Influence of loading site and ceramic strength on the failure of teeth restored with ceramic inlays

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Influence of loading site and ceramic strength on the failure of teeth restored with ceramic inlays

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감사의 글

2007 년에 석사과정을 마치고 박사과정에 입학할 때만 해도 이렇게 오래 걸릴 줄 몰랐었는데 벌써 7 년의 시간이 흘렀습니다. 처음에 실험이 제대로 진행이 되지 않는 것 같아서 방황하다 중간에 건강상의 문제로 장기 휴학을 하게 되었습니다. 이대로 포기해야 하는 걸까 의기소침해 있던 제 모습이 생각납니다. 하지만 그랬던 저를 믿어주시고 끊임없이 격려해 주셔서 결국 실험을 잘 마무리 하고 이런 결과물을 얻도록 지도해 주신 노병덕 교수님께 특별한 감사의 인사를 드립니다.

또한 논문을 심사하시면서 전체적인 그림을 보게 해 주신 박성호 교수님, 단어 하나 하나 세심하게 검토해 주신 박정원 교수님, 부족한 영작 실력을 채워준 이윤 교수님 그리고 적재적소에 필요한 조언을 해 주신 김광만 교수님 모두 감사를 드립니다.

보존과에 뒤늦게 들어와 수련 받을 때 많은 것을 알려주시고 가르쳐 주셨고 수련을 마친 후에도 반갑게 맞아주셨던 이찬영 교수님, 이승종 교수님, 김의성 교수님, 정일영 교수님, 신수정 교수님께 감사를 드립니다. 실험하면서 많은 도움을 주신 회사 관계자분들, 치과생체재료공학교실 유재용, 김지연 선생님, 보존과 후배인 김유경, 권기현 선생님 그리고 통계에 많은 도움을 주신 정회인 선생님께도 감사의 마음을 전합니다.

직장에서 제 실험과 논문 진행 과정에 많은 관심과 배려를 보여 주신 강철구, 윤승환, 이광출, 김윤수 동료 원장님께도 깊은 감사를 드립니다.

마지막으로 항상 뒤에서 기도로 응원해 주시는 양가 부모님, 밝고 건강하게 크고 있는 기특한 아이들 다은이와 지훈이, 무엇보다 내 인생의 반쪽으로 부족한 남편을 잘 내조해 주고 있는 아내 권은용과 함께 이 기쁨을 나누고 싶습니다.

2014 년 12 월 저자 씀

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ABSTRACT

Influence of loading site and ceramic strength

on the failure of teeth restored with ceramic inlays

Dongkeun Jeon D.D.S., M.S.D

(Directed by Prof. Byoung-Duck Roh, D.D.S., M.S.D., Ph.D.)

The purpose of this study was to evaluate the influence of ceramic material strength and loading site on the failure of teeth restored with ceramic inlays using a universal testing machine.

Ninety intact, caries-free human maxillary premolars were divided randomly into six groups (n=15): Group 1, Class II mesio-occluso-distal (MOD) cavity preparation and restoration with IPS Empress CAD and compressive force loaded on inlay; Group 2, MOD cavity preparation and restoration with IPS e.max CAD and compressive force loaded on inlay; Group 3, MOD cavity preparation and restoration with IPS Empress CAD and compressive force loaded on tooth; Group 4, MOD cavity preparation and restoration with IPS e.max CAD and compressive force loaded on tooth; Group 5, MOD cavity preparation and no restoration and compressive force loaded on tooth; and Group 6, intact teeth and compressive force loaded on tooth.

Class II MOD preparation was as follows. The pulpal floor was formed at a depth of 2 mm from the occlusal cavosurface margin of the preparation, and the isthmus was half of the intercuspal distance. The proximal box width was 1.5 mm, and the axial wall was 2 mm in height. Margins were prepared with 90-degree cavosurface angles.

Specimens were tested in a universal testing machine at 1.0 mm/min using two steel sphere plungers (3 mm and 6 mm in diameter). Peak load to fracture (N) was measured for each specimen. Means were calculated and analyzed with a one-way ANOVA and Tukey's test (α=0.05).

The mean peak fracture loads (N, mean ± S.D.) were as follows: Group 1 - 689.4 ± 138.3, Group 2 - 813.6 ± 151.8, Group 3 - 1236.0 ± 292.4, Group 4 - 1244.1 ± 379.4, Group 5 - 822.3 ± 258.6, Group 6 - 1363.0 ± 342.5.

