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# A 13- to 17-Year Retrospective Evaluation of the Clinical Performance of Anterior and Posterior Lithium Disilicate Restorations on Teeth and Implants

This retrospective study evaluated the clinical outcomes of lithium disilicate prostheses on teeth and implants. A total of 860 restorations, including crowns, veneers, and onlays, were delivered to 312 patients. Patients with uncontrolled gingival inflammation and/or periodontitis were excluded, while patients with occlusal parafunctions were included. The retrospective observational period ranged between 13 and 17 years. The mechanical and esthetic performance of the restorations were rated according to the modified California Dental Association (CDA) criteria. The recorded data were analyzed statistically. In total, 26 mechanical complications were noticed: 17 ceramic chippings, 5 core fractures, and 4 losses of retention. Mechanical complications occurred predominantly in posterior areas; monolithic prostheses showed the lowest percentage of structural problems. The clinical scores of layered and monolithic restorations were fully satisfactory according to the modified CDA rating. The cumulative survival and success rates ranged from 95.46% to 100% and 93.75% to 100%, respectively, up to the 17-year follow-up. Although patient selection and the rigorous application of validated clinical protocols were considered paramount, the use of lithium disilicate prostheses on teeth and implants was reported to be a viable and reliable treatment option in the long term. *Int J Periodontics Restorative Dent 2025;45:369–383. doi: 10.11607/prd.7074*

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The increasing demand for esthetics led to the development of innovative all-ceramic materials, including heterogeneous silica-based ceramics and homogeneous polycrystalline cores.[1,2]

Silica-based ceramics present optimal esthetics due to the utmost translucency and opalescence of the glassy matrix; the clinical performances were reported to be reliable, as they can be etched and offer excellent bonding, thus providing satisfactory mechanical resistance due to an adhesive monoblock with dental substrates.[3,4]

Oppositely, polycrystalline zirconia cores show outstanding mechanical properties, with much higher fracture toughness than dental tissues, but are not sensitive to conventional etching because of the absence of silica.[5] Although several surface treatments were described to improve the bond strength to resin cements, the adhesive performances of zirconia are promising but need further validation.[6]

Glass-based materials were proposed mainly for single restorations and short-span fixed dental prostheses (FDPs) in anterior areas[7]; conversely, polycrystalline frameworks can be used to fabricate single restorations, FDPs and full arch prostheses.[5] Both ceramics can be used on teeth and implants.[5,7]

To merge the esthetics of glass with the resistance of zirconia, intermediate ceramics were developed, adding different fillers to an amorphous matrix. Among them, lithium disilicate ($LS_2$) rapidly gained popularity because of its captivating optical and mechanical properties, which make it a very versatile solution.[1,7,8]

$LS_2$ was developed as a pressable glass-based ceramic (eg, IPS e.max Press, Ivoclar Vivadent; LiSi Press, GC) with improved translucency and physical characteristics. Restorations can be fabricated in a bilayered (layering an $LS_2$ core with fluoroapatite ceramic) or monolithic manner, avoiding any risk of chipping.[9] Later, with the introduction of CAD/CAM technologies, $LS_2$ blocks (ie, IPS e.max CAD, Ivoclar Vivadent; LiSi Blocks, GC; CEREC Tessera, Dentsply Sirona) were produced, showing optimal biomechanical properties.[10]

Due to high flexural strength (350 to 500 MPa), etchability, and translucency, $LS_2$ is suitable for different indications, offering optimal biomimetic performances in limited thicknesses, ensuring a conservative clinical approach.[7,9] $LS_2$ represents a reliable option to fabricate full and partial single restorations: bilayered restorations are preferred in anterior areas, particularly at the buccal aspects, to extol the optical appearance, whereas monolithic restorations can be used to restore posterior segments to avoid possible chipping.[7,9] Staining techniques can be useful to paint superficial characterizations onto monolithic restorations and use them in anterior areas as well, saving dental tissues and avoiding endodontic treatments.[11] Because of its flexural strength, $LS_2$ can be used to produce short-span FDPs in anterior areas (up to the first premolars).[7,12]

$LS_2$ contains silica and can be luted with resin cements after acid etching to create an adhesive monoblock with dental substrates, particularly enamel, and improve the clinical performances.[13,14]

The use of all-ceramic materials gained popularity due to CAD/CAM techniques as well, particularly the ability to perform milling units.[15] Regarding implants, different materials (such as titanium and zirconia) can be processed to customize abutments and full-arches, offering optimal mechanical resistance and showing fit values comparable to those of conventional frameworks.[16,17] $LS_2$ restorations can be cemented onto titanium and zirconia with resin cements to improve esthetics.[18]

The present retrospective study aimed to evaluate the clinical performances of $LS_2$ prostheses on teeth and implants in anterior and posterior areas. The observational evaluation assessed the mechanics and esthetics of $LS_2$ restorations in different prosthetic configurations over a period of 13 to 17 years.

## Materials and Methods

### Study Population

Between June 2006 and December 2010, 860 $LS_2$ restorations were delivered by six expert prosthodontists (G.F., G.D., G.C., M.D.L., A.M., and R.S.) to 312 patients: 169 women (ages 19 to 71 years) and 143 men (ages 19 to 61 years). These subjects were in need of various prosthetic treatments and were recruited from consecutive patients at the authors' dental practices. All patients were informed about the study guidelines in accordance with the revised Declaration of Helsinki[19] and STROBE guidelines[20] and gave written informed consent.

Patients were included in the study if they met the following inclusion criteria: periodontally healthy, good oral hygiene, received previous vital or endodontic treatment and achieved a sound state, and having opposing natural dentition or fixed prostheses. All recruited patients were in good general health, and 34% were smokers (> 5 cigarettes/day). Preliminary oral hygiene was

**Table 1** Descriptive Characteristics of the Study Groups

| Group | | Follow-up | | Cumulative survival rate | Cumulative success rate |
|---|---|---|---|---|---|
| | | Range | Mean | | |
| Anterior crowns | Layered (n = 209) | 14–17 y | 15.2 y | 98.57% | 97.61% |
| | Monolithic (n = 22) | | | 95.46% | 95.46% |
| Posterior crowns | Layered (n = 65) | 13–16 y | 14.8 y | 96.92% | 95.39% |
| | Monolithic (n = 132) | | | 95.46% | 93.94% |
| Implant crowns | Layered (n = 7) | 13–16 y | 14.6 y | 100% | 100% |
| | Monolithic (n = 45) | | | 97.78% | 97.78% |
| Anterior veneers | Layered (n = 239) | 13–17 y | 15.1 y | 97.91% | 96.24% |
| | Monolithic (n = 40) | | | 100% | 100% |
| Posterior veneers | Layered (n = 26) | 14–17 y | 15.4 y | 100% | 100% |
| | Monolithic (n = 13) | | | 100% | 100% |
| Onlays | Layered (n = 16) | 13–15 y | 14.8 y | 100% | 93.75% |
| | Monolithic (n = 46) | | | 97.83% | 97.83% |

