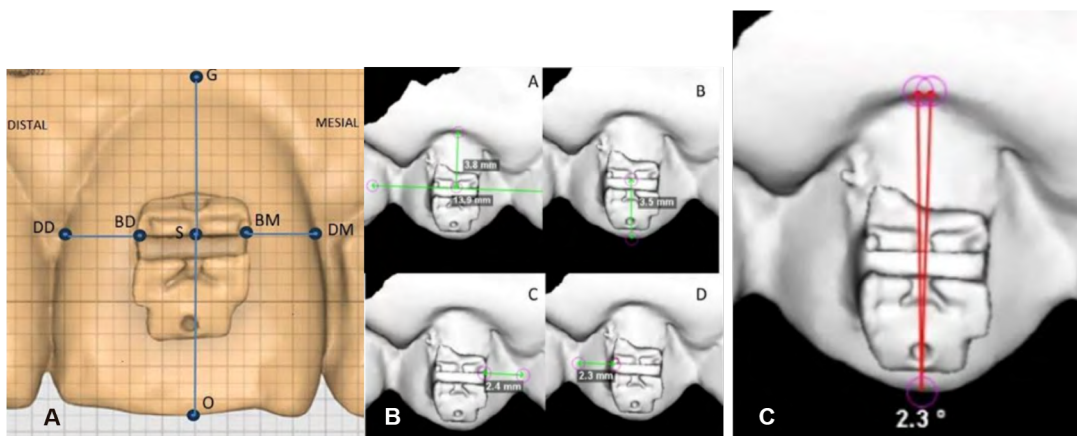


Figure 3. Linear and angular measurements used for bracket position assessment. A. Reference points used for linear measurement. B. Linear measurements (mm). C. Angular measurement (°).

RANDOMIZATION

Randomization was performed before trial commencement using a computer-generated random sequence (<http://www.randomization.com/>) with permuted blocks of four and a 1:1 allocation ratio. In the split-mouth design, the transfer tray material (PVS or HM) was randomly assigned to one hemiarch of each participant. Allocation concealment was ensured using sequentially numbered, opaque, sealed envelopes. Sequence generation and preparation of then allocation envelopes were performed by individuals who were independent of participant recruitment, treatment allocation, and outcome assessment.

BLINDING

Patients, outcome assessors, and statisticians were blinded to group allocation. However, blinding of the clinician performing the indirect bonding procedure was not feasible due to the nature of the intervention.

REPRODUCIBILITY

To assess measurement reproducibility, five models were randomly selected and remeasured after a two-week interval for intraoperator and interoperator reliability. Maximum acceptable errors were defined as 0.5mm for linear measurements (occlusogingival and mesiodistal) and 1° for angular measurements (tip). Agreement and measurement reliability were evaluated using Bland–Altman plots, paired t-tests for systematic error, and the Dahlberg formula for random error.

STATISTICAL ANALYSIS

Statistical analyses were performed in R version 4.6.0 (R Foundation for Statistical Computing, Vienna, Austria) using the RStudio integrated develop-

ment environment (Version 2026.04.0+526; Posit Software, PBC, Boston, MA, USA). A linear mixed-effects model was used to compare bracket positioning accuracy between tray materials (PVS and HM). The bracket was considered the analytical unit. Tray material and tooth were included as fixed effects, whereas patient was included as a random effect to account for the clustering of repeated bracket measurements within the same individual inherent to the split-mouth design. Adjusted estimated marginal means (EMMs), adjusted mean differences, 95% confidence intervals (95% CIs), and p values were estimated. Statistical significance was set at $p < 0.05$.

RESULTS

STUDY REPRODUCIBILITY

Reproducibility analysis demonstrated high agreement according to the Bland–Altman method, with interoperator error values ranging from 0.1311 to 0.2556 (Table 1). The intraoperator and interoperator errors calculated using the Dahlberg formula were within the predefined acceptable limits (0.5 mm for linear measurements and 1° for angular measurements), with no evidence of systematic error ($p > 0.10$) (Supplemental).

