**Analysis of translucency of glass-ceramics fabricated by different techniques**

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**Summary**

**The purpose of the study** was to analyse translucency of glass-ceramics fabricated by different techniques and investigate the effect of the corrosive medium on the grade of translucency.

**Materials and methods:** Three specimens of each type of IPS e.max ceramics (Ivoclar Vivadent, Schaan, Liechtenstein) were made in three colours (A2, C2 and B3) by three fabrication techniques (layering– e.max Ceram Dentin; heat-pressing – e.max Press; CAD/CAM – e.max CAD). Specimens were made in the form of plates (10 mm x 12 mm x 0.8 mm). L\*a\*b\* values were measured by a spectrophotometer (X-Rite DTP 20 Pulse, Neu Isenburg, Germany) before and after exposure to 4% acetic acid at 80 °C for 16 hours (ISO 6872). Statistical data were analysed using the IBM SPSS 22 software.

**Results:** IPS e.max Ceram Dentin had significantly the lowest translucency, and IPS e.max Press the highest translucency of all colours (A2, C2, B3), both prior and after exposure to acid (p<0.001). The difference in translucency among colours was evident in the IPS e.max Ceram Dentin material, both before and after exposure to acid with a great effect size (p<0.001; η2 = 0.702 and 0.741), and in the IPS e.max Press material (p<0.001, effect size 0.547 and 0.576). CAD/CAD specimens showed uniform translucency values between three colours. Further, exposure to a corrosive medium did not result in a statistically significant change of translucency in any of the materials tested.

**Conclusions**: Different types of glass-ceramics showed significant differences in grades of translucency both with respect to the fabrication technique and colour. Exposure to a corrosive medium did not result in a statistically significant change of translucency.

**Key words**: glass-ceramics, translucency, corrosion, spectrophotometer

**Introduction**

Aesthetics has become a primary criterion for successful fixed prosthodontics treatment, especially regarding restoration of the front teeth. The aim of aesthetic dentistry is to create a restoration which does not differ in colour from natural teeth (1, 2). Therefore, optical properties of restorative materials are of exceptional importance. In dental prosthodontics, ceramic materials are considered superior materials to composites from the aesthetical point of view because of their excellent optical properties (3).

The colour and appearance of teeth is a complex phenomenon which includes a number of factors (4-6). Natural teeth are not of a uniform structure and are characterised by different colour and grades of translucency from the cervical to the incisal part. Translucency is the relative amount of passage of light through an object or diffuse reflexion from its surface (1). Translucency of the restorative material gives natural appearance and vitality to the restoration. Therefore, in order to achieve optimum aesthetic results, in addition to mimicking the colour of natural teeth, it is equally important to mimic their translucency (2).

Translucency of dental ceramics depends on the interaction between the ceramic material and the incident light. Mixed white light on the surfaces of a ceramic crown conducts itself in accordance with the physical laws of reflection and refraction because of different optical densities of these two media. Thus, a part of the light is reflected and a part is refracted and passes through the other medium. If a smaller amount of light is reflected, and a greater part passes through (is refracted), the restoration will be transparent. The amount of light that is absorbed, reflected or transmitted depends on the relations between incident light wave lengths and the size and the number of particles (7-10).

Glass-ceramics is a material that mimics dental tissue to an excellent extent, and has the best optical properties among all prosthetic materials (9, 10). The advantage of glass-ceramic over other restorative materials is its translucency, which allows the passage of light in the same way as in natural teeth. It was created by developing silicate ceramics by procedures of controlled glass crystallisation. It is characterised by great mechanical resistance, hardness and stability to temperature changes (15). The fabrication of glass-ceramic restorations is based on the fabrication of the entire restoration from the same material or fabrication of the core and layers of veneering ceramics. Core are more or less translucent, but do not have much similarity with natural teeth (12). Glass-ceramic restorations can be fabricated in a dental laboratory by using three fundamental techniques – layering, heat-pressing and computer-aided design and computer-aided manufacturing (CAD/CAM) (13). The quality of a ceramic material depends on its components; type and amount of glass matrix and the type, amount, size and distribution of grains, techniques of fabrication and treatment of the restoration, and cycles and temperature of firing and cooling (6, 14). Since properties of any material are in the function of its structure, errors occurring during the fabrication or treatment of the restoration in the dental laboratory will make the microstructure of ceramics irregular and will result in unwanted effects (15).

