Comparison of resin-bonded prosthesis groove parallelism with the use of four tooth preparation methods

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Statement of problem. A precise preparation is required to develop resistance form resulting in mechanical stability of the framework for resin-bonded prostheses (RBPs).
Purpose. The effects of 4 methods of tooth preparation (freehand, guiding pin, extraoral parallelometer, and intraoral parallelometer) on the deviation of proximal grooves from a preestablished path of insertion (guide planes) were investigated under clinical conditions.
Material and methods. Tooth preparation of proximal grooves was performed by 32 dentists on resin substitutes of posterior segments intraorally with a single test patient. A Latin-square randomized cross-over design was selected as the experimental design.
Results. The significant least angular deviation of proximal grooves from path of insertion was achieved with an intraoral parallelometer (mean ± SD 3.15 ± 1.67 degrees). Compared with freehand tooth preparations (4.37 ± 2.11 degrees), neither use of a guiding pin (4.10 ± 1.62 degrees) nor an extraoral parallelometer (5.06 ± 2.33 degrees) improved the results.
Conclusion. Divergence of guiding grooves from path of insertion was reduced with the use of an intraoral parallelometer. This should improve mechanical stability of posterior RBPs. (J Prosthet Dent 1999;82:398-409.)

CLINICAL IMPLICATIONS

The survival rate of resin-bonded prostheses was poorer than conventional fixed partial dentures. Mechanical stability of the framework (macroretention) and bond strength at the enamel-resin composite-metal interfaces (microretention) are critical factors that affect longevity of posterior RBPs. This study indicated that precision of tooth preparation for guiding grooves in the posterior region of the mouth can be improved with the use of an intraoral parallelometer. This could increase resistance to dislodgment by functional horizontal or rotational stresses and result in greater survival of posterior RBPs.

Resin-bonded prostheses (RBPs) have been a proven minimally invasive treatment option for replacement of a single tooth, with sound or almost intact adjacent abutments.[1] Despite improved bonding systems available for micromechanical retention of retainers to acid-etched tooth surfaces,[2] the survival rate of RBPs[3,4] remains inferior compared with conventional fixed partial dentures (FPDs).[5] More efficient retention and resistance forms of abutments increased the success rate of RBFPDs and these improvements were more crucial for posterior RBPs because of increased functional loads.[6-8]

Recent in vitro studies of posterior tooth preparation design on bond strengths of resin-bonded retainers have suggested that tooth preparation design had a substantial effect on strength and durability of a bond. An increase in bonding area and placement of opposing proximal grooves resulted in improved bonding values.[9] Conversely, an elevated convergence angle of guide planes (namely, an increased tapering of tooth preparations) reduced the retentive strength of posterior resin-bonded retainers.[10]

A 5-year follow-up study evaluated the influence of 2 tooth preparation designs and several bonding systems on the survival of posterior RBPs.[11] A "conventional" design involving only minor tooth preparations,

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This project was carried out as thesis and submitted in partial fulfillment of the degree in medicine (MD) of P. Berger (1993, in German).
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such as the creation of a path of insertion (guide planes), was compared with a "modified" design that also included 2 proximal grooves (1 groove on each abutment).[12] Details about the preparation forms of abutments used in this study were described in a previous 2.5 year interim report.[12] Overall survival rate without any debonding during the 5-year follow-up period was low (mean ± SD, 53% ± 3%). However, the "modified" design was significantly more retentive than the conventional design (62% vs 46%). No significant differences with regard to survival without debonding between the bonding systems were found, but the effect of the location of RBPs (maxilla vs mandible) was significant. Maxillary posterior RBPs were more retentive than mandibular RBPs (65% vs 40%). It was concluded that tooth preparation design, including proximal grooves, was beneficial to survival of posterior RBPs.

Mechanical stability of the framework can be achieved with tooth preparation of guide planes, retentive guiding grooves, and rest seats on the abutments.[13,14] Guide planes should be prepared parallel to one another to create a distinct vertical path of insertion. Appropriate tooth preparation of guide planes establishes a single path of insertion that restricted movement of the uncemented framework, except along the path of insertion. Proximal grooves provide resistance to lingual displacement of the metal framework. Guiding grooves ideally should be parallel to one another and to the path of insertion / guide planes, which allows an optimal fit with complete seating of the framework, without reshaping inner surfaces of the retainers or elevation of the taper of tooth preparations. Attempts to improve fit by adjusting metal frames usually result in impairment of macromechanical retention. However, intraoral readjustment of imprecisely prepared (divergent) guiding grooves usually conflicts with the aim for minimally invasive tooth preparation.

The use of paralleling instruments was recommended to maximize parallelism of proximal grooves.[14,15] The purpose of this study was to evaluate: (1) the effects of 4 posterior tooth preparations on deviation of proximal grooves from a preestablished path of insertion (guide planes), (2) the differences between maxillary and mandibular tooth preparations, (3) a possible session effect (period effect) during the study, and (4) a possible influence of dentist's experience on divergence of guiding grooves from parallelism.

MATERIAL AND METHODS

Tooth preparation methods evaluated in this clinical experimental study were (1) freehand tooth preparations, and tooth preparations with (2) a guiding pin, (3) an extraoral parallelometer, and (4) an intraoral parallelometer. All tooth preparations of guiding grooves were performed intraorally with a single test patient.

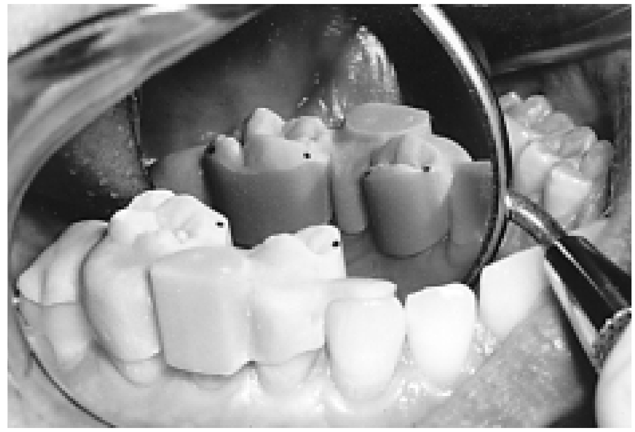

Fig. 1. Intraoral view of resin substitute seated on posterior teeth represents edentulous space of 1 tooth (second premolar) with adjacent partially prepared abutments (first premolar, first molar).

This 26-year-old male patient had caries-free dentition and harmoniously formed dental arches with an Angle Class I relationship. There were no clinical signs or symptoms of temporomandibular disorders. Mandibular movements were unrestricted and maximal interincisal active opening far exceeded the width required for intraoral tooth preparations. Tooth preparations of guiding grooves were performed on resin substitutes constructed for posterior segments of both dental arches of the test patient. They represented an edentulous space of 1 tooth (second premolar) with adjacent, partially prepared abutments (first premolar, first molar) (Fig. 1).