**Table 2** Anatomical Distribution of Lithium Disilicate Restorations

| | Veneers | | | | Crowns | | | | Onlays | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Layered | | Monolithic | | Layered | | Monolithic | | Layered | | Monolithic | |
| Site | Max | Mdb | Max | Mdb | Max | Mdb | Max | Mdb | Max | Mdb | Max | Mdb |
| Central incisors | 64 | 27 | 12 | 3 | 43 | 3 | 12 | 4 | – | – | – | – |
| Lateral incisors | 47 | 29 | 9 | 2 | 47 | 3 | 11 | 4 | – | – | – | – |
| Canines | 39 | 26 | 9 | 5 | 29 | 8 | 8 | 11 | – | – | – | – |
| First premolars | 11 | 9 | 5 | 4 | 40 | 18 | 28 | 23 | 2 | 2 | 5 | 6 |
| Second premolars | 5 | 8 | 2 | 2 | 38 | 23 | 30 | 28 | 3 | 1 | 5 | 11 |
| First molars | – | – | – | – | 13 | 8 | 17 | 10 | – | 4 | 3 | 7 |
| Second molars | – | – | – | – | 4 | 4 | 9 | 4 | 1 | 3 | 2 | 7 |
| Total | 166 | 99 | 37 | 16 | 214 | 67 | 115 | 84 | 6 | 10 | 15 | 31 |

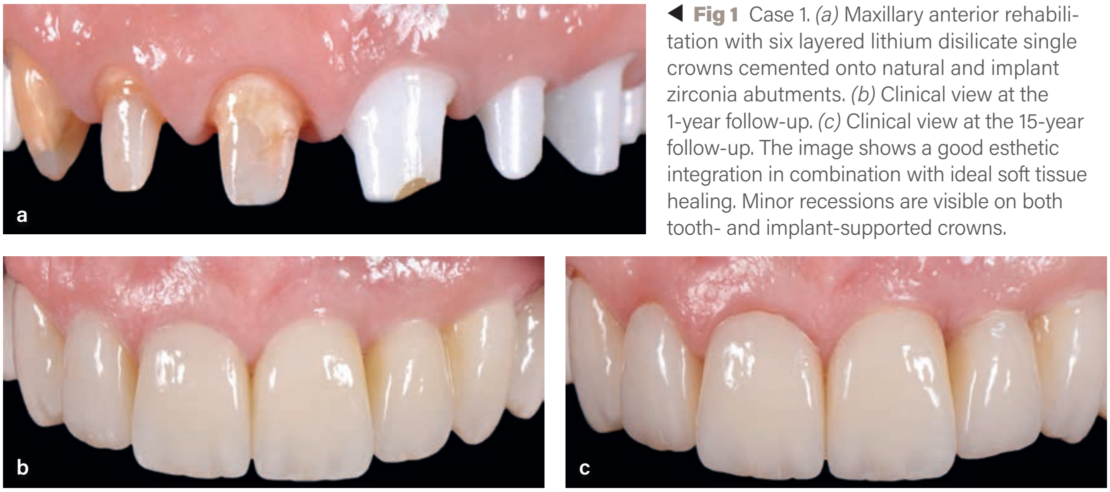
Max = maxilla; Mdb = mandible.

performed by dental hygienists, and periodontal health was maintained by enrolling the patients in a program of periodical periodontal maintenance.

According to patient needs, partial and full coverage single restorations for placement on teeth and implants in anterior (premolar to premolar) and posterior regions were fabricated as follows: 480 crowns (329 maxillary, 151 mandibular), 62 onlays (21 maxillary, 41 mandibular), and 318 veneers (203 maxillary, 115 mandibular) (Tables 1 and 2). Of these, 261 restorations were made in parafunctional patients (30.3%). The prostheses were fabricated with pressed or milled $LS_2$, either as layered or monolithic. Patients were recalled at follow-up at least annually for clinical and radiologic evaluations. The observational period ranged from 13 to 17 years (Figs 1 and 2).

### Ceramic Laminate Veneers

A total of 318 $LS_2$ veneers were fabricated (203 maxillary, 115 mandibular) (see Table 2). The following tooth preparation was used, according to the mock-up guided preparation technique: 0.2 to 0.8 mm cervical chamfer, 0 to 0.8 mm axial



◀ **Fig 1** Case 1. *(a)* Maxillary anterior rehabilitation with six layered lithium disilicate single crowns cemented onto natural and implant zirconia abutments. *(b)* Clinical view at the 1-year follow-up. *(c)* Clinical view at the 15-year follow-up. The image shows a good esthetic integration in combination with ideal soft tissue healing. Minor recessions are visible on both tooth- and implant-supported crowns.

◀ **Fig 2** Case 2. Maxillary and mandibular tooth preparations for anterior *(a)* maxillary crowns and *(b)* mandibular veneers. *(c)* Clinical view at the 1-year follow-up. *(d)* Clinical view at the 12-year follow-up. Satisfactory biomimetic integration and good soft tissue health can be seen. Minor recessions are visible at cervical margin levels.

reduction, and 0 to 1.5 mm incisal reduction (according to wax-up and presence of discoloration). The axial reduction was made with tapered round-end burs, preserving the maximum amount of enamel (particularly at the periphery) to achieve the best adhesion. The interproximal contact areas were opened only in case of class III restorations or when changing the emergence profile was necessary (diastemata or interdental triangles). An incisal butt joint was used in 262 veneers while a palatal chamfer was made in 56 restorations. The buccal thickness of laminates ranged from 0.2 to 0.8 mm cervically, 0.2 to 1.2 mm in the middle third, and 0.3 to 0.9 mm incisally. Centric contacts at the veneer-tooth interface were avoided. When possible, the cervical margins were located supra- or juxtagingivally to simplify impression-making and inspection of marginal adaptation, thus con-

▲ **Fig 3** Case 3. *(a)* Tooth preparations for laminate veneers. *(b)* Lithium disilicate veneers 1 month after cementation. *(c)* Clinical view at the 14-year follow-up. Ideal esthetics and soft tissue integration can be seen.

tributing to maintaining periodontal health. When the emergence profile of teeth had to be modified, the restoration margins were placed at the gingival crest or into the crevice. A total of 265 veneers were layered and 53 restorations were monolithic.