Apart from the properties of the restorative material itself, the environment, i.e. the oral cavity, also affects the stability of the restoration. In this context it should be stressed that restorative materials and restorations should possess long-term stable optical properties in the oral cavity. Continuous exposure to an aqueous medium, pH changes due to the intake of various beverages and foods, changes elicited by agents for cleaning of the oral cavity combined with dynamic loads, cause tribocorrosion changes on the surface of the restoration. Corrosion in the mouth, besides being a form of electrochemical corrosion and galvanism, also represents corrosion caused by acid products of microorganisms. The greater the share of the glass matrix, the greater the effect of corrosion processes and the deterioration of the restoration has been reported (16, 17).

Contemporary dental materials are subject to control and biocompatibility testing in accordance with European and American standards. However, all controls do not absolutely guarantee the stability of the material in the mouth. Ceramics is considered to be a material resistant to corrosion, i.e. a biologically inert material, however, no material is completely inert (18, 19).

The purpose of this study was, with the aid of a spectrophotometer, to quantitatively measure and compare optical properties of translucency on three types of glass-ceramic specimens in three different colours fabricated by three different techniques before and after exposure to a corrosive medium, 4 % acetic acid (ISO 6872). The following research hypotheses were tested:

1. Translucency of glass-ceramics depends on the fabrication technique.

2. Translucency of glass-ceramics fabricated by the same technique depends on the colour.

3. Corrosion has an effect on the change of translucency.

**Materials and procedures**

Nine specimens of IPS e.max glass-ceramics (Ivoclar Vivadent, Schaan, Liechtenstein) were made in the form of plates with dimensions 10 mm x 12 mm x 0.8 mm ± 0.05 mm in three colours (A2, C2, B3). The tested glass-ceramics specimens are presented in Table 1. The grade of IPS e.max Press and IPS e.max CAD ceramics was HT (high translucency).

All specimens were prepared by the same dental technician by standard procedures in accordance with the manufacturer’s directions. IPS e.max Press specimens were made by using wax models, which were, after firing, pressed in moulds by the technique of heat-pressing of ingots. IPS e.max Ceram Dentin specimens were made by powder condensation technique, by manual mixing of the ceramic powder with distilled water and firing (Programat EP 5000, Ivoclar Vivadent, Schaan, Liechtenstein). IPS e.max CAD specimens were made from factory-made blocks with the use of a milling machine (Amann Girrbach Ceramill Motion 2, Koblach, Austria).

After preparation, unglazed specimens were polished to obtain a smooth and even surface by using polishers, rubbers and silicon carbamide discs (Komet Dental, Gebr. Brasseler GmbH & Co. KG, Lemgo, Germany) and were ultrasonically washed and cleaned in distilled water for 15 minutes (ISO 3696).

In the first part of the study, measurements of L\*a\*b\* values of glass-ceramic specimens in three colours (A2, C2 and B3), fabricated by three different fabrication techniques were determined. Measurements were conducted instrumentally by using a calibrated spectrophotometer and colorimeter X-Rite DTP 20 Pulse (45°/0°measuring geometry, 2°standard observer, illuminant D65). The numerical value of translucency is based on the CIE L\*a\*b\* three-dimensional system and represents the difference in colour of a specific specimen measured on achromatic backgrounds. Consequently, two series of measurements were conducted (measurement of specimens against standard white background, and measurement of the same specimens against standard black background). Ten measurements on each of nine different plates were made against each background, changing the position of the measuring instrument (spectrophotometer) at five different places first on one and then on the other side of the surface of the specimen. Measurements were monitored by ColorShop X software integrated into the X-Rite spectrophotometer). After measuring L\*a\*b\* values, the numerical value of translucency was calculated in accordance with the following equation:

TP= [(L\*w-L\*b)2 + (a\*w-a\*b)2 + (b\*w-b\*b)2]1/2

When the material is absolutely turbid (opaque), the translucency value is about zero. Consequently, the higher the value of translucency the greater the translucency grade (21).

All specimens were then exposed to 4% acidic acid at 80 °C for 16 hours (ISO 6872). Following exposure to the corrosive medium, measurements of the translucency were repeated as described in the first part.

Statistical analysis

The normality of the distribution was verified by the Shapiro-Wilk test. In order to compare the differences in translucency between different types of materials and colours, one-way analyses of variance (ANOVA) with the Student-Newman-Keuls *post-hoc* test were used. In order to compare translucency before and after exposure to acid, a mixed type of two-way ANOVA with intervention and material factors and three-way ANOVAs with intervention, material and colour factors and t-tests for dependent specimens were used for the assessment of differences within each material and each colour. Effect sizes were quantified by η2, and for dependent specimens using the equation r = √(t2/t2+df). Statistical data were analysed by IBM SPSS 22 software. The level of significance was set at p < 0.05.

**Results**

Table 2 shows the comparison between translucency of glass-ceramics of different colours fabricated by different fabrication techniques before and after exposure to acetic acid.