Table 1. Concordance measures according to Bland Altman plots, interobserver agreement from linear (mm) and angular measurements (°).

Variable	Mean of differences		95% CI	
	Mean	SD	Lower	Upper
Mesial	-0,0100	0,0821	-0,1709	0,1509
Distal	-0,0325	0,0950	-0,2186	0,1536
Occlusal	0,0225	0,1032	-0,1798	0,2248
Gingival	0,0000	0,0669	-0,1311	0,1311
Tip	0,0275	0,1164	-0,2006	0,2556

SD, standard deviation; CI, confidence interval.

PARTICIPANT FLOW

A total of 52 patients were assessed for eligibility. Of these, 39 were excluded for not meeting the inclusion criteria, and three declined to participate. Twenty-six hemiarches were randomized in a 1:1 allocation ratio to indirect bonding with either PVS (n=13) or HM (n=13). Two teeth were excluded due to bracket-tooth bond failures; therefore, a total of 128 teeth were analyzed. The study consisted of six women and seven men (age: 25.53 ± 9.457 years; Little's irregularity index 1.069 ± 0.783).

NUMBERS ANALYZED FOR EACH OUTCOME, ESTIMATION AND PRECISION, SUBGROUP ANALYSES

Table 2 summarizes the descriptive linear (mm) and angular ($^{\circ}$) measurements of bracket positioning accuracy for the PVS and HM transfer trays. In both groups, mean linear deviations were small, ranging from 0.20 to 0.32 mm across all dimensions. Mean tip deviations were $0.53 \pm 0.46^{\circ}$ for the PVS group and $0.40 \pm 0.43^{\circ}$ for the HM group. Overall, both transfer tray materials demonstrated small linear and angular deviations. The statistical comparison between tray materials, accounting for the split-mouth design, is presented in Table 3. Linear mixed-effects models showed

no statistically significant differences between the PVS and HM transfer trays for any of the evaluated outcomes. The adjusted mean differences ranged from -0.042 to 0.122 , and all 95% confidence intervals included zero. Likewise, all p-values were greater than 0.05, indicating comparable bracket positioning accuracy between the two tray materials (Table 3).

Table 4 summarizes the measurements according to tooth type for both PVS and HM. HM exhibited lower median error values in the mesial position of the Upper first premolar (UFP) (median: 0.10; IQR=0.1), distal position of the upper lateral incisor (ULI) (median: 0.10; IQR=0.5), occlusal position of the ULI (median: 0.10; IQR=0.1), gingival position of the ULI (median: 0.10; IQR=0.1), and tip measurement of the upper central incisor (UCI) (median: 0.40; IQR=0.3), of the ULI (median: 0.20; IQR=0.5), and the upper second premolar (USP) (median: 0.40; IQR=0.5).

Regarding bracket displacement or movement, the distal measurement in PVS group showed lower mesial displacement (31.7%) compared with the HM group, whereas the opposite pattern was observed for distal displacement; greater displacements were identified in the HM group for the distal, occlusal, and gingival measurements compared with PVS (Figure 4 and Supplemental Material).

Table 2. Linear (mm) and angular ($^{\circ}$) measurements of bracket positioning accuracy for PVS and HM transfer trays (n=128 teeth).

Group Variable	PVS			HM		
	Mean (SD)	Median (IR)	CI 95% Lower; Upper	Mean (SD)	Median (IR)	CI 95% Lower; Upper
Mesial	0,28(0,24)	0,30(0,2)	0,22;0,34	0,32(0,28)	0,20(0,3)	0,25;0,39
Distal	0,27(0,22)	0,20(0,3)	0,21;0,33	0,23(0,29)	0,20(0,2)	0,16;0,30
Occlusal	0,21(0,17)	0,20(0,2)	0,17;0,25	0,20(0,14)	0,20(0,2)	0,17;0,24
Gingival	0,25(0,19)	0,20(0,3)	0,20;0,30	0,24(0,17)	0,20(0,2)	0,19;0,28
Tip	0,53(0,46)	0,40(0,4)	0,41;0,64	0,40(0,43)	0,30(0,3)	0,30;0,51

PVS, Polyvinylsiloxane. HM, Hot melt adhesive. SD, Standard deviation. IR, Interquartile range. CI, confidence interval.

