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Electrical Properties of Two Types of Lithium-Based Glass Ceramics

Električna svojstva dviju vrsta staklene keramike na bazi litija

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Abstract
The dental ceramic materials are constantly being developed due to their continuous clinical application in the field of esthetic dentistry. Glass ceramics (GC) materials are also of special interest for dental application due to their specific properties; and thus, they can be applied as crowns, veneers and small bridges. **Purpose:** However, due to a variety of different GC materials, it is of keen interest to inspect their morphology and ion-diffusion, which also governs aging properties. **Material and methods:** In this study, two different GC materials were processed, i.e., lithium silicate (LS-10) and lithium disilicate (LS-20). The aforementioned properties can be inspected by using impedance spectroscopy (IS) and scanning electron microscopy (SEM). **Results:** SEM study suggested that LS-10 material is harder to mechanically process by computer-aided design/computer-aided manufacturing (CAD/CAM) technology. Furthermore, IS measurements showed that LS-20 (vs. LS-10) has more pronounced resistance properties. **Conclusion:** According to IS data, it was concluded that LS-20 (vs. LS-10) has more pronounced resistance properties that point out to hindered ion-diffusion and to better aging properties.

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Introduction

Glass ceramics (GC) are polycrystalline materials in everyday use due to their specially tailored properties (1–4). They are ceramic materials that are composed of crystals in the glass-matrix (5). GC materials of special interest are based on crystals with high mechanical properties. In that respect, the most recent types of GC materials for the application in dentistry are based on lithium disilicate (LS-20), lithium silicate or similar crystals (1, 6).

However, these GC materials also have additional additives, pigments, stabilizers, etc. that govern their mechanical and optical properties; and hence, they are suitable for dental application. In dentistry, LS-20 can be replaced by the zirconia-reinforced lithium silicate glass ceramic material (i.e., LS-10) as it has similar application and comparable properties as LS-20. According to Zimmermann et al. (7), LS-20 (vs. LS-10) material has higher resistivity to fracture. However, the authors did not conduct electrical measurements of these materials and the correlation with fracture resistivity was not discussed. Currently, there are more and more GC materials on the market due to their constant development (8–10).

Uvod

Staklokeramika je polikristaličan materijal s posebnim svojstvima koja mu omogućuju svakodnevnu primjenu (1 – 4). Takve keramike sastoje se od kristala u staklenoj matrici (5). Posebno su zanimljive one s kristalima dobrih mehaničkih svojstava pa se tako posljednje generacije staklokeramika temelje na litijevim disilikatnim (LS-20) i litijevim silikatnim ili sličnim kristalima (1,6).

Uz to, te keramike sadržavaju dodatne aditive, pigmente, stabilizatore i slično koji im povećavaju optička svojstva kako bi bile prikladne za korištenje u dentalne svrhe. U dentalnoj medicini se LS-20 može zamijeniti cirkonijevim oksidom ojačanim litijevim silikatnim staklokeramikama (LS-10) koje imaju slična svojstva kao i LS-20. Prema mišljenju Zimmermanna i suradnika (7), materijal LS-20 (u usporedbi s LS-10) otporniji je na pucanje. Međutim, autori nisu obavili električna mjerenja te nisu raspravljali o njihovoj korelaciji sa spomenutim svojstvima. Zato što se konstantno razvijaju, trenutačno je na tržištu sve veći izbor staklokeramičkih materijala (8 – 10).

Indikacije za staklokeramiku najčešće su estetske ljuske, krunice i mali mostovi (11) koji se mogu jednostavno pripre-

GC indications are mostly for the fabrication of veneers, crowns and small bridges (11). They are easily produced by the utilization of digital technology, i.e., computer-aided design/computer-aided manufacturing (CAD/CAM) technology (12–14). Computer-aided design (CAD) and Computer-aided Manufacturing (CAM) can be defined by three different procedures which are conducted by using: scanners (intraoral or extraoral), software (CAD and CAM or jointed in single one for in- office use) and milling units. Therefore, the appearance of the final CAD/CAM product (e.g., crowns) is governed by the quality of each step conducted by a dental technician.

