タイトル

磨耗効率に関する補助歯と樹脂コードの比較研究

著者

三穂 乙暁

ジャーナル

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Grinding Efficiency of Abutment Tooth with Both Dentin and Core Composite Resin on Axial Plane

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ABSTRACT

This study was conducted to evaluate grinding efficiency in the cases of both dentin and core composite resin. Test pieces were prepared with a boundary between bovine dentin and one of three commercially available core composite resins. Grinding was performed in five runs for each set of conditions involving two loads (0.5 and 0.25 N) and two feed rates (1 and 2 mm/s).

Observations of the grinding surface were made using a 3D laser microscope. In addition, to determine grinding efficiency, we analyzed tomographic images of the grinding surfaces of the test pieces, captured perpendicular to the feed direction. Using a non-ground surface for reference, portions with only dentin, portions with both dentin and core composite resin, and portions with only core composite resin were separately analyzed to determine the angle of the grinding surface. Composite resins were subjected to the Vickers hardness test and SEM image examination. Data were statistically analyzed using one-way analysis of variance and multiple comparison tests. Multiple regression analysis was performed for load, feed rate, and Vickers hardness of build-up material by number of runs. When grinding was performed with constant load and feed rate settings, a greater grinding angle was found for the portions in which both the dentin and composite resin were ground simultaneously and in which only the composite resin was ground than that for portions in which only the dentin was ground.

A correlation was found between grinding efficiency for the portions in which both the dentin and composite resin were ground simultaneously and in which only the composite resin was ground and grinding load or feed rate, with particularly high correlation observed between grinding efficiency and grinding load.

Keywords: Core build-up, Composite resin, Grinding efficiency, Continuity of grinding surfaces, Multiple regression analysis
INTRODUCTION

Demand for metal-free dental repair is increasing from the point of view of aesthetics. As a result, composite resin is applied instead of metal core build-up\textsuperscript{2,10,19}. In particular, dual-cure composite resins, are mainly applied in the direct core build-up method in combination with fiber posts. This abutment tooth preparation must be finished to a smooth, angle-free, gentle curve\textsuperscript{20}. In clinical practice, both a composite resin and the dentin are often present on the axial plane of the abutment tooth, resulting in a change in the angle at the boundary with the build-up material at the time of abutment tooth preparation. Suggested causes for this roughness include differences in the mechanical properties of the composite resin and dentin and the manner in which the grinding tools were used. Most reports on the grinding efficiency of core build-up material\textsuperscript{11,13,21} and on grinding tools\textsuperscript{9} evaluated resin cutting depth or time spent grinding under constant loads. One study, which featured adjustments to the load on an air turbine handpiece and feed rate,\textsuperscript{4} reported on the relationship between load and machinability and between machinability and number of runs using the bar. However, in this previous study, the dentin and composite resin were separated. In a clinical setting, the grinding conditions of load and feed rate exerted by the operator on the tool during grinding can vary. Consideration must be given to consecutively grinding the core build-up material surface and the surface of the abutment tooth. The present study was conducted on the assumption of the preparation of a commonly clinically encountered abutment tooth, which has both the dentin and core composite resin on its axial plane. After continuous grinding from the dentin to the composite resin, the resulting grinding surface was examined to evaluate the topography of the grinding profile and the influence of the number of runs using a diamond point, grinding load, and feed rate on grinding efficiency.

MATERIALS AND METHODS

1. Preparation of test piece
A bovine mandibular anterior tooth crown was used as the residual tooth substance to be built up. The tooth was fixed in an epoxy ring 23 mm in inside diameter and 25.4 mm high using epoxy resin (Scandiplex; Fritsch Japan Co., Ltd., Yokohama, Japan). The tooth was polished with #120 waterproof abrasive paper under running water, using an automated polishing machine (Automet 2 & Ecomet 3; Buehler, IL, USA) to expose the dentin. Cavities 10 mm long, 7 mm wide, and 3 mm deep were formed on this dentin surface. Each cavity was filled with one of three dual-cure, automatic mixing type composite resins for core build-up. The resins were then cured in accordance with the manufacturer’s instructions (Table 1). After curing, each sample was polished with #600 waterproof abrasive paper using the automated polishing machine until a uniform surface was obtained. A 4-mm-wide cut was then applied perpendicular to the surface in the tooth axis to obtain a test piece 4 mm wide and approximately 23 mm long with a dentin-composite resin boundary perpendicular to the polished horizontal surface and at right angles with respect to the long side. The sample was stored in 37 °C distilled water for 48 h (Fig. 1).

