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Abstract

Purpose: This retrospective study aimed to evaluate the survival and success rates of ceramic partial laminate veneers. Scanning electron microscopy was used to evaluate fractures and marginal defects.

Methods: In total, 31 patients received 79 partial laminate veneers on the maxillary anterior teeth. After adhesive luting, restorations were evaluated by calibrated clinicians for up to eight years using modified United States Public Health Service (USPHS) criteria. In addition, epoxy resin replicas were fabricated from silicone impressions and analyzed using scanning electron microscopy. Survival analyses were performed using the Kaplan-Meier and log-rank tests ($\alpha = 0.05$). Success was analyzed in percentages by comparing the baseline and last follow-up.

Results: The cumulative survival rates were 100% after 1 year; 95.9% (SE 2.8%) after 5 years; and 61.4% (SE 25.3%) after 8 years. No significant differences ($P > 0.05$) were observed between functional and non-functional restorations. Changes in the USPHS criteria evaluation were only observed for adaptation: 12.5% (SE 4.7%), marginal discoloration: 4.2% (SE 3.0%), color match: 4.2% (SE 3.0%), and fractures: 16.7% (SE 5.3%). Scanning electron microscopy evaluations revealed undetected initial cracks and deficiencies in the restorations.

Conclusions: Partial laminate veneers displayed good survival rates during the long-term follow-up. The main problems observed were related to the quality of the margins, color mismatch, and restoration integrity. However, in most cases, restoration replacement was not required.

Keywords: Partial laminate veneers, Sectional veneers, Ceramic fragments, Ceramic partial veneer, Laminate veneers

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1. Introduction

The continuous improvement in adhesive technologies has allowed the development of diverse, minimally invasive treatment alternatives. In the anterior region, several causes can lead to the need for restoration, including decay; structurally compromised teeth due to fractures and trauma; morphological corrections (e.g., diastema and conoid teeth), or misaligned teeth [1,2]. Restorative approaches in the anterior region range from minimal intervention using direct resin composites to more invasive procedures using indirect laminate veneers or full crowns [3-6].

Current trends in dentistry seek the maximum preservation of sound tooth structures [7]. Full crowns depart from these conservative principles, since they require the removal of a considerable amount of healthy tissue, including most of the remnant enamel, from the tooth preparation surface in dentin [8]. Accordingly, 63% to 72% by weight of coronal structure can be lost when preparing an anterior tooth for a crown. This increases the risk of pulp exposure, thus compromising vitality and biomechanical integrity [9].

Ceramic laminate veneers are a minimally invasive treatment that has been extensively used in the anterior region because of its esthetic advantages and long-term success [10-15]. Conventional ceramic veneers require a minimum reduction of 0.3 to 0.5 mm, to achieve sufficient thickness for ceramic restoration [16,17]. However, a larger enamel reduction may be needed depending on esthetic requirements. For instance, a 0.8 to 1.2 mm preparation is needed in darkened teeth to obtain the correct color integration of the ceramic restoration [18,19].

Direct resin composites have also been extensively used for the restoration of esthetically compromised anterior teeth, mainly because of their minimal tissue removal requirements. Accordingly, tooth preparation is usually limited to surface smoothing to avoid sharp angles, which is immediately followed by phosphoric acid

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Fig. 1. Representative image of ceramic partial laminate veneers. A: Ceramic partial laminate veneers on maxillary central incisors. The blue line indicates the limit of tooth preparation. Note that the ceramic restorations do not cover the entire labial surface. B: Finished case. Appropriate optical integration can be achieved with ceramic partial laminate veneers, preserving sound tooth structure.

