# Study on Experimental LED Curing Light Unit

OUCHI Satoko[1)], ONDA Kohei[2)], HATSUOKA Yoshinori[2)],

YOSHIKAWA Kazushi[2)], and YAMAMOTO Kazyo[2)]

[1)] Graduate School of Dentistry, Department of Operative Dentistry, Osaka Dental University

[2)] Department of Operative Dentistry, Osaka Dental University.

Corresponding author: Satoko Ouchi

1-5-17, OTEMAE CHUO-KU, OSAKA 5400-0008, JAPAN

PHONE: 81-6-6910-1087 FAX: 81-6-6910-1052

E-mail: satoko-o@cc.osaka-dent.ac.jp

Experimental LED Curing Light Unit

[Abstract]

**Purpose**: We experimentally prepared a novel LED curing unit (MI-head) with a small tip (diameter: 2.1-mm) capable of irradiating light close to the gingival wall. In this study, a conventional LED light curing unit, Pen Cure, and the MI-head were compared to investigate the influence of the curing unit on adhesion applied to the gingival wall of class II cavities. **Methods**: Dentin adherend surfaces were prepared on extracted bovine teeth. Clearfil Mega Bond (MB) was applied to the surface, followed by light irradiation using Pen Cure or the MI-head at various irradiation distances and durations. Resin paste was then applied, and tensile bond strength (TBS) was measured after the specimens were placed in a 37°C water bath for 24h. Class II cavities were prepared in extracted human teeth. After setting the matrix, MB was applied to the tooth surface, followed by light irradiation from the cuspal side using Pen Cure, or from the gingival wall side of the cavity using the MI-head. Incremental filling of the resin paste was then performed, and a thermal stress was loaded. Each sample was immersed in 5% basic fuchsin solution for 24h, and marginal leakage was observed under an optical microscope. A class II cavity was prepared on the mesial side of the left first molar in an artificial mandibular model, and the light intensities of Pen Cure and the MI-head were measured under the same irradiation conditions as employed in the marginal leakage test. **Results**: Although TBS was significantly higher when irradiated with MI-head, marginal leakage could not be prevented. The light intensity of Pen Cure was significantly higher than that of the MI-head. **Conclusion**: The results of this study suggest that improvements in the irradiation method and prolonged irradiation are necessary to achieve adequate bond strength by the bonding agent applied to class II cavities using the MI-head.

Key words: LED curing light unit, bonding resin, irradiation distance

[Introduction]

The composite resin (CR) bonding system has markedly advanced since the development of a bonding system incorporating a dentin primer, the GLUMA system, in the 1980s[1,2]. These bonding systems have increased bond strength and the simplification of steps leading to improvements in the mechanical properties and esthetics of CR such that the bonding system can now be sued to treat all regions[3-8]. And the concept of minimal intervention[9-11] has also expanded in dentistry. CR has recently been increasingly used to restore class II cavities.

The sufficient polymerization and bond strength of bonding resin are essential for CR restoration[12,13]. Although a matrix is needed when a class II cavity is to be restored with CR, it is impossible to irradiate the bonding resin from the adjacent surface when a metal matrix is used; therefore, light is applied from the occlusal surface. Moreover, the tip of curing units cannot come into close proximity to the gingival wall for the CR restoration of class II cavities, which results in increased irradiation distance. Curing units with a large tip diameter are also restricted by the pairing tooth and irradiation from the optimal position is difficult in many cases. Therefore, the amount of light reaching the site is insufficient, and the resulting insufficient bonding resin polymerization on the gingival wall may reduce the bond strength between CR and the tooth [3,4,14].

A decrease in the durability of CR restorations has been shown to markedly affect the oral environment, and this needs to be improved because the number of cases treated with CR restoration is increasing. For accurate and adequate polymerization in CR restoration, reliable and sufficient polymerization of bonding resin is necessary for CR restoration.[15].

In the present study, we experimentally prepared a LED curing unit with a small tip diameter as shown in Fig. 1(MI-head, J. Morita Manufacturing). This curing unit has a pen-type design, similar to the conventional curing unit, Pen Cure (J. Morita Manufacturing). In addition, the tip of MI-head is small (diameter: 2.1-mm) and can be advanced deeply into the cavity. Insufficient irradiation of the gingival wall was a limitation associated with previous curing units with a large diameter of curing tip; however, this curing unit enables irradiation of the gingival wall, which indicates its usefulness for CR restoration in the future. We compared Pen Cure and MI-head to investigate the influence of the irradiation distance on the adhesion of bonding resin.

[Materials and Methods]

The materials and irradiation conditions are shown in Tables 1 and 2, respectively.