IPS e.max Ceram Dentin had significantly the lowest translucency, and IPS e.max Press the highest translucency (in all colours before and after exposure to acid p < 0.001).

The difference in translucency among colours was evident in IPS e.max Ceram Dentin material, both before and after exposure to acid with a great effect size (p < 0.001; η2 = 0.702 and 0.741) and in IPS e.max Press material (p < 0.001 with effect size 0.547 and 0.576). The IPS e.max Ceram Dentin colour A2 had significantly the lowest, and the colour B3 the highest translucency, both before and after exposure to acid. The IPS e.max Press colour A2 had significantly lower translucency than the colour C2 and the colour B3, both prior and after exposure to acid. No significant difference was observed between the colour C2 and the colour B3.. Using the material IPS e.max CAD the differences among colours were not statistically significant either before or after exposure to acid (Table 2).

Analysis of the effect of corrosion

The two-way ANOVA did not show a significant interaction of the corrosion test and the material tested with respect to translucency. The three-way ANOVA did not detect a significant interaction of the corrosion test, the material used and the colour with respect to translucency.

Acid caused a significant reduction in translucency only in the IPS e.max CAD specimen colour B3 (p = 0.006) with the effect size of 58% (Figure 1.).

The amount of change of translucency due to the exposure in acid was almost equal in all colours (Figure 2).

**Discussion**

By review of relevant literature, translucency of ceramic materials, which is a very important property for the aesthetic appearance of materials, has not been thoroughly investigated. The knowledge of optical properties of specific restorative materials makes their use in the clinical practice easier. Thus, the aim of this paper was to contribute to the clarification of this complex issue. Ceramics covering the indications from fabrication of thin veneers to fixed partial dentures were tested. Technological durability and long-term stable optical properties of the restoration depend on the mechanical properties of the material which are determined by its composition and microstructure, the course of fabrication in a dental laboratory, the quality of the finishing treatment of the restoration, the connective agent and the quality of the entire fabrication procedure (3, 22, 23). It is considered that the layering technique is liable to greatest errors because of the human factor and possible oversights in manual procedures.

Statistically significant differences among glass-ceramics fabricated by different techniques were recorded in this study; therefore the first research hypothesis is accepted. The specimen made by heat-pressing technique (IPS e.max Press) had the greatest degree of translucency, which is in accordance with a research conducted by Bagis and collaborators (21). However, those authors stated that specimens fabricated by computer-aided manufacturing (IPS e.max CAD) had the lowest translucency, whereas in this study the lowest translucency was measured in the specimen fabricated by the layering technique (IPS e.max Ceram Dentin). This can be explained by the fact that e.max Press and e.max CAD ceramics were selected in the high grade of translucency (HT), whereas e.max Ceram Dentin was optically relatively thick. However, a similarity is observed in that glass-ceramics fabricated by computer-aided manufacturing showed a lower grade of translucency than glass-ceramics fabricated by heat-pressing technique.

Significant differences were observed in this study by analysing the translucency of specimens of different colours fabricated by the same technique; therefore the second research hypothesis is accepted. It was established that specimens fabricated by the layering technique and heat-pressing technique showed deviations in translucency, in contrast to the specimens fabricated by computer-aided manufacturing which showed no difference, both before and after exposure to corrosion. Specimens fabricated by the layering technique showed the lowest translucency in all colours. Specimens of the colour A2 had the lowest translucency, whereas translucency of the colour B3 was the greatest. Among specimens fabricated by the heat-pressing technique, the colour A2 again showed the lowest translucency, whereas the colours C2 and B3 showed the same values. Specimens fabricated by computer-aided manufacturing did not show difference in the grade of translucency of different colours.

The layering technique is liable to greatest variations because ceramic powder is manually mixed with the liquid. The final condensation is conditioned by the size of the ceramic grain, the amount of the liquid introduced during modelling and the condensation technique itself. Thus, great differences in the final product from one technician to another may occur. Condensation procedures have a significant effect on optical and mechanical properties of the ceramic material. Chu and collaborators emphasised that the precise ceramic powder/liquid ratio in accordance with the manufacturer’s directions does not always ensure proper thickness and porosity and consequently the translucency or opacity of the restoration (24). The importance of the chemical structure of the components and the size of crystals inserted in the glass matrix is also emphasised (8).

In contrast to the layering technique, factory-made semi-finished products (IPS e.max Press ceramic ingots or IPS e.max CAD blocks for milling) are structurally more stable. Their ceramic particles were pressed in the factory under high temperature and pressure which results in a very thick material with a homogeneous microstructural picture (21).