Table 1. Adhesive luting protocol for partial laminate veneers

Conditioning sequence of the tooth	
1	Cleaning of the tooth surface using pumice
2	Enamel etching using H_3PO_4 (38%, Ultradent) (30 s)
3	Rinsing (30 s)
4	Application of the adhesive (Syntac, Ivoclar Vivadent, Schaan, Liechtenstein), no photopolymerization
Conditioning sequence of partial laminate veneers	
1	After try-in using glycerin pastes, cleaning with water
2	Etching of the ceramic using 5% hydrofluoric acid (60 s)
3	Rinsing with abundant water
4	Ultrasonic cleaning in distilled water (5 min)
5	Air drying
6	Silane (Monobond Plus, Ivoclar Vivadent) application (1 min)
7	Adhesive application Syntac (Ivoclar Vivadent)
8	Composite resin cement (Variolink Veneer, Ivoclar Vivadent) application on the intaglio of the restoration
9	Placement of the restoration
10	Excess removal using a microbrush
11	Photopolymerization (1-3 s)
12	Removing excess cement using a scalpel and scaler
13	Glycerine application
14	Photopolymerization (40 s from each side)
15	Rinsing with water
16	Polishing of the margins if needed (Sof-Lex, 3M ESPE, Seefeld, Germany)

conditioning [20,21]. Thus, direct resin composites offer several advantages to both patients and clinicians, including a reduction in treatment costs and clinical working times (i.e., fewer clinical appointments), as well as reversibility and reparability of the treatment. For these reasons, most clinicians consider resin composites as the material of choice when maximum preservation of the tooth structure is required [22-24].

In addition to the aforementioned restorative alternatives, the use of small partial glassy restorations-partial laminate veneers (PLVs), sectional veneers, or ceramic fragments-has become increasingly popular over the last few years [25-28]. PLVs are thin pieces of glass-matrix ceramic fragments without a defined shape that are used to restore small defects in the anterior teeth (**Fig. 1**). As tooth preparation is not required for this type of restoration, as for conventional laminate veneers, and minimal to no prep is accepted, the maximum amount of enamel surface structure is conserved. Thus, retention relies completely on adhesion, which is primarily achieved by bonding to the conditioned glassy surface [29-31]. Despite their growing popularity, available data in the literature on PLVs are limited to a few *in vitro* studies [32,33] and case reports [2,25-28], without any clinical information available at present. In this context, the objective of this multicenter retrospective clinical trial was to study the long-term clinical performance of ceramic PLVs with up to 8 years of clinical service.

2. Materials and Methods

This retrospective study investigated the survival and success rates of ceramic partial laminate veneers by clinically evaluating restored anterior teeth with ceramic partial laminate veneers (Creation CC, Creation Willi Geller International GmbH) of patients referred to four specialized restorative dentists in three different clinics. They were the clinicians who performed the restorative procedures (RK, AB, GK, and MG). The STROBE (The Strengthening the Reporting of Observational Studies in Epidemiology) guidelines were followed [34].

All patients provided informed consent and the study was approved by the Medical Ethical Review Board of University Medical Center Groningen as a non-intervention study. The inclusion criteria were as follows: age of at least 18 years; ability to read and sign the informed consent document; physical and psychological ability to tolerate checkups; no active periodontal or pulpal diseases; and teeth (upper incisors/canines) restored with PLVs due to the need for minimal morphology corrections (e.g., diastema, conoid teeth, misalignment) or minor fractures. Patients with non-vital teeth were excluded from the study. PLV treatments were conducted using specific materials and standardized techniques (**Table 1**).

The last clinical evaluations (follow up) of patients were conducted between 1/2018 and 10/2018. At this checkup, standardized photographs were taken and the restorations were clinically evaluated by an independent and calibrated clinician. The need for replacement and partial fractures (chippings) were defined as failures.

Table 2. List of modified United States Public Health Service (USPHS) criteria used for the clinical evaluation of the partial laminate veneers