Table 3. Comparison of bracket positioning accuracy between PVS and HM transfer trays.

Outcome	PVS (EMM, 95% CI Lower; Upper)	HM (EMM, 95% CI Lower; Upper)	Adjusted mean difference (95% CI Lower; Upper)	p
Mesial	0.280 (0.201; 0.358)	0.322 (0.244; 0.400)	-0.042 (-0.125; 0.041)	0.314
Distal	0.270 (0.191; 0.349)	0.233 (0.155; 0.311)	0.036 (-0.049; 0.122)	0.401
Occlusal	0.214 (0.174; 0.254)	0.200 (0.160; 0.239)	0.015 (-0.041; 0.070)	0.604
Gingival	0.252 (0.208; 0.297)	0.234 (0.190; 0.278)	0.018 (-0.043; 0.080)	0.560
Tip	0.527 (0.415; 0.639)	0.405 (0.295; 0.515)	0.122 (-0.032; 0.276)	0.120

Linear mixed-effects models. PVS, Polyvinylsiloxane. HM, Hot melt adhesive. EMM, Estimated Marginal Means. CI, confidence interval. Adjusted mean differences were obtained from linear mixed-effects models including tray material and tooth as fixed effects and patient as a random effect. Positive values indicate greater measurements for PVS relative to HM. Adjusted mean difference corresponds to PVS – HM.

Table 4. Linear (mm) and angular (°) positioning accuracy by tooth type for PVS and HM transfer trays (n=128).

Variable	Group Tooth type	PVS			HM		
		Mean (SD)	Median (IR)	CI 95% Lower; Upper	Mean (SD)	Median (IR)	CI 95% Lower; Upper
Mesial	UCI	0,32(0,12)	0,30(0,1)	0,24; 0,39	0,32(0,24)	0,30(0,2)	0,17; 0,46
	ULI	0,27(0,44)	0,40(0,2)	0,00; 0,54	0,47(0,38)	0,40(0,3)	0,24; 0,46
	UC	0,25(0,17)	0,30(0,3)	0,15; 0,35	0,28(0,32)	0,20(0,1)	0,08; 0,47
	UFP	0,32(0,20)	0,30(0,2)	0,20; 0,44	0,22(0,20)	0,10(0,1)	0,09; 0,34
	USP	0,24(0,10)	0,30(0,2)	0,17; 0,31	0,33(0,15)	0,30(0,2)	0,24; 0,42
Distal	UCI	0,38(0,21)	0,30(0,2)	0,26; 0,51	0,26(0,23)	0,20(0,3)	0,13; 0,40
	ULI	0,26(0,34)	0,20(0,1)	0,05; 0,47	0,06(0,41)	0,10(0,5)	-0,18; 0,31
	UC	0,22(0,14)	0,20(0,1)	0,14; 0,31	0,21(0,35)	0,20(0,1)	-0,01; 0,42
	UFP	0,26(0,20)	0,20(0,2)	0,14; 0,38	0,28(0,15)	0,30(0,1)	0,19; 0,37
	USP	0,21(0,14)	0,20(0,2)	0,11; 0,31	0,35(0,19)	0,30(0,1)	0,24; 0,47
Occlusal	UCI	0,24(0,15)	0,30(0,2)	0,15; 0,33	0,18(0,14)	0,20(0,2)	0,10; 0,27
	ULI	0,18(0,10)	0,20(0,1)	0,12; 0,24	0,14(0,10)	0,10(0,1)	0,08; 0,20
	UC	0,22(0,20)	0,20(0,1)	0,09; 0,34	0,23(0,17)	0,20(0,3)	0,13; 0,33
	UFP	0,19(0,19)	0,20(0,1)	0,08; 0,31	0,21(0,12)	0,20(0,2)	0,14; 0,28
	USP	0,23(0,22)	0,20(0,2)	0,08; 0,37	0,25(0,17)	0,30(0,3)	0,14; 0,35
Gingival	UCI	0,34(0,23)	0,40(0,3)	0,20; 0,48	0,30(0,24)	0,30(0,1)	0,16; 0,44
	ULI	0,18(0,16)	0,20(0,1)	0,08; 0,28	0,18(0,18)	0,10(0,1)	0,07; 0,29
	UC	0,21(0,19)	0,20(0,2)	0,09; 0,32	0,25(0,16)	0,20(0,1)	0,15; 0,34
	UFP	0,27(0,14)	0,20(0,2)	0,19; 0,35	0,22(0,11)	0,20(0,1)	0,15; 0,28
	USP	0,25(0,21)	0,20(0,3)	0,12; 0,39	0,24(0,16)	0,30(0,3)	0,14; 0,34
Tip	UCI	0,72(0,70)	0,60(0,3)	0,30; 1,15	0,39(0,23)	0,40(0,3)	0,25; 0,53
	ULI	0,43(0,24)	0,40(0,2)	0,29; 0,58	0,34(0,33)	0,20(0,5)	0,14; 0,54
	UC	0,59(0,56)	0,40(0,4)	0,26; 0,93	0,26(0,17)	0,30(0,3)	0,16; 0,36
	UFP	0,47(0,34)	0,40(0,2)	0,26; 0,67	0,38(0,29)	0,40(0,2)	0,21; 0,56
	USP	0,40(0,28)	0,50(0,3)	0,21; 0,59	0,64(0,79)	0,40(0,5)	0,16; 1,12