Based on the results obtained under *in vitro* experimental conditions, the following conclusions were drawn. The ceramic strength did not statistically influence fracture resistance. However, the mean fracture load of the IPS e.max CAD inlay was superior to that of the IPS Empress CAD inlay when the force was loaded on the ceramic restoration. The main fracture type differed according to the loading site. When force was loaded on the ceramic inlay, the proximal box fracture was the main type of fracture. When force was loaded on teeth, the cuspal fracture was the main type of fracture. Future studies on the failure of teeth restored with inlays should consider the loading site.

Keywords: Ceramic inlay; CAD/CAM ; Fracture; IPS Empress; IPS e.max; loading site

Influence of loading site and ceramic strength on the failure of teeth restored with ceramic inlays

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I. Introduction

While intact teeth rarely fracture from masticatory force, fracture occurs in teeth that have been weakened by caries and cavity preparations required for restorations. Preparations for large cavities, such as Class II MOD cavities, especially weaken the remaining tooth structure (Ausiello et al., 1997; Dalpino et al., 2002; Mondelli et al., 1980). The loss of structures, such as marginal ridges and occlusal enamel, causes teeth to be more susceptible to fracture (Blaser et al., 1983; Edelhoff and Sorensen, 2002; Mondelli et al., 1980; Nothdurft et al., 2008). Many dental materials are used to minimize this problem.

Traditional non-adhesive restoration materials, such as amalgam or gold inlays, do not reinforce the weakened tooth structure (Eakle and Staninec, 1992; McCullock and Smith, 1986; Studer et al., 2000). The use of adhesive materials reinforces weakened teeth (Cotert et al., 2001; Denehy and Torney, 1976). Bonded indirect restoration could be an ideal option for restoring teeth weakened by large cavity preparation (Dalpino et al., 2002).

However, how restorative materials reinforce the remaining tooth structure is controversial. In studies on the fracture resistance of composite resin, partial reinforcement of composite resin was reported (Caplan et al., 1990; Reel and Mitchell, 1989; Watts et al., 1995). On the contrary, other studies reported no significant difference in fracture resistance between intact teeth and teeth restored with composite resin (Ausiello et al., 1997; Dalpino et al., 2002; de Freitas et al., 2002).

Some studies reported that fracture resistance in the case of ceramic inlays was comparable to that in intact teeth (Bremer and Geurtsen, 2001; Dalpino et al., 2002). In contrast, other studies reported that it was inferior to that in intact teeth (Dietschi et al., 1990; St-Georges et al., 2003).

This conflicting result was due to the unified loading site in the previous study.

Many researchers conducting *in vitro* studies on fracture resistance have used universal testing machines and steel sphere plungers. In some studies on the fracture resistance of inlays, the compressive force was positioned onto the restorative material (Bremer and Geurtsen, 2001; Minami et al., 2009). However, in other studies, the sphere plungers contacted only the tooth structure (Santos and Bezerra, 2005; St-Georges et al., 2003).

In addition, one of the factors contributing to previous conflicting results was the strength of the restorative material. For example, Bremer and Geurtsen found the fracture resistance of molars restored with CEREC ceramic inlays to be superior to that of molars restored with IPS Empress ceramic inlays (Bremer and Geurtsen, 2001). IPS Empress inlays are characterized by a lower flexural strength (120 MPa) than CEREC ceramic inlays (130 MPa). In the case of onlays, the fracture resistance of partial-coverage restorations is material dependent. For example, zirconia material has been found to show higher fracture resistance than lithium disilicate ceramic (Saridag et al., 2013).

On the contrary, generally no significant difference between the resistance to fracture of different types of ceramics (EX-3, Vitadur Alpha) has been detected (Habekost Lde et al., 2006).

Therefore, in this study, two types of ceramics with different ceramic strengths were selected. It is known that IPS e.max CAD exhibits better physical properties than IPS Empress CAD. According to the manufacturer's scientific documents, the flexural strength of IPS e.max CAD is 360 MPa, and that of IPS Empress CAD is 160 MPa.

The purpose of this study was to evaluate the effect of loading site and ceramic strength on the failure of premolars restored with ceramic inlays.