The conductivity properties of zirconia materials have been thoroughly investigated by Badwal et al. (15, 16). However, the conductivity properties of glass-ceramics materials such as LS-10 and LS-20 dental materials have not been systematically studied (17). These properties are of keen interest for the clinical application as they could be used to predict aging properties of GC materials. Therefore, it would be beneficial to inspect electrical properties of LS-10 and LS-20 dental materials.

We were interested in comparing Equivalent Electrical Circuit (EEC) parameters data of both LS-10 and LS-20 materials. A special interest was focused on analyzing the resistivity values, as they should point out some defects in the structure that might reduce the material's clinical application. Also, the (pseudo)capacitance values should reveal more data regarding the role of cations and their mobility in the probed LS-10 and LS-20 glass ceramic materials.

miti digitalnom tehnologijom, odnosno CAD/CAM-om (računalno potpomognut dizajn i izrada). CAD/CAM se sastoji od triju različitih dijelova – skenera (ordinacijski ili laboratorijski), programa (CAD i CAM koji mogu biti i objedinjeni u ordinacijskim sustavima) i glodalice. Konačni rezultat CAD/CAM izrade (npr. krunice) ovisi o kvaliteti svih komponenti sustava i kontroli dentalnoga tehničara.

Vodljivost cirkonijevih oksidnih materijala temeljito je ispitao Badwal sa suradnicima (15, 16). No provodljivost staklokeramičkih materijala kao što su LS-10 i LS-20 nije dovoljno istražena (17). Ispitivanje vodljivosti može biti itekako zanimljivo kada je riječ o kliničkoj primjeni zato što se može koristiti za predviđanje starenja materijala. Zbog toga je potrebno ispitati električna svojstva materijala LS-10 i LS-20.

Također je zanimljivo usporediti parametre ekvivalentnoga električnoga kruga (EEC) za materijale LS-10 i LS-20. Posebna pozornost bit će usmjerena na analizu vrijednosti otpora jer bi ona trebala upozoriti na neke nedostatke u strukturi koji bi mogli smanjiti kliničku primjenu materijala. Vrijednosti (pseudo)kapaciteta također bi trebale otkriti više podataka o ulozi iona i njihovoj pokretljivosti u ispitivanim staklokeramičkim materijalima LS-10 i LS-20.

Materials and methods

Preparation of the Samples

The samples in this study were prepared by using two different materials: zirconia-reinforced lithium-silicate glass (LS-10) ceramics (Celtra Duo, DentsplySirona, Bensheim, Germany) and lithium disilicate (LS-20) ceramics (IPS e.max CAD, Ivoclar, Vivadent, Schaan, Liechtenstein). These materials are different in their composition; however, their exact composition is not provided by the manufacturer(s). The samples were prepared as discs (10 mm in diameter and 1 mm in thickness). The shaping process was conducted by using a dental milling unit (Cerec, MCXL, DentsplySirona, Bensheim, Germany). The utilization discs dimension enabled us to conduct all analyses in this study without the modification of the as-prepared discs. The discs were not additionally crystalized.

SEM investigation

Scanning electron microscope (SEM) images were recorded on a JSM-7000F, thermal field emission scanning electron microscope (FE-SEM) manufactured by Jeol Ltd. (Tokyo, Japan). The samples were not coated by a conductive layer. Hence, each sample was examined without any modifications of discs.

Impedance Spectroscopy

Prior to electrochemical investigations, the discs were polished and then, gold electrodes, 7 mm in diameter, were

Materijal i metode

Priprema uzoraka

Uzorci potrebni u ovoj studiji pripremljeni su od dvaju različitih materijala – litijeva silikata ojačanoga cirkonijevim dioksidom (LS-10) (Celtra Duo, DentsplySirona, Bensheim, Njemačka) i litijeve disilikatne (LS-20) staklokeramike (IPS e.max CAD, Ivoclar, Schaan, Lihtenštajn). Ti su materijali različiti po sastavu, no proizvođači ne navode točne podatke. Uzorci su pripremljeni kao diskovi (promjera 10 mm i debljine 1 mm), a oblikovani su dentalnom glodalicom (Cerec, MCXL, DentsplySirona, Bensheim, Njemačka). Dimenzija uporabnih diskova omogućila je obavljanje svih analiza u ovome radu bez modifikacije pripremljenih diskova. Diskovi nisu dodatno kristalizirani.