Category	Score	Criteria
Adaptation	0	Smooth margin
	1	All margins closed or possess minor voids or defects (enamel exposed)
	2	Obvious crevice at margin, dentin or base exposed
	3	Debonding from one end
	4	Debonding from both ends
Color match	0	Very good color match
	1	Good color match
	2	Slight mismatch in color or shade
	3	Obvious mismatch, outside the normal range
	4	Gross mismatch
Marginal discoloration	0	No discoloration evident
	1	Slight staining, can be polished away
	2	Obvious staining, cannot be polished away
	3	Gross staining
Surface roughness	0	Smooth surface
	1	Slightly rough or pitted
	2	Rough, cannot be refinished
	3	Surface deeply pitted, irregular grooves
Fracture of restoration	0	No fracture
	1	Minor crack lines over restoration
	2	Minor chipping of restoration (1/4 of restoration)
	3	Moderate chipping of restoration (1/2 of restoration)
	4	Severe chipping (3/4 restoration)
	5	Debonding of restoration
Fracture of tooth	0	No fracture of tooth
	1	Minor crack lines in tooth
	2	Minor chipping of tooth (1/4 of crown)
	3	Moderate chipping of tooth (1/2 of crown)
	4	Crown fracture near cementoenamel junction
	5	Crown-root fracture (extraction)
Wear of restoration	0	No wear
	1	Wear
Wear of antagonist	0	No wear
	1	Wear of antagonist
Caries	0	No evidence of caries continuous with the margin of the restoration
	1	Caries evident continuous with the margin of the restoration
Postoperative sensitivity	0	No symptoms
	1	Slight sensitivity
	2	Moderate sensitivity
	3	Severe pain
Gingival health	0	No sign of inflammation
	1	Light inflammation of the gingiva (small bleeding)
	2	Moderate to severe inflammation of the gingiva
Approximal contact	0	Contact
	1	No contact

Clinical success was evaluated using a modified version of the United States Public Health Service (USPHS) criteria (**Table 2**) [35,36]. Each parameter was assessed using visual and tactile observations (probe and mirror). Restoration was evaluated as being in or out of function. Restored teeth considered functional were, for example, restorations with incisal overlap in a functional area. Restorations that are not functional could be proximal or vestibular restorations. To evaluate the functional aspect, the restorations were evaluated using articulation paper (Arti-check 40 μm, Bausch, Nashua, USA).

High-precision polyvinyl siloxane (PVS) impressions were obtained after clinical evaluation. The teeth were cleaned for the impressions using cotton pellets and 0.5% sodium hypochloride, followed by a copious water rinse. First impressions were made and discarded. Thereafter, extra light body material (Aquasil Ultra + XLV, Dentsply, St Paul, USA) was used with heavy body material in a tray

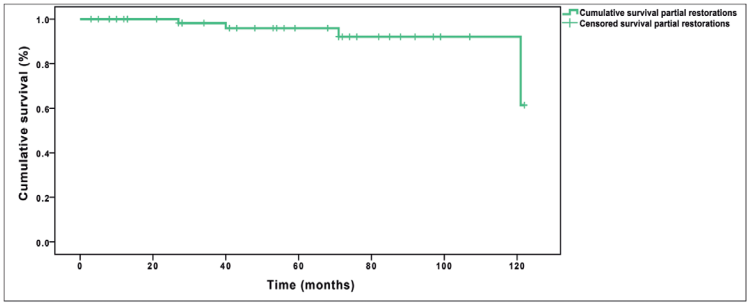

Figure 2a

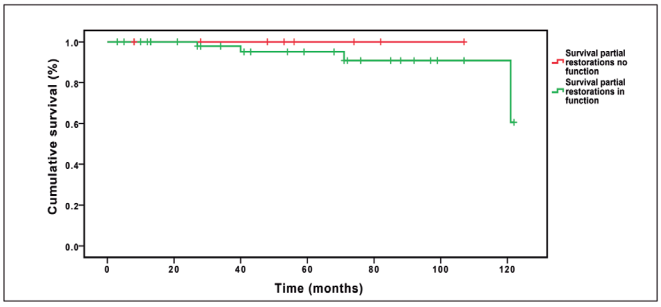

Figure 2b

Fig. 2a. Cumulative survival of partial laminate veneers (CI=95%; n=79, events n=4)
Fig. 2b. Cumulative survival of partial laminate veneers with and without the function (CI=95%; function n=64, no function n=14, and events n=4)

(Aquasil Ultra + Heavy body, Dentsply). The impressions were poured with a cold-mounting epoxy resin (EpoxyCure2, Buehler, IL, USA). After final curing, the replicas were sputter-coated with a 3-nm-thick layer of gold (80%) and palladium (20%) (90 s, 45 mA; Balzers SCD 030, Balzers, Liechtenstein) and analyzed using a dual beam FEG-SEM/FIB microscope (LyraTESCAN, Brno, Czech Republic) according to the replica technique [37].