1. Measurement of tensile bond strength (TBS) and observation of fracture surface

Bovine mandibular incisors frozen after extraction were thawed immediately before the test. Enamel on the labial side of the crown was removed using a model trimmer (J. Morita Manufacturing), and the tooth was ground using waterproof abrasive paper #600 to prepare a flat dentin surface. Masking tape having a hole with a 3.0-mm inner diameter was applied to this surface to specify the adherend surface area, to which a mold with a 2.0-mm-height (2.0-mm-mold) was set. Clearfil Mega Bond (MB, Kuraray Noritake Dental) as a 2-step bonding system was applied to the surface following manufacture's instruction, followed by 10s light irradiation from the 2.0-mm-mold using Pen Cure as a control. Under the conditions except the control, the surface was covered with a 6.0-mm tube-form jig (6.0-mm-jig) after bond application so as to surround the 2.0-mm-mold. (Fig. 2) The reason for the coverage with a 6.0-mm-jig was that the irradiation distance from the occlusal surface of a class II cavity to the gingival wall was assumed to be 6.0-mm. Light irradiation was applied using Pen Cure from the 6.0-mm-jig for 10s, 20s, 40s, and 60s (coded as P10s, P20s, P40s, and P60s). Under conditions of M10s and M20s, the tip of MI-head was inserted in a 6.0-mm-jig, and the surface was irradiated from approximately 0.5-mm above the adherend surface while moving the tip. Under conditions of M10s and M20 s, the MI-head was placed in the 6.0-mm-jig and light was irradiated from approximately 0.5-mm above the adherend surface while moving the tip to avoid concentrating of irradiated light at one point. Under conditions of M10s-2 and M20s-2, the MI-head was placed in the 6.0-mm-jig and light was irradiated from 2.0-mm above the adherend surface while moving the tip. The 2.0-mm-mold was then filled with the resin, Clearfil Majesty LV (LV, Kuraray Noritake Dental), up to a 2.0-mm height of the mold in all samples, and then irradiated from the 6.0-mm-jig for 20s using Pen Cure. Samples were immersed in 37°C water for 24h after bonding, and TBS was measured at a crosshead speed of 0.3 mm/min using a universal tester (MI-20, Intesco) (n=8). In addition, the adherend surface area was specified on the dentin surface by applying masking tape with a 2.0-mm hole. The bonding resin was irradiated at M10s, M20s, M10s-2, and M20s-2 using the MI-head without moving the tip and then processed as described above to compare TBS between those after irradiation with and without moving the tip of the MI-head. The data obtained was analyzed by a one-way ANOVA and Tukey's HSD test ($p<0.05$).

After being put it in a vacuum pump for 24h, gold vapor deposition was applied to the samples after TBS measurements using a conventional method, and tensile fracture surfaces were observed under a scanning electron microscope (JSM-5610LU, JOEL Ltd., SEM). The destruction pattern was judged as follows: when interface exposure was observed in 70% or more of the area, destruction or the adhering cured material in dentin was observed in 70% or more of the area, and other destruction patterns were classified as interfacial, cohesive, and mixed failures.

2. Marginal leakage test

Anonymized extracted human teeth frozen in saline were thawed immediately before the experiment. A class II cavity (a rectangular cylindrical cavity with 2.5-mm bucco-lingual and 1.0-mm mesio-distal widths as the gingival wall and a 6.0-mm depth from the tip of the cusp) was prepared. After setting a metal matrix band, a 20s primer treatment with MB was applied and sufficiently dried by air blowing following the manufacturer's instructions, and the bonding resin was applied. Under the irradiation conditions of P10s, P20s, P40s, and P60s after air blow drying, the cavity was irradiated from the cusp top. MI-head was set close to the gingival wall at M10s and M20s, and light was irradiated from a distance of approximately 0.5-mm while moving the tip. Light was irradiated from 2.0-mm above the gingival wall at M10s-2 and M20s-2 while moving the tip. On the other hand, the bonding system was applied to the tooth surface before setting a matrix band, and irradiation was applied for 10s using Pen Cure from 3 directions: from the occlusal surface and buccal and lingual sides (coded as P30s). The cavity was then filled with LV, up to a 2.0-mm height from the gingival wall and irradiated for 20s using Pen Cure. The cavity was then filled with paste-type Clearfil Majesty (CM, Kuraray Noritake Dental) up to the occlusal surface and irradiated for 20s using Pen Cure. all samples were stored in a 37°C water bath for 24h after filling, polished using Soflex Discs (3M ESPE, USA), and the subjected to 5-55°C thermal stress loading 5,000 times. After stress loading, the root apex was sealed with FujiII LC (LC, GC), and the sample was covered with nail varnish while leaving an uncovered 1.0-mm lateral margin of the gingival wall. All samples were immersed in 0.5% basic fuchsin solution (KISHIDA CHEMICAL) for 24h and cut at the center of the cavity between the buccal and lingual sides. Marginal leakage was observed under a light microscope and evaluated following the criteria shown in Fig. 3 (n=8). Statistical analysis was performed employing the Mann-Whitney U-test ($p<0.05$).

This study was approved by the Medical Ethics Committee of Osaka Dental University (Approval No: 110735).

3. Measurement of light intensity

Light intensity was measured using Quest X (QuestTMX, B&W Tek Ink, USA). A cavity was prepared on the right first molar of the artificial mandibular model, similar to that in the marginal leakage test. A hole was made from the bottom of the model to the gingival wall in order to insert a fiber for measurement into the gingival wall of the cavity, and the fiber was fixed (Fig. 4). The light intensity of Pen Cure was measured at the tip of the cusp (6.0-mm above the fiber position). The MI-head was placed in the cavity, and the light intensity was measured 0.5 and 2.0-mm above the fiber. As a control, the light intensity of Pen Cure was measured 0-mm above the fiver position without using the artificial model (n=8). The data obtained was analyzed by a one-way ANOVA and Tukey's HSD test ($p<0.05$).

[RESULTS]

1. TBS test

Measurement results are shown in Table 3 and Fig. 5.

When the curing tip of Pen Cure was placed 6.0-mm from the adherend surface, TBS was significantly lower than that of the control even though the irradiation time was extended to 40s, and TBS equivalent to that of the control was obtained by P60s. When the adherend surface was irradiated from 0.5-mm using the MI-head, TBS equivalent to that of the control was obtained by M20s irradiation (the adherend surface was 3.0-mm in diameter). However, when the tip was 2.0-mm away from the adherend surface, TBS acquired by M20s-2 was significantly lower than that of the control. A higher TBS was obtained in the adherend surface with a 3.0-mm diameter than in that with a 2.0-mm diameter.