SEM istraživanje

SEM slike dobivene su korištenjem pretražnoga elektronskoga mikroskopa JSM-7000F, s emisijom polja elektrona (FE-SEM) proizvođača Jeol Ltd. (Tokio, Japan). Uzorci nisu bili obloženi vodljivim slojem. Zato je svaki uzorak ispitan bez modifikacije diskova.

Spektroskopija impedancije

Prije elektrokemijskih istraživanja diskovi su polirani, a zatim su po površini uzorka raspršene zlatne elektrode (7 sputtered onto both sides of the samples using an SC7620 sputter coater (Quorum Technologies Ltd., Laughton, East Sussex, UK). The complex impedance values were collected by utilizing an impedance analyzer (Novocontrol Alpha-AN dielectric spectrometer, Novocontrol Technologies GmbH & Co. KG, Hundsangen, Germany) over the frequency range from 0.04 Hz to 1 MHz and at 423 K. The temperature was controlled to an accuracy of ± 0.5 K.

Results

Morphology investigations

Figure 1 depicts samples LS-10 and LS-20 that were prepared in the dental laboratory by using a dental milling unit, which is part of CAD/CAM technology (18). The morphology of the LS-20 (vs. LS-10) specimen is more diverse as it consists of more tubes, grains and fibers (Figure 1). In addition, LS-20 material is characterized by a needle-like lithium disilicate material of approximately 3-6 µm in length. This diversity in the LS-20 morphology suggests that this sample has more surface defects that can serve as centers for degradation and/or aging (see, e.g., (18, 19)).

At this point of the study, it would be interesting to inspect the possibility of monitoring the changes in LS-10 vs. LS-20 porosity by using electrical measurements' data. However, in order to do that, it is necessary to conduct a more thorough study of the electrical data than those communicated in our previous work (19).

mm) uređajem SC7620 za nanošenje raspršivača (Quorum Technologies Ltd., Laughton, East Sussex, UK). Vrijednosti kompleksne impedancije prikupljene su korištenjem analizatora impedancije (Novocontrol Alpha-AN dielektrični spektrometar, Novocontrol Technologies GmbH & Co. KG, Hundsangen, Njemačka) u frekvencijskom rasponu od 0,04 Hz do 1 MHz i na 423 K. Temperatura je kontrolirana do točnosti od ± 0,5 K.

Rezultati

Morfološka ispitivanja

Na slici 1. uzorci su LS-10 i LS-20 koji su pripremljeni u zubotehničkom laboratoriju korištenjem dentalne glodalice koja je dio CAD/CAM tehnologije (18). Morfologija uzorka LS-20 (u odnosu prema LS-10) raznolikija je jer se sastoji od više cjevčica, zrna i vlakana (slika 1.). Uz to, materijal LS-20 karakterizira igličasti litijev disilikatni materijal dužine približno 3 do 6 µm. Ta raznolikost u morfologiji LS-20 sugerira da ovaj uzorak ima više površinskih defekata koji mogu poslužiti kao središta degradacije i/ili starenja (vidi, npr., 18, 19).

U ovom stadiju studije bilo bi zanimljivo ispitati mogućnost praćenja promjena poroznosti LS-10 u odnosu prema LS-20 korištenjem podataka dobivenih električnim mjerenjima. No da bi se to postiglo, potrebno je provesti temeljitiju studiju električnih podataka od onih u našem ranijem radu (19).

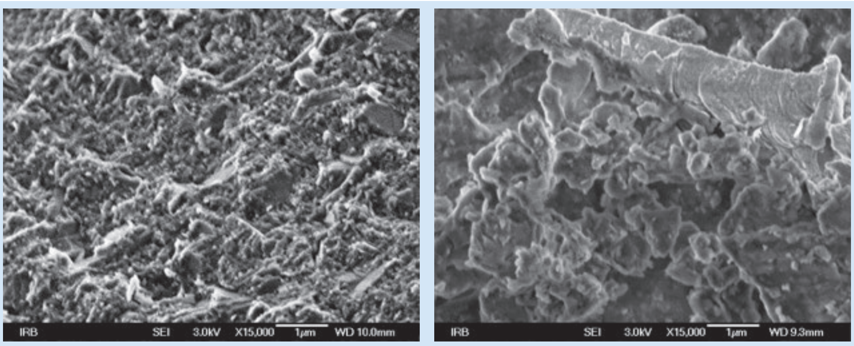

Figure 1 SEM images of samples LS-10 (left) and LS-20 (right). Magnification is X15000. The difference in the morphology agrees well to our previously reported study (19).

