Irena Sailer | Vincent Fehmer | Bjarni Pjetursson

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FIXED RESTORATIONS

A CLINICAL GUIDE TO THE SELECTION OF MATERIALS AND FABRICATION TECHNOLOGY

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Dedication

"To our families and mentors who inspired us"

Irena, Vincent, and Bjarni

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CHAPTER 1
Current restorative materials

Jens Fischer

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1.1.1 Introduction

In this chapter:

- Requirements for restorative materials
- Overview of current materials for fixed restorations
- Conclusions

In the past, material selection in fixed prosthodontics was mainly based on metal-ceramics and on a few all-ceramic alternatives. Metal-ceramic restorations were selected in clinical situations with need for high stability (eg, in the posterior region or in the case of multiple-unit fixed dental prostheses), whereas all-ceramic restorations were recommended in single tooth replacement with high esthetic demands, especially in the anterior region. These materials were traditionally processed by manual fabrication technologies such as casting, pressing, or layering[1,2]. Restorative dentistry with all-ceramic restorations has suffered from a prolonged learning curve. Several of the early systems disappeared shortly after being introduced due to an unacceptable number of mechanical failures[3].

Nowadays, clinicians and technicians can choose from a wide range of reliable materials. Digital technologies such as intraoral optical scans and computer-aided design/computer-aided manufacturing (CAD/CAM) procedures have opened up new treatment pathways in fixed prosthodontics. New digital fabrication workflows were defined and in parallel advanced materials were developed and adjusted to the specific requirements of numerically controlled processing such as high-strength ceramics and composites. In these digital workflows, the restorations are fabricated by means of computer-aided milling from prefabricated blanks, increasingly replacing conventional manual processing.

The different materials available today exhibit differences in properties, influencing the esthetics and the long-term performance of the restorations. As multiple alternatives exist for each clinical situation, it is more difficult to select the most appropriate material for the respective clinical situation today than in the past[4–6]. As a consequence of the transformation in present technology, selection of the restorative material requires understanding of the interaction between material properties and clinical performance[7].

After an introduction to the requirements for restorative materials and the behavior of the different material classes used in dentistry, this chapter will provide an overview of the current material options for fixed restorations and their clinically relevant properties, indications, and limitations.

1.1.2 Requirements for restorative materials

In the oral cavity, restorative materials have to meet three requirements: *biocompatibility, longevity,* and *esthetics*.

Biocompatibility

The term biocompatibility implies that the material shall do no harm to the living tissues, achieved through chemical and biological inertness[8]. As every material potentially dilutes or degrades depending on the environment, the extent of decomposition, and the quality and amount of released substances determine the degree of biological complications. A possible host response might be localized or systemic toxicity, hypersensitivity, or genotoxicity[9]. The restriction to biocompatible components strongly limits the room for the development of new materials.

Due to the strict regulations for medical devices, manufacturers have to prove biocompatibility of their materials. International standards help the choosing of the appropriate tests and in interpreting the results. Tests must be done with every novel material prior to approval. Biological tests are employed in a sequence, ending up with animal tests[9]. Furthermore, manufacturers of medical devices are forced by law to perform a systematic post market surveillance of the materials and devices. Measures have to be taken to minimize risk and unexpected side effects must be notified to the authorities. Fortunately, it can be concluded that biological and immunological adverse reactions attributed to dental materials are rare and the reported adverse effects are acceptable[9].

On the other hand it is unrealistic to assume that absolute material inertness is attainable and biological behavior is definitely predictable by means of biological tests[10]. Hence, the biocompatibility of dental materials must always be weighed against their benefit[11]. Controlled clinical trials are currently still the best way to assess the clinical response to materials. But even these tests have significant limitations. Therefore, practice-based research networks and practitioner databases are increasingly considered as a valuable alternative[10].

Longevity

The long-term success of a restoration mainly depends on its mechanical performance. From the technical side the success of a restoration can be controlled by the durability of the *material*, the nature of the *design*, the quality of the *processing*, and the effectiveness of the *finishing*.