All of the $LS_2$ veneers were cemented adhesively with a rubber dam. The intaglio surface was etched with 4.5% hydrofluoric acid (IPS Ceramic Gel, Ivoclar Vivadent; or Porcelain Etch, Ultradent) for 20 seconds. The acid was then thoroughly washed with water, and the ceramic surface was dried. A silane coupling agent (Monobond S, Ivoclar Vivadent; or RelyX ceramic primer, 3M ESPE) was applied on the intaglio surface. The tooth surface was etched with 37% phosphoric acid gel (Ultra-Etch, Ultradent) for 30 seconds. After thoroughly rinsing the surface with water for 30 seconds, a bonding agent (OptiBond FL, Kerr) was rubbed onto both the tooth and the ceramic intaglio surface; a dentin primer (OptiBond FL) was applied only on areas of exposed dentin. The cementation was performed as follows: The veneers with a thickness < 0.5 mm were luted with flowable composites (Gradia Direct Flo, GC; Tetris Evo-Flow, Ivoclar) or light-curing cements (Variolink Veneer, Ivoclar Vivadent), and the veneers with a thickness of 0.5 to 0.8 mm were luted using dual-curing composite systems (Variolink II, Ivoclar Vivadent). Excess cement removed at the margins with microbrushes and interproximally with dental floss. The restoration margins were covered with glycerin gel to block the oxygen, and the resin cements were light cured for 30 seconds on each surface. The margins were finished with plastic scalers and/or blades to remove cement remnants. The occlusal contacts were carefully checked, adjusted, and polished (Fig 3).

### Tooth-Supported Single Crowns

A total of 480 crowns were fabricated (329 maxillary, 151 mandibular) to be placed on teeth (see Table 2). Tooth preparations were performed according to the wax-up, as follows: 0.3 to 1 mm overall axial reduction, 1.5 mm incisal/occlusal preparation, 0.4 to 1 mm circumferential chamfer at the margins; and all angles were rounded to avoid sharp edges and possible areas of stress concentration. The total occlusal convergence of preparation ranged between 5 and 10 degrees, depending on the length of the abutment teeth. In anterior areas, the margins were located at the gingival crest or slightly into the sulcus, depending on esthetic needs. Differently, in posterior regions, the prosthetic margins were placed supra- or juxtagingivally to preserve enamel, make impression-making easier, and facilitate the assessment of marginal adaptation.

The restoration thickness ranged between 0.3 and 1 mm on the axial surfaces and the interproximal walls; to achieve proper biomechanics, the minimum thickness in the incisal/occlusal areas was 1.5 mm. A total of 480 single crowns (183 anterior, 297 posterior) were made, 407 restorations were pressed (243 layered, 164 monolithic), and

▲ **Fig 4** Case 4. *(a)* Tooth preparation for a full crown on a vital tooth. *(b)* Clinical view at the 1-year follow-up. *(c)* After 40 months of clinical service, chipping with a buccal crack line can be seen.

21 CAD/CAM restorations were milled (8 layered, 13 monolithic). All of the restorations were cemented adhesively with dual-curing (Multilink Automix, Ivoclar; or Variolink II) or self-adhesive resin cements (RelyX Unicem, 3M ESPE), according to the manufacturers' instructions. The rubber dam was used to lute 68 crowns; for the other cases, partial dam and thin gingival retraction cords (N.000 Ultrapak, Ultradent) were used for isolation. After cementation, the occlusal static and dynamic occlusal contacts were checked, adjusted, and polished (Fig 4).

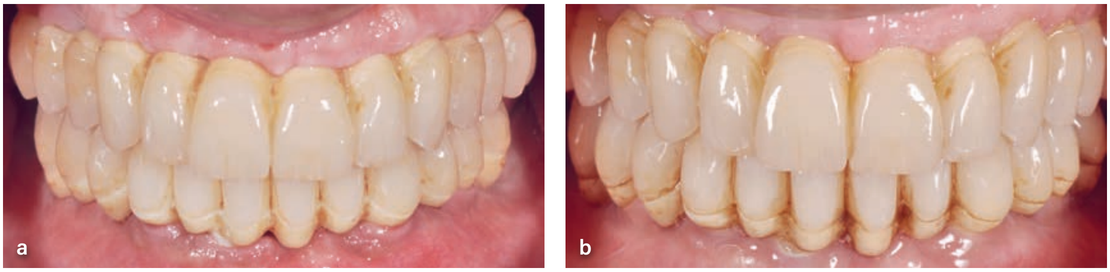
### Onlays

A total of 62 onlays were fabricated (21 maxillary, 41 mandibular) (see Table 2). Composite buildups were made to facilitate impression-making and cementation. The cavities were prepared with a minimum occlusal thickness of 2 mm. Sixteen onlays were layered, and 46 were monolithic and stained. For cementation, the prepared teeth were isolated with a rubber dam, and flowable composite resin (Gradia Direct Flo; or Tetric EvoFlow, Ivoclar) or dual-curing resin cements (Variolink II) were used per the manufacturers' instructions, as previously described. The occlusal contacts were adjusted and polished.

### Implant-Supported Restorations

A total of 52 implant-supported restorations (30 maxillary, 22 mandibular) were fabricated for placement on 36 implants: 9 screw-retained single crowns, 7 cement-retained single crowns, 2 screw-retained zirconia full-arches (for a total of 26 restorations), 1 screw-retained four-unit zirconia FDP, and 2 screw-retained three-unit titanium FDPs. The implant abutments and frameworks were designed to sustain prosthetic elements with a minimum circumferential thickness of 1.5 mm and at least 2 mm of occlusal clearance. In case of titanium, an opaque layer was used to mask the grayish appearance of the metal structures. The $LS_2$ restorations were cemented onto zirconia and titanium with dual-curing (Multilink Automix) or self-adhesive cements (RelyX Unicem). The restorations were treated as tooth crowns, and no treatment was carried out on framework materials. For screw-retained restorations, when the screw access hole did not take up the buccal area, extraoral cementation was performed, avoiding the risk of entangling the cement excess in the peri-implant soft tissues. The screw access holes were filled with polytetrafluoroethylene tapes and composites (Figs 5 and 6).