The null hypothesis is as follows.

1. The loading site has no influence on the fracture resistance or fracture pattern of ceramic-restored teeth.

2. The ceramic strength has no influence on the failure of premolars restored with ceramic inlays.

II. Materials & Methods

1. Selection and Preparation of Teeth

Ninety intact, caries-free human maxillary premolars of similar size and shape were selected and stored in normal saline without collecting patients' information. The teeth were divided into six groups of 15. The group number, assignment, and loading site are shown in Table 1.

Table 1. Group number, assignment, loading site (n=15)

Group	Assignment	Loading site
Group 1	MOD prep. + IPS Empress CAD inlay	Inlay
Group 2	MOD prep. + IPS e.max CAD inlay	Inlay
Group 3	MOD prep. + IPS Empress CAD inlay	Tooth
Group 4	MOD prep. + IPS e.max CAD inlay	Tooth
Group 5 (control)	MOD prep. + unrestored	Tooth
Group 6 (control)	Intact	Tooth

Class II MOD preparations were made in 75 premolars with a water-cooled high-speed handpiece and diamond burs (#845KR, Brasseler, GmbH, KG).

The pulpal floor was formed at a depth of 2 mm from the occlusal cavosurface margin of the preparation. Moreover, the isthmus was half the intercuspal distance. The proximal box width was 1.5 mm, and the axial wall was 2 mm in height. All preparations were made in the longitudinal axis of the tooth and were free from undercuts. Margins were prepared with 90-degree cavosurface angles (Fig. 1.).

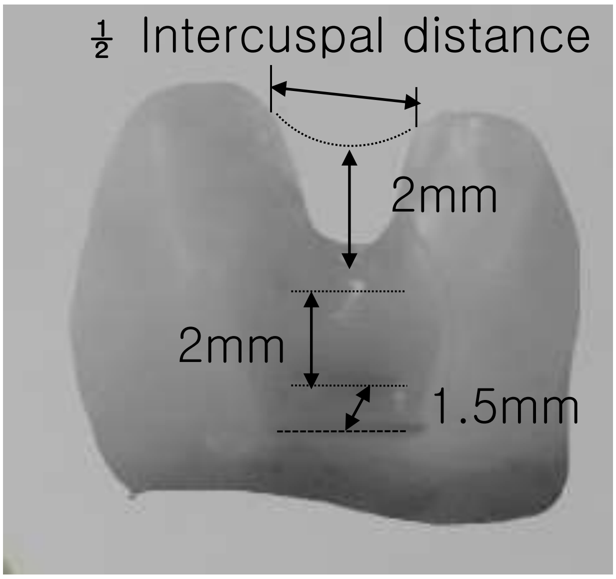


Fig. 1. Dimensions of Class II MOD cavity.

2. Class II MOD Inlay Fabrication

To fabricate the ceramic inlays, a CAD/CAM device (CEREC AC, Sirona Dental Systems GmbH, Bensheim, Germany) was used according to the manufacturer's instructions. After preparation, a thin contrast powder (Vita CEREC Powder, Patterson Dental Company, St. Paul, MN, USA) was applied on the dry surface before the optical impression. CEREC Bluecam (Sirona Dental Systems GmbH, Bensheim, Germany) was used for the optical impression. After obtaining the images, the inlay was designed with computer software (CEREC AC version 4.2).

The inlays were fabricated using two types of ceramic blocks (Table 2). Thirty inlays were machined from leucite-based glass-ceramic blocks (IPS Empress CAD; Ivoclar Vivadent, Schaan, Liechtenstein), and the others were machined from lithium disilicate ceramic blocks (IPS e.max CAD; Ivoclar Vivadent, Schaan, Liechtenstein). IPS e.max CAD blocks were milled and then underwent a crystallization process in a Programat P300 (Ivoclar Vivadent, Schaan, Liechtenstein) furnace under a crystallization temperature of 820–840℃ (Program no.81) to precipitate the crystal. Teeth were then rinsed of the contrast powder, and the inlays were placed to check the fit in their preparation.