Slika 1. SEM slike uzoraka LS-10 (lijevo) i LS-20 (desno); povećanje je x 15 000; razlika u morfologiji dobro se slaže s našim ranije objavljenim radom (19)

Electrical properties

The LS-10 and LS-20 experimental data presented in the Nyquist spectra (Figure 2) show both the presence of two depressed semicircles and a straight line in the far low frequency region. It appears that LS-10 sample has more observable capacitance behavior than LS-20 sample, which can be attributed to higher amount of "free" ions available for charge transfer. Additionally, higher number of "free" ions in LS-10 can also point out accelerated aging of the material, which is of potential interest for the clinical application. The aforementioned observation is supported by the lower imaginary impedance values (Figure 2 (left)). On the other hand, the LS-20 sample has higher resistance, which again can be attributed to a lower number of free charge carriers and/or higher crystallinity that can hinder ion-diffusion through the material.

Električna svojstva

Eksperimentalni podatci LS-10 i LS-20 prikazani u Nyquistovu spektru (slika 2.) pokazuju i dva polegnuta polukruga i ravne linije u niskofrekventnom području. Čini se da uzorak LS-10 ima uočljivije kapacitivno ponašanje od uzorka LS-20, što se može pripisati većoj količini „slobodnih" iona dostupnih za prijenos naboja. Dodatno, veći broj „slobodnih" iona u LS-10 također može upućivati na ubrzano starenje materijala, što je potencijalno zanimljivo kada je riječ o kliničkoj primjeni. Prethodno navedeno opažanje podupiru niže imaginarne vrijednosti impedancije (slika 2. lijevo). S druge strane, uzorak LS-20 ima veću otpornost, što se opet može pripisati nižem broju slobodnih nositelja naboja i/ili većoj kristalnosti koja može otežati difuziju iona kroz materijal.

The ongoing analysis suggests that a more in-depth study of conductivity properties should be implemented in this study. This can be accomplished by using the Distribution Function of Relaxation Times (DRT) (20, 21) and/or the Electrical Equivalent Circuit (EEC) analyses (22–24). It should be noted that nowadays, both approaches are widely accepted in EIS study but DRT (vs. EEC) is a model-free approach (21). On the other hand, EEC is capable of providing EEC parameters values (25–27) that can be used in the comparison process, which is vital in material study and herein as well. Consequently, in this study, it was decided to apply the EEC approach.

According to the aforementioned debate, LS-10 and LS-20 spectra can be modeled/analyzed by the following transfer function (see EEC in Figure 2):

$$Z(\omega_i) = \frac{1}{1/R_g + Y_g(i\omega_i)^{n_g}} + \frac{1}{1/R_{gb} + Y_{gb}(i\,\omega_i)^{n_{gb}}} + Y_{el}(i\omega_i)^{n_{el}},$$

where R_g, R_{gb}, ω, i are the grain and grain boundary resistances, the angular frequency, the imaginary unit and coefficients Y_g, Y_{gb}, Y_{el}, n_b, n_{gb} and n_{el} are related to the constant phase elements (28) related to grain (g), grain boundaries (gb) and electrode polarization (el) (16).