To fabricate resin substitutes, the anterior teeth and corresponding parts of the alveolar processes were removed from both maxillary and mandibular master casts (Silky Rock, Frankonia Dental GmbH, Erlangen, Germany). Master casts were placed in a mold and their bases embedded in dental stone (Silky Rock, Frankonia Dental GmbH) to the mucogingival junction that left the posterior teeth and adjacent portions of the alveolar processes exposed. Keyways were applied to the borders of the stone beds. These modified master casts were duplicated with addition type silicone impression material (President light body and President putty soft, Coltene AG, Altstätten, Switzerland) for multiple working casts (articulation plaster, Kentzner-Kaschner Dental GmbH, Ellwangen, Germany).

Patterns of resin substitutes were then modeled on both modified master casts with acrylic resin (Quick 3 / 60 denture base, Ivoclar AG, Schaan, Liechtenstein; and Palavit G, Heraeus Kulzer GmbH, Wehrheim, Germany) and dental wax (DeTrey Dentsply GmbH, Dreieich, Germany). The proximal and lingual surfaces of abutments (first premolars, first molars) were shaped to constitute parallel guide planes. The occlusal-cervical

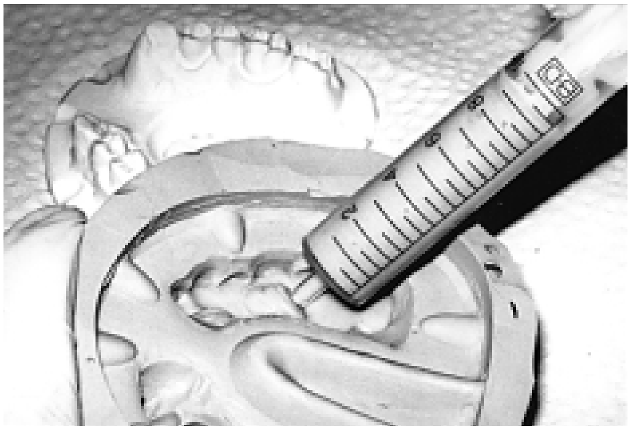

Fig. 2. Injection of autocuring resin into impression of patterns of resin substitutes before its assembly with working cast (shown in background).

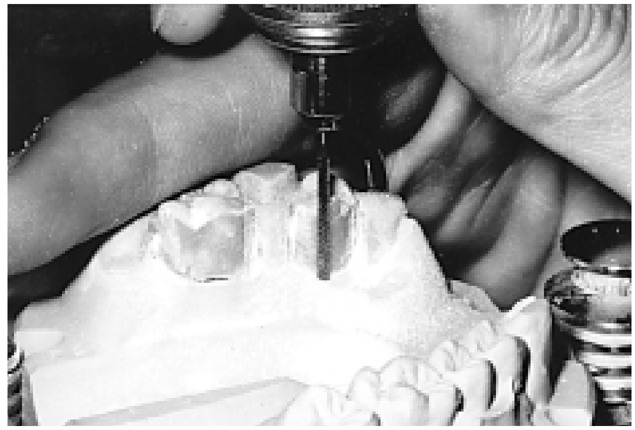

Fig. 4. Creation of distinct path of insertion by refining guide planes.

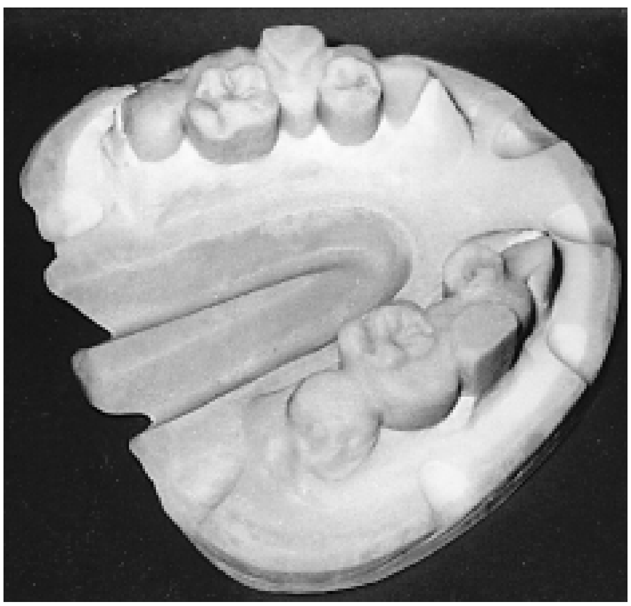

Fig. 3. Resin substitutes seated on working cast after polymerization and separation from impression.

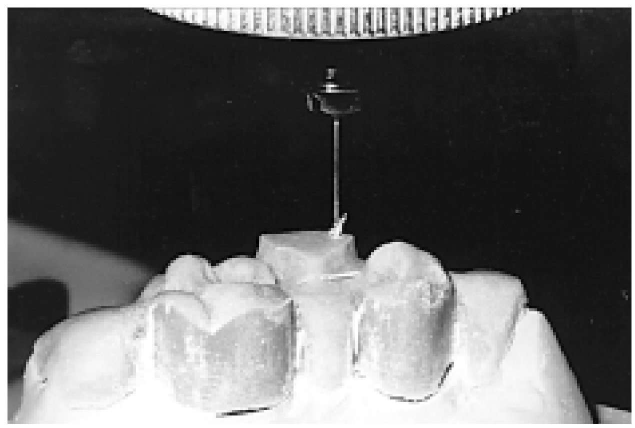

Fig. 5. Drilling of pin-hole parallel to guide planes for insertion of guiding or reference pin.

height of the guide planes was 9.5 mm in the maxilla and 10 mm in the mandible. Lingual surfaces of neighboring teeth (canines, second premolars, second molars) were covered with a layer of wax to protect natural teeth from injury during intraoral tooth preparations. Several impressions (President light body and President putty soft, Coltene AG) of patterns on modified master casts were made to obtain analogs of working casts. Autopolymerizing resin (Pekatray autocuring resin, Bayer, Leverkusen, Germany) was injected in the impression (Fig. 2) and the impression finally assembled with the working cast. Polymerization was completed in a pressure pot with cold water for 15 minutes at 2.5 bar to eliminate internal porosity of resin (Fig. 3).