The results were inserted into REDCap (REDCap, version 7.3.2-2018, Vanderbilt University, Nashville, Tennessee) and converted to a specially designed document. Then, they were translated into SPSS (IBM SPSS Statistics 24.0, Armock, NY, USA) for data analysis. Kaplan-Meier cumulative analysis was used to evaluate survival. Log-rank (Mantel-Cox-Savage) analysis was used to compare the two groups of PLVs with and without function. Statistical significance was set at $P < 0.05$. Success was measured from qualitative data comparing the baseline and last follow-up and was analyzed in percentages.

3. Results

A total of 31 patients who had received 79 ceramic PLVs were included. Four patients reported wearing night guards to protect their teeth from nighttime bruxing habits. Twenty-four patients (52 restorations) were evaluated clinically. Impressions and replicas were obtained for all participants. Seven patients could not attend the checkups. The mean observation time was 49 months, with a minimum of 3 months and a maximum of 122 months.

The cumulative survival was 100% after 1 year; 95.9% (SE 2.8%) after 5 years; and 61.4% (SE 25.3%) after 8 years (**Fig. 2a**). Four of the restorations failed. The reasons for failure were chipping after 27, 71, and 121 months. Only one of the restorations was replaced because of color mismatch (**Table 3**). Of the 79 evaluated restorations, 64 were functional (in contact with an antagonistic tooth). All of them survived for 5 years, reaching 60.6% (SE 25%) after 8 years (**Fig. 2b**). No significant differences were found between functional and non-functional restorations ($P = 0.470$).

Twenty-four patients (52 restorations) were evaluated using modified USPHS criteria. **Table 4** presents the results. The four failed restorations were excluded from the analysis. The number of restorations available for evaluation and the changes in the percentages were noted. Parameters including the surface roughness of the restoration, fracture of the tooth, caries, postoperative sensitivity, health of the gingiva, approximal contacts, and wear of the restoration and antagonist did not change between baseline and the last follow-up. In analyzing the restoration margins, 6 out of 48 restorations (12.5%; SE 4.7%) showed adaptation defects, and 2 restorations (4.2%; SE 3.0%) had discolored margins. Two restorations (4.2%; SE, 3.0%) showed a discrepancy in color match. The most common problem was the occurrence of fractures (8 out of 48, i.e., 16.7%; SE 5.3%), with four of them having only small chippings (less than 1/4th of the restoration) (**Table 4**). These were scored in terms of the success rate as restorations that did not need to be replaced.

Table 3. Failures experienced, what was the failure and reason of failure

Month	Failure	Reason
27 months	Chipping	Unknown
40 months	Change	Wrong color
71 months	Chipping incisal aspect	Unknown
121 months	Chipping incisal aspect	Trauma with glass
	Total	**4**

All restorations in the clinical evaluation were analyzed using the replica technique and stereomicroscopy. Representative scanning electron microscopy (SEM) images of fractures, cracks, and failures are shown in the FEG-SEM images in **Figure 3**.

4. Discussion

This multicenter retrospective clinical trial investigated the survival and success rates of PLVs performed in three different dental clinics with four operators. To date, only a few *in vitro* studies and clinical reports on this noninvasive approach have been published [2,25-28,32,33]. To the best of our knowledge, this is the first clinical study conducted on ceramic PLVs with up to 8 years of follow-up.

In the present study, no differences were found between PLVs. However, most of these failures are associated with trauma. Among the observed fractures, half corresponded to minor cracks and were not considered failures. As previously shown in an *in vitro* study of this type of restoration, cracks do not necessarily have a negative effect on fracture strength [32]. They may occur during tooth preparation, the adhesive luting procedure, or during function, where environmental factors, such as thermal changes and fatigue, may play an important role [38]. Although PLVs often do not require specific tooth preparation, further reasons for crack initiation may be related to the presence of sharp angles, which are critical during the seat-