To extract EEC parameters from the impedance data presented in Figure 2 one can apply the Levenberg-Marquardt algorithm (LMA) (29, 30). In addition, the Nelder-Mead algorithm (NMA) can be utilized for the same purpose (31), which is frequently applied in the impedance spectroscopy

Obavljena analiza sugerira da bi se u ovom radu trebala provesti opširnija studija svojstava vodljivosti. To se može postići korištenjem funkcije distribucije vremena relaksacije (DRT) (20, 21) i/ili električnoga ekvivalentnoga kruga (EEC) (22 – 24). Treba napomenuti da su danas oba pristupa široko prihvaćena u EIS studiji, ali treba imati na umu da je DRT (u usporedbi s EEC-om) pristup bez upotrebe matematičkoga modela (21). S druge strane, EEC analiza daje vrijednosti EEC parametara (25 – 27) koje se mogu koristiti u procesu usporedbe, što je u ovom radu ključno u proučavanju materijala. Zato je odlučeno da se u ovoj studiji primijeni EEC pristup.

Prema navedenoj raspravi, spektri LS-10 i LS-20 mogu se modelirati/analizirati sljedećim matematičkim modelom (vidi EEC na slici 2.):

$$Z(\omega_i) = \frac{1}{1/R_g + Y_g(i\omega_i)^{n_g}} + \frac{1}{1/R_{gb} + Y_{gb}(i\,\omega_i)^{n_{gb}}} + Y_{el}(i\omega_i)^{n_{el}},$$

gdje su R_b, R_{gb}, ω, i otpori zrna i granica zrna, kutna frekvencija, imaginarna jedinica i koeficijenti Y_b, Y_{gb}, Y_{el}, n_b, n_{gb} i n_{el} povezani s elementima konstantne faze (28) koji se odnose na zrno (g), granice zrna (gb) i polarizaciju elektrode (el) (16).

Za određivanje EEC parametara iz impedancijskih podataka na slici 2. može se primijeniti Levenberg-Marquardtov algoritam (LMA) (29, 30). Iako se za istu namjenu može koristiti Nelder-Meadov algoritam (NMA) (31) koji se često primjenjuje u analizi spektroskopije impedancije (31 – 33). Zanimljivo, ako korišteni EEC (1) ima, na primjer, razmjer-

Table 1 Equivalent Electrical Circuit (EEC) parameters obtained by extracting parameters values by using (1) and Levenberg-Marquardt algorithm (LMA). LS-10 and LS-20 samples were investigated by EEC model.

Tablica 1. Parametri ekvivalentnoga električnoga kruga (EEC) dobiveni izdvajanjem vrijednosti parametara s pomoću (1) Levenberg-Marquardtova algoritma (LMA); uzorci LS-10 i LS-20 ispitani su EEC modelom

Sample	R_g (Ω cm)	Y_g (S s^n cm^{-2})	n_g	R_{gb} (Ω cm)	Y_{gb} (S s^n cm^{-2})	n_{gb}	Y_{el} (S s^n cm^{-2})	n_{el}
LS-10	3.26 10^5	5.78 10^{-11}	0.883	2.60 10^5	9.07$10^{-10}$	0.733	6.56 10^{-6}	0.594
LS-20	1.79 10^6	2.00 10^{-11}	0.999	6.20 10^7	7.38 10^{-10}	0.608	2.25$10^{-7}$	0.307