Refinement of guide planes and establishment of a distinct path of insertion was performed extraorally in the dental laboratory with cylindrical crosscut burs of various diameters in a technical handpiece attached to a paralleling device (Milling machine F1, Degussa AG, Frankfurt, Germany) (Fig. 4). A pin-hole parallel to the guide planes (path of insertion) was drilled in the occlusal surface of resin substitutes with a spiral drill (Type C1, 0.750 mm, Les Fils d'Auguste Maillefer SA, Ballaigues, Switzerland) (Fig. 5). A guiding pin was lowered into this pin-hole to display the path of insertion when intraoral tooth preparation of proximal grooves was performed with a guiding pin as an orientation aid (Fig. 6). A reference pin was inserted into the pin-hole for subsequent determination of angular deviation of guiding grooves from the predetermined path

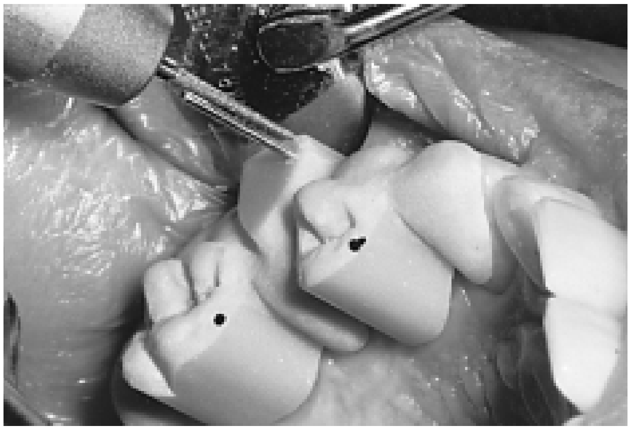

Fig. 6. Guiding pin inserted in pin-hole on occlusal surface of resin substitute displaying path of insertion.

Fig. 7. Extraoral parallelometer in form of spherical spirit-level clipped on contra-angle handpiece.

Table I. Experimental design: Latin-square cross-over. A Latin-square is an arrangement of letters (representing the treatments) in a square of columns and rows (representing 2 heterogeneity factors). Each treatment, traditionally denoted with Latin letters, occurs exactly once in each row and once in each column. Two experienced and 6 inexperienced dentists were randomly assigned to each sequence of methods of tooth preparation

Sequence	Session 1	Session 2	Session 3	Session 4
Sequence 1	E	I	G	F
Sequence 2	G	E	F	I
Sequence 3	I	F	E	G
Sequence 4	F	G	I	E

Methods of tooth preparation: *F*, freehand; *G,* guiding pin; *E,* extraoral parallelometer; *I,* intraoral parallelometer.

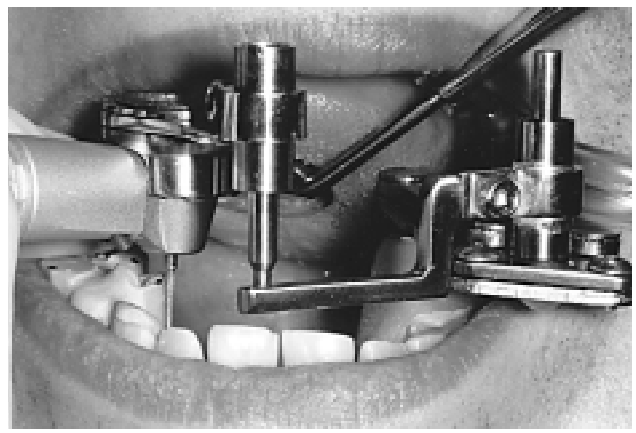

Fig. 8. Intraoral parallelometer anchored to contralateral posterior teeth.

of insertion (Fig. 7). A total of 512 standardized resin substitutes were produced.

Thirty-two dentists (8 clinic-staff members and 24 senior dental students) participated in this study. A Latin-square crossover design was selected as the experimental design (Table I). The advantage of this design over a completely randomized design was more effects can be tested with fewer patients. Dentists completed the 4 methods of tooth preparation in 4 consecutive sessions at intervals of approximately 1 week. During each session, the dentist used 1 of the 4 tooth preparation methods to prepare 4 guiding grooves on 4 resin substitutes corresponding to 4 quadrants of the test patient. Tooth preparations were performed in a standardized order. Dentists started with the third quadrant, continued in the first and fourth, and terminated with the second quadrant. Proximal grooves were always prepared from mesial to distal, for example, from the mesial surface of the mesial abutment (first premolar) to the distal surface of the distal abutment (first molar). A contra-angle handpiece (W&H 99 LX2, Dentalwerk Bürmoos GmbH, Burmoos, Austria) was used at a maximal speed of 64000 rpm and a constant amount of cooling water for all tooth preparations. Tapered diamond burs (Komet Nr. 8850-314-012, Gebr. Brasseler, Lemgo, Germany) with a convergence angle of 4 degrees 14 minutes and a length of the working part of 10 mm were used (Fig. 8).

The freehand tooth preparation was performed without a guiding tool. Only the extraorally prepared proximal and lingual surfaces of abutments (guide planes) provided information regarding the path of insertion. A 10-mm long steel pin (Yellow Elgiloy orthodontic wire ductile–030, 0.762 mm, Rocky Mountain Orthodontics, Denver, Colo.) was inserted in the pin-hole on the occlusal surface of the resin substitutes for a tooth preparation with a guiding pin to display the path of insertion (Fig. 6). The spherical spirit-level (Paraxis, Yoshida Dental Trd., Tokyo, Japan) was used for tooth preparation with an extraoral paral-

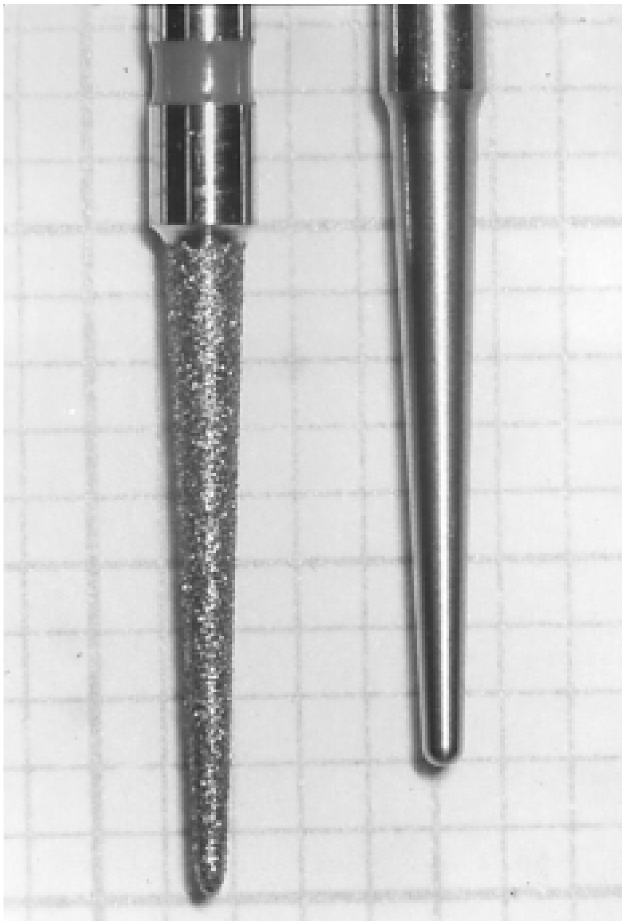

Fig. 9. Tapered heads of diamond bur and stainless steel pin are congruent regarding size and convergence angle. For optimal fit in guiding groove head of steel pin is 2 mm shorter than working part of diamond bur.