Table 4. Results of success using modified USPHS-criteria

Category	Score	Number of restorations	Percentage	Last follow-up	Percentage
Adaptation	0	23	44.2%	13	27.1%
	1	29	55.8%	35	72.9%
	2	-		-	
	3	-		-	
	4	-		-	
Color match	0	51	98.0%	45	93.7%
	1	1	2.0%	3	6.3%
	2	-		-	
	3	-		-	
	4	-		-	
Marginal discoloration	0	52	100%	46	95.8%
	1	-		2	4.2%
	2	-		-	
	3	-		-	
Surface roughness	0	52	100%	48	100%
	1	-		-	
	2	-		-	
	3	-		-	
Fracture of the restoration	0	52	100%	40	75.0%
	1	-		4	12.5%
	2	-		4	12.5%
	3	-		-	
	4	-		-	
	5	-		-	
Fracture of the tooth	0	52	100%	48	100%
	1	-		-	
	2	-		-	
	3	-		-	
	4	-		-	
	5	-		-	
Wear of the restoration	0	52	100%	48	100%
	1	-		-	
Wear of the antagonist	0	52	100%	48	100%
	1	-		-	
Caries	0	52	100%	48	100%
	1	-		-	
Postoperative Sensitivity	0	52	100%	48	100%
	1	-		-	
	2	-		-	
	3	-		-	
Gingival health	0	52	100%	48	100%
	1	-		-	
	2	-		-	
Approximal contact points	0	52	100%	48	100%
	1	-		-	

ing of extremely thin restorations (~0.1 mm thick). Accordingly, crack growth may be triggered during the luting procedure because of the polymerization shrinkage stress of the resin cement or seating pressure exerted by the clinician [39]. The infiltration of cracks in ceramic restorations has been recently reported [35]. This technique involves the infiltration of a highly filled preheated adhesive and could be an alternative to replacement, thus extending the survival of the bonded ceramic restoration.

Cracks were initiated by surface or bulk defects in the material. Glassy ceramics may rapidly lead to catastrophic failure, a direct consequence of their high brittleness and low toughness. However, the risk of failure diminishes when glassy ceramics are placed over a more homogeneous and regular surface [40]. The mechanical behavior of PLVs was recently studied *in vitro* by Gresnigt *et al*. [32]. The results of this study showed that PLVs display similar fracture strength to conventional ceramic laminate veneers and direct resin composites. In light of the results of the present study, PLVs appear to be able