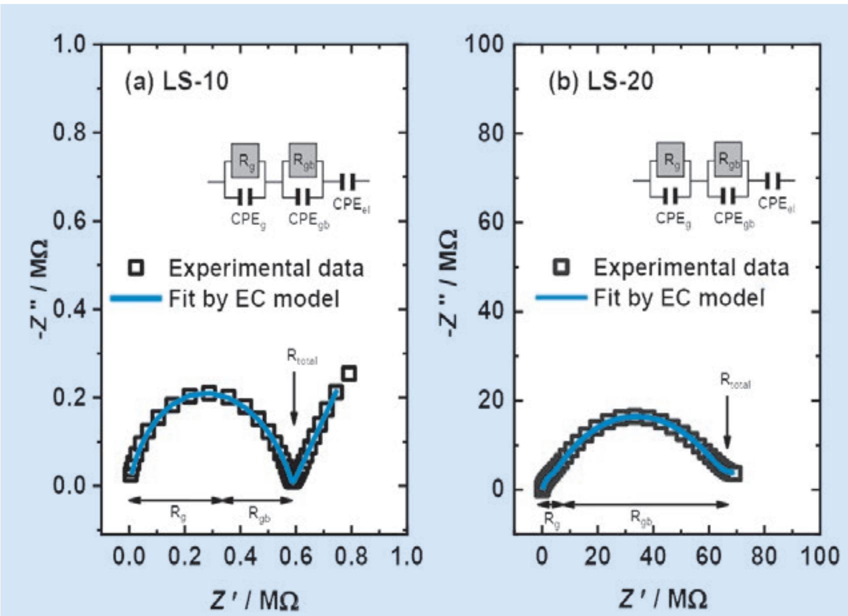

Figure 2 The complex (Nyquist) spectra of LS-10 and LS-20 data. The spectra show two overlapped depressed semicircles and the straight line in the low frequency region. The Equivalent Electrical Circuit (EEC) used for data extraction is also given.

Slika 2. Složeni (Nyquistov) spektar podataka LS-10 i LS-20; spektri pokazuju dva preklapajuća polegnuta polukruga i ravnu liniju u području niske frekvencije; također je prikazan ekvivalentni električni krug (EEC) koji se koristi za ekstrakciju podataka study (31–33). However, when the applied EEC, e.g. (1), has a rather small number of unknowns (i.e., dimensions), NMA can be chosen against LMA. However, if a more complex EEC is applied, it is recommended to apply LMA over NMA (32). In this study, LMA was applied to extract EEC parameters (Table 1) by using EEC model (1). Data are shown in Figure 2.

Discussion

From the point of the clinical application, centers and defects shown in Figure 2 can destabilize bonding between clinical reconstruction and the biological environment. Therefore, prior to dental application, it is advisable to inspect morphology of dental biomaterials such as LS-10 and LS-20 (Figure 1). Also, it appears that LS-10 (vs. LS-20) was less damaged by the milling process. This is in agreement with the study performed by Zarone et al. (6), which clearly stated that machinability of LS-10 (vs. LS-20) is more difficult.

The occurrence of depressed semicircles (Figure 2) is usually observed in IS study (see, e.g., (20)), which indicates a deviation from the pure capacitor behavior (28). This kind of irregularity usually occurs due to non-homogeneous compositions of the investigated materials. Since these LS materials have diverse components such as pigments, additives, ZrO_2 additions, lithium disilicate and lithium silicate embedded in a glassy matrix (1, 6), the deviations from pure capacitive behavior are expected.

The complex spectra in Figure 2 mirror different processes that occur in the high and low frequency regions that can be assigned to ionic diffusion in the grain (g) and at grain boundaries (gb) (15, 34). Also, the straight line in the low frequencies, which is clearly visible in LS-10 spectrum, can be attributed to the electrode polarization effect (el) induced by the accumulation of mobile ions at the electrode surface (16, 35, 36).

Furthermore, Table 1 clearly points to differences between LS-10 and LS-20 spectra shown in Figure 2. It is clear that grain resistance (R_g) is higher for LS-20 (vs. LS-10) specimen, which suggests a hindered diffusion of the migration ions within the grains. The hindered ion-diffusion properties reflect the resistivity of the LS-20 material to aging, which is important information regarding the clinical application. Interestingly, Y_g values that can be observed as the grain (pseudo)capacitance show the similar values although n_g value for LS-20 is closer to 1, which indicates pure capacitance (37). Furthermore, the pseudocapacitance of the grain boundary is alike for both LS-10 and LS-20 samples, which suggests that the concentration of the migrating ions is similar in both samples. However, this statement should be analytically confirmed.

Moreover, the higher n_{gb} value (0.733) of LS-10 (vs LS-20) sample might point to a more homogenous grain boundary. One interesting observation can be extracted from Y_{el} values (Table 1); i.e., it seems that the concentration of the free migrating ions accumulated at the electrode is higher in the case of LS-10. In addition, n_{el} values (LS-10) are close to 0.5; and thus, this constant phase element can be discussed in terms of the Warburg element (38).

no mali broj nepoznanica (tj. dimenzija), može se izabrati NMA umjesto LMA-e. Međutim, ako se primjenjuje složeniji EEC, preporučuje se primjena LMA-e umjesto NMA-e (32). U ovom radu LMA je primijenjen za određivanje EEC parametara (tablica 1.) korištenjem EEC modela (1) i podataka prikazanih na slici 2.

