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様式３

論　文　内　容　の　要　旨

氏　名　（　姫　芳芳　）	
論文題名	Optical simulation analysis of the light reaching the inner surface of the metal-free restorations （メタルフリーレストレーション装着時の光照射に関する光学シミュレーション解析）

【Purpose】

With the development of esthetic dentistry, metal-free materials such as resin/ceramic hybrid material, lithium disilicate glass-ceramic, and zirconia are increasingly used for crown prostheses. For bonding metal-free crowns, resin cements are commonly used because of their optimal physicochemical properties and bonding strength. The light-curing cements can only be activated in the presence of a light source that stimulates photo-initiators. The polymerization reaction can be affected by extrinsic factors such as translucency and thickness of the crowns, in addition to the amount of light energy. It is difficult to measure the lights that pass through the metal-free crowns. As the solution to this problem in this research, the optical simulation technic is focused on. The purpose of this study is to analyze the irradiance of light on the inner surface of metal-free crowns made of various materials using optical simulation techniques.

【Methods And Materials】

Experiment 1: The effect of material, thickness, irradiation distance, and two types of LED light for the irradiance on the inner surface of the restoration samples were analyzed. PENCURE 2000（Morita, Suita, Japan）and MiniLED (Kavo dental system, Bismarckring, Germany) were used for illuminating samples. Samples were prepared with a radius of 6 mm and different thicknesses (0.5 mm interval from 1.0 mm to 2.5 mm) with lithium disilicate glass-ceramics (Rosetta SM A1-HT, HASS, Gangneung, Korea: LD), resin/ceramic hybrid material (Disk HC A2-LT, Shofu, Kyoto, Japan: HR), and zirconia ceramic (KZR-CAD Zr DISC SHT-A2, Yamakin, Osaka, Japan: ZI). The irradiation distances from the port of LED light to samples were set from 0.0 to 6.0 mm with a 1.0 mm interval. The irradiance was measured with a LED radiometer (ThreeH, Guangzhou, China). Student’s test, One-way ANOVA test, and Dunnett's test were performed in LED light and thickness, irradiation distance, and material ($p < 0.05$ and 95% CI).

Experiment 2: The optical properties of materials were measured, because they were necessary for optical simulation. LD, HR, and ZI were prepared as 30 mm X 30 mm, and their total reflectance and total transmittance was measured using a UV-VIS-NIR spectrophotometer (UV-3600, Shimadzu, Kyoto, Japan). The bidirectional transmittance distribution function (BTDF) and bidirectional reflection distribution function (BRDF) were measured using a Three-dimensional variable angle photometer (GP-200, Murakami color research laboratory, Tokyo, JAPAN). According to the size of the PENCURE 2000 light-emitting port, a light-emitting model was made in optical simulation software (LightTools 9.1, Synopsys, California, USA). The wavelength distribution and the quantity of light of PENCURE 2000 were input to this software. The illuminance distribution measured by an Imaging colorimeter with conoscope lens (ProMetric® I, Konica Minolta, Osaka, Japan) was also input into the software. The same sample models and measured conditions with Experiment 1 were set on LightTools 9.1. The light source

model was irradiated on the sample model with optical properties, and the irradiance values were simulated. The simulated and measured irradiance values of Experiment 1 were compared using the Spearmans' correlation coefficient. The level of significance was considered to be $p < 0.05$.

Experiment 3: To simulate and analysis the irradiance on the inner side of three metal-free crown models, the dental model and the standard abutment models of upper left 1st molar (26) and 2nd molar (27) were scanned using a scanner (EDGE, DOF, Kyoto, Japan), and the crown model was designed using CAD software (DentalCAD 3.0, Exocad, Woburn, USA). Light receiving surfaces were set on the inner surface of the crown models. The light source model was irradiated from the occlusal surface of 26, the irradiance on the inner surface of the crown models was calculated. Same irradiating simulations were performed from buccal side and occlusal side between 26 and 27. In addition, photographs of the inner side of the crowns while irradiating in the standard mode of PENCURE 2000 were taken using a camera with an aperture of F32 and a shutter of 1/60 (α77II, Sony, Tokyo, Japan).

【Results and Discussion】

Experiment 1: Regarding the thickness of samples, the irradiance passing through the thickness 1.5 mm, 2.0 mm, and 2.5 mm showed a significantly difference with thickness of 1.0 mm ($p < 0.05$). Regarding the distance from LED lights, the irradiance of 1.0-6.0 mm was significantly lower than that of 0.0 mm ($p < 0.05$), the irradiance on the HR and ZI were significantly lower than that of LD ($p < 0.05$), two LEDs also showed difference ($p < 0.05$). LD had the highest irradiance value followed HR, ZI under the same irradiation distance and sample thickness. In the same material, the specimen was thicker, the irradiance was lower.

Experiment 2: Total transmittances, total reflectance, BTDF, and BRDF were different between three materials, it considered that optical properties of each material were necessary for optical simulations. The Spearmans' correlation coefficient between the simulated irradiance (with the same measuring conditions with Experiment 1) and measured irradiance in Experiment 1 were LD: 0.99, HR: 0.99, ZI: 0.97 ($p < 0.05$), they revealed high correlations. It was suggested that this optical simulation analysis had a highly equivalency to assessing the light irradiance of metal-free crown.

Experiment 3: The simulated irradiance showed that when irradiation is carried out from the occlusal surface, the highest irradiance of the inner surface of the crown was LD, followed by HR, and ZI. The irradiance in the cusp was higher than fossa. The simulation results showed that the irradiance values were below 400mW/cm^2 which is necessary for polymerization in HR and ZI. As irradiating from the occlusal side and buccal side between 26 and 27, the irradiances were below 400mW/cm^2 at proximal surfaces in all samples. According to the simulation, the light in some regions was insufficient to promote polymerization.

【Conclusion】

The optical simulation model established in this research successfully simulated and analyzed the irradiance of the inner surface of the metal-free crowns, which are practically difficult to measure. This research provides dentists with more information to the light methods and light times that need to be considered when curing different materials and parts of the restoration, and this method of simulation analysis can be used to provide effective assistance for the invention of new dental LED curing lights.

様式７

論文審査の結果の要旨及び担当者

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論文審査の結果の要旨

本研究は、メタルフリークラウン装着時に、照射した光がクラウン内面にどのように到達するのかを、光学シミュレーション手法を用いて明らかにすることを目的とした。その結果、クラウン内面に到達する光量を定量的に解析することが可能となり、クラウンの材料、照射方法、およびクラウン内面の部位により到達する光量が異なることが示された。

以上の研究成果は、メタルフリークラウン装着時の光照射の方法を検討する上で有用な示唆を与えるものであり、よって、博士（歯学）の学位論文として価値のあるものと認める。