The results on the fracture surface after the TBS test are shown in Table 4.

Cohesive failure of CR and adhesive failure were observed in the fractured surface irradiated at P10s and P20s from a 6.0-mm irradiation distance; however, both cohesive failure of dentin and adhesive failure were frequently noted at P40s and P60s with a prolonged irradiation time. In contrast, the cohesive failure of dentin was noted in groups using the MI-head with a short irradiation distance. When irradiation was applied from a 0.5-mm distance using the MI-head, the cohesive failure of dentin was only observed in the central region of the fracture surface.

2. Marginal leakage test

The marginal leakage test results and photographs of typical cases by the score are shown in Table 5 and Fig. 6, respectively.

Using Pen Cure, marginal leakage was observed in all samples when the bonding resin was irradiated for the time specified by the manufacturer, and marginal leakage could not be prevented even though the irradiation time was prolonged to P20s, P40s, and P60s. Furthermore, marginal leakage could not be prevented using the MI-head. Score 0 was most frequently observed at P30s and M20s-2.

3. Light intensity test

The results are shown in Fig. 7.

Light intensity was significantly lower under all irradiation conditions than that irradiated from a 0-mm distance using Pen Cure. The intensity of light irradiated from a 6.0-mm distance using Pen Cure was significantly lower than that a 0-mm distance.

[Discussion]

Recent advances in bonding systems and the development of adhesive monomers have increased the strength of bonds and improved adaptation with cavities[16]. Because CR restoration in dental practice has increased due to CR restoration being recognized as a treatment method with favorable outcomes, the concept of minimally invasive treatment[9-11] has spread. The increase in the light energy has facilitated the polymerization of bonding resin and CR within a short time[17,18].

However, even though light intensity has improved, an increase in the irradiation distance reduces the light energy reaching the target of irradiation, leading to decrease degree of polymerization of resin monomers[5,6]. Therefore, a decrease in adhesion to the cavity floor (particularly the gingival wall) may occur during the CR restoration of class II cavities. The insufficient polymerization of bonding resin causes marginal leakage and may result in secondary caries and discomfort, such as pulpal irritation[4-7,19]. We investigated the adhesion on the gingival wall of class II cavities using the MI-head, which has a small tip that is capable of being inserted deep into cavities.

The results obtained in this study revealed that the bonding strength was significantly lower at P10s and P20s than that of the control. TBS at P10s was less than half that of the control, and no TBS equivalent to that of the control was obtained even at P20s with a pronged irradiation time. No equivalent TBS could be obtained until the irradiation time was prolonged to 60s, which suggests that the sufficient polymerization of bonding resin cannot be obtained following the manufacturer's instructions when the irradiation distance is increased.

When irradiation was performed using the MI-head, the fractured surface revealed light concentration on the center of the adherend surface and resulting dentin cohesive failure in the central area and adhesive failure in the surrounding area. However, when irradiating from a 2.0-mm distance, dentin cohesive failure localized in the central region was not observed on the fracture surface, suggesting that bonding resin had been completely and evenly irradiated.

Dye penetration close to the corner of the cavity was noted on the marginal leakage test at P10s and P20s in many cases, which suggested the necessity of extending the irradiation time for bonding resin on the gingival wall because of the longer irradiation distance in these cases. The degree of leakage was the lowest at P30s, and this may have been due to sufficient polymerization of the bonding resin in the entire cavity being obtained by irradiation from 3 directions. Changes in the irradiation direction or sufficient prolongation of the irradiation time may be necessary when a narrow, deep cavity, such as a class II cavity, is irradiated using Pen Cure. One reason for the reduction in TBS with an increase in the irradiation distance may be the insufficient polymerization of bonding, which may be due to a reduction in light intensity reaching the adherend surface. Another reason may be a difficulty in irradiating light from a position at which light with the most stable intensity can be irradiated, resulting in an insufficient or unstable light intensity[20].

Light intensity measurements revealed that higher intensity was detected when the measurement device was set at the center of the LED of Pen Cure, but decreased to approximately half when the position slightly deviated from the center, suggesting that technical difficulties increase with the irradiation distance. In contrast, TBS equivalent to that of the control was obtained by a 20s or longer irradiation time using the MI-head, which suggested that a close irradiation distance and stable light intensity led to the sufficient polymerization of bonding resin. However, although leakage close to the corner was frequently noted on the marginal leakage test, that from the gingival wall margin of the cavity decreased. Due to the small tip of the MI-head as a curing unit, light concentrates on one point even when irradiation is performed while moving the tip. Therefore, although bonding resin polymerization in the irradiated area is adequate, that in the surrounding area tends to be insufficient. Thus, even when the degree of polymerization differs, no dye penetration is observed in the irradiated area, but dye penetration may occur when polymerization is insufficient, leading to dye penetration into the cavity. Such dye penetration was defined as wraparound penetration, and counted separately. Although irradiation was applied from a 0.5-mm distance while moving the tip, the light may have been concentrated on the margin of gingival wall, decreasing irradiation to the other wall regions, through which the number of wraparound leakages may have increased. Light was applied from a 2.0-mm distance using the MI-head to widen the irradiation field. Although no marked irradiation time-associated difference was noted, TBS was significantly higher than that at P10s. The high TBS has been attributed to light not being concentrated on one point due to its application from a 2.0-mm distance, resulting in homogeneous bonding resin polymerization. However, as shown in Fig. 7, the reduction in light intensity could not be avoided, and no TBS equivalent to that of the control was obtained. Moreover, marginal leakage could not be prevented completely in the marginal leakage test, although a decrease was observed in wraparound leakage. TBS, similar to that of the control, could be obtained after irradiation for 10s when the adherend surface was 2.0-mm in diameter. Therefore, the MI-head may be useful for the adhesion on the gingival wall in the CR restoration of class II cavities; however, additional light irradiation of other wall regions is necessary to prevent marginal leakage.