▶ **Fig 5** Case 5. Clinical view at the 15-year follow-up of a full-mouth rehabilitation with lithium disilicate single crowns cemented on natural and implant-supported abutments.



▲ **Fig 6** Case 6. *(a)* Implant-supported full-arch rehabilitation. This patient was treated with two screw-retained zirconia frameworks combined with monolithic lithium disilicate crowns. The crowns were cemented extraorally with adhesive cement. *(b)* Clinical view at the 15-year follow-up. Good surface stability can be seen, as well as minor pigmentations at the interface between the crowns and the zirconia frameworks.

### Clinical Evaluation

All patients were evaluated at baseline (delivery day) and at least annually for a period of 13 to 17 years. At each recall, standardized photographs and radiographs were taken. Data forms were used by blinded operators to record the mechanical and esthetic outcomes. Ceramic surface, marginal integrity, marginal discoloration, and color match were assessed according to the modified criteria of the California Dental Association (CDA) quality assessment system,[21] rating the different clinical parameters as A (excellent), B (good), C (satisfactory), or D (not satisfactory).

Patient satisfaction was evaluated with nominal scores (unacceptable, acceptable, good, excellent). In case of mechanical complications, the restoration was considered as a failure.

### Statistical Analysis

A statistical software (SPSS version 28.0.1, IBM) was used to run descriptive statistics. The minimum and maximum follow-up periods were recorded for all study groups. The cumulative survival rate (CSurvR) and success rate (CSuccR) were calculated using Kaplan-Meier curves; all study groups were divided into layered and monolithic. Each mechanical complication, either minor (chipping, loss of retention) or major (core or framework fracture), was considered as a statistical event. Log-rank test was run to compare the survival curves of layered vs monolithic and pressed vs milled prostheses. The level of statistical significance was set at $P = .05$.

## Results

All procedures were carried out by expert prosthodontists and skilled dental technicians (G.F., G.D., G.C., M.D.L., A.M., and R.S.). A total of 860 prostheses were evaluated from 13 to 17 years in 312 patients. No patient was lost at follow-up. Complications are summarized in Table 3.

**Table 3** Complications Recorded During the Overall Observational Period

| Restoration | Type | Event | Location | Timing | Manufacturing |
|---|---|---|---|---|---|
| Anterior veneers | Layered | Chipping | Max CI | 4 mo | Pressed |
| | | | Max 1PM | 8 mo | Milled |
| | | | Max CI | 39 mo | Pressed |
| | | | Max CA | 42 mo | Pressed |
| | | | Max LI | 58 mo | Pressed |
| | | Core fracture | Max LI | 10 mo | Pressed |
| | | | Mdb CA | 42 mo | Milled |
| | | | Mdb CI | 4 y | Pressed |
| | | Retention loss | Mdb 1M | 3 y | Milled |
| | Monolithic | – | – | – | – |
| Posterior veneers | Layered | – | – | – | – |
| | Monolithic | – | – | – | – |
| Anterior tooth-supported crowns | Layered | Chipping | Max 2PM | 29 mo | Pressed |
| | | | Mdb 1M | 35 mo | Milled |
| | | | Max CI | 40 mo | Pressed |
| | | Core fracture | Max CI | 7 mo* | Pressed |
| | | | Max LI | | Pressed |
| | Monolithic | Chipping | Max CA | 2 y | Pressed |
| Posterior tooth-supported crowns | Layered | Chipping | Mdb 2PM | 9 mo | Pressed |
| | | | Max 1M | 33 mo | Milled |
| | | | Max 1PM | 3 y | Pressed |
| | | | Mdb 1PM | 38 mo | Pressed |
| | | Retention loss | Mdb 1PM | 1 y | Pressed |
| | | | Mdb 2PM | 17 mo | Pressed |
| | | Root fracture | Max 1PM | 30 mo | Pressed |
| | Monolithic | Chipping | Max 2PM | 33 mo | Milled |
| | | | Mdb 1PM | 5 y | Pressed |
| | | Core fracture | Max 2M | 1 y | Pressed |
| | | | Mdb 2M | 2 y | Pressed |
| | | | Max 2M | 3 y | Pressed |
| | | | Mdb 1M | 3 y | Pressed |
| | | | Mdb 2M | 3 y | Milled |
| | | Endo treatment | Mdb 1M | 18 mo | Pressed |
| Onlays | Layered | Chipping | Mdb 1PM | 57 mo | Pressed |
| | | | Max 2PM | 190 mo | Pressed |
| | Monolithic | Chipping | Mdb 2M | 43 mo | Milled |
| | | | Mdb 2M | 57 mo | Pressed |
| | | Retention loss | Max 2PM | 18 mo | Milled |
| Implant-supported crowns | Layered | – | – | – | – |
| | Monolithic | Chipping | Max CA | 2 y | Pressed |

CA = canine; CI = central incisor; Endo = endodontic; LI = lateral incisor; Max = maxilla; Mdb = mandible; 1M = first molar; 2M = second molar; 1PM = first premolar; 2PM = second premolar.
*Both events occurred in the same patient.

**Ceramic Laminate Veneers**

CSurvR of 97.91% and CSuccR of 96.24% were reported for anterior $LS_2$ layered veneers; differently, anterior monolithic veneers achieved 100% for both CSurvR and CSuccR. For posterior veneers, both layered and monolithic restorations showed CSurvR and CSuccR of 100%. See Table 1 for complete CSurvR and CSuccR data on anterior and posterior positions.

For manufacturing, pressed veneers reported CSurvRs and CSuccRs of 99.32% and 97.95%, respectively, while milled veneers reported CSurvRs and CSuccRs of 96.16% and 88.46%, respectively.

Minor chipping was reported in five veneers in the maxilla; none of them impaired function, so they were polished intraorally and kept in situ for follow-up.

Core fractures were observed in three anterior layered veneers (one maxillary lateral incisor, one mandibular central incisor, one mandibular canine). All of the fractures occurred with ceramic materials as opponents, and replacement was necessary. The failed restorations were prepared with incisal butt joints, and the replacements were carried out with a new preparation involving the palatal surfaces with a mini-chamfer. One veneer on a mandibular lateral incisor was affected by loss of retention; the restoration was rebonded and still in service at the 17-year follow-up.