Table 2. Ceramic blocks used in this study

Product	Composition	LOT	Manufacturer
IPS Empress CAD	Leucite-based glass ceramic	M13138 L33522	Ivoclar Vivadent Schaan, Liechtenstein
IPS e.max CAD	Lithium disilicate glass ceramic	N03151 T15512	

3. Cementation

The teeth were embedded in self-curing acrylic resin at a position 1 mm below the cement-enamel junction (CEJ) and surrounded with a plastic tube. In Groups 1 to 4, the entire cavity was etched with 37% phosphoric acid (DenFil Etchant-37, Vericom) for 30 seconds. Then, an adhesive system (Syntac, Ivoclar Vivadent) was applied as directed by the manufacturer, and an adhesive agent (Heliobond, Ivoclar Vivadent) was applied.

For the restoration, the inlays were prepared with 4% hydrofluoric acid (Porcelain Etchant, Bisco) for 60 seconds in IPS Empress CAD and for 20 seconds in IPS e.max CAD. A silane agent (Monobond N, Ivoclar Vivadent) was applied for 60 seconds. After applying the adhesive system, in Groups 1 to 4, ceramic restorations were cemented with dual-cured resin cement (Variolink N, Ivoclar Vivadent). The restorations were placed with finger pressure using a brush to remove excess cement. The inlays were then light cured for a total of three minutes (one minute per surface, LED, Guilin Woodpecker Medical Instrument). They were kept in saline for 1 week before testing.

4. Testing

Specimens were tested in a universal testing machine (model 3366; Instron Corp, Canton, MA U.S.A.) in which a steel sphere plunger was mounted in the crosshead moving at a speed of 1.0 mm/min. In Groups 1 and 2, a 3-mm diameter sphere plunger was in contact with the inlays (Fig. 2). In Groups 3 to 6, a 6-mm diameter sphere plunger was in contact with the area between the buccal and palatal cusp of the tooth (Fig. 3). After positioning, it was confirmed that the 3-mm diameter sphere plunger contacted only the surface of the inlays and the 6-mm diameter sphere plunger contacted only the surface of teeth. The compressive load at fracture was recorded for each specimen, and the fracture type was recorded.

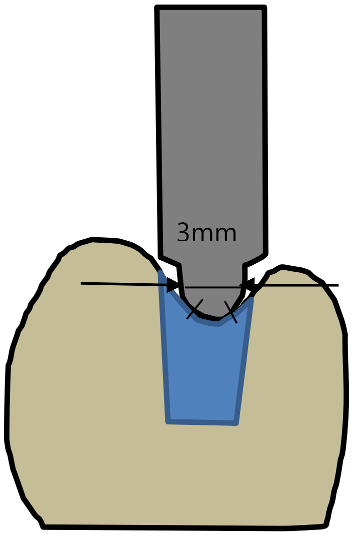


Fig. 2. 3-mm diameter sphere plunger in contact with inlay, mesio-occlusal pit of inlay.

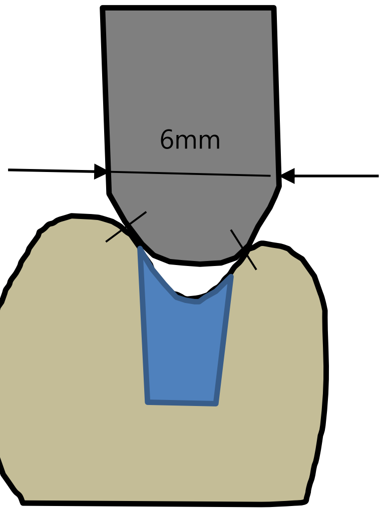


Fig. 3. 6-mm diameter sphere plunger in contact with area between buccal and palatal cusp.

5. Statistical Analysis

Statistical analysis of the results was performed using a one-way ANOVA and Tukey's test to compare Groups 1 to 6. A confidence level of 95% was used. All statistical analyses were carried out using SPSS 21 for Windows (SPSS Inc., Chicago, IL, USA).

III. Results

1. Fracture Load

The mean peak fracture loads (N) for each group are reported in Table 3. There was no significant difference among Groups 1, 2, and 5 (p>0.05) or Groups 3, 4, and 6 (p>0.05). Groups 1, 2, and 5 had lower fracture resistance than Groups 3, 4, and 6 (p<0.05).

Prepared maxillary premolars with MOD cavities lost 39.7% of their strength when tested occlusally with a compressive load.