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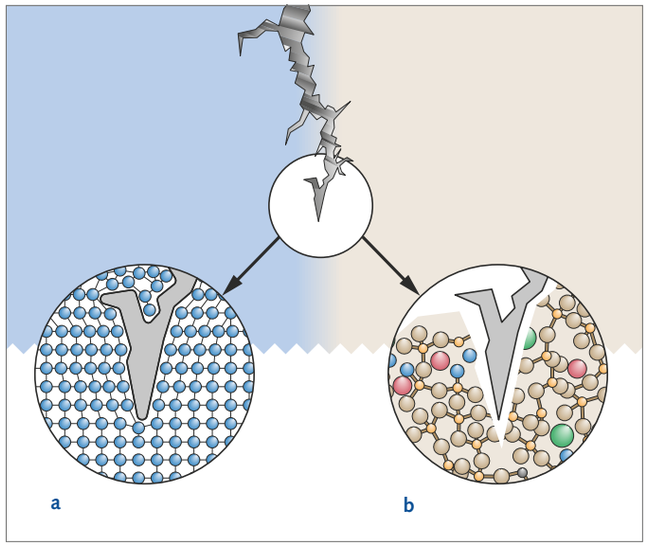

Figs 1-1-1 Schematic representation of crack propagation in materials. **(a)** Plastic material (eg, metals). **(b)** Brittle material (eg, ceramics).

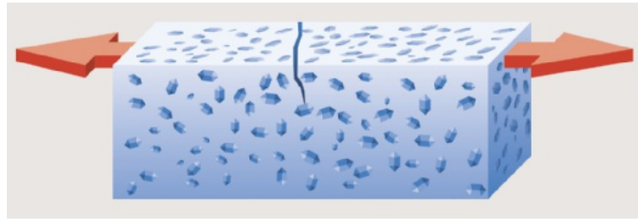

Fig 1-1-2 Schematic representation of crack propagation in particle-reinforced materials under tensile stress (red arrows). When the crack tip strikes a particle, crack propagation is impeded, or at least decelerated.

Material

The mechanical behavior of dental materials is mainly characterized by elasticity, flexural strength, fracture toughness, and hardness. These properties are basically given by the type and strength of the bondings between the atoms.

Elasticity is the ability of the material to resume its initial shape after loading, measured in GPa (= 10^3 N/mm^2). Stressing a material beyond its limit of elasticity leads to plastic deformation, a permanent distortion. Brittle materials such as ceramics only show minimal or no plasticity, which means they fracture very soon after reaching the limit of elasticity. The stress where fracture occurs is the flexural strength, measured in MPa (= N/mm^2). The resistance against crack growth is called fracture toughness, measured in MPa$\sqrt{m}$.

Elasticity, flexural strength, and fracture toughness are bulk properties. Hardness in contrast is a surface property, which is defined as the resistance to localized deformation induced by mechanical indentation or abrasion. Harder materials therefore show less risk of surface damage. Flexural strength and hardness are correlated to a certain extent.

The main risk for mechanical failure of restorations are flaws at the surface, which might act as a starting point for microcracks. In case of tensile loading, a microcrack opens and stress develops at the tip of the crack. Stress which exceeds the strength of the material leads to crack propagation. Under cyclic loading – such as mastication – crack growth happens in a micrometer scale. But over time the crack grows significantly. Finally, catastrophic failure occurs when the residual cross-section is too small to withstand the load.

It is important to understand the fracture mechanisms of the different materials. In metals the crack tip is rounded out by plastic flow and thus the risk of fracture is significantly reduced (Fig 1-1-1). In ceramics plastic flow is not possible due to the covalent bonds. The crack tip remains sharp and crack growth is a significantly higher risk than in metals. That is the reason for the well-known brittle behavior of ceramics. To increase strength and in particular toughness, strengthening mechanisms on the microscopic level to impede crack propagation are employed. In brittle materials this might be achieved by internal compression or by particles, which act as obstacles against crack growth (Fig 1-1-2). The objective of such strengthening mechanisms is to stop crack growth or at least to hamper it, like a hurdler who is not as fast as a sprinter.

The term *durability* includes not only the mechanical characteristics specified above but resistance to wear and aging as well. The degradation of the materials by wear and aging depends on the mechanical properties and also on the susceptibility to the oral environment including humidity, temperature, and loading characteristics. Water for instance may attack the material's bonds especially at phase boundaries or microcracks, thus promoting degradation.