PVS, Polyvinylsiloxane. HM, Hot melt adhesive. SD, Standard deviation. IR, Interquartile range. CI, confidence interval. UCI, Upper central incisor. ULI, Upper lateral incisor. UC, Upper Canine. UFP, Upper first premolar. USP, Upper second premolar.

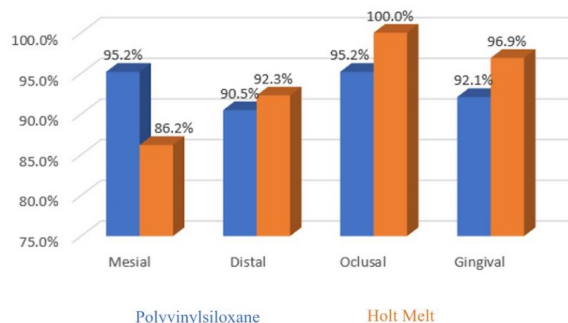


Figure 4. Comparison of bracket displacement between the PVS and HM groups.

DISCUSSION

MAIN FINDINGS IN THE CONTEXT OF THE EXISTING EVIDENCE, INTERPRETATION

This randomized clinical trial was designed to evaluate the accuracy of two transfer tray materials for the indirect bonding of self-ligating brackets: polyvinyl siloxane (PVS) and hot melt adhesive (HM). The selection of these materials was based on their distinct physical and clinical properties. PVS is widely recognized for its optimal rigidity in transfer tray fabrication, excellent elastic recovery, and long-term dimensional stability, making it a reference material in contemporary dentistry (11, 20). In contrast, HM, an FDA-approved ethylene-vinyl acetate copolymer, has recently gained attention for indirect bonding applications due to its low cost, malleability, and biocompatibility (6,7).

Therefore, no statistically significant differences were observed between transfer tray materials for angular or linear bracket positioning accuracy. These results suggest that both transfer tray materials provide comparable clinical performance. These findings are consistent with those reported by Chaudhary *et al.* (8), who found that PVS exhibited lower transfer error in the vertical dimensions (occlusal and gingival) compared with other tray materials. In agreement with previous

studies, PVS was confirmed as a highly precise material for indirect bonding procedures (1,8,11, 20). Therefore, both tray materials may provide clinicians with reliable accuracy for indirect bracket bonding procedures (21).