2. Grinding efficiency tester settings

The grinding efficiency tester consisted of a sample grinding portion and a sample fixing portion. The sample grinding portion consisted of an air turbine handpiece (Osadatron TDL Head 4H; Osada Electric Co., Ltd., Tokyo, Japan), a parallelometer (Bachmann parallelometer Model 82; Inoue Attachment Co., Ltd., Tokyo, Japan) for attaching the turbine, and a push-pull gauge (Analog push-pull gauge; Japan Instrumentation System Co., Ltd., Nara, Japan) for defining load. The air turbine handpiece was attached to the parallelometer and positioned to work with a horizontal movement to enable the push-pull gauge to be pressurized perpendicular to the polished surface. The sample fixing portion consisted of an automatic linear motion stage (Suruga Seiki Co., Ltd., Shizuoka, Japan) for fixing and moving the test piece at constant speed.
The rotation shaft of a straight cylinder-type diamond point 1.4 mm in diameter (FG Regular 211, Shofu Inc., Kyoto, Japan) attached to the air turbine and the dentin-resin boundary line on the polished surface of the test piece were placed parallel to the dentin-composite resin boundary. The air turbine was operated at a rotation speed of 340000 rpm in up-cut mode, and then load was applied to the turbine head at a right angle with respect to the polished surface using the push-pull gauge. The surface was then ground while water was injected at an air pressure of 0.25 Mpa and flow rate of 50 ml/min. The automatic linear motion stage was moved 10 mm parallel to the polished surface. Grinding was begun on the dentin side, passing 5 mm of the dentin and the boundary; approximately 5 mm of the composite resin was ground (Fig. 2).

3. Grinding conditions

The grinding load was set at two levels (0.5 and 0.25 N) perpendicular to the polished surface by the push-pull gauge and the grinding feed rate at two levels (1 and 2 mm/s). The grinding efficiency test was performed over five runs for each set of conditions, with the diamond point replaced every five runs under constant conditions.

4. Examination and measurement of grinding surfaces

The grinding surfaces were examined and measured using a LEXT OLS400 3D measuring laser microscope (Olympus Corporation, Tokyo, Japan). In addition, we analyzed tomographic images of the grinding surfaces of the test pieces, captured perpendicular to the feed direction.

5. Analysis of grinding results

1) Evaluation of number of runs using the diamond point

The profile of the dentin grinding surface was examined for each of the first five runs using
the diamond point. In profile determination, the angle of the grinding surface was determined with the non-ground surface as the reference line (Fig. 3).

- Point “a”': Point 4.2 mm from the dentin-build-up material boundary toward the dentin on the grinding line
- Point “b”': Point 1.4 mm from the dentin-build-up material boundary toward the dentin on the grinding line
- Angle $\alpha$: Angle between the reference line and the straight line passing through points “a” and “b”

2) Evaluation of dentin and core composite resin

In the profile determination, the angle of the grinding surface was determined with the non-ground surface as the reference line, and the areas were used as indices of machinability (Fig. 3).

- Point “c”': Point at which an angle change occurs on the grinding line
- Point “d”': Point in the dentin-build-up material boundary on the grinding line
- Point “e”': Point 1.4 mm from the dentin-build-up material boundary toward the build-up materials on the grinding line
- Angle $\beta$: Angle between the straight line passing through points “a” and “b” and the straight line passing through points “c” and “d”
- Angle $\gamma$: Angle between the straight line passing through points “a” and “b” and the straight line passing through points “d” and “e”
- Area $Z_1$: Area surrounded by the grinding line between points “c” and “d,” the line passing through point “c” and parallel to the straight line passing through points “a” and “b,” and the line passing through point “d” and perpendicular to the reference line
- Area $Z_2$: Area surrounded by the grinding line between points “d” and “e,” the line passing through point “d” and parallel to the straight line passing through points “a” and “b,” and the line passing through point “e” and perpendicular to the reference line
In the evaluation of the angle of the grinding surface by the number of runs using the diamond point, diamond point grinding was stable in the 3rd, 4th, and 5th runs of grinding. For this reason, the grinding of portions having both bovine dentin and composite resin and portions having only composite resin was determined based on the results of the 3rd, 4th, and 5th runs.