Rasprava

Kada je riječ o kliničkoj primjeni, centri i defekti prikazani na slici 2. mogu destabilizirati vezu između kliničke restauracije biološkoga okoliša. Zato se prije dentalne aplikacije preporučuje pregledati morfologiju dentalnih biomaterijala poput LS-10 i LS-20 (slika 1.). Također se čini da je LS-10 (u odnosu prema LS-20) manje oštećen u postupku glodanja. To se dobro slaže s radom Zaronea i suradnika (6) koji jasno ističu da je obradivost LS-10 teža (u odnosu prema LS-20).

Pojava polegnutih polukrugova (slika 2.) obično se uočava u analizi IS-a (vidi, npr. (20), što upućuje na odstupanje od čistoga kapacitivnoga ponašanja (28). Ta vrsta nepravilnosti obično nastaje zbog nehomogenoga sastava ispitivanih materijala. Budući da ti LS materijali imaju različite komponente kao što su pigmenti, aditivi, dodatci ZrO_2, litijev disilikat i litijev silikat koje su ugrađene u staklenu matricu (1,6), mogu se očekivati odstupanja od čistoga kapacitivnoga ponašanja.

Spektri na slici 2. odražavaju različite procese koji se pojavljuju u područjima visoke i niske frekvencije, a mogu se pripisati ionskoj difuziji u zrnu (g) i na granicama zrna (gb) (15, 34). I ravna linija u niskim frekvencijama, koja je jasno vidljiva u spektru LS-10, može se pripisati efektu polarizacije elektrode (el) induciranom akumulacijom pokretnih iona na površini elektrode (16, 35, 36).

Nadalje, u tablici 1. jasno se vide razlike između LS-10 i LS-20 spektara prikazanih na slici 2. Jasno je da je otpor zrna (R_g) veći za LS-20 uzorak (u odnosu prema LS-10), što sugerira otežanu difuziju migracijskih iona unutar zrna. Svojstva otežane ionske difuzije upućuju na otpornost materijala LS-20 na starenje, što je važna informacija u vezi s kliničkom primjenom. Zanimljivo, vrijednosti Y_g koje se mogu promatrati kao (pseudo) kapacitivnost zrna pokazuju slične vrijednosti, iako je vrijednost n_g za LS-20 bliža 1, što upućuje na čisti kapacitet (37). Dalje, pseudokapacitivnost granice zrna ista je za uzorke LS-10 i LS-20, što sugerira da je koncentracija migrirajućih iona slična u oba uzorka, iako bi tu tvrdnju trebalo analitički potvrditi.

Štoviše, viša vrijednost n_{gb} (0,733) uzorka LS-10 (u odnosu prema LS-20) mogla bi upućivati na homogeniju granicu zrna. Zanimljivo zapažanje može se izvući iz Y_{el} vrijednosti (tablica 1.) – naime, čini se da je koncentracija slobodnih migrirajućih iona nakupljenih na elektrodi veća u slučaju LS-10. Osim toga, n_{el} vrijednosti (LS-10) blizu su 0,5 i zato se o ovom elementu konstantne faze može raspravljati u smislu Warburgova elementa (38).

Conclusion

In this study, two different types of glass ceramics dental materials (LS-10 and LS-20) were examined by SEM and Impedance Spectroscopy techniques. The acquired approaches clearly pointed to different properties of the investigated materials.

According to SEM study, LS-10 (vs. LS-20) material was tougher and harder to process/shape by CAD/CAM, which can be clearly observed from a more compact morphology of the milled sample. At the same time, LS-20 specimen showed the presence of the needle-like lithium disilicate crystal(s).

The conductivity investigations data have shown that LS-10 has a more pronounced capacitive behavior. At the same time, the resistivity component of LS-20 was more prominent. According to Electrical Equivalent Circuit (EEC) analyses, it is clear that the main difference in the resistance component of both LS-10 and LS-20 samples originated from both the grain and grain boundary resistances. This study suggests that the LS-20 material is more suitable for clinical application as it has more pronounced electrical resistivity properties that imply a more hindered aging process.