**Tooth-Supported Single Crowns**

CSurvRs and CSuccRs of 98.57% and 97.61%, respectively, were recorded for anterior layered tooth-supported crowns, while anterior monolithic single crowns both showed CSurvRs and CSuccRs of 95.46%. For posterior layered tooth-supported crowns, CSurvRs and CSuccRs of 96.92% and 95.39% were reported, respectively. Differently, posterior monolithic crowns achieved 95.46% for CSurvRs and 93.94% for CSuccRs (see Table 1).

Regarding the manufacturing, pressed tooth-supported crowns reported CSurvRs and CSuccRs of 98.28% and 95.82%, respectively, while milled tooth-supported crowns reported CSurvRs and CSuccRs of 95.24% and 80.95%, respectively.

Minor chipping was reported for nine restorations (four maxillary, five mandibular), and two chipped crowns were monolithic, one per arch. Such cohesive fractures occurred predominantly in posterior areas; five chippings did not impair function, so they were polished intraorally, while the other four required replacement. Catastrophic core fractures were noticed in the same patient 7 months after cementation, on two layered crowns (central and lateral maxillary incisors), opposing ceramic materials, and needed replacement.

In molar areas, five posterior monolithic restorations fractured 1 to 3 years after delivery: two in the maxilla (both second molars) and three in the mandible (one first molar and two second molars) (Figs 7 and 8). All of these restorations had an occlusal thickness < 1.5 mm and were cemented with a rubber dam, but on wide areas of exposed dentin. The fractured crowns were replaced with new monolithic zirconia restorations.

Loss of retention occurred on two layered mandibular crowns (first and second premolars); the restorations were rebonded and still in function at the last follow-up. One monolithic crown in the mandible (first molar) was affected by pulpitis and required a root canal treatment 18 months after cementation; endodontic therapy was performed through the restoration, and the access hole was then built up with composites. Although the restoration was still in service at the last follow-up, it was statistically considered as a failure. Moreover, one nonvital maxillary first premolar restored with a layered crown was extracted because of root fracture.

**Onlays**

CSurvRs and CSuccRs of 100% and 93.75%, respectively, were found for layered onlays, while monolithic onlays both showed CSurvRs and CSuccRs of 97.83% (see Table 1).

Regarding manufacturing, pressed onlays both reported CSurvRs and CSuccRs of 90.91%; differently, milled onlays both recorded CSurvRs and CSuccRs of 93.11%.

Minor chipping was observed on four onlays: one layered onlay on a maxillary second premolar (natural tooth as opponent), one layered restoration on a mandibular first premolar (ceramic

▲ **Fig 7** Ceramic fracture on a mandibular first molar. The restoration had an occlusal thickness of about 1 mm and was cemented onto a substrate with a prevalence of dentin.

▲ **Fig 8** Ceramic fracture on a mandibular second molar. The restoration had an occlusal thickness of about 1 mm and was cemented onto a substrate with a prevalence of dentin.

material as opponent), and two monolithic onlays on mandibular second molars (one ceramic and one tooth opponent). The chipped areas were repaired intraorally using composites adhesively bonded under rubber dam. Loss of retention was reported on one monolithic maxillary onlay on a second premolar; the restoration was rebonded and still in service at the last follow-up.

### Implant-Supported Restorations

CSurvRs and CSuccRs of 100% were recorded for layered implant-supported crowns, while monolithic implant crowns both showed CSurvRs and CSuccRs of 97.78% (see Table 1).

Regarding manufacturing, pressed implant-supported crowns reported CSurvRs and CSuccRs of 100% and 90.91% respectively; differently, milled implant-supported crowns both recorded CSurvRs and CSuccRs of 100%.

Minor chipping was observed in one monolithic crown on a maxillary canine. Such limited cohesive fracture did not impair function; the area was polished intraorally and the restoration was kept in situ.

### Statistical Analysis

Because any complication was considered as a statistical event, the CSurvRs of $LS_2$ restorations ranged between 95.46% and 100%, while the CSuccRs ranged between 93.75% and 100%, according to Kaplan-Meier survival curves (see Table 1; see Appendix Figs 1 to 4, available in the online version of this article).

Log-rank tests comparing the survival analyses of layered vs monolithic prostheses were not statistically significant in any group ($P > .05$, Table 4).

Conversely, log-rank tests comparing the survival analyses of pressed vs milled restorations were statistically significant for veneers and crowns ($P < .05$), while no statistically significant differences were noticed for onlays and implant crowns ($P > .05$, Table 5).

### Clinical Evaluation

According to the modified CDA quality assessment system criteria, the ratings of layered and monolithic restorations were fully satisfactory (Table 6). The lowest (88.4%) amount of A (excellent) ratings was noticed for the color match of monolithic restorations; nonetheless, it was considered satisfactory by patients and clinicians. With the exception of the failed restorations, no prosthesis was rated C (satisfactory) or D (not satisfactory) for any criteria. Patient satisfaction scores were predominantly "excellent" for all prosthesis types (88.1%); only a few restorations were rated "good" (10.8%) or "acceptable" (1.1%), and none were reported as unacceptable.

The lowest percentage of mechanical complications was noticed in monolithic restorations. No monolithic veneer failed, but two monolithic crowns on natural teeth and one implant-supported restoration showed minor chippings. All failed crowns had ceramic restorations as opponents.

Secondary decay was not detected; margin and contour quality were clinically satisfactory and

**Table 4** Log-Rank Tests Comparing Survival Curves of Layered vs Monolithic Lithium Disilicate Restorations

| Groups | Log-rank | *P* |
|---|---|---|
| Layered anterior crowns vs monolithic anterior crowns | 0.367 | > .05 |
| Layered posterior crowns vs monolithic posterior crowns | 0.102 | > .05 |
| Layered anterior veneers vs monolithic anterior veneers | 1.211 | > .05 |
| Layered posterior veneers vs monolithic posterior veneers | 2.059 | > .05 |
| Layered onlays vs monolithic onlays | 0.414 | > .05 |
| Layered implant crowns vs monolithic implant crowns | 0.178 | > .05 |

**Table 5** Log-Rank Tests Comparing Survival Curves of Pressed vs Milled Lithium Disilicate Restorations

| Groups | Log-rank | *P* |
|---|---|---|
| Pressed veneers vs milled veneers | 3.347 | < .05 |
| Pressed crowns vs milled crowns | 3.224 | < .05 |
| Pressed onlays vs milled onlays | 0.261 | > .05 |
| Pressed implant crowns vs milled implant crowns | 1.930 | > .05 |

**Table 6** Frequency of Clinical Ratings of Lithium Disilicate Restorations According to the Modified CDA Quality Assessment System Criteria

| | A | | B | | C | | D | |
|---|---|---|---|---|---|---|---|---|
| Parameter | Layered | Monolithic | Layered | Monolithic | Layered | Monolithic | Layered | Monolithic |
| Color match | 96.8% | 88.4% | 3.2% | 9.9% | 0% | 1.7% | 0% | 0% |
| Ceramic surface | 94.2% | 96.3% | 4.6% | 3.7% | 1.2% | 0% | 0% | 0% |
| Marginal discoloration | 95.0% | 94.9% | 3.6% | 4.0% | 1.4% | 1.1% | 0% | 0% |
| Marginal integrity | 97.6% | 98.7% | 1.2% | 1.3% | 1.2% | 0% | 0% | 0% |

A = excellent; B = good; C = satisfactory; D = not satisfactory.

interproximal contact areas were well maintained over the whole observation.