6. Evaluation of Vickers hardness and SEM images
For each composite resin sample of the test piece and polished surface of the dentin, Vickers hardness was determined under loading conditions of 3 N at 15 s using a hardness-testing machine (MVK-1 Shimadzu Corporation, Kyoto, Japan). For each test piece, five measurements were taken with the mean value adopted as the hardness of the test piece; six test pieces were allocated for each composite resin. The mirror-polished surfaces of the three core composite resins were examined using SEM images.

7. Statistical analyses
Data on load and feed rate were statistically analyzed using one-way analysis of variance, with multiple comparisons also performed for each build-up material and each number of runs. A p-value less than 0.05 was considered statistically significant. Multiple regression analysis was conducted for load, feed rate, and build-up material sample Vickers hardness value for each number of runs.

RESULTS

1. Examination of grinding surfaces using a 3D laser microscope
The portion of the dentin to be ground has a declining surface until a given load is exerted. In the present study, after the load was stabilized, the dentin grinding surface was formed with a declined gradually increasing in depth in some cases and with a nearly horizontal plane in other cases. When the grinding diamond point reached the composite resin, the grinding
surface changed its angle to increase depth. The diamond point then ground only the composite resin, resulting in a grinding surface that had nearly constant declination (Fig. 4).

2. Evaluation of grinding efficiency by number of runs using the diamond point
The number of runs using the diamond point was evaluated at the declination ($\alpha$) in the portions in which only the dentin was ground. The value of $\alpha$ changed drastically between the 1st and 2nd runs of grinding, shifting from approximately 1° in the 1st run to 5° in the 2nd, with a significant difference from the other grinding conditions observed at a load of 0.5 N and a feed rate of 1 mm/s. In contrast, in the 3rd, 4th, and 5th runs of grinding, the value of $\alpha$ exhibited a converging tendency in the range of 0.5° to −0.1° on average, with no significant differences in $\alpha$ observed among the grinding conditions (Fig. 5).

3. Evaluation of dentin and core composite resin consecutive grinding portion
1) Declination ($\beta$) in the portions in which both the dentin and composite resin were simultaneously ground and declination ($\gamma$) in the portions in which only the composite resin was ground
A significant difference in $\beta$ was noted among the grinding conditions only in C-Core. The values of $\beta$ showed a decreasing trend from the 3rd through the 5th runs in A and B-Core (Fig. 6). In all samples, a high $\gamma$ value was obtained at a load of 0.5 N and a feed rate of 1 mm/s in the 3rd run of grinding, with significant differences in $\gamma$ found among the various grinding conditions. In the 4th and 5th runs, however, C-Core alone exhibited a large $\gamma$ value at a load of 0.5 N and a feed rate of 1 mm/s, with significant differences found among the various grinding conditions (Fig. 7).
2) Area ($Z_1$) of the portions in which both the dentin and composite resin were simultaneously ground and area ($Z_2$) of the portions in which only the composite resin was ground
In C-Core, significant differences in Z1 were found in the 3rd run of grinding between 0.5 N load and 1 mm/s feed rate and 0.25 N load and 2 mm/s feed rate. In the 4th and 5th runs of grinding, significant differences from other grinding conditions were found at a load of 0.5 N and a feed rate of 1 mm/s.

In A-Core as well, significant differences were found in the 4th run of grinding between 0.5 N load and 1 mm/s feed rate and 0.25 N load and 1.2 mm/s feed rate. The entire Z1 was approximately 0.05 mm² or less on average, markedly smaller than the Z2 described below (Fig. 8).

In all samples, the Z2 was high at a load of 0.5 N and a feed rate of 1 mm/s in the 3rd run of grinding.