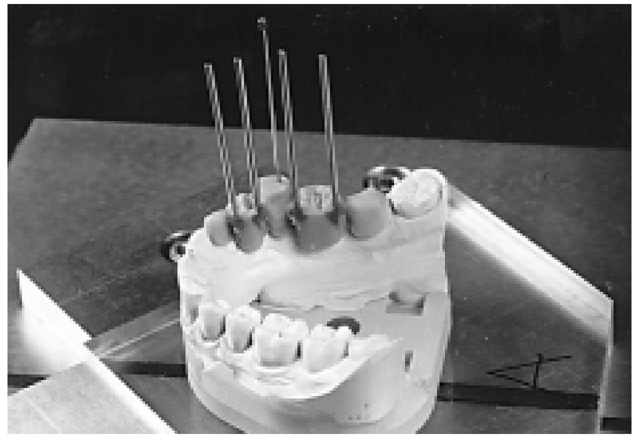

Fig. 10. Resin substitute seated on surveying platform, reference pin displaying path of insertion. Steel pins fixed in guiding grooves reveal their axes.

lelometer. The spirit level was attached to a contra-angle handpiece with a custom-made nonprecious alloy clip (Wiron 88, BEGO GmbH, Bremen, Germany) (Fig. 7). A ball-and-socket joint allowed the dentists to individually adjust the spirit-level in their field of vision.

The Parallel-a-Prep instrument (C.D. Charles Inc, Skokie, Ill.) (Fig. 8) was used for tooth preparation with an intraoral parallelometer. The attachment tray of the instrument is anchored to the dental arch with a hard setting polyether impression material (Ramitec, ESPE Gmbh & Co Kg, Seefeld, Germany). A draw angle pointer was used to line up the bearing post of the instrument with axial surfaces of abutments. A draw angle pointer represents a surveying accessory of the guiding device and consists of a 90-degree angled-guide rod attachable to the bearing post through a tube. The vertical post can be tilted in all directions while the post set screws are loose. The guide rod is moved parallel along the post axis and is used to select the angle of tooth preparation most suitable for minimal reduction of tooth structure and maximal area for retention. Once the appropriate path of insertion is determined, the post set screws are tightened, the guide rod removed, and the contra-angle handpiece attached to the post.

Before tooth preparations were initiated intraorally, each method was detailed for the dentists, and difficulties were emphasized. One mesial and one distal surface guiding groove were oriented parallel to the extraorally refined guide planes (preestablished path of insertion) on each abutment. The length of proximal grooves extended over the entire height of guide planes. The depth is commonly limited to half the diameter of a diamond bur. Dentists were instructed to complete tooth preparation of a groove in 1 step without interruption. No additional modifications were allowed, such as corrections by addition of taper, for compliance with a minimally invasive tooth preparation. All intraoral tooth preparations were supervised by 1 investigator to ensure strict adherence to the respective method of tooth preparation. A bite block device plane (Adult 10, Trident, Italy) was used to stabilize the mandible and to maintain a constant interincisal opening of 43 mm.

The angular deviation of proximal grooves from the path of insertion (guide planes) was used to express their divergence from parallelism. To determine angular deviation, the path of insertion was displayed with a reference pin (Yellow Elgiloy orthodontic wire ductile–030, 0.762 mm, Rocky Mountain Orthodontics) then lowered in the pin-hole on the occlusal surface of resin substitutes (Fig. 10). Highly polished stainless steel pins were secured to prepared guiding grooves with hard sticky wax (Deiberit 502, Ludwig Böhme KG, Bad Sachsa, Germany) to disclose their axes (Fig. 10). These pins were machined by the diamond

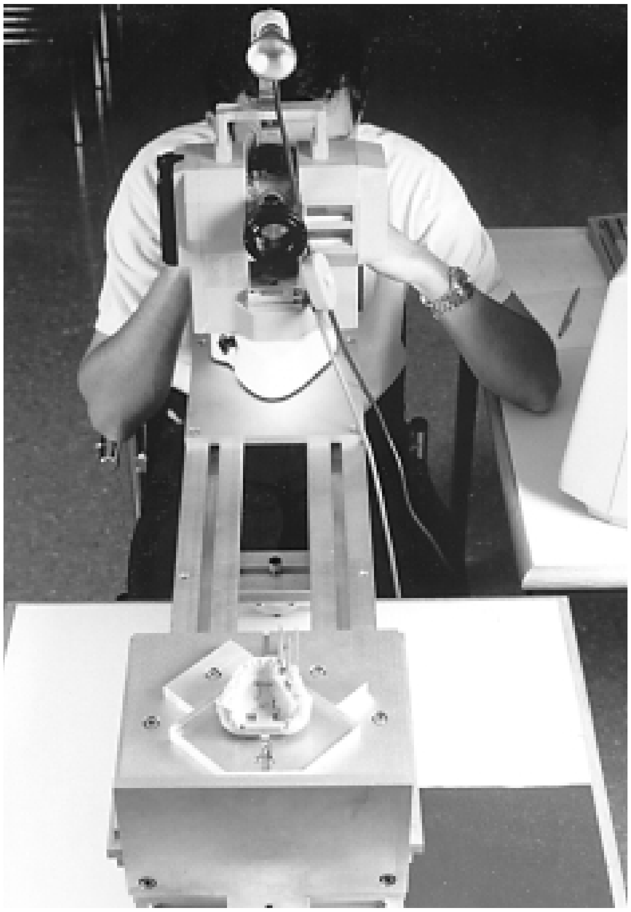

Fig. 11. Front view of surveying equipment.

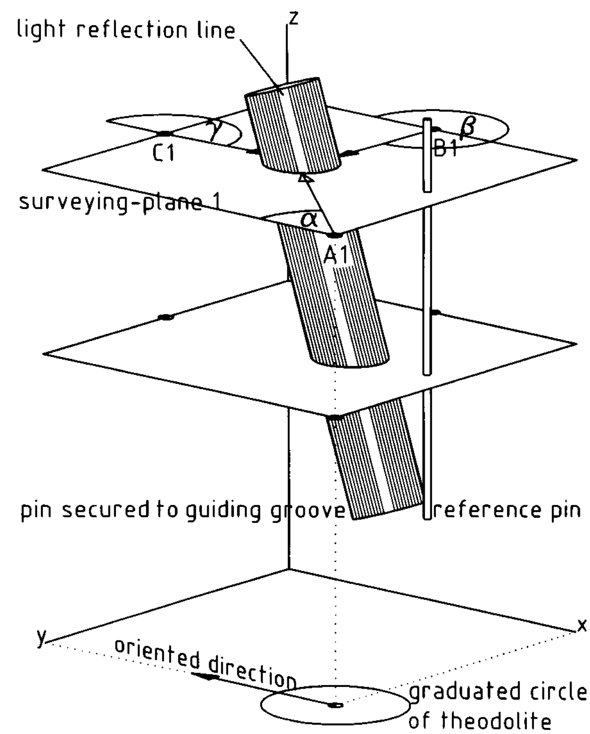

Fig. 12. Schematic representation of trigonometric point determination. Light reflection lines on pin surface observed with theodolite instrument from 3 surveying positions (*A1*, *B1*, *C1*) in upper surveying plane. Observed directions (*arrows* pointing toward light reflection lines) measured with reference to "oriented direction" and expressed as rotational angles (α, β, γ).

bur manufacturer (Gebr. Brasseler). These stainless steel pins also had a cylindrical shank and a tapered head congruent with the size and convergence angle of diamond burs used for tooth preparations (Fig. 9).