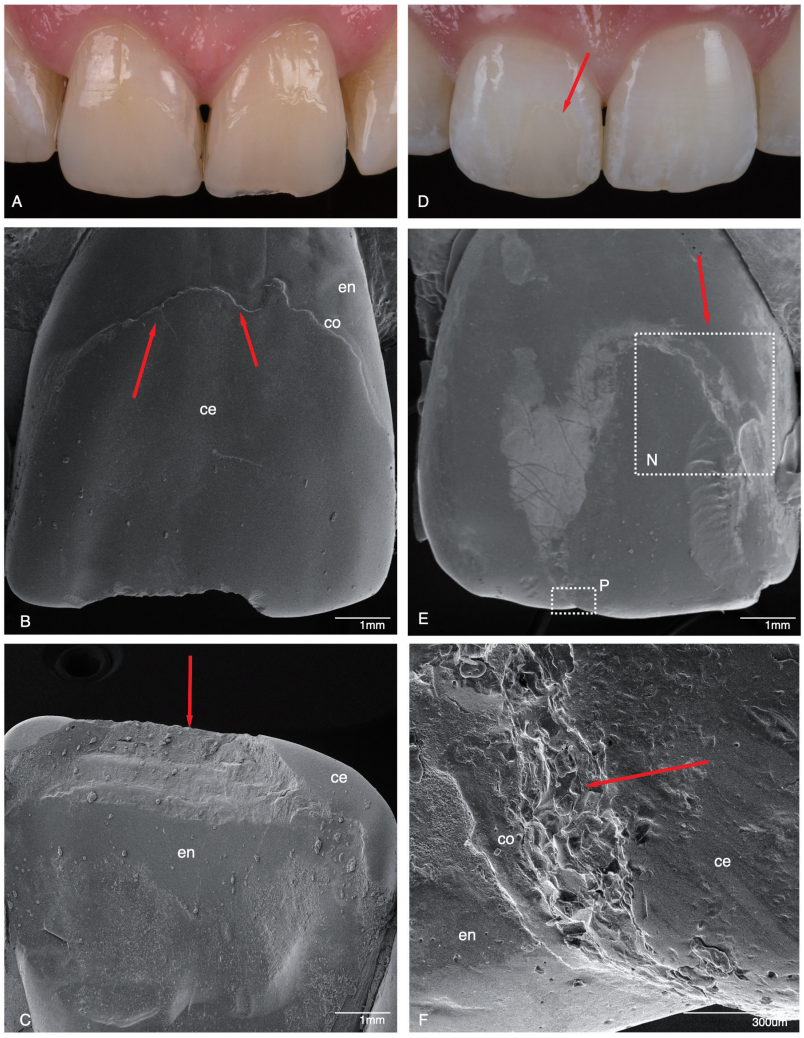

Fig. 3. en: enamel; ce: ceramic; co: composite. (Clinical Case 1: 3A to 3C). 3A – Clinical view of ceramic PLV 10 years after adhesive luting. A fracture is evident at the incisal edge of 21. 3B – 53X SEM image shows fracture of the ceramic in the incisal edge. Luting composite (co) is evident between the ceramic (ce) and tooth enamel (en). Red arrows indicate the probable area of marginal chipping. 3C – 49X SEM image showing the occlusal view of the fractured incisal edge. (Clinical Case 2: 3D to 3F). 3D – Frontal clinical view of the failed PLV restoration of tooth 11, during the follow up after 10 years. 3E – SEM image showing an overview from the buccal aspect; dashed line indicates fracture/chipping of the ceramic. 3F – 492X SEM image showing degraded bonding interface at the incisal edge of element 11. In this situation, the rough aspect, i.e., the exposed inorganic fillers, is mainly due to the degradation of the polymeric surface of the luting composite (co).

to withstand forces occurring in the maxillary anterior region, even when receiving occlusal function.

Despite the high occurrence of voids and finishing defects (present in 72.9% of the restorations), only 4.2% of the restorations exhibited marginal discoloration or slight staining. PLVs do not require a finishing line, which has an area of adhesive continuity but an interphase at their margins [41]. Therefore, unlike conventional ceramic laminate veneers and full crowns, tooth preparation may not always be necessary, and a small overcontour of the PLV is commonly performed by the dental technician to avoid sub-contours and to facilitate the positioning of the restoration over the tooth. This interphase is then reduced by the clinician after restoration seating by polishing the ceramic surface until the overcontour is removed [26]. In this context, the observed defects at the PLV margins do not necessarily imply replacement of the restorations, as repolishing may successfully extend their clinical service. Moreover, subtle modification of the enamel surface using abrasive discs or ultrafine diamond points could result in less interfacial mismatch, creating slightly more space for PLV seating and guiding the dental technician regarding the extension limits of the restoration. Further studies on this topic are required to better understand this.

In addition to staining, water sorption can lead to hydrolytic degradation of the adhesive interphase and favor the wear of the resin cement line [42]. The material used for adhesive luting (Variolink Veneer) was composed of a polymeric network based on urethane dimethacrylate (UDMA). Different types of copolymers, such as UDMA, TEGDMA, and Bis-GMA, are present in many restorative resin composites and luting resin cements and are susceptible to hydrolytic degradation [43]. Further dislocation of the inorganic fillers, as a consequence of organic matrix degradation, can create voids or defects in the material (**Fig. 3F**). This may lead to the accumulation of biofilms and food particles, thereby increasing marginal staining.

Thus, regular surface maintenance, including refining and repolishing protocols of the adhesive interphase, is critical and strongly recommended.

Color changes may be important for the aesthetic appearance of the restoration. In an *in vitro* study by Elter *et al.* [33], the color stability of PLVs exposed to beverages, such as coffee, was tested. The leucite-reinforced feldespathic (IPS In Line, Ivoclar Vivadent) PLV bonded with a light-cure resin cement (Variolink Veneer) obtained better color stability and integration than lithium disilicate and resin nano-ceramic restorations. This highlights the need for the correct material selection for this type of restoration. In the same vein, special instructions need to be given to patients who have undergone tooth bleaching prior to restorative treatment with PLVs, as well as to smokers and patients who have a diet with high-staining potential [44-46].

5. Conclusions

Partial laminate veneers displayed good survival rates during the long-term follow-up. The main problems observed were related to the quality of the margins, color mismatch, and restoration integrity, highlighting the need for periodic refurbishment.

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Conflicts of interest

The authors have no commercial interest in any of the materials used in this study. The authors declare that they have no conflict of interest.

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Informed Consent

All patients provided informed consent for this study.

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