With A-Core, significant differences in machinability were found among different loads and feed rates, whereas with B-Core, significant differences in machinability were only noted among different loads. C-Core also exhibited a high machinability value at a load of 0.5 N and a feed rate of 2 mm/s, with significant differences noted in load and feed rate.

In the 4th and 5th runs of grinding, a high machinability value was obtained for C-Core at a load of 0.5 N and a feed rate of 1 mm/s. In the 3rd, 4th, and 5th runs of grinding, the grinding surface area decreased as the number of runs increased. At a load of 0.25 N and a feed rate of 2 mm/s, small grinding surface areas were obtained under all conditions except for A-Core in the 3rd run of grinding (Fig. 9).

4. Vickers hardness of composite resins

The hardness (Hv) of each build-up material was determined to be 71.4±8.5, 57.4±4.8, and 67.0±5.0 for A, B, and C-Core, respectively. The hardness (Hv) of dentin was 77.4±2.6.

5. SEM imaging of composite resins

SEM imaging of sample composite resins revealed a larger number of irregular-shaped fillers
approximately 20 µm in particle diameter with A-Core and with lower microfiller density, than with other composite resins. For B-Core fillers, which were relatively spherical compared with A-Core, approximately 10 µm particle diameters were observed. For C-Core, many irregular-shaped fillers smaller than approximately 10 µm in particle diameter and many fine fillers smaller than 0.2 µm in diameter were observed (Fig. 10).

6. Multiple regression analysis
With load, feed rate, and Vickers hardness as explanatory variables, multiple regression analysis of the machinability of Z1 and Z2 revealed a correlation with load and feed rate, with a significance level of <0.05 in all 3rd, 4th, and 5th runs of grinding. In comparing the correlations of load and feed rate with the machinability, load exhibited a correlation equivalent to or greater than that of feed rate. The coefficient of determination was higher in the 3rd than in the 4th or 5th runs, demonstrating greater interpretability. No correlation with Vickers hardness was found (Table 2).

DISCUSSION

1. Test pieces
All core composite resins used in the present study were of the automatic mixing type, which is commonly used for crown dentin characterized by minimal bubbling during kneading. The resins had been polymerized using the dual cure method, ensuring adequate setting even in the innermost portion and stable bending strength compared with the chemical polymerization method\(^{14}\). To eliminate the influence of polymerization depth and kneading, the test pieces were stored for 48 h before use.

Bovine dentin was chosen as the experimental dentin for the assumed abutment tooth. The tensile strength of human dentin and bovine dentin is influenced by the orientation of the dentinal tubules; actual measurements ranged from 34.5 to 64.5 MPa for human teeth, nearly
the same as for bovine teeth (38.9 to 67.6 MPa)\(^3\).

2. Measurements

Use of a high-resolution 3D laser microscope in the direction of specimen depth (0.01 μm) enabled the obtaining of topographical images without preparing a section of the ground portion of the test piece\(^{15}\), facilitating examination of the boundary between the dentin and composite resin. The area of the portion in which both the dentin and composite resin were simultaneously ground was extremely small, hindering evaluation of this area on the same scale as those for area determination in portions where only the composite resin was ground. Therefore, the continuity of the grinding surfaces was evaluated based on angle.

3. Loads and feed rates

When a rotary grinding tool is used to grind a piece, the cutting resistance is divided into principal, feed, and thrust force\(^{12}\). Available reports on the evaluation of cutting resistance include a study that determined a combined load of approximately 60 to 100 g for the three directions applied during grinding using a 3D measuring load\(^{18}\) and a study that revealed a mean cutting pressure in the vertical direction of 30.4 ± 12.9 g and a maximum cutting pressure of \(\leq 100\) g\(^{22}\).

However, other studies found that the reduction in air turbine rotation rate was proportional to the increase in load\(^{7}\) and that the air turbine sometimes became disabled due to stop in to at grinding loads of 50 and 60 gf\(^4\).

Based on the above information, the loads used in this study were 0.5 N and 0.25 N. There was little likelihood of the diamond point cutting into the grinding surface, when using a 1.4-mm diameter cylinder type for which the load can be applied perpendicular to the grinding surface.