[Conclusions]

The results of this study suggest that improvements in the irradiation method and prolonged irradiation are necessary to achieve adequate bond strength of the bonding agent applied to class II cavities using the MI-head.

Acknowledgements

We would like to thank the members of the Department of Operative Dentistry, Osaka Dental University, for their advice and help.

This research was supported in part by Osaka Dental University Research Funds (12-01).

[REFERENCE]

1) Munksgaard EC, Asmussen E. Bond strength between dentin and restorative resins mediated by mixtures of HEMA and glutaraldehyde. J Dent Res 1984; 63: 1087-1089.

2) Munksgaard EC, Hansen EK, Asmussen E. Effect of five adhesives on adaptation of resin in dentin cavities. Scand J Dent Res 1984; 92: 544-548.

3) Vanherle G & Smith DC. Posterior composite resin, Dental restorative materials, 1st ed. Peter Szule Publishing 1985; Netherlands : 455-464.

4) Daido H, Kaneshiro N, Hosoda H. New technique for classII restoration with visible light-curing composite resin. Dent Mater J 1987; 6: 218-227.

5) Fujii S. Study on marginal leakage of visible light-cured composite restoration. Jpn J Conserv Dent 1988; 31: 1043-1061. (in Japanese)

6) Darbyshire PA, Messer LB & Douglass WH. Microleakage in classIII composite restoration bonded to dentin using thermal and load cycling. J Dent Res 1988; 67: 585-587.

7) Eakle WS, Nakamoto DK. Microleakage in MOD resin composite with three dentin bonding agents. Dent Mater 1989; 5: 361-364.

8) Hembree JH Jr. Microleakage at the gingival margin of class II composite restorations with glass-ionomer liner. J Prosthet Dent 1989; 61: 28-30.

9) Tyas MJ, Anusavice KJ, Frencken JE, Mount GJ. Minimal intervention dentistry-a review. FDI commission Project: 1-97, Int Dent J 2000; 50: 1-12.

10) Peters MC, McLean ME. Minimally invasive operative care. I. Minimal intervention and concepts for minimally invasive cavity preparations. J Adhes Dent 2001; 3: 7-16.

11) Peters MC, McLean ME. Minimally Invasive Operative care. II. Contemporary techniques and materials. J Adhes Dent 2001; 3: 17-31.

12) Hotta M, Yamamoto K, Nishio M, Kondou M, Kimura K. Tensile strength of bonding agents. Jpn J Conserv Dent 1989; 32: 916-919. (in Japanese)

13) Hotta M, Kondoh K, Kamemizu H. Effect of primers on bonding agent polymerization. J Oral Rehabil 1998; 25: 792-799.

14) Yoshikawa T, Takatsu T, Hosoda H. Study on marginal integrity of the composite resin restorations -in relation to curing environment and morphological nature of surrounding dentin-. Jpn J Conserv Dent 1989; 32: 639-655. (in Japanese)

15) Ikemura K, Endo T, Kadoma Y. A review of the developments of multi-purpose primers and adhesives comprising novel dithiooctanoate monomers and phosphonic acid monomers. Dent Mater J 2012; 31: 1-25.

16) Ohkuma K, Ito S, Sugizaki J, Tsukamoto N, Saito T. Development of new monomer inducing dentin remineralization. Jpn J Conserv Dent 2009; 52: 330-339. (in Japanese)

17) Miyazaki M, Fujii S, Sato H, Sato T, Ando S, Onose H. A study on visible light curing unit -curing characteristics of light-cured resins polymerized with LED curing unit-. Jpn J Conserv Dent 2002; 20: 165-174. (in Japanese)

18) Cwewkja E, Cakirer B. Effect of short curing times with a high-intensity light-irradiating diode or high-power halogen on shear bond strength of metal brackets before and after thermocycling. Angle Orthod 2011; 81: 510-516.

19) Uno S, Morigami M, Sugizaki J, Yamada T. A study on nanoleakage in cervical restorations bonded with three generations of resin bonding systems. Adhes Dent

2008; 26: 118-123. (in Japanese)

20) Arikawa H, Kanie T, Fujii K, Takahashi H, Ban S. Effect of inhomogeneity of light from light curing units on the surface hardness of composite resin. Dent Mater J 2008; 27: 21-28.

# 試作 LED 光照射器に関する研究

○黄地智子[1]，恩田康平[2]，初岡昌憲[2]，吉川一志[2]，山本一世[2]