Table 3. Mean and standard deviation of fracture load (N, mean ±S.D.) (n=15)

	Restorative material	Loading site	Mean ±S.D.
Group 1	IPS Empress CAD	Inlay	689.4 ± 138.3 [a]
Group 2	IPS e.max CAD	Inlay	813.6 ± 151.8 [a]
Group 3	IPS Empress CAD	Tooth	1236.0 ± 292.4 [b]
Group 4	IPS e.max CAD	Tooth	1244.1 ± 379.4 [b]
Group 5	Unrestored	Tooth	822.3 ± 258.6 [a]
Group 6	Intact	Tooth	1363.0 ± 342.5 [b]

Means represented by the same letter are not significantly different (p>0.05).

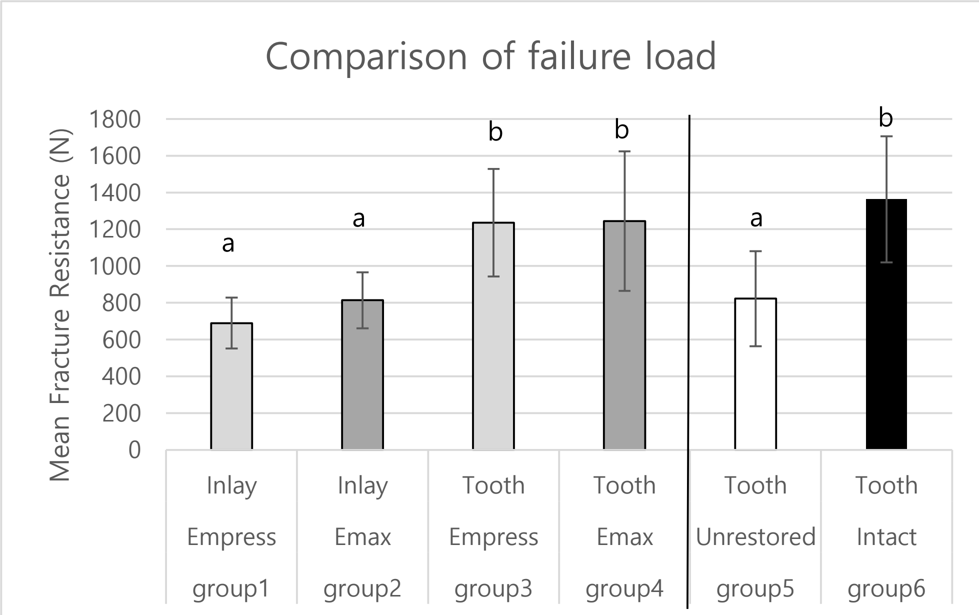


Fig. 4. Comparison of Failure Load.

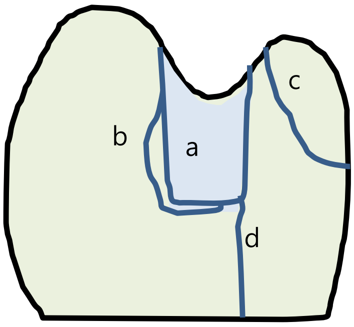
Means represented by the same letter are not significantly different (p>0.05).

As seen in Fig. 4, there was a significant difference between loading sites (p<0.05). However, there was no significant difference between IPS Empress CAD and IPS e.max CAD (p>0.05).

When force was loaded on teeth, prepared teeth were less fracture resistant compared to intact teeth and teeth restored with ceramic inlays (p<0.05). There was no significant difference in fracture resistance between intact teeth and teeth restored with ceramic inlays (p>0.05).

2. Fracture Types

In Groups 1 and 2, specimens were fractured in the proximal box of restoration. In Groups 3 to 6, specimens were fractured mainly in the cusp when the loading force was on the teeth.



a. Restoration
b. Restoration and part of teeth
c. Cuspal fracture
d. Unfavorable fracture

Fig. 5. Fracture Types.

Table 4. Fracture Types

	restoration	restoration + part of teeth	Cuspal fracture	Unfavorable fracture
Group 1	12	3	0	0
Group 2	11	4	0	0
Group 3	0	3	9	3
Group 4	0	4	6	5
Group 5	NA	NA	9	6
Group 6	NA	NA	13	2

IV. Discussion

Many researchers have investigated whether restorations enhance the strength of prepared teeth. However, results have been conflicting because of different testing methods and materials. Therefore, in this study, two separated loading sites were selected, ceramic materials with different strengths but similar properties were used, and the same adhesive cementation technique was applied.