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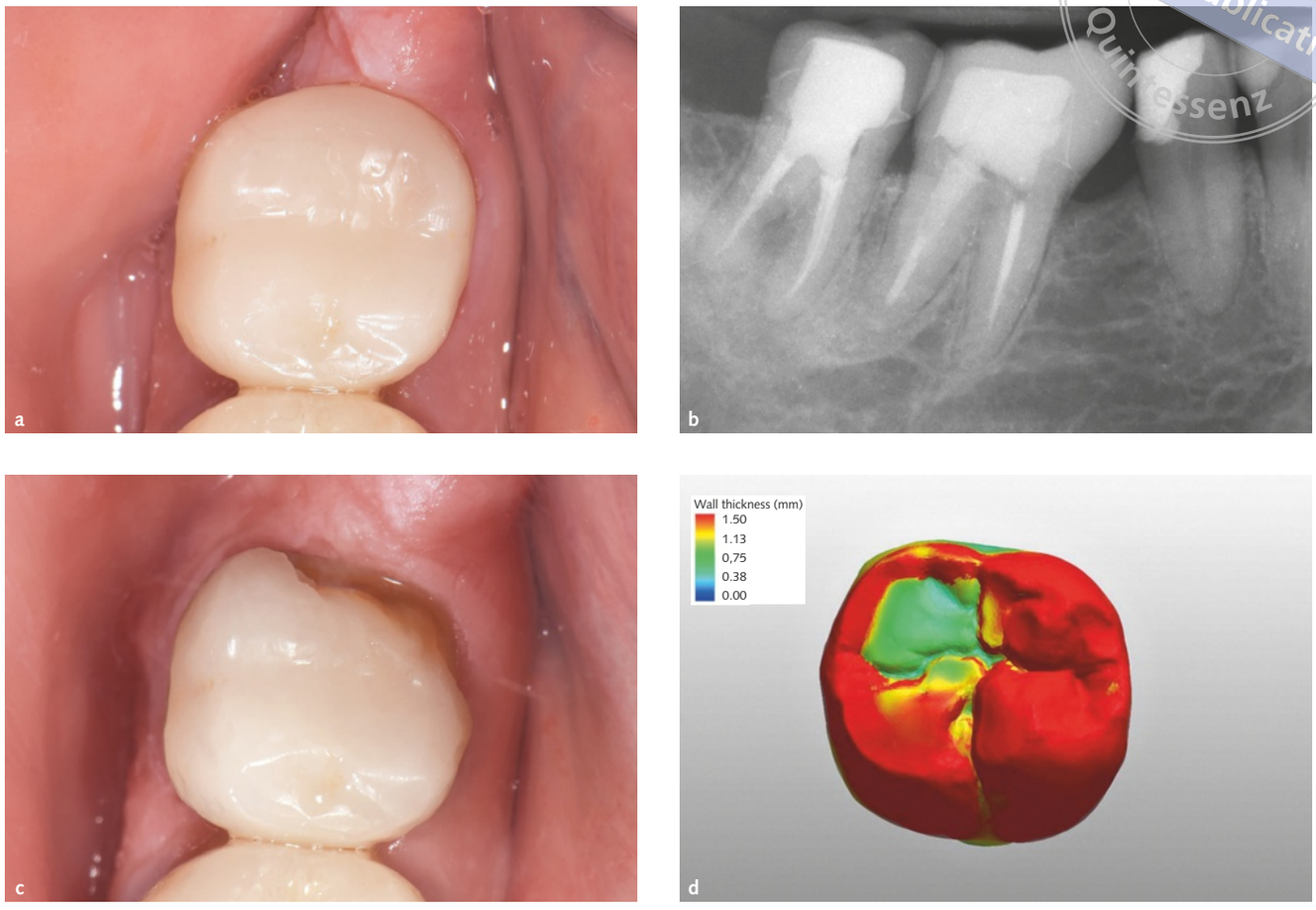

Figs 1-1-3a to 1-1-3d Insufficient thickness of the crown and sharp edges of the preparation caused fracture of the restoration. **(a)** Restoration on tooth 47 after cementation. **(b)** Radiograph after cementation. The insufficient occlusal thickness of the restoration and the sharp edge of the distal preparation are obvious. **(c)** Fracture of the restoration after 1 year in function. **(d)** Analysis of wall thickness on the basis of the CAD design.