Regarding patients with occlusal parafunctions, 261 restorations were delivered in 94 patients (30.3%). Of all the technical complications recorded during the follow-up period, 12 (33%) occurred in parafunctional patients. Catastrophic fractures were reported mainly in layered prostheses placed in anterior areas, although one root fracture and one monolithic core fracture were seen at posterior teeth. Technical complications mostly affected pressed restorations in parafunctional patients (Table 7).

Log-rank tests comparing the survival analyses of restorations delivered to parafuntional vs nonparafunctional patients showed no statistically significant differences (z = 0.46, *P* = .64) .

## Discussion

In the present retrospective study, $LS_2$ restorations showed very high long-term success rates, ranging between 93.75% and 100% after 13 to 17 years; such results were comparable to those of other studies.[7,9,12,22,23] Different variables can contribute to the clinical outcomes; particularly, $LS_2$ restorations should be bonded carefully using proper adhesive protocols.[2,7,13] Furthermore, the quality and quantity of residual tooth structures is crucial, particularly at prosthetic margins where enamel represents a potential guarantee for stability over time. The more enamel is preserved, the more reliable the adhesion and the more limited the aging of the bonding interfaces will be.[7] This was proven by an investigation about porcelain veneers that

**Table 7** Complications Recorded in Parafunctional Patients

| Restoration | Type | Event | Location | Timing | Manufacturing |
|---|---|---|---|---|---|
| Anterior veneers | Layered | Chipping | Max 1PM | 8 mo | Milled |
| | | | Max CA | 42 mo | Pressed |
| | | Core fracture | Max LI | 10 mo | Pressed |
| | | | Mdb CA | 42 mo | Milled |
| | | | Mdb CI | 4 y | Pressed |
| Anterior tooth-supported crowns | Layered | Core fracture | Max CI | 7 mo* | Pressed |
| | | | Max LI | | Pressed |
| Posterior tooth-supported crowns | Layered | Root fracture | Max 1PM | 30 mo | Pressed |
| | Monolithic | Chipping | Max 2PM | 33 mo | Milled |
| | | Core fracture | Mdb 2M | 2 y | Pressed |
| | | | Mdb 1M | 3 y | Pressed |
| Onlays | Layered | Chipping | Mdb 2PM | 190 mo | Pressed |

CA = canine; CI = central incisor; LI = lateral incisor; Max = maxilla; Mdb = mandible; 1M = first molar; 2M = second molar; 1PM = first premolar; 2PM = second premolar.
*Both events occurred in the same patient.

reported an estimated survival probability of 93.5% after 10 years[24]; furthermore, a systematic review showed that glassy laminate restorations could achieve very satisfactory survival rates after 5 years of service, with very low percentages of complications.[25]

Regarding the present study, the authors shifted the principles of adhesion to enamel to improve the longevity of restorations from veneers to crowns, preserving as much enamel as possible during preparation and fabricating very thin restorations.

All mechanical complications occurred in prostheses with an occlusal thickness < 1.5 mm that were cemented onto teeth, in which most of the occlusal surfaces were dentin, cementum, and/or composites. Such an occurrence could be related to the different elastic moduli between enamel and dentin, as the quality of adhesion onto these substrates is not similar.[26] For these reasons, restorations cemented on teeth that maintain a certain amount of enamel but also show wide areas of exposed dentin cannot receive a strong and rigid support from the substrate, possibly compromising the outcomes.

Contrarily, no mechanical drawbacks were noticed in restorations luted onto at least 80% of enamel, independent of occlusal thickness. Regarding technical complications, 63% of mechanical drawbacks were reported on prostheses that had ceramic materials as opponents, with 33% occurring in patients showing parafunctions. The remaining 37% of mechanical problems were observed in subjects that had natural teeth as opponents and that did not show any evident sign of parafunctions. Considering that 30.3% of the included patients showed parafunctions, $LS_2$ may be considered a viable option for the treatment of dysfunctional subjects, particularly with monolithic restorations avoiding chipping. In fact, the long-term clinical observation of patients presenting bruxism usually showed wear in functional areas but no chipping or fractures[27] (Figs 9 and 10).

According to the nomenclature used in general fractography, the present study considered every kind of cohesive fracture of restorative materials, even of core structures, as chipping. Although monolithic restorations were not bilayered, during the observational follow-up period, point-like contacts causing microcohesive abrasions and/or fractures of the cores were observed and classified as chippings.

According to the modified CDA rating, all of the restorations were assessed as satisfactory for marginal integrity, color, and surface, with the only exception of monolithic onlays and crowns, which

▶ **Fig 9** Cusp wear of a mandibular canine after 13 years of clinical service. This bruxer patient received a lithium disilicate full-mouth rehabilitation on natural abutments in the anterior areas and on implants in the posterior segments.

▶ **Fig 10** Wear on the buccal surfaces of mandibular anterior restorations after 16 years. This patient was treated with lithium disilicate laminate veneers on mandibular anterior teeth.

did not show optimal color blending in 9.1% of cases. Case selection is paramount to obtaining a natural tooth-like appearance of monolithic restorations, as several clinical variables could influence the esthetic outcome, such as the color of substrates, ceramic core thickness, proper choice of $LS_2$ ingots for translucency, and color and value of adjacent teeth. It is worth remembering that the $LS_2$ ceramics used herein represented the first generation of $LS_2$; nowadays, excellent optical, mechanical, and manufacturing properties of latest-generation $LS_2$ ceramics were reported to show optimal biomechanical properties and camouflage potential.