Accurate bracket positioning is essential in orthodontic treatment and must be individualized according to each patient's treatment objectives. The placement of the bracket in each spatial dimension directly influences tooth movement. Therefore, precise bracket positioning is critical to achieving the intended tooth displacement while minimizing undesirable movements associated with inaccurate bonding (22). Errors during bracket bonding may affect tooth position in all three spatial dimensions: vertical, horizontal, and axial. Vertical discrepancies (gingival/occlusal) may result in intrusive or extrusive movements and alterations in torque expression, producing additional root and crown displacement toward the buccal or lingual/palatal surfaces. Horizontal discrepancies (mesial/distal) may induce rotational movements around the tooth's longitudinal axis, whereas axial discrepancies may generate tip alterations, causing clockwise or counterclockwise root inclination (23,24).

Our results demonstrated minor variations in bracket position between the pre-transfer and post-transfer models, likely associated with factors inherent to the clinical procedure. In particular, the tray-seating stage appears to play a critical role, as accuracy, stability, and operator control during seating may influence the final bracket position. Additionally, patient-related factors such as mouth opening and interarch space may affect both the vertical positioning of the brackets and the accuracy of bracket transfer during indirect bonding procedures (21).

While PVS has been shown to be highly accurate, the lack of solid evidence on the accuracy of HM limits its clinical recommendation.

Some studies have studied the design and efficacy of HM cuvette without assessing their accuracy, highlighting the need for studies that evaluate this variable to ensure its clinical use (5-7,16).

No statistically significant differences were observed between PVS and HM according to tooth type. Nevertheless, HM demonstrated a tendency toward lower error values in the maxillary first premolars (UFP), maxillary lateral incisors (ULI), maxillary central incisors (UCI), and maxillary second premolars (USP) compared with PVS. Chaudhary *et al.* (8) reported findings favoring PVS over 3D-printed trays in maxillary lateral incisors, canines, and first and second premolars. Similarly, Schmid *et al.* (9) identified greater transfer difficulties in teeth with increased buccal convexity, such as canines, premolars, and molars.

Accurate bracket positioning is fundamental to successful orthodontic treatment, as it directly influences the proper alignment of teeth within their supporting bone bases (21-23). In the present study, a tendency toward distal bracket displacement after transfer was observed, consistent with the findings reported by Grunheid *et al.* (10). Displacement analysis revealed a greater frequency of mesial displacement in the PVS group (95.2%) compared with the HM group (86.2%). Conversely, greater displacement in the distal, occlusal, and gingival directions was observed in the HM group relative to PVS. These differences may be related to the intrinsic physical properties of each transfer tray material, as well as to individual biological and clinical factors.

LIMITATIONS

This study has several limitations that should be acknowledged. First, methodological differences in the acquisition and analysis of pre- and post-transfer intraoral images, compared with previously published studies, may limit direct comparison of the findings. In addition, modifica-

tion of the HM handling protocol by incorporating a warm-water rinse before tray removal resulted in debonding of two brackets, which were subsequently excluded from the analysis. This event may reflect the increased rigidity of the HM tray during removal and could represent an uncontrolled source of variability in the bracket-tooth bond interface. Furthermore, the temperature-sensitive malleability of HM should be carefully considered during clinical handling to minimize potential tray distortion. The present randomized clinical trial evaluated bracket transfer accuracy exclusively in the maxillary arch, from the right second premolar to the left second premolar, without including molars or mandibular teeth, which may present greater clinical difficulty due to limited intraoral access. Additionally, despite efforts to obtain highly accurate digital scans of bracket positioning, light reflection from the metallic bracket surfaces may have generated image distortions in certain cases, potentially affecting measurement accuracy, as previously reported by other authors (9). The use of a metal opacifying agent has been suggested to reduce bracket glare during scanning procedures and thereby improve scan accuracy while minimizing distortion in the obtained measurements.