Methods and high-precision equipment for surveying were selected to determine the axes of the pins. The use of a surveyor allows for the determination of trigonometric points, which are used primarily when targets are not directly accessible. The pin axis was not directly accessible for measurement because only the pin surface was observed. The axis of a pin that represented a straight line was mathematically defined by 2 points in a 3-dimensional system. In this study, coordinates of these 2 points along the axis of a pin were computed on the basis of measurements recorded from observations of the pin surface with a theodolite instrument.

A theodolite instrument is commonly used to observe "directions" from surveying positions to targets and is an instrument for angular measurements of these observed directions. It consists of a measuring telescope and reading devices and is rotated and directed toward a target by an observer (Fig. 11). Directions of observations are measured on the graduated horizontal circle of the theodolite and expressed as rotational angles with respect to the "oriented" direction (Fig. 12). On the basis of these rotational angles and the known coordinates of surveying positions, coordinates of the point of intersection of measured directions, namely, the target point, were computed.

The surface of a pin was observed from predefined surveying positions in 2 horizontal surveying planes with an electronic theodolite (ELTA 3, Carl Zeiss GmbH, Oberkochen, Germany) applying so-called "short-distance surveying." A small light reflection line on the surface of a pin was used as observation target (Fig. 12). The light was emitted from a source attached to the theodolite, from the surveying position (Fig. 11). Therefore, the axis of a pin was located on the extension line beyond light reflection observed from this position.

Assuming that error-free measurements were feasible, the directions from 2 surveying positions intersect in a point corresponding to the center of a pin. However, it is impossible to obtain error-free measurements due to limitations of measuring instruments and human error.[16] Measurements can be repeated several times or supported by measurements from additional

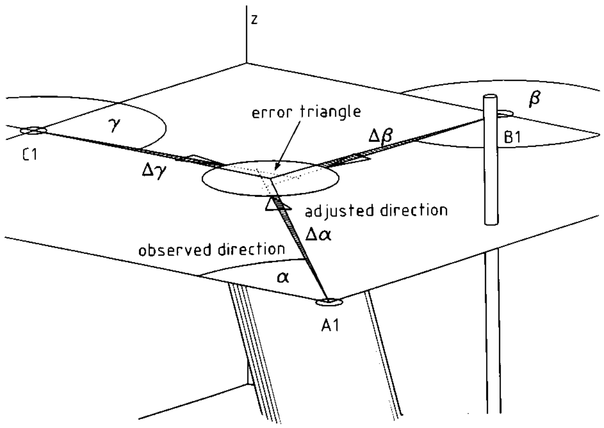

Fig. 13. Improvement of accuracy in point determination by additional observation (overdetermination). Intersection point of 2 observed directions (*A1*, *B1*) may not correspond to center of pin. Conversely, "error triangle" occurred introducing third observed direction from *C1.* Observed directions (α, β, γ) were adjusted by the least-squares method (Δα, Δβ,Δγ) to obtain unique intersection of directions (point along pin axis).

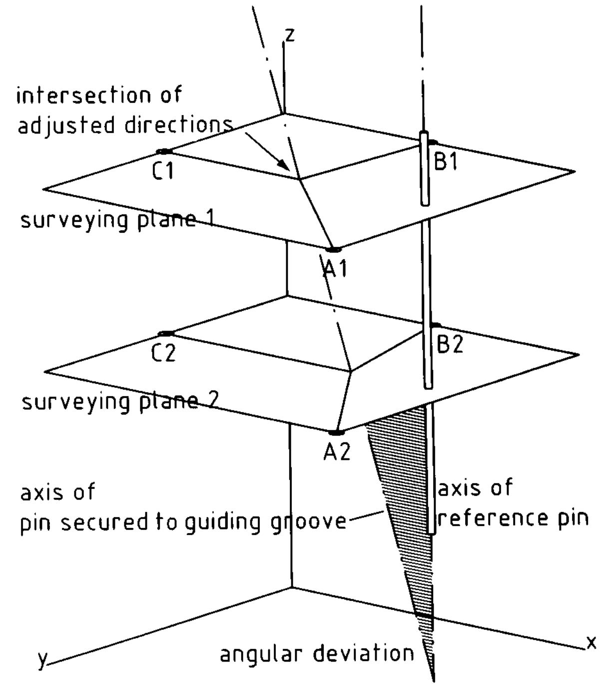

Fig. 14. Pin axes were defined by intersection coordinates of adjusted directions in both surveying planes. Divergence from parallelism was expressed as angular deviation of pin secured to guiding groove from reference pin, namely, path of insertion.

surveying positions to improve accuracy ("overdetermination"). Even in these instances unavoidable measurement discrepancies resulted in a so-called "error triangle" instead of a unique intersection of directions (Fig. 13). The error triangle represented an area that included the aimed target point. This point can be computed by applying adjustments to the measured directions according to the "least squares method."[14]

Measured directions were recorded from 3 surveying positions in each surveying plane. The corresponding rotational angles were recorded automatically with the theodolite instrument and transmitted online to a computer. All additional computations were performed with a software program developed by the authors. In the first step, least-squares adjustments were applied to measured directions. In the second step, the pin axis was determined by computation of intersection coordinates of adjusted directions in both surveying planes. The axis of a pin secured to a guiding groove was finally set in relation to the axis of the reference pin.

For each proximal groove, an angle was computed that represented the deviation of an axis of a proximal groove from the preestablished path of insertion (Fig. 14). Precision of the entire measuring system was evaluated by repeated measurements of the same object. When pins were removed between each measurement and replaced, the precision, expressed as the standard deviation, was 0.11 degree.