The current study investigated the influence of ceramic strength on the failure of teeth restored with ceramic inlays, and each loading force contacted the restoration or the tooth, thereby evaluating the determining factor.

The mean fracture loads reported in the current study for IPS Empress CAD inlays and IPS e-max CAD inlays, when the steel sphere plunger contacted the inlay surface, were 689.4 N and 813.6 N. The IPS e.max CAD inlay showed a higher mean fracture load than the IPS Empress CAD inlay. However, there was no statistically significant difference between the materials.

These results are in agreement with those found by Habekost and others (Habekost Lde et al., 2006). They found that there was no significant difference in fracture resistance between different feldspathic ceramic inlays when the force was loaded on the ceramic restoration.

When the steel sphere plunger contacted the teeth beyond the margin of inlay, the mean fracture loads for teeth bonded with IPS Empress CAD inlay and teeth bonded with IPS e.max CAD inlay were 1236.01 N and 1244.06 N, respectively. The mean fracture load of prepared teeth was 822.25 N, and that of intact teeth was 1363.04 N. There was no statistically significant difference between the IPS Empress CAD inlay and the IPS e.max CAD inlay when the loading force contacted the teeth. However, there was a significant difference between loading sites (p<0.05). This means the effect of ceramic strength decreased according to the loading site, and loading site was the determining factor rather than ceramic strength.

In the present study, prepared maxillary premolars with MOD cavities showed 60.3% of their strength when tested occlusally with a compressive load. There was no significant difference in the fracture resistance of bonded ceramic inlays and intact teeth. These results showed that adhesive cementation improved the strength of prepared teeth and were in accordance with those of researchers who verified the full reinforcement of teeth restored with ceramic inlays when compared with intact teeth (Bremer and Geurtsen, 2001; Dalpino et al., 2002; Desai and Das, 2011; Saridag et al., 2013). There was a difference in the experimental conditions, such as cavity dimensions, loading method, and type of teeth.

Prepared teeth were inferior to other groups when the loading force contacted the tooth (p<0.05). It is known that for Class II MOD preparations, the depth and width of the preparation affect the postoperative fracture resistance (Khera et al., 1991). St-Georges reported that preparing maxillary premolars with large and deep MOD preparations weakened the teeth by 59%. The teeth restored with ceramic inlays (VITA Mark II, Vita Zahnfabrik) showed a slight increase in fracture resistance of 16.8% (407.21 N) when compared with unrestored teeth (348.51 N), and bonded ceramic inlays did not significantly reinforce weakened teeth (St-Georges et al., 2003). In St-Georges' study, the loading force contacted teeth, but extensive cavity preparation and different adhesive strength of cementation and strength of materials induced these different results.

The shape and the diameter of the load application device define the contact with the restoration or tooth. In this study, two sphere plungers were used: one 3 mm in diameter and one 6 mm in diameter. The 3-mm diameter sphere plunger was acceptable for contacting only the restoration, and the 6-mm diameter sphere plunger was acceptable for contacting only the tooth. This is another variable that affected the peak fracture load. Habekost et al. reported that a 10-mm loading sphere exhibited significantly higher resistance values compared to those observed for a 3-mm sphere (Habekost Lde et al., 2006). The alteration of sphere size changes the position of load applications, modifying the concentration of tension patterns (Larson et al., 1981). When applied to clinical situations, the mastication of small and hard food could contact only the restoration. This may increase the risk of restoration fracture. In detail, the 3-mm diameter sphere plunger may have better simulated the clinical environment than the 10-mm diameter sphere based on the high percentage of restorative materials fractures (Habekost Lde et al., 2006).

The irregular anatomy of natural teeth led to variability in the fracture load of the inlays, consistent with other studies on fracture strength tests (Attia and Kern, 2004; Tsitrou et al., 2009). This is consistent with a brittle fracture system with a dispersion of flaws of different sizes. Despite standard procedures of collecting, storing, and preparing the teeth and the conditions of milling the inlays, it is impossible to control the size and distribution of the internal flaws of each tooth structure or milling block (Tsitrou et al., 2009).