GENERALIZABILITY

This randomized clinical trial is innovative because it represents one of the few *in vivo* studies comparing the accuracy of PVS and HM transfer trays for the indirect bonding of self-ligating brackets, whereas previous investigations have primarily focused on conventionally ligated brackets. The present study employed a standardized bonding protocol, including tray thickness and fabrication procedures, thereby enhancing the comparability and reliability of the findings. Additionally, the sample size provided adequate statistical power to support the study outcomes. Furthermore, the limited evidence currently available regarding the accuracy of HM trays underscores the clinical relevance of the present findings.

The HM protocol may simplify the indirect bonding procedure because of its ease of manipulation and practical handling characteristics. Future studies should investigate the use of 3D-printed transfer trays to further improve the accuracy and customization of indirect bonding techniques, as well as incorporate additional measurements such as torque and rotational discrepancies (25,26). Further randomized clinical trials are also recommended to identify and control clinical factors that may influence bonding outcomes, including long-term bracket debonding rates.

CONCLUSIONS

Within the clinical conditions evaluated in this study, both PVS and HM transfer trays provided accurate bracket placement during indirect bonding. HM may represent a clinically viable alternative due to its satisfactory accuracy and potential accessibility for a broader range of patients and practitioners. Further studies are needed to confirm these findings under different clinical conditions and treatment settings.

DECLARATIONS

AUTHOR CONTRIBUTION STATEMENT: Conceptualization and design: C.V.F.M., M.M.Z.P., J.P.B.C.; Literature review: C.V.F.M., M.M.Z.P., G.N.G., M.F.P.L.; Methodology and validation: C.V.F.M., M.M.Z.P., J.P.B.C.; Formal analysis: E.A.I.P., J.P.B.C.; Investigation and data collection: C.V.F.M., M.M.Z.P., G.N.G., M.F.P.L.; Resources: G.N.G., M.F.P.L.; Data analysis and interpretation: C.V.F.M., M.M.Z.P., J.P.B.C., E.A.I.P.; Writing-original draft preparation: C.V.F.M., M.M.Z.P., J.P.B.C., E.A.I.P., G.N.G., M.F.P.L.; Review & editing: C.V.F.M., M.M.Z.P., J.P.B.C., E.A.I.P., G.N.G., M.F.P.L. Supervision: C.V.F.M. and M.M.Z.P.; Funding acquisition: G.N.G. and M.F.P.L.

REFERENCES

1. Castilla A.E., Crowe J.J., Moses J.R., Wang M., Ferracane J.L., Covell D.A. Jr. Measurement and comparison of bracket transfer accuracy of five indirect bonding techniques. *Angle Orthod.* 2014 Jul; 84 (4): 607-14.
2. Panayi N.C., Tsolakis A.I., Athanasiou A.E. Digital assessment of direct and virtual indirect bonding of orthodontic brackets: A clinical prospective cross-sectional comparative investigation. *Int Orthod.* 2020; 18 (4): 714-21.
3. Silverman E., Cohen M., Gianelly A.A., Dietz V.S. A universal direct bonding system for both metal and plastic brackets. *Am J Orthod.* 1972; 62 (3): 236-44.
4. Cortesi R., Molinari L. A simple and efficient procedure for indirect bonding. *Prog Orthod.* 2010; 11 (2): 180-4.
5. Mezomo M., de Lima E.M.S., de Menezes L.M., Weissheimer A. Indirect bonding with thermal glue and brackets with positioning jigs. *Prog Orthod.* 2011; 12 (2): 180-5.
6. Kulkarni N.B., Goyal S. Comparison of Bracket Failure Rate between Two Different Materials Used to Fabricate Transfer Trays for Indirect Orthodontic Bonding. *J Contemp Dent Pract.* 2022 Mar 1; 23 (3): 307-312.
7. Starling C.R., Lima L.S., Bittencourt, M.A.V. Indirect orthodontic bonding with drop-shaped hot glue tray: a simple and cost-effective technique. *Bioscience Journal.* 2021; 37: e37088.
8. Chaudhary V., Batra P., Sharma K., Raghavan S., Gandhi V., Srivastava A. A comparative assessment of transfer accuracy of two indirect bonding techniques in patients undergoing fixed mechanotherapy: A randomised clinical trial. *J Orthod.* 2021; 48 (1): 13-23.
9. Schmid J., Brenner D., Recheis W., Hofer-Picout P., Brenner M., Crismani A.G. Transfer accuracy of two indirect bonding techniques-