The arithmetic mean of the angular deviations of all 4 proximal grooves of each resin substitute formed the outcome variable for statistical analysis. This outcome measurement was researched because clinical guiding grooves from all abutments contribute to fit and mechanical stability (macroretention) of a framework. However, some angle readings that contributed to a mean would not interfere with seating of a restoration, despite a high reading, such as in the case of occlusal convergence of a groove axis along the radius of an abutment toward its center. In this study, only angular measurements were considered without separation of those angular deviations that would interfere with restoration placement from those that would not interfere. Analysis of variance (ANOVA) was selected to assess effects of methods for tooth preparation, location of tooth preparation within the dentition (maxilla vs mandible), session (period effect), dentist's experience, and sequence of tooth preparation modalities on deviation of guiding grooves from a predetermined path of insertion. *P* values $<.05$ were considered to be significant. Multiple comparisons were performed to illustrate differences among the 4 methods of tooth preparation. Adjustments for multiple comparisons were accomplished according to Bonferroni,[17] and *P* values $<.0083$ were also considered significant.

Testing of interactions was possible only with limitations because a Latin-square is not a completely crossed design. Furthermore, certain combinations of effects might completely inflate the design because they are

Table II. Descriptive statistics for experimental design. Each cell contains mean and SD (in degrees) of angular deviation of proximal grooves, based on mean of 4 proximal grooves of each resin substitute, prepared by 8 dentists on 32 resin substitutes in both maxilla and mandible

Sequence	Session 1	Session 2	Session 3	Session 4
Sequence 1 (E-I-G-F)	Maxilla: 5.15(1.86)	Maxilla: 3.36(1.47)	Maxilla: 3.93(1.68)	Maxilla: 3.91(1.98)
	Mandible: 6.45(2.22)	Mandible: 4.22(2.17)	Mandible: 4.06(1.39)	Mandible: 4.87(2.57)
Sequence 2 (G-E-F-I)	Maxilla: 4.02(1.44)	Maxilla: 4.62(1.80)	Maxilla: 3.36(1.48)	Maxilla: 2.86(1.27)
	Mandible: 5.00(1.89)	Mandible: 5.82(2.53)	Mandible: 5.31(2.69)	Mandible: 2.18(1.13)
Sequence 3 (I-F-E-G)	Maxilla: 3.25(1.37)	Maxilla: 3.64(1.50)	Maxilla: 4.54(2.32)	Maxilla: 3.45(1.77)
	Mandible: 2.69(1.45)	Mandible: 4.82(2.52)	Mandible: 5.56(2.64)	Mandible: 4.37(1.72)
Sequence 4 (F-G-I-E)	Maxilla: 4.46(1.97)	Maxilla: 3.85(1.43)	Maxilla: 3.53(1.73)	Maxilla: 3.23(1.37)
	Mandible: 4.59(1.40)	Mandible: 4.09(1.47)	Mandible: 3.09(2.02)	Mandible: 5.09(2.58)

Methods of tooth preparation: *F*, freehand; *G*, guiding pin; *E*, extraoral parallelometer; *I*, intraoral parallelometer.

Table III. ANOVA summary table (model: overall + tooth preparation method + location + session + dentist's experience + sequence + error)

Effect	DF	Sum of squares	Mean square	F value	*P* value
Tooth preparation method (F, G, E, I)	3	240.44	80.148	22.67	<.001*
Location (maxilla vs mandible)	1	61.15	61.15	17.30	<.001*
Session (1, 2, 3, 4), (period effect)	3	35.42	11.81	3.34	.02*
Dentist's experience (yes/no)	1	0.31	0.31	0.09	.771
Sequence (1, 2, 3, 4)	3	19.80	6.60	1.87	.13
Error	448	1583.60	3.53		
Residual	52	239.79	4.61	1.30	.08

**P* values < .05 considered significant.

not independent from each other (for example, sequence of tooth preparation would inflate session). The design was balanced against those interactions and these interactions would not affect the results. Nevertheless, with this setting, the following interactions (only 2-way interactions) can be tested: method of tooth preparations × dentist's experience, location × dentist's experience, session × dentist's experience; sequence × dentist's experience, method of tooth preparation × location, session × location, and sequence × location.

Table IV. Means, SDs, minimal, and maximal values (in degrees) of angular deviation of guiding grooves dependent on 4 methods of tooth preparation (for each method n = 128 resin substitutes). ANOVA revealed a significant effect of tooth preparation method (*P*<.001)

Tooth preparation	Mean	SD	Minimal	Maximal
Intraoral parallelometer	3.15	1.67	0.61	8.52
Guiding pin	4.10	1.62	1.31	9.01
Freehand	4.37	2.11	1.47	12.41
Extraoral parallelometer	5.06	2.33	1.01	11.55

RESULTS

Throughout this clinical experimental study, 2048 guiding grooves were prepared on 512 resin substitutes. The deviation of axes of proximal grooves from a preestablished path of insertion (guide planes) was expressed by means of an angle. Despite various influencing factors, a mean angle of 4.15 degrees (SD 2.06) for all guiding grooves (n = 2048) was recorded, with a minimum of 0.05 degrees and a maximum of 21.72 degrees. The arithmetic mean of angular deviations of all 4 proximal grooves of each resin substitute represented the outcome variable used for subsequent descriptive and confirmatory statistical analysis.

Table II lists descriptive data that corresponded to the Latin-square cross-over design applied in our study (Table I). Rows represent the 4 sequences of tooth preparation methods, whereas columns represent the 4 consecutive sessions. Each cell contains values of angular deviation of proximal grooves that describe 1 method of tooth preparation. There was a statistically significant influence of method of tooth preparation, location of tooth preparation within dentition (maxilla vs mandible), and session (period effect) on the deviation of guiding grooves from path of insertion (Table III). Table IV provides an additional description of the angular deviation of guiding grooves dependent on 4 methods of tooth preparation (for each method n = 128 resin substitutes). ANOVA revealed a statistically significant influence of the method of tooth

Table V. Multiple comparisons of 4 tooth preparation methods

Comparison	DF	Sum of squares	Mean square	F value	*P* value
Freehand vs extraoral parallelometer	1	30.39	30.39	8.60	.0035*
Freehand vs intraoral parallelometer	1	95.43	95.43	27.00	.0000*
Freehand vs guiding pin	1	4.77	4.77	1.35	.2459
Extraoral parallelometer vs intraoral parallelometer	1	233.53	233.53	66.06	.0000*
Extraoral parallelometer vs guiding pin	1	59.25	59.25	16.76	.0001*
Intraoral parallelometer vs guiding pin	1	57.52	57.52	16.27	.0001*

Adjustments according to Bonferroni, *P values < .0083 considered significant.