[1]大阪歯科大学　大学院歯学研究科　歯科保存学専攻

[2]大阪歯科大学　歯科保存学講座

責任者連絡先:黄地智子

〒540-0008  大阪府大阪市中央区大手前 1-5-17  大阪歯科大学歯科保存学講座

TEL: 06-6910-1087, FAX: 06-6910-1052, E-mail: satoko-o@cc.osaka-dent.ac.jp

試作 LED 光照射器

抄録

【目的】ヘッド部が小さく（直径 2.1mm）歯肉壁まで近接させて光照射を行うことができる新規 LED 光照射器（以下，MI ヘッド）を試作した．これと従来型 LED 光照射器であるペンキュアが II 級窩洞の歯肉壁の接着に与える影響について比較，検討を行った．【材料および方法】抜去ウシ歯に象牙質被着面を形成し，クリアフィルメガボンドを用いて歯面処理を行いペンキュア及び MI ヘッドにて照射距離および照射時間を変えて光照射を行った．その後コンポジットレジン（以下，CR）充填を行い，24 時間 37℃水中保管後，引張接着強さ（以下，TBS）を測定した．ヒト抜去歯に II 級窩洞を形成し，隔壁後クリアフィルメガボンドを用いて歯面処理を行いペンキュアの場合は咬頭頂から，MI ヘッドは窩洞の歯肉壁に近接させて照射条件を変えて光照射を行った. その後 CR を充填し, サーマルストレスを負荷した. 各試料を 5%塩基性フクシン水溶液に 24 時間浸漬した後，光学顕微鏡下で色素浸透状態を観察した．下顎人工模型の左側第一大臼歯近心に II 級窩洞を形成し模型に色素浸透試験と同様の照射環境でペンキュアと MI ヘッドの光強度を測定した．【結果】TBS の測定で MI ヘッドは有意に高い値を示したが，色素浸透試験の結果では色素浸透を防ぐことはできなかった．光強度はペンキュアのほうが有意に高い値を示した．【結論】

MIヘッドを使用して2級窩洞のボンディング材に十分な接着力を与えるためには，照射方法の工夫や光照射の追加が必要であることが示唆された.

キーワード：LED 光照射器，ボンディング材，照射距離

**Table1 Materials used**

| | Materials | Code | Compositions | Lot | Manufacture |
|---|---|---|---|---|---|
| CR | Clearfil Majesty LV （shade A3） | LV | TEGDMA, Silanated barium glass filler, Silanted colloidal silica, Hydrophobic aromatic dimethacrylate | 3D0004 | Kuraray Noritake Dental |
| | Clearfil Majesty （shade A3） | CM | Bis-GMA, Hydrophobic aliphatic dimethacrylate, Hydrophobic aromatic dimethacrylate,Silanated barium glass filler, Pre-polymerized organic filler including nano filler | 0175AA | |
| Bonding system | Clearfil Mega Bond | MB | MDP, BisGMA, HEMA, Hydrophilic dimethacrylate, CQ, N, N-diethanol p-toluidine, Silanated colloidal silica, water | 011581 | |
| Grass ionomer cement | FujiII LC | LC | Powder: Aluminofluorosilicate glass, Pigment Liquid: PAA, distilled water, HEMA, CQ | 1301241 | GC |

**Table2 Light curing list**

| Curing light unit | Irradiation time | Irradiation distance | Code | Manufacture |
|---|---|---|---|---|
| Pen Cure | 10seconds | 2mm | control | Morita Manufacturing |
| | 10seconds | 6mm | P10s | |
| | 20seconds | 6mm | P20s | |
| | 40seconds | 6mm | P40s | |
| | 60seconds | 6mm | P60s | |
| MI-head | 10seconds | 0.5mm | M10s | |
| | 20seconds | 0.5mm | M20s | |
| | 10seconds | 2mm | M10s-2 | |
| | 20seconds | 2mm | M20s-2 | |

**Table3 Results of TBS (3mm diameter)**

| **Light curing list** | **control** | **P10s** | **P20s** | **P40s** | **P60s** | **M10s** | **M20s** | **M10s-2** | **M20s-2** |
|---|---|---|---|---|---|---|---|---|---|
| MPa | 26.6 (a) | 12.6 (b) | 14.4 (bc) | 20.8 (d) | 25.7 (ade) | 18.7 (cdf) | 24.8 (ade) | 16.9 (bcdfg) | 18.1 (cdfg) |
| SD | 2.9 | 3.8 | 1.7 | 3.4 | 4.3 | 2.3 | 3.9 | 4.5 | 1.7 |

no significant difference in the same sign $p>0.05$

**Table4 Results of SEM images**

| | Interfacial Failure | Cohesive Failure of CR | Mixed Failure | Adhesive Failure | Cohesive Failure of dentin |
|---|---|---|---|---|---|
| control | | | 1 | 3 | 4 |
| P10s | | | 8 | | |
| P20s | | | 8 | | |
| P40s | | | 4 | 3 | 1 |
| P60s | | | 6 | 2 | |
| M10s | 3 | | 4 | | 1 |
| M20s | 1 | | 3 | | 4 |
| M10s-2 | | 1 | 5 | 2 | |
| M20s-2 | | 2 | 5 | 1 | |

**Table5 Results of marginal leakage**

| | Score0 | Score1 | Score2 | Score3 |
|---|---|---|---|---|
| P10s | 1 | 1 | 5 | 1 |
| P20s | 2 | 1 | 4 | 1 |
| P40s | 1 | 1 | 4 | 2 |
| P60s | 1 | 1 | 6 | 0 |
| P30s | 3 | 4 | 0 | 1 |
| M10s | 0 | 1 | 3 | 4(*3) |
| M20s | 2 | 0 | 2(*1) | 4(*4) |
| M10s-2 | 2 | 4 | 0 | 2(*2) |
| M20s-2 | 3 | 4(*2) | 0 | 1 |