Design

Several mistakes can be made when designing a restoration. Insufficient dimensioning in crown walls or connectors of fixed dental prostheses is one reason for failures. Instructions of the manufacturers have to be strictly followed. Further, sharp edges increase the risk of failure due to an uncontrolled stress development (Fig 1-1-3). And finally, restorations made by materials, which require a thermal treatment should be designed with an even wall thickness as far as possible to get a homogeneous stress distribution during cooling. That applies especially for veneering ceramics, which must be layered in a uniform thickness and adequately supported by the framework both for metal-ceramic and all-ceramic bilayers.

Processing

A shaping process always requires machining, a thermal treatment such as sintering or pressing or a polymerization process. If not processed properly, defects might be created in the material, thus reducing the strength of the restoration (Fig 1-1-4). The manufacturer's instructions must be meticulously followed.

Finishing

Materials, if machined, sintered, pressed, or polymerized, must be finished with material specific tools and appropriate speed, feed, and pressure of the tools to avoid damage at the surface. For ceramics, as an alternative a glaze firing (a heat treatment without additional application of glaze) or glazing (a heat treatment with additional application of glaze) can be performed (Fig 1-1-5). However, if the restoration is not handled in a way appropriate to the material, it might occur that subsurface damage is not sufficiently eliminated by the finishing procedure and residual flaws potentially act as an origin for microcracks.

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Esthetics

Materials for restoring teeth have to mimic the esthetic appearance of the tooth itself. The tooth is a complex structure of a dentin core, providing the color of the tooth, and a more translucent enamel layer. The replacement of dental hard tissue by a dental material needs to balance *color, translucency, refraction and reflection, opalescence,* and *fluorescence*. Some materials show a *blending quality*, also named the "chameleon effect." These requirements strongly restrict the choice of materials to ceramics and resins. As a compromise metals may be used when covered by tooth-colored veneers.

Color

Coloring of resins and ceramics is obtained by using inorganic pigments, mostly metal oxides (Fig 1-1-6).

Translucency

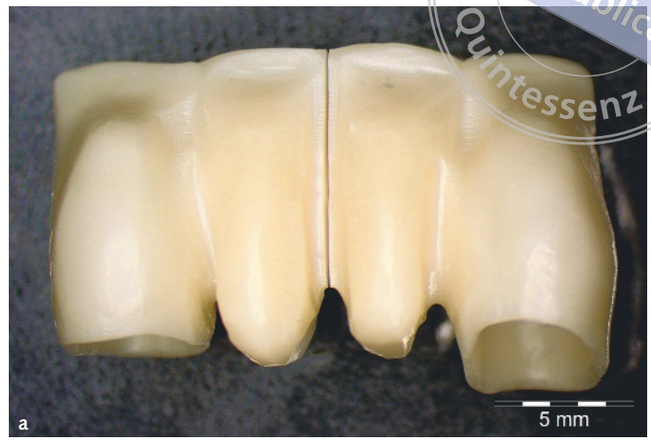
When there is no light absorption and no optical obstacle in the material, light passes through a material like a windowpane without being scattered. This effect is called translucency (Fig 1-1-7).

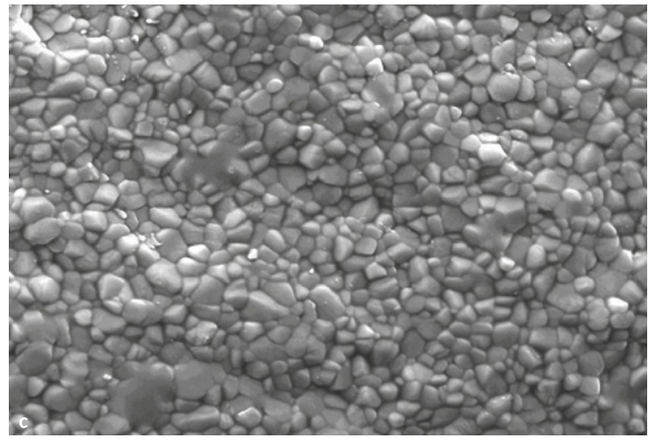