Wang found out that the translucency of the glass-ceramics restoration is significantly affected by the type and thickness of the veneering dental ceramics. The translucency of dental ceramics increases exponentially with reduced thickness (7). Lim showed comparable values of translucency measured by a spectrophotometer (higher values) and by spectroradiometer (25). Other authors bring into correlation the translucency of dental ceramics with illumination (26, 27), the impact of glazed/unglazed surface of glass-ceramics (28) and the impact of the cement and the colour of the prepared tooth (29).

By artificial exposure of specimens to a corrosive medium an insight is gained into the stability of glass-ceramics and the stability of the translucency property in the oral cavity compromised by corrosion in a significantly more rapid and simpler manner than in *in vivo* studies. The use of acetic acid is justified for more reasons; it is often used in households, its pH (2.4) is very similar to that of some beverages, and such pH is also present in the areas below plaque. Such lower pH is also often present in the mouth of patients suffering from stomach diseases.

It is known that, because of the effect of the corrosive medium on the ceramic restoration there is a disruption of bonds in the fundamental structural units of glass, silica tetrahedrons, which means that a greater amount of glass matrix in the material with the same corrosive effect of the environment results in greater corrosion. Blocks for computer-aided manufacturing contain significantly much less glass matrix than ceramics used in the layering technique and are therefore chemically more stable (30, 31, 32). However, the effect of the acid on the translucency of glass-ceramics was not statistically significant in this study for any of the fabrication techniques; therefore the third research hypothesis is rejected. The results are in accordance with the results obtained by other authors (20, 21). A conclusion can be made that ceramic materials are chemically stable. Some studies bring into relation the appearance of roughness on the surface of the restoration resulting from long-term exposure to an acid medium and consequent changes in the optical properties (19, 27). However, additional research on this complex topic is needed.

**Conclusion**
Under the limitation of this study, a conclusion can be made that different types of glass-ceramics showed significant differences in the grades of translucency, both with respect to the fabrication technique and with respect to colour. Exposure to a corrosive medium did not result in a statistically significant change in translucency. Thus, glass-ceramics fabricated by all fabrication techniques showed excellent chemical stability.

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Conflict of interest

None to declare

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**Figure 1** Comparison of translucency before and after exposure to acid with respect to material and colour



**Figure 2** Comparison of the amount of change in translucency due to exposure to acid between materials and colours

**Table 1** Layout of tested glass-ceramics

|  |  |  |  |
| --- | --- | --- | --- |
| **Trade mark**  | **Glass-ceramics type** | **Fabrication technique** | **Number of specimens** |
| IPS e.max Press | lithium-disilicate | heat-pressing technique | 3 |
| IPS e.max CAD | CAD/CAM | 3 |
| IPS e.max Ceram Dentin | nano-fluorapatite | layering technique | 3 |

**Table 2.** Comparison of translucency before and after corrosion among materials of the same colour; t0 = translucency before exposure to corrosive medium; t1 = translucency after exposure to corrosive medium

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  | **AS±SD** | **p\*** | **η2** |
| **Translucency t0** | A2 | IPS e.max Ceram Dentin | 7.58±0.92a |  |  |
| IPS e.max Press | 16.50±0.33b |  |  |
| IPS e.max CAD | 14.17±0.85c | <0.001 | 0.966 |
| C2 | IPS e.max Ceram Dentin | 8.61±0.34a |  |  |
| IPS e.max Press | 17.53±0.50b |  |  |
| IPS e.max CAD | 13.87±1.17c | <0.001 | 0.963 |
| B3 | IPS e.max Ceram Dentin | 9.69±0.30a |  |  |
| IPS e.max Press | 17.58±0.58b |  |  |
| IPS e.max CAD | 14.27±0.50c | <0.001 | 0.981 |
| **Translucency t1** | A2 | IPS e.max Ceram Dentin | 7.50±0.69a |  |  |
| IPS e.max Press | 16.18±0.30b |  |  |
| IPS e.max CAD | 13.95±0.68c | <0.001 | 0.978 |
| C2 | IPS e.max Ceram Dentin | 8.62±0.41a |  |  |
| IPS e.max Press | 17.52±0.68b |  |  |
| IPS e.max CAD | 13.87±1.33c | <0.001 | 0.949 |
| B3 | IPS e.max Ceram Dentin | 9.62±0.48a |  |  |
| IPS e.max Press | 17.47±0.62b |  |  |
| IPS e.max CAD | 13.75±0.36c | <0.001 | 0.979 |

\*ANOVA and Student-Newman-Keuls *post-hoc* test. Types of materials which have different letters in the exponent have a statistically significant difference within the same colour.