From the point of clinical application, the material like LS-20 that inhibits both the ion-diffusion and the aging process is preferable. The findings of this study have clearly implied that a more thorough electrical analysis of dental glass ceramics materials should be performed. The electrical data and EEC parameters values obtained in this study can be used to predict the resistivity of dental material to ion-diffusion and the aging process.

Conflict of interest

The authors declare no conflict of interest.

Author's contribution: M.J. and M.Ž. - Conceptualization; L.P. and T.K..- formal analysis; M.J., T.K., L.P. - investigation; M.J. and M.Ž. - methodology; T.K. L.P.- software; M.J., M.Ž.; - supervision; M.Ž. – Writing original draft; M.J, M.Ž, - Writing review and editing. All authors have read and agreed to the published version of the manuscript.

Zaključak

U ovom su istraživanju dvije različite vrste staklokeramičkih dentalnih materijala (LS-10 i LS-20) ispitivane tehnikama SEM-a i impedancijske spektroskopije. Upotrijebljene tehnike jasno su upozorile na različita svojstva ispitivanih materijala.

Prema SEM studiji materijal LS-10 (u odnosu prema LS-20) bio je čvršći i teži za obradu/oblikovanje s pomoću CAD/CAM-a, što se može jasno vidjeti iz kompaktnije morfologije mljevenog uzorka. Istodobno su u uzorku LS-20 uočeni igličasti kristali litijeva disilikata.

Podatci o ispitivanju vodljivosti pokazali su da se LS-10 izraženije kapacitivno ponaša. Istodobno je bila je izraženija komponenta otpora u LS-20. Prema analizama električnoga ekvivalentnoga kruga (EEC) jasno je da glavna razlika u komponenti otpora uzoraka LS-10 i LS-20 potječe iz otpora zrna i granica zrna. Ova studija pokazuje da je materijal LS-20 prikladniji za kliničku primjenu zato što ima izraženija svojstva električnoga otpora koja impliciraju sporiji proces starenja.

Kada je riječ o kliničkoj primjeni, poželjan je materijal poput LS-20 jer inhibira i difuziju iona i proces starenja. Nalazi u ovom radu jasno su pokazali da je potrebna temeljitija analiza električnih svojstva dentalnih staklokeramičkih materijala. Podatci o vodljivosti i vrijednosti EEC parametara dobiveni u ovoj studiji mogu se koristiti za predviđanje otpornosti dentalnoga materijala na difuziju iona i proces starenja.

Sukob interesa

Autori nisu bili u sukobu interesa.

Doprinos autora: **M. J., M. Ž.** – konceptualizacija; **L. P., T. K..** – formalna analiza; **M. J., T. K., L. P.** – istraživanje; **M. J., M. Ž.** – metodologija; **T. K. L. P.** – softver; **M. J., M. Ž.** – nadzor; **M. Ž.** – pisanje izvornoga nacrta; **M. J, M. Ž.** – recenzija i redaktura. Svi su autori pročitali tekst i složili se sa završnom verzijom.

Sažetak

Dentalni keramički materijali kontinuirano se razvijaju zbog svakodnevne primjene u području estetske dentalne medicine. Tako su za dentalnu primjenu posebno zanimljivi staklokeramički (GC) materijali zbog specifičnih svojstava zbog kojih se mogu primijeniti kao krunice, ljuskice i mali mostovi. **Cilj:** Kako postoje mnogo različitih GC materijala, vrlo je važno ispitati njihovu morfologiju i ion-difuzijska svojstva koja utječu na starenje. **Materijal i metode:** U ovom istraživanju ispitana su dva različita GC materijala – litijev silikat (LS-10) i litijev-dislikat (LS-20). Gore navedena svojstva mogu se ispitati s pomoću impedancijske spektroskopije (IS) i pretražnom elektronskom mikroskopijom (SEM). **Rezultati:** Ispitivanja s pomoću SEM-a pokazala su da je materijal LS-10 teže mehanički obraditi tehnologijom računalno potpomognutoga dizajna/proizvodnje (CAD/CAM). **Zaključak:** IS mjerenja pokazala su da LS-20 (u usporedbi s LS-10) ima naglašenija otporna svojstva koja upućuju na njegovo bolje svojstvo starenja.

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