$p<0.05$

*: Number of wraparound leakage

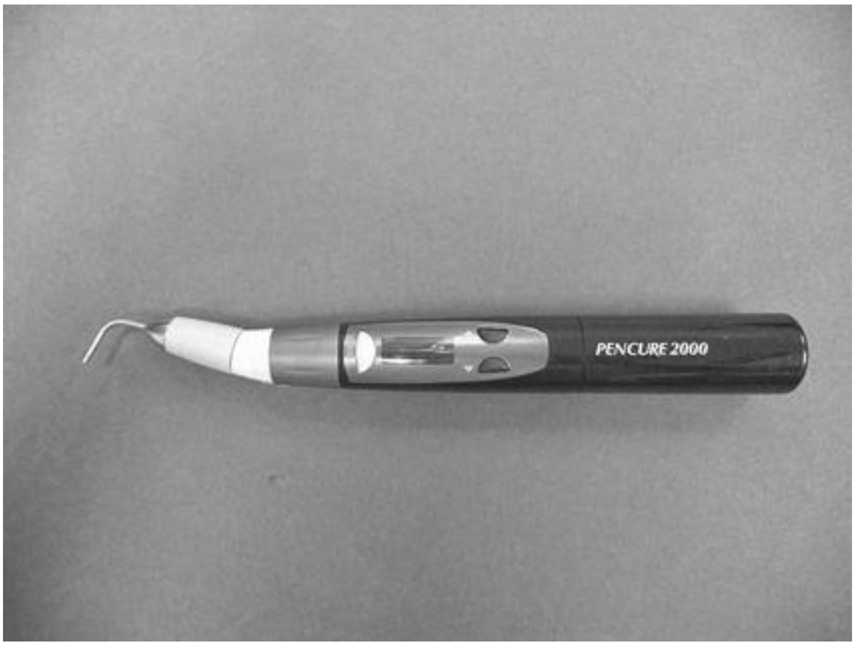



**Fig 1. MI-head**
**LED curing unit with a small head (2.1 mm diameter)**

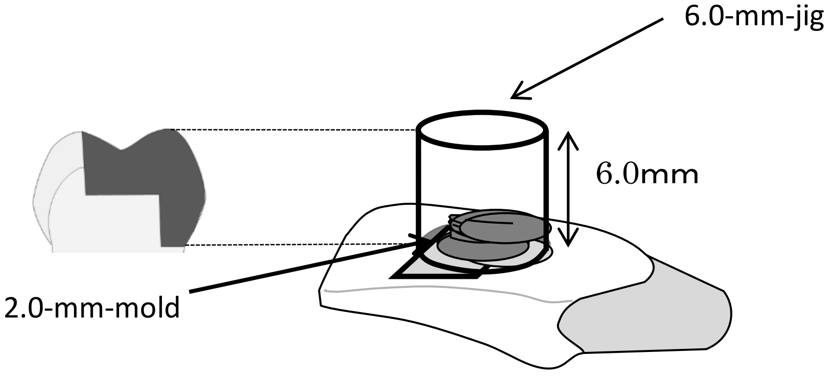



**Fig 2. Figure of attached jig**

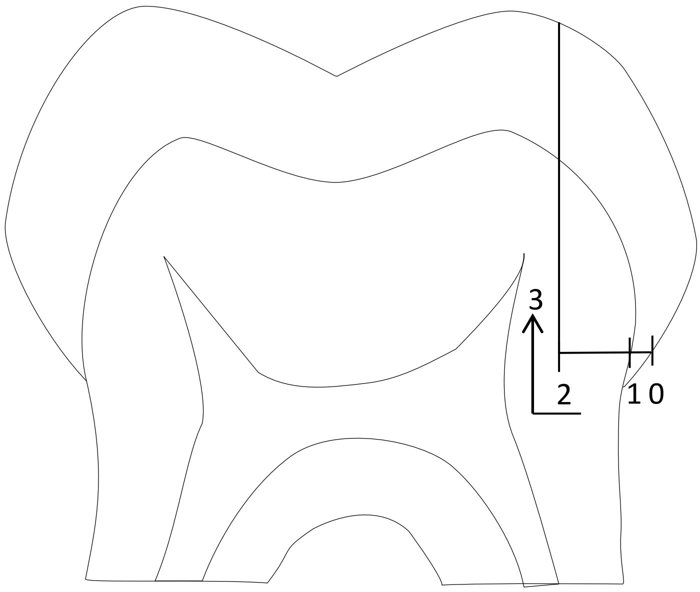



**Fig 3. Method of scoring leakage**

Score0: no leakage
Score1: leakage to enamel
Score2: leakage to dentin～not to line angle
Score3: leakage to line angle