- an in vitro study with 3D scanned models. *Eur J Orthod.* 2018; 40 (5): 549-55.
10. Grünheid T., Lee M.S., Larson B.E. Transfer accuracy of vinyl polysiloxane trays for indirect bonding. *Angle Orthod.* 2016 May; 86 (3): 468-74.
 11. Pottier T., Brient A., Turpin Y.L., Chauvel B., Meuric V., Sorel O., et al. Accuracy evaluation of bracket repositioning by indirect bonding: hard acrylic CAD/CAM versus soft one-layer silicone trays, an in vitro study. *Clin Oral Investig.* 2020; 24 (11): 3889-97.
 12. Niu Y., Zeng Y., Zhang Z., Xu W., Xiao L. Comparison of the transfer accuracy of two digital indirect bonding trays for labial bracket bonding. *Angle Orthod.* 2021 Jan 1; 91 (1): 67-73.
 13. World Medical Association. Declaration of Helsinki, Ethical Principles for Scientific Requirements and Research Protocols. Declaration of Helsinki, Ethical Principles for Scientific Requirements and Research Protocols. 2013.
 14. Pandis N., Fleming P.S., Hopewell S., Altman D.G. The CONSORT Statement: Application within and adaptations for orthodontic trials. *Am J Orthod Dentofacial Orthop.* 2015 Jun; 147 (6): 663-79.
 15. Little R.M. The Irregularity Index: A quantitative score of mandibular anterior alignment. *Am J Orthod.* 1975; 68 (5): 554-63.
 16. Reddy Aileni K., Rachala M.R., Mallikarjun V., Ramana Reddy S. Gum and Gun: A New Indirect Bonding Technique. *J Indian Orthod Soc.* 2012; 46: 287-91.
 17. Gündoğ H., Arman Özçırpıcı A., Pamukçu H. Transfer Accuracy of Three Indirect Bonding Trays: An In Vitro Study with 3D Scanned Models. *Turk J Orthod.* 2023; 36 (1): 1-9.
 18. 3M Unitek. MBT™ Versatile+ Appliance Bracket Placement Guide. (Internet). (cited nov 7 2024). Available from: <https://multimedia.3m.com/mws/media/96705O/mbt-versatile-bracket-placement-guide-ifu.pdf>
 19. Plaza S.P., Tamara J.C., Ariza J. Assessment of threedimensional changes after orthodontic treatment of low-complexity cases, using self-ligating brackets, conventional brackets or bracketless fixed system. *Clin Orthod.* 2022; 21 (4): 79-91.
 20. Sabbagh H., Khazaei Y., Baumert U., Hoffmann L., Wichelhaus A., Janjic Rankovic M. Bracket Transfer Accuracy with the Indirect Bonding Technique-A Systematic Review and Meta-Analysis. *J Clin Med.* 2022; 11 (9): 2568.
 21. Joiner M. In-house precision bracket placement with the indirect bonding technique. *Am J Orthod Dentofacial Orthop.* 2010 Jun; 137 (6): 850-4.
 22. Thomas A.A., Sivakumar A. An evaluation of the accuracy of bracket positioning with and without loupes using 3Shape Ortho Analyzer software. *J Taibah Univ Med Sci.* 2023; 18 (1): 98-103.
 23. Armstrong D., Shen G., Petocz P., Darendeliler M.A. A comparison of accuracy in bracket positioning between two techniques - Localizing the centre of the clinical crown and measuring the distance from the incisal edge. *Eur J Orthod.* 2007; 29 (5): 430-6.
 24. Maheshwari R.K., Garg A., Virang B., Bhadauria U.S. The effect of tooth morphology and vertical bracket positioning on resultant stress in periodontal ligament - A three-dimensional finite element study. *Med Pharm Rep.* 2019; 92 (3): 294-9.
 25. Bachour P.C., Klabunde R., Grünheid T. Transfer accuracy of 3D-printed trays for indirect bonding of orthodontic brackets. *Angle Orthod.* 2022 May 1; 92 (3): 372-379.
 26. Hofmann E.C., Sülle J., von Glasenapp J., Jost-Brinkmann P.G., Koch P.J. Indirect bonding: an in-vitro comparison of a Polyjet printed versus a conventional silicone transfer tray. *Angle Orthod.* 2022 Nov 1; 92 (6): 728-737.