Table VI. Means, SDs, minimal, and maximal values (in degrees) of angular deviation of proximal grooves in maxilla and mandible (for each jaw n = 256 resin substitutes). ANOVA revealed a significant effect of location of tooth preparation (P<.001)

Location	Mean	SD	Minimal	Maximal
Maxilla	3.82	1.73	0.61	9.95
Mandible	4.51	2.31	0.64	12.41

Table VII. Decrease of divergence from parallelism of proximal grooves (in degrees) at 4 consecutive sessions (for each session n = 128 resin substitutes). ANOVA revealed that the effect of session (period effect) was significant (P=.02)

Session	Mean	SD	Minimal	Maximal
1st session	4.45	2.00	0.65	10.85
2nd session	4.30	2.00	1.18	11.36
3rd session	4.17	2.16	0.85	12.41
4th session	3.75	2.05	0.61	11.55

Table VIII. Means, SDs, minimal, and maximal values (in degrees) of angular deviation of proximal grooves dependent on dentist's experience (for experienced dentists n = 256 resin substitutes, for inexperienced dentists n = 384 resin substitutes). ANOVA revealed that the effect of dentist's experience was not significant (P=.771)

Dentist's experience	Mean	SD	Minimal	Maximal
Experienced	4.13	2.02	0.61	10.85
Inexperienced	4.18	2.08	0.65	12.41

preparation on the extent of divergence from parallelism (P<.001) (Table III).

In Table V the results of multiple comparisons between the 4 tooth preparation methods are summarized. Comparisons disclosed statistically significant differences, except a comparison between freehand tooth preparation and tooth preparation with a guiding pin. Tooth preparation with an intraoral parallelometer demonstrated the significantly least divergence of guiding grooves from a predetermined path of insertion. Tooth preparation with an extraoral parallelometer recorded the greatest degree of angular deviation. A significantly greater extent of divergence from parallelism was recorded for freehand tooth preparation and tooth preparation with aid of a guiding pin than with an intraoral parallelometer. Conversely, both methods demonstrated less divergence from parallelism than the extraoral parallelometer method. This difference was also statistically significant.

Proximal grooves were prepared in the maxilla as well as the mandible. ANOVA revealed that a substantially better result was recorded for the maxilla than the mandible (P<.001) (Table III). A mean angular deviation of 3.82 degrees (SD 1.73) was reported for guiding grooves prepared in the maxilla (n = 256 resin substitutes), a mean angle of 4.51 degrees (SD 2.31) for grooves prepared in the mandible (n = 256 resin substitutes) (Table VI). ANOVA indicated that among 2-way interactions tested, only the interaction between method of tooth preparation and location was statistically significant (P=.01). After closer inspection, a greater extent of divergence from parallelism was recorded in the mandible with freehand tooth preparations (P=.01), tooth preparations with a guiding pin (P=.05) and with an extraoral parallelometer (P=.01). There was no such difference between maxilla and mandible when tooth preparations were made with an intraoral parallelometer (P=.49). In the mandible, the least angular deviation was clearly achieved with the use of an intraoral parallelometer (Fig. 15).

Dentists performed each method of tooth preparation in 1 of 4 sessions at intervals of approximately 1 week. From the first to the fourth session (each session n = 128 resin substitutes) the results improved (Table VII). This period effect over sessions was statistically significant in the analysis of variance (P=.02) (Table III). There was no significant difference between experienced and inexperienced dentists (P=.771) (Table III). Mean angular deviations recorded for experienced (n = 128 resin substitutes) and less experienced dentists (n = 384 resin substitutes) were 4.13 (SD 2.02) and 4.18 (SD 2.08) degrees, respectively (Table VIII). The effect of the sequence of tooth preparation modalities on diver-

Table IX. Means, SDs, minimal, and maximal values (in degrees) of angular deviation of guiding grooves with regard to sequence of tooth preparation methods (for each sequence n = 128 resin substitutes). ANOVA revealed that the effect of sequence was not significant (P=.13)

Sequence	Mean	SD	Minimal	Maximal
Sequence 1 (E-I-G-F)	4.49	2.10	1.17	10.88
Sequence 2 (G-E-F-I)	4.14	2.16	0.61	12.40
Sequence 3 (I-F-E-G)	4.03	2.10	0.64	11.35
Sequence 4 (F-G-I-E)	3.99	1.85	0.84	11.55

Methods of tooth preparation: *F,* freehand; *G,* guiding pin; *E,* extraoral parallelometer; *I,* intraoral parallelometer.

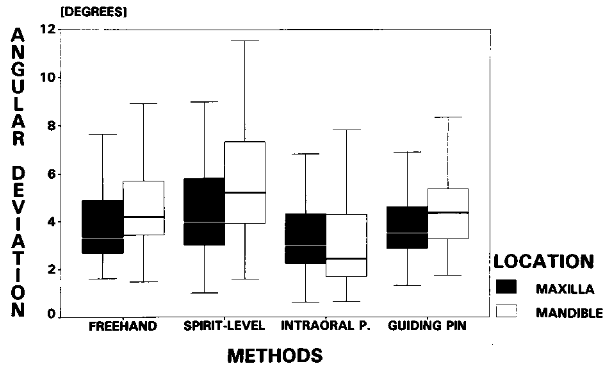

Fig. 15. Angular deviation of proximal grooves from path of insertion (median, quartile; in degrees) dependent on intraoral location of tooth preparation (each box n = 64 resin substitutes).

gence of guiding grooves from parallelism were not significant (ANOVA, P=.13) (Tables III and IX), which indicated that no carry-over effects occurred between sessions.

DISCUSSION

Resin-bonded fixed partial dentures (RBFPDs) are considered a minimally invasive treatment modality for replacement of missing teeth in both anterior and posterior segments. However, survival rates of posterior RBPs are rather low compared with anterior RBPs.[4] Several clinical studies reported significantly higher longevity rates for posterior RBPs when proximal grooves were placed in the abutments compared with minimal tooth preparations including only guide planes and rest seats.[7,8,11] Therefore, a retainer design was advocated that incorporates proximal grooves to improve resistance form and increase clinical success.

Abutment preparation for posterior RBPs consists of (1) tooth preparation of parallel guide planes, namely, creation of a distinct vertical path of insertion and (2) tooth preparation of proximal grooves and occlusal rest seats.[13,14] Micropreparation of grooves confined to enamel and with a path of draw compatible with one another and with the axial walls is a critical step requiring high technical skill. Ideally, proximal grooves should be parallel to one another and to the path of insertion to develop maximal resistance to lingual displacement of retainers.

Accurate intraoral assessment of the extent of groove divergence is difficult. Correction for lack of parallelism by increasing groove taper might conflict with the aim for minimally invasive tooth preparation and result in overpreparation. Failure to align the grooves correctly also creates problems during laboratory fabrication of a prosthesis. If a framework is waxed in obstructive undercuts on a refractory cast, insertion, and complete seating on the master cast requires time-consuming adjustments to the inner surfaces of retainers. Even a previous block out of undercuts on a refractory cast ultimately reduces mechanical retention similar to reshaping internal surfaces of retainers.