Regarding grinding settings, the rotating diamond point was first positioned, and then set on
the test piece. Then, the load was specified using an analog push-pull gauge, and the air turbine was positioned when the load conditions were reached.

Regarding feed rate, a previous study had the feed rate for the experimental system set between 0.04 and 2.10 mm/s. Another study measuring the grinding speeds of a number of subjects determined that the grinding tool feed rate ranged from 1.61 to 10 mm/s. Accordingly, we asked 19 dentists with 2 to 19 years of experience in clinical practice to form a mandibular first molar lingual surface in an epoxy model and measured their working speeds (Fig. 11), obtaining a mean of 1.51 mm/s, a maximum of 2.49 mm/s, and a minimum of 0.76 mm/s. With these values in mind, we selected feed rates of 1 and 2 mm/s for the present study.

4. Grinding the dentin

Previous studies on machinability have reported that the machining performance of diamond points decreases due to abrasive grain wear, dropping with an increasing number of runs. While findings on composite resin machinability have been controversial, decreasing or not depending on the number of runs using a diamond point, dentin machinability remained relatively unchanged. In the present study, in the 1st and 2nd runs of dentin grinding during initial use of a diamond point, the grinding surface had a mean angle of approximately 3.8° to 5.1° at a load of 0.5 N and a feed rate of 1 mm/s, indicating an increasing trend in grinding efficiency. At other loads and feed rates, the mean angle ranged from 0.8° to 2.4°, indicating a small declination of the grinding surface. At a speed and feed load of all 3rd, 4th, and 5th runs, the angle of the ground surface was observed to be stable at 0.5° below average. This observation may be attributed to the stabilization of the morphology of the diamond point abrasive grain and other factors following two grinding runs for 5 mm each of the dentin and composite resin. Here, we analyzed the work materials to determine how composite resin grinding efficiency is altered under stable conditions of dentin grinding.
efficiency.

5. Description of portions in which both the dentin and composite resin were simultaneously ground

At the boundary between the dentin and composite resin, grinding occurs with the involvement of diamond point curvature and cutting depth. During this period, the diamond point grinds the dentin and composite resin at different ratios. The machinability of the target region was extremely small. With load, feed rate, and Vickers hardness as explanatory variables, multiple regression analysis of the machinability of Z1 revealed a correlation with load and feed rate in all 3rd, 4th, and 5th runs of grinding.

6. Description of portions in which only the composite resin was ground

In the 3rd run of grinding for A-Core, B-Core, and C-Core, and in the 4th and 5th runs for C-Core, the machinability of Z2 increased at a load of 0.5 N and a feed rate of 1 mm/s. When the load was 0.25 N in the 3rd run for A-Core, B-Core, and C-Core, the machinability of Z2 was small at feed rates of both 1 and 2 mm/s. In the 4th and 5th runs, the machinability of Z2 was small under all grinding conditions for all cores and under all conditions except the C-Core grinding conditions of 0.5 N load and 1 mm/s feed rate, with \( \gamma \) exhibiting the same tendency.

The hardness of a composite resin indicates the degree of toughness of the material, including a broad range of other properties. Grinding refers to deforming and cutting a work material by a shearing force. The factor that is most closely related to machinability is the toughness of the work material. All three composite resins used in the present study exhibited values of Vickers hardness with smaller tendencies than that of dentin. Although machinability differed depending on the grinding conditions, all of the composite resins exhibited greater machinability than did dentin.
However, multiple regression analysis found no correlation between Vickers hardness values and composite resin machinability. The mechanical properties of composite resin are influenced by filler particle size, distribution, content, and other factors\(^1\). A previous study found that machinability decreased when a small spherical filler with a mean particle diameter of 0.2 µm was used, with increases with increasing content when irregular-shaped or spherical fillers were used\(^5\). The composite resins used in the present study have been reported to have filler contents of approximately 70% (w/w) to 80% (w/w). In the present study, C-Core samples tended to exhibit greater machinability than did A-Core and B-Core, reflecting the influence of filler size and shape, choice of filler, filler content and density, and other factors. C-Core, which had a filler of small particles, was believed to be the most susceptible to the influence of grinding load and feed rate.