In the case of the loading force on inlays, the fracture pattern revealed that most of them were isthmus fractures and they fell out of the proximal box. Soares and others reported similar results using feldspathic ceramic in extensive inlays (Soares et al., 2004). This means that currently, the properties of IPS Empress CAD and IPS e.max CAD blocks do not match those of natural teeth. In the case of the loading force on teeth, cusp fractures were common. Eakle and others reported that the lingual cusp of maxillary premolars fractures more often than the buccal cusp *in vivo* (Eakle, 1986).

V. Conclusion

The first null hypothesis was rejected, while the second one was accepted.

Based on the results obtained under *in vitro* experimental conditions, the following conclusions can be reached.

1. The ceramic strength did not statistically influence fracture resistance when the force was loaded on the ceramic restoration. However, the mean fracture load of the IPS e.max CAD inlay was superior to that of the IPS Empress CAD inlay.

2. The ceramic strength did not influence fracture resistance when the force was loaded on teeth.

3. The main fracture type differed according to the loading site. In the case of force loaded on ceramic inlays, the proximal box fracture was the main type of fracture. In the case of force loaded on teeth, the cuspal fracture was the main type of fracture.

4. Future studies on the failure of teeth restored with inlays should consider the loading site.

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국문요약

힘을 가한 위치와 세라믹 강도가 세라믹 인레이로 수복한 치아의 실패에 미치는 영향

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전 동 근

이 연구의 목적은 세라믹 재료의 강도와 압축력을 가하는 위치가 Class II MOD 세라믹 인레이로 수복한 치아의 실패에 어떤 영향을 미치는 지, 인스트론을 이용하여 평가하는 것이었다.

90 개의 건전한, 우식이 없는 상악 소구치를 15 개씩 6 개의 군으로 나누었다. 1 군은 Class II MOD 와동형성후 IPS Empress CAD 로 수복하여 압축력을 수복물에 가한다. 2 군은 MOD 와동형성후 IPS e.max CAD 로 수복하여 압축력을 수복물에 가한다. 3 군은 MOD 와동형성후 IPS Empress CAD 로 수복하여 압축력을 치아에 가한다. 4 군은 MOD 와동형성후 IPS e.max CAD 로 수복하여 압축력을 치아에 가한다. 5 군은 음성대조군으로 MOD 와동형성만 하고 압축력을 치아에 가한다. 6 군은 양성대조군으로 와동형성하지 않은 건전한 상태로 두고 압축력을 치아에 가한다.

와동 형성의 규격은 다음과 같다. 치수저는 교합면에서 2 mm 깊이로 형성하고 isthmus 는 교두간 거리의 1/2, 인접면 박스의 넓이는 1.5 mm, 축벽은 2 mm 높이로 한다. 변연은 모두 90 도로 형성했다.

시편들은 1.0 mm/min 으로 움직이는 직경 3 mm 와 6 mm 의 두 개의 강철구를 이용하여 만능시험기로 시험했다, 최대 파절값 (N)을 측정했고 평균을 계산하였으며 one-way ANOVA and Tukey test 로 95%의 유의수준으로 통계분석을 하였다.

평균 파절값 (N, mean ± S.D.)은 1 군 - 689.4 ± 138.3, 2 군 - 813.6 ± 151.8, 3 군 - 1236.0 ± 292.4, 4 군 - 1244.1 ± 379.4, 5 군 - 822.3 ± 258.6, 6 군 - 1363.0 ± 342.5 으로 나왔다.

이번 실험의 조건에서 얻은 결과로 다음의 결론을 내릴 수 있었다. 세라믹 강도는 수복물에 힘을 가할 때 IPS e.max CAD 인레이의 파절 강도가 IPS Empress CAD 인레이보다 높았으나 통계적으로는 영향이 없었고 치아에 힘을 가할 경우에도 차이가 없었다. 힘을 가하는 위치에 따라 파절의 양상이 달랐는데 인레이에 힘을 준 경우 인접면 박스의 파절이 주된 파절이었고 치아에 힘을 가한 경우 교두 파절이 주된 양상이었다. 이후에 인레이로 수복한 치아의 파절에 관한 연구를 디자인할 때 힘을 가하는 위치를 고려해야 한다.

핵심이 되는 말: 세라믹 인레이; CAD/CAM ; 파절; IPS Empress; IPS e.max; 힘의 위치