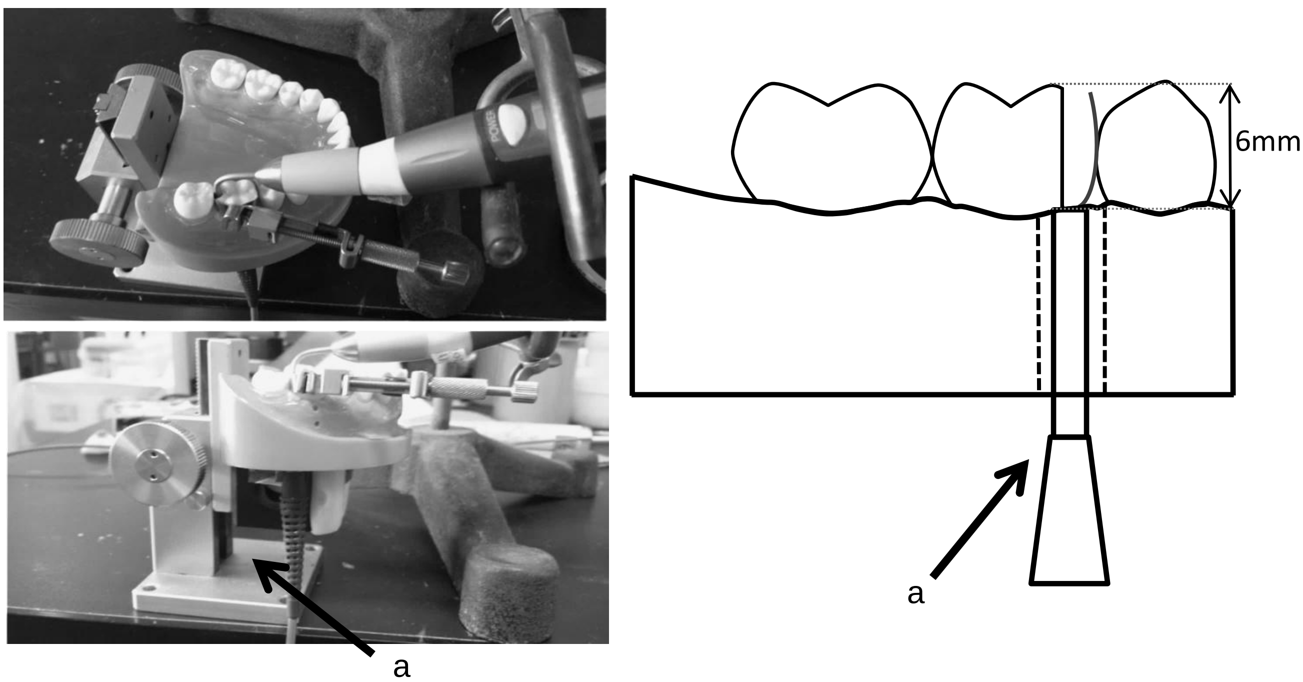



**Fig 4. Method of meaguring light intensity**

a: fiber for measurement

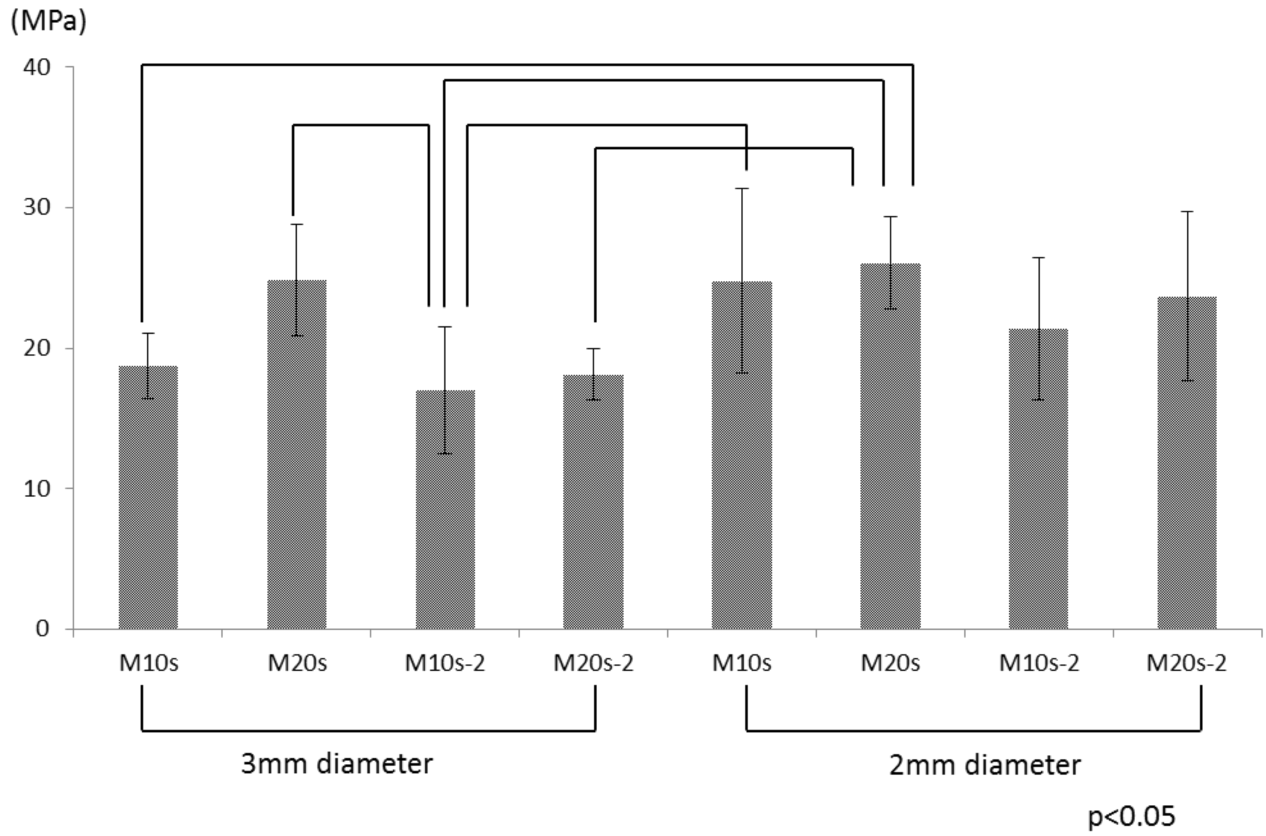



**Fig 5. Results of TBS(3mm diameter and 2mm