Approximation of tooth preparation to the ideal, in particular tooth preparation of guiding grooves, may be accomplished through the use of paralleling devices, suggested by several authors.[14,15] Our study was designed to evaluate the suitability of different paralleling devices for improvement of groove parallelism compared to freehand tooth preparation. Tooth preparation of proximal grooves was performed intraorally on resin substitutes. Extraorally preestablished axial surfaces of abutments served as vertical reference planes. The mean of angular deviations of all grooves of each resin substitute formed the outcome variable used for statistical analysis. This outcome measure was selected because clinical grooves from abutments contribute to mechanical retention of a framework.

Our study demonstrated that the task for dentists, to prepare parallel guiding grooves to a preestablished path of insertion, could be realized only for single grooves. A complex 3-dimensional visualization was required to complete the task. First, the axis of the diamond bur was deduced from its tapered surface. Likewise, the path of insertion was determined from the proximal and lingual surfaces of abutments. Finally, agreement of both axes was reached. Tilting of the diamond bur was avoided even with limited accessibility when approaching the tapered diamond bur to cylindrical axial surfaces of abutments.

Conversely, occlusal cervical height of axial surfaces of resin substitutes was larger than in clinical reality and measured 9.5 mm in the maxilla and 10 mm in the mandible. This height resulted from complete coverage of lingual surfaces of natural teeth with resin, which provided protection against injury during intraoral tooth preparations. The height also allowed tooth preparation of longer guiding grooves required to firmly secure steel pins for subsequent surveying. The larger axial surfaces and the green-colored autocuring resin used for fabrication of resin substitutes presumably had a favorable impact on results. The well-contrasting appearance of large green surfaces contributed to a clearer observation of guide planes and probably facilitated detection of the path of insertion.

The use of the intraoral parallelometer (Parallel-a-Prep) was the most efficient method for tooth preparation of nearly parallel proximal grooves. Two reasons were attributed to lack of parallelism. A predictable locking apparatus could not be achieved, despite the use of a polyether impression material with high final rigidity to anchor the attachment tray of the parallelometer to a dental arch. Conversely, a friction-free axial movement of the contra-angle handpiece required a minimal space between the bearing tube and post of the parallelometer, allowing also a minimal tilt of the contra-angle handpiece.

The guiding pin represented concentrated information regarding the path of insertion. The dentist had to visualize the pin with a mouth mirror in 2 planes perpendicular to one another and to align the assumed axis of a diamond bur to the pin. The accessibility to the posterior region of the mouth was reduced because of handling the mouth mirror. This situation could have contributed to results that were not significantly better when compared with a freehand tooth preparation. The tooth preparation method with an extraoral parallelometer recorded the worst results. This method required the dentist to follow an air bubble at a constant angle during the entire tooth preparation. Moreover, even a minimal head movement of the test patient resulted in misinterpretation of the path of insertion, despite the constant position of the air bubble.

All tooth preparations were performed under close supervision of a senior researcher to ensure strict adherence to a particular method of tooth preparation. The intraoral parallelometer allowed only vertical and horizontal movements of a handpiece. Any attempt to increase tooth preparation taper by twisting a handpiece resulted in limitation of freedom of movement or even inability to move a handpiece vertically or horizontally. Therefore, it appears improbable that dentists could have overridden this method. The results of the study also suggested that there was reliance on the method of tooth preparation with an extraoral parallelometer. If dentists relied on the method of freehand tooth preparation instead of the extraoral parallelometer as an orientation aid, the results of both methods would have been similar. However, the use of an extraoral parallelometer yielded substantially poorer results and a greater deviation of proximal grooves from path of insertion when compared with freehand tooth preparations. Conversely, the main difference between freehand tooth preparations and tooth preparations with a guiding pin was the manner in which the path of insertion was detected. Therefore, it was not surprising that similar results were achieved with both methods.

ANOVA revealed a statistically significant effect on the location of tooth preparation within the dentition on deviation of proximal grooves from the path of insertion. A significantly better result was recorded for the maxilla than for the mandible, despite the tooth preparation modality. Among the 2-way interactions tested, only the interaction between method of tooth preparation and location was statistically significant. On closer examination, an appreciably greater deviation of proximal grooves from path of insertion was recorded in the mandible with regard to freehand tooth preparations and tooth preparations performed with a guiding pin and an extraoral parallelometer. There was no significant difference between maxilla and mandible with regard to tooth preparations performed with an intraoral parallelometer. Surprisingly, the least angular deviation was clearly achieved in the mandible with an intraoral parallelometer.

A multipractice clinical study on the 5-year survival rate of posterior RBPs evaluated the effects of 2 abutment preparation designs and the effect of location of restorations within the dentition.[11] A conventional design involved only minor preparations, such as the creation of a path of insertion (guide planes) and occlusal rest seats, whereas a modified design in addition included 2 proximal grooves (one groove on each abutment).[12] Survival without debonding during a follow-up period was statistically in favor of the modified design (62% vs 46%) and the effect of location (maxilla vs mandible) was significant. Maxillary posterior RBPs exhibited greater retention than mandibular RBPs (65% vs 40%). Virzijden et al[12] mentioned some possible causes for the higher failure rate in the mandible such as differences in crown length, different points of impact during occlusal function, deformation of the mandible during function, and a more difficult isolation method in the mandible. However, no detailed information was provided that involved the use of paralleling devices and precision of tooth preparation (actual resistance form of abutments). Therefore, the question remains whether the use of an intraoral parallelometer or application of 2 opposing grooves on each abutment would have improved the success rate of mandibular RBPs. A significant period effect over sessions was discovered, despite the method of tooth preparation. There was a constant decrease in the degree of divergence from parallelism from the first to fourth session. The progressive familiarity of the dentists with the procedure was responsible for this beneficial result.

The results of this investigation cannot be directly applied to the anterior region because tooth preparations for proximal grooves were evaluated in posterior segments of the mouth. However, there are frequently shorter guiding grooves in the anterior region. Even minor adjustments of inner surfaces of retainers can severely compromise mechanical retention of a framework. Moreover, limited interocclusal space, short clinical crown height, and translucent incisal edges of anterior teeth are factors that restrict an adequate surface-bonding area. Therefore, an intraoral parallelometer can be equally suited for the anterior segments to develop a precise, minimally invasive preparation, namely, to optimize the resistance form of anterior abutments.

CONCLUSION

The following conclusions were drawn from this study:

1. This study indicated that under clinical conditions precise tooth preparation of proximal grooves on resin substitutes in the posterior quadrant of the mouth can be improved with the use of an intraoral parallelometer. The tooth preparations with an intraoral parallelometer demonstrated a substantial reduction in divergence of proximal grooves from a preestablished path of insertion when compared with freehand tooth preparations and tooth preparations performed with a guiding pin or an extraoral parallelometer.
2. The least amount of deviation of guiding grooves from a predetermined path of insertion in the mandible was achieved with the use of an intraoral parallelometer.
3. Scientific evidence for a cause-and-effect relationship exists between resistance form of abutments and longevity of posterior RBPs. However, additional clinical studies are indicated to determine the impact of precision groove preparation on longevity of posterior resin-bonded prostheses.

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