SUPPLEMENTARY

Table 1. Concordance measures according Bland Altman plots, intraobserver agreement for linear (mm) and angular measurements (°).

Variable	Operator 1				Operator 2			
	Mean of differences		95% CI		Mean of differences		95% CI	
	Mean	SD	Lower limit	Upper limit	Mean	SD	Lower limit	Upper limit
Mesial	0,035	0,1089	-0,1785	0,2485	-0,015	0,0813	-0,1743	0,1443
Distal	0,025	0,0786	-0,1291	0,1791	-0,04	0,0681	-0,1734	0,0934
Occlusal	-0,01	0,0968	-0,1997	0,1797	-0,035	0,0671	-0,1665	0,0965
Gingival	0	0,0649	-0,1272	0,1272	-0,01	0,1252	-0,2555	0,2355
Tip	-0,01	0,1252	-0,2555	0,2355	-0,005	0,1877	-0,3729	0,3629

SD, standard deviation; CI, confidence interval.

Table 2. Method error, intraobserver agreement for linear (mm) and angular measurements (°).

Variable	Operator 1				Operator 2			
	Measure 1	Measure 2	Method error		Measure 1	Measure 2	Method error	
	Mean (SD)	Mean (SD)	Dahlberg*	p value†	Mean (SD)	Mean (SD)	Dahlberg*	p value†
Mesial	3,28 (0,79)	3,24 (0,82)	0,27	0,17	3,26 (0,78)	3,28 (0,77)	0,17	0,42
Distal	3,32 (0,63)	3,29 (0,61)	0,17	0,17	3,32 (0,63)	3,36 (0,65)	0,19	0,20
Occlusal	5,14 (0,53)	5,15 (0,51)	0,19	0,65	5,15 (0,52)	5,19 (0,51)	0,14	0,30
Gingival	4,76 (0,80)	4,76 (0,81)	0,13	1	4,75 (0,79)	4,76 (0,76)	0,28	0,72
Tip	2,09 (0,68)	2,10 (0,71)	0,25	0,72	2,06 (0,65)	2,07 (0,69)	0,40	0,91

SD, standard deviation; *Dahlberg Formula; † p value from a Houston paired t test.

Table 3. Method error, interobserver agreement for linear (mm) and angular measurements (°).

Variable	Operator 1 Vs Operator 2			
	Operator 1	Operator 2	Method error	
	Mean (SD)	Mean (SD)	Dahlberg*	p value†
Mesial	3,26 (0,80)	3,27 (0,77)	0,17	0,59
Distal	3,30 (0,62)	3,34 (0,64)	0,20	0,14
Occlusal	5,22 (0,46)	5,20 (0,45)	0,25	0,34
Gingival	4,76 (0,81)	4,76 (0,77)	0,13	1
Tip	2,09 (0,69)	2,06 (0,67)	0,25	0,30

SD, standard deviation; Dahlberg Formula*; p value from a Houston paired t test †.

Table 4. Linear displacement in material trays (%).

Variable	Movement	Group	
		PVS	HM
Mesial	No movement	4,8	4,6
	Mesial	33,3	35,4
	Distal	61,9	60,0
Distal	No movement	6,3	6,2
	Mesial	31,7	36,9
	Distal	61,9	56,9
Occlusal	No movement	12,7	13,8
	Occlusal	39,7	36,9
	Gingival	47,6	49,2
Gingival	No movement	12,7	12,3
	Occlusal	41,3	43,1
	Gingival	46,0	44,6

PVS, Polyvinylsiloxane. HM, Hot melt adhesive.