Multiple regression analysis was performed for load, feed rate, and Vickers hardness in portions in which only the composite resin was polished. The results demonstrated a correlation between the machinability of portions in which only the composite resin was ground and the grinding load and feed rate. In particular, machinability moderately or strongly correlated with load. In addition, high interpretability ($r^2$) was observed for the 3rd run of grinding. As such, caution is suggested when determining the grinding load and feed rate to use in grinding composite resin with the initial use of a diamond point.

In clinical practice, it is desirable to be able to grind a formation consisting only of composite resin as early as possible, using the grinding of fast speed and a feather touch.

7. **Continuity of grinding surfaces**

The area of the portion in which both the dentin and composite resin were simultaneously ground was extremely small, hindering evaluation of this area under the same conditions as those for area determination in portions where only the composite resin was ground. Therefore, the continuity of grinding surfaces was evaluated based on angle.
Once grinding was initiated, the angle (α) of the dentin grinding surface exhibited minimal variation, with grinding proceeding nearly horizontally. However, in the portions in which both the dentin and composite resin were ground simultaneously, the angle (β) of the ground surface increased in all cases, irrespective of composite resin, number of runs, or grinding conditions (Fig. 12). In contrast, in portions where both the dentin and composite resin were ground simultaneously, the angle (β) of the ground surface was nearly the same as the angle (γ) of the ground surface in portions where only the composite resin was ground (Fig. 13). Hence, when composite resin began to be ground on the dentin grinding surface, the angle of the grinding surface increased. However, even after the grinding surface changed from a portion in which both the dentin and composite resin were ground to a portion in which only the composite resin was ground, the grinding direction remained unchanged, with only a small change in grinding angle. Ample caution should therefore be exercised in clinical settings when the boundary between the dentin and composite resin is ground, as the angle of the grinding surface changes when the rotating diamond point begins grinding the composite resin.

**Conclusion**

We observed the grinding surfaces of continuously ground bovine dentin and built-up composite resin, the appearance of the ground surface produced when grinding from the dentin to the composite resin, the effect of the use of the diamond point, and the effects of the feed rate and load applied during grinding, and reached the following conclusions.

1. With the newly adopted diamond point, the dentin grinding angle varied widely between the 1st and 2nd runs of grinding, even under constant conditions of load and feed rate. In the 3rd, 4th, and 5th runs, the grinding conditions had reduced influence.
2. When grinding was performed with constant load and feed rate settings, a greater grinding angle was found for portions in which both the dentin and composite resin were ground
simultaneously and in which only the composite resin was ground than that for portions in which only the dentin was ground.

3. A correlation was found between the machinability of the portions in which both the dentin and composite resin were ground simultaneously and in which only the composite resin was ground and grinding load or feed rate, with a particularly high correlation observed between machinability and grinding load.
REFERENCES


Figure legends

Table 1 Grinding efficiency test samples

Table 2 Results of multiple regression analysis

Fig. 1 Test piece 4 mm wide and approximately 23 mm long with a dentin-composite resin boundary perpendicular to the polished horizontal surface and at right angles with respect to the long sides

Fig. 2 Magnified view of the grinding portion

Fig. 3 Measurement reference values on transverse section

Fig. 4 Example observation of ground surface using a 3D laser measuring microscope

Fig. 5 Angle (α) of portion in which only dentin was ground

Fig. 6 Angle (β) of transfer from dentin to a portion in which both dentin and build-up material were ground simultaneously

Fig. 7 Angle (γ) between dentin and the portion in which the build-up material was ground

Fig. 8 Area (Z1) of portion in which both dentin and build-up material were ground simultaneously

Fig. 9 Area (Z2) of portion in which only build-up material was ground

Fig. 10 SEM images of various core samples

Fig. 11 Relationship between core preparation speed and number of years of experience of 19 dentists

Fig. 12 Differences in angles α and β among various grinding conditions in 3rd grinding run

Fig. 13 Differences in angles β and γ among various grinding conditions in 3rd grinding run
Table 1 Grinding efficiency test samples