Regarding implant-supported prostheses, the integration of $LS_2$ restorations with titanium and zirconia reported excellent outcomes for function, esthetics, and loss of retention. Only one monolithic restoration cemented onto a zirconia framework experienced chipping 6 days after cementation. The crowns fractured in a subject treated with an implant-supported full-arch restoration, and this premature failure was likely due to uneven occlusal balancing; the chipped fragment was rebonded, the occlusal contacts were adjusted and polished, and the restoration was still in service at the last recall.

The manufacturing technologies used to mill and/or press $LS_2$ show unique characteristics to be employed in different clinical situations. Particularly, the potential to choose between ingots and blocks with different translucencies and opacities allows the best camouflaging core to be selected, but in cases with severe substrate discoloration, this makes it very challenging to achieve satisfactory esthetic outcomes.[8–11] Furthermore, the etchability of $LS_2$ improves the reliability of adhesion and makes it easier to intraorally manage possible complications.[2,13] In case of chipping, the possibility to repair the damaged area using validated adhesive protocols facilitates daily clinical practice with easy handling procedures and favorable prognoses.[28,29]

Although the statical analyses showed significant differences between pressed and milled veneers and crowns, it is worth noting that the sample size for such groups was very heterogeneous, and this may have influenced the statistical significance.

Regarding the limitations of this study, it was a retrospective and multipractice study; consequently, although the same rigorous approach was strictly followed, different experienced clinical operators and skilled dental technicians as well as several clinical variables could have confounded the clinical evidence and statistical results. Considering these limitations, further in vivo clinical trials would be advisable to confirm the reported data.

## Conclusions

In accordance with the results of the present retrospective investigation, the use of $LS_2$ restorations in fixed prosthodontics on teeth and implants proved to be a reliable clinical approach in the long-term, up to 17 years of service.

Both layered and monolithic restorations showed excellent biomimetic results, although different clinical indications could be given according to the different needs of each clinical case and careful selection of patients. In posterior areas, monolithic $LS_2$ restorations could be considered a viable alternative to conventional glass ceramics.

In teeth supporting posterior restorations, the presence of residual enamel on the occlusal surface represents a crucial factor for reliability; this aspect could influence the occlusal thickness of restorations, to the extent that an occlusal thickness of at least 1.5 mm is recommended in cases of substrates with wide areas of dentin and/or composites.

The selection of $LS_2$ ceramics represents a valid option in different clinical scenarios, extolling undeniable biologic, mechanical, and esthetic advantages.

## Acknowledgments

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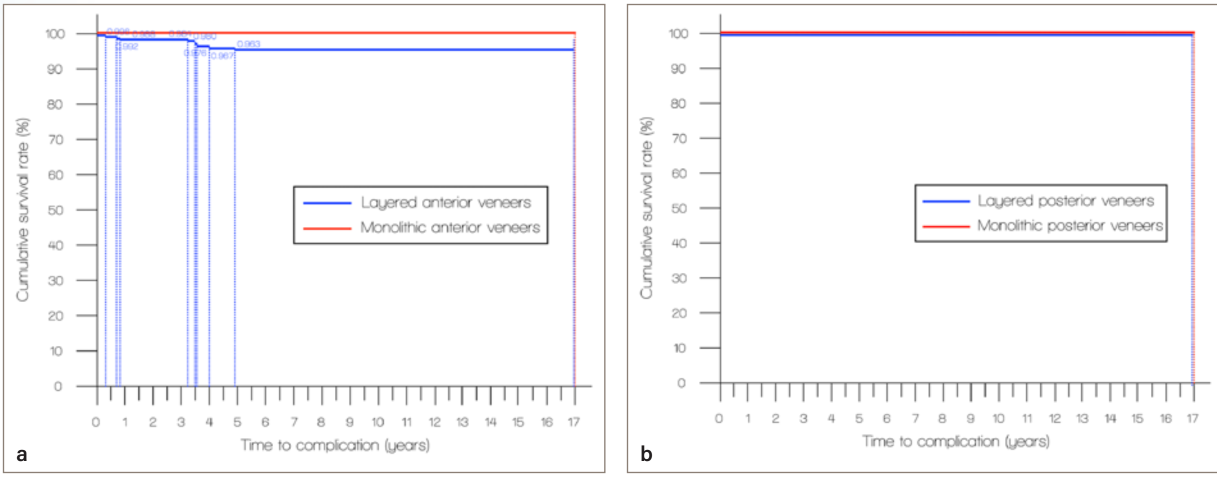
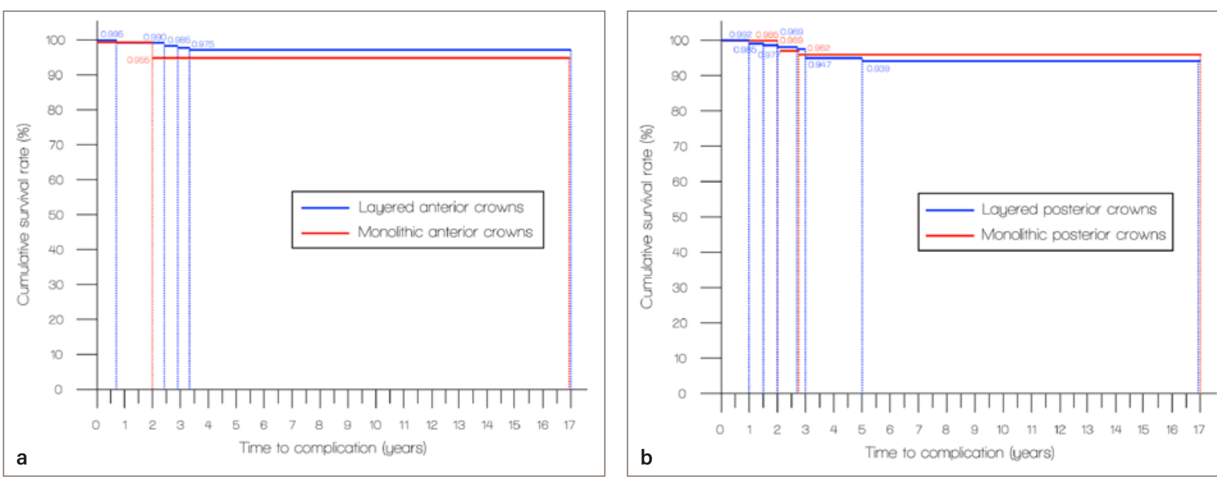
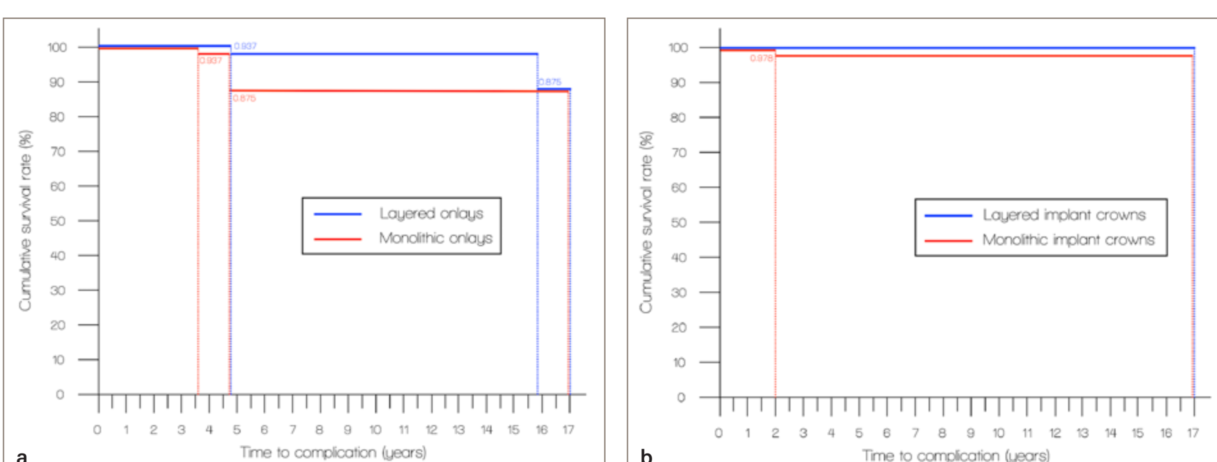
# Appendices