diameter)**

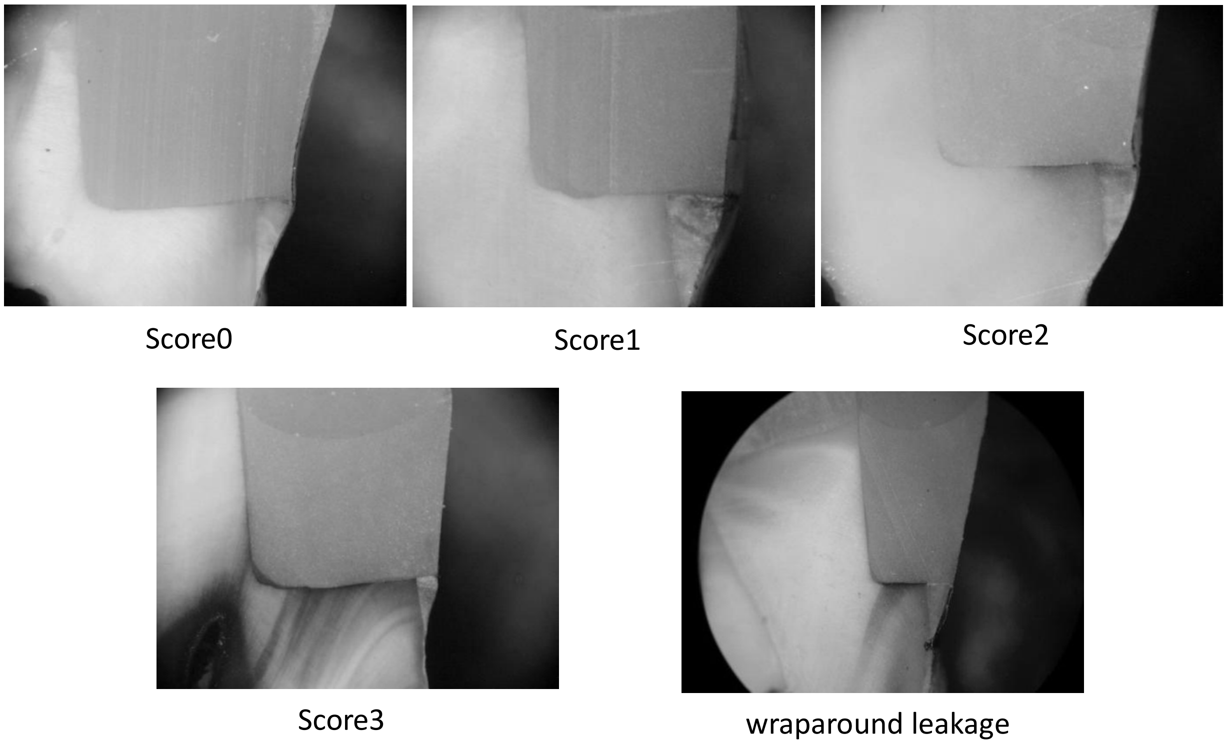
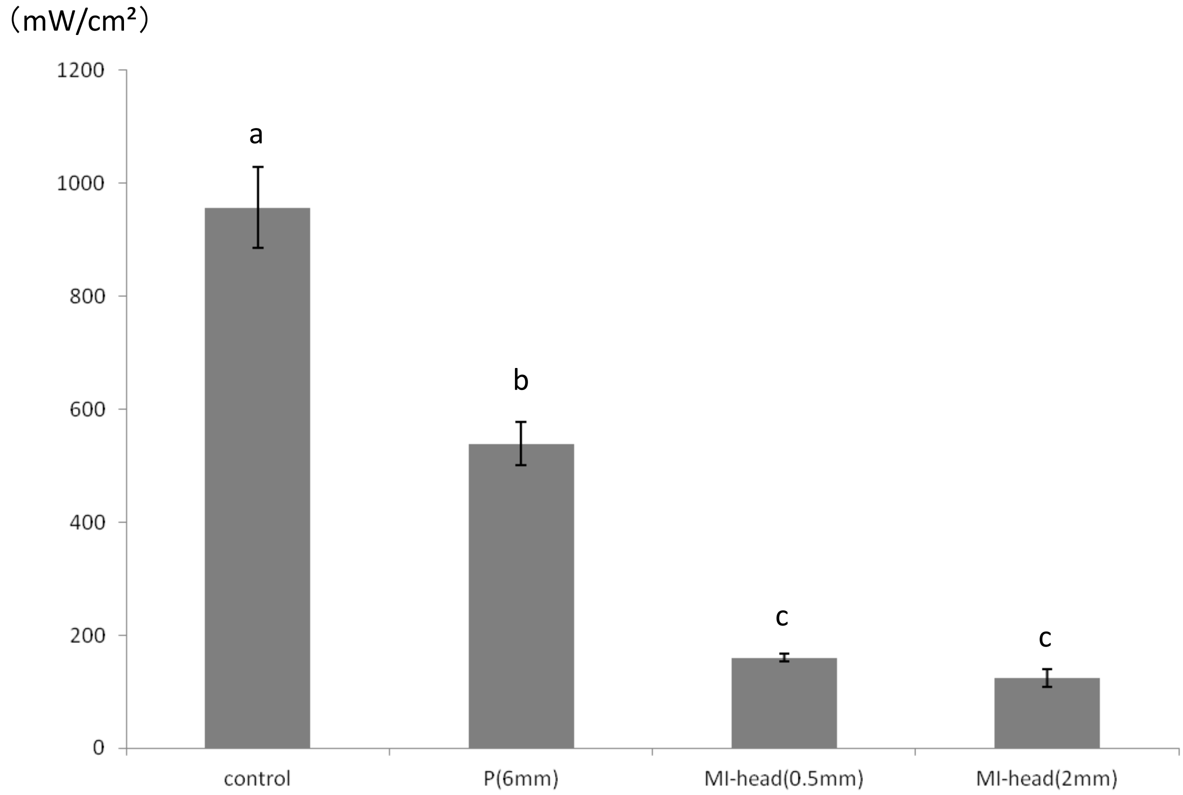



**Fig 6. Results of leakage image**




$p>0.05$

no significant difference in the same sign



**Fig 7. Light intensity**