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Light exposure: Alpha-Light II (effective wavelength = 400 to 600 nm )
*1: 300 seconds *2: 180 seconds
Table 2 Results of multiple regression analysis

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Fig. 1 Test piece 4 mm wide and approximately 23 mm long with a dentin-composite resin boundary perpendicular to the polished horizontal surface and at right angles with respect to the long sides.
1) Straight cylinder type diamond point (FG Regular 211, 1.4 mm diameter)

Fig. 2 Magnified view of the grinding portion
Fig. 3 Measurement reference values on transverse section
Fig. 4 Example observation of ground surface using a 3D laser measuring microscope

- Dentin
- Boundary
- Composite resin
Fig. 5 Angle (α) of portion in which only dentin was ground

- Load value 0.5 N, Feed rate 1 mm/s
- Load value 0.5 N, Feed rate 2 mm/s
- Load value 0.25 N, Feed rate 1 mm/s
- Load value 0.25 N, Feed rate 2 mm/s

Number of grinding runs

n=15  * P < 0.05
Fig. 6 Angle (\(\beta\)) of transfer from dentin to a portion in which both dentin and build-up material were ground simultaneously.
Fig. 7 Angle ($\gamma$) between dentin and the portion in which the build-up material was ground

- Load value 0.5 N, Feed rate 1 mm/s
- Load value 0.5 N, Feed rate 2 mm/s
- Load value 0.25 N, Feed rate 1 mm/s
- Load value 0.25 N, Feed rate 2 mm/s

n=5  * P<0.05
Fig. 8 Area (Z1) of portion in which both dentin and build-up material were ground simultaneously

- Third grinding run
- Fourth grinding run
- Fifth grinding run

Load value 0.5 N, Feed rate 1 mm/s
Load value 0.5 N, Feed rate 2 mm/s
Load value 0.25 N, Feed rate 1 mm/s
Load value 0.25 N, Feed rate 2 mm/s

n=5 * P<0.05
Fig. 9 Area (Z2) of portion in which only build-up material was ground

- A-Core
- B-Core
- C-Core

Third grinding run

- Load value 0.5 N, Feed rate 1 mm/s
- Load value 0.5 N, Feed rate 2 mm/s
- Load value 0.25 N, Feed rate 1 mm/s
- Load value 0.25 N, Feed rate 2 mm/s

Fourth grinding run

- Load value 0.5 N, Feed rate 1 mm/s
- Load value 0.5 N, Feed rate 2 mm/s
- Load value 0.25 N, Feed rate 1 mm/s
- Load value 0.25 N, Feed rate 2 mm/s

Fifth grinding run

- Load value 0.5 N, Feed rate 1 mm/s
- Load value 0.5 N, Feed rate 2 mm/s
- Load value 0.25 N, Feed rate 1 mm/s
- Load value 0.25 N, Feed rate 2 mm/s

n=5  *  P<0.05
Fig. 10 SEM images of various core samples
Fig. 11 Relationship between core preparation speed and number of years of experience of 19 dentists
Fig. 12 Differences in angles $\alpha$ and $\beta$ among various grinding conditions in 3rd grinding run

A-Core  
B-Core  
C-Core  

$n=5$
Fig. 13 Differences in angles $\beta$ and $\gamma$ among various grinding conditions in 3rd grinding run

- **A-Core**
  - Load value 0.5N, Feed rate 1mm/s
  - Load value 0.5N, Feed rate 2mm/s
  - Load value 0.25N, Feed rate 1mm/s
  - Load value 0.25N, Feed rate 2mm/s

- **B-Core**
  - Load value 0.5N, Feed rate 1mm/s
  - Load value 0.5N, Feed rate 2mm/s
  - Load value 0.25N, Feed rate 1mm/s
  - Load value 0.25N, Feed rate 2mm/s

- **C-Core**
  - Load value 0.5N, Feed rate 1mm/s
  - Load value 0.5N, Feed rate 2mm/s
  - Load value 0.25N, Feed rate 1mm/s
  - Load value 0.25N, Feed rate 2mm/s

$n=5$ T-Test $* P < 0.05$