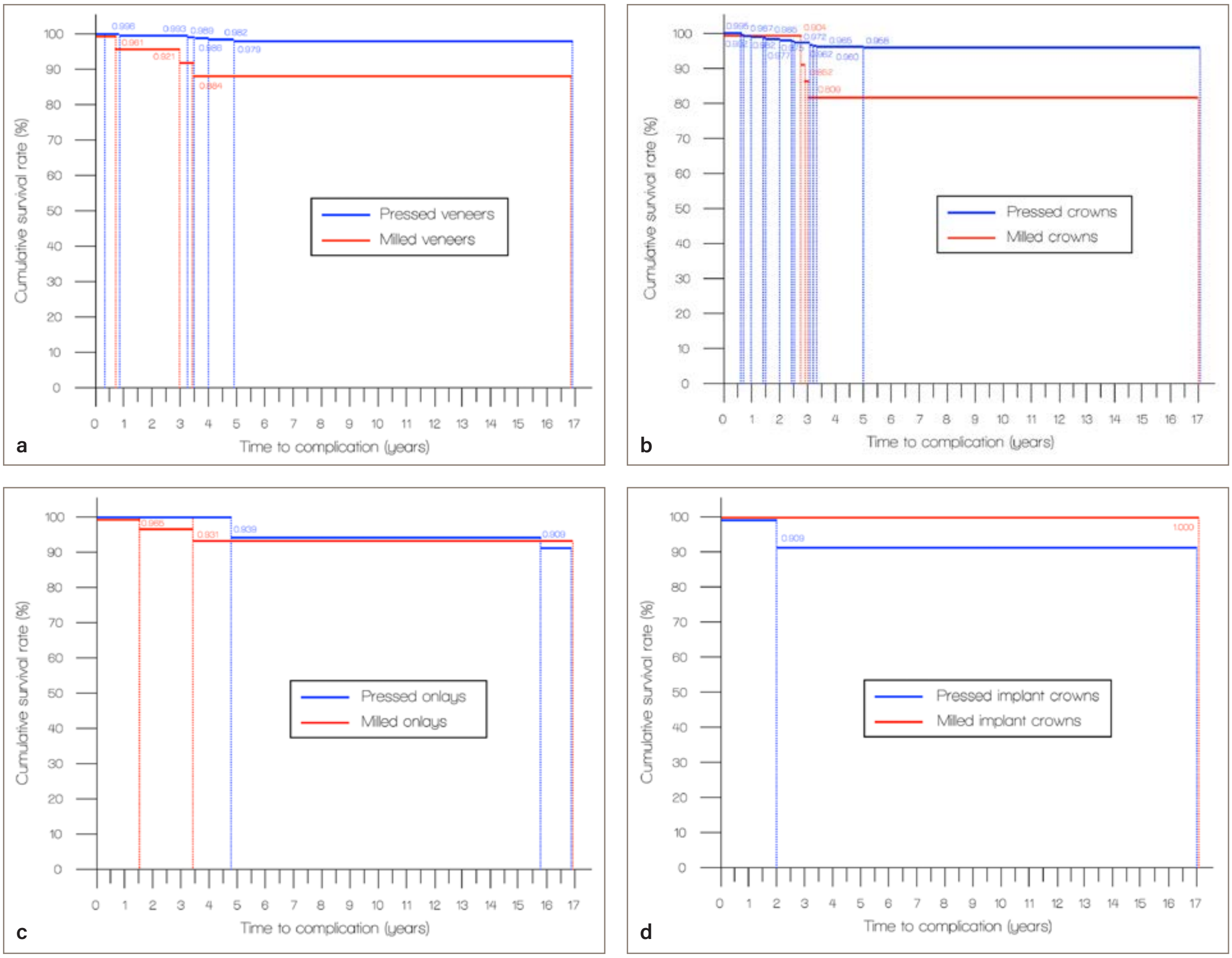

▲ **Appendix Fig 1** Kaplan-Meier curve of complication onset in relation to time for lithium disilicate layered vs monolithic *(a)* anterior and *(b)* posterior veneers.




▲ **Appendix Fig 2** Kaplan-Meier curves of complication onset in relation to time for lithium disilicate layered vs monolithic tooth-supported *(a)* anterior and *(b)* posterior crowns.




▲ **Appendix Fig 3** Kaplan-Meier curves of complication onset in relation to time for lithium disilicate layered vs monolithic *(a)* onlays and *(b)* implant-supported crowns.




▲ **Appendix Fig 4** Kaplan-Meier curves of complication onset in relation to time for lithium disilicate pressed vs milled *(a)* veneers, *(b)* crowns, *(c)* onlays, and *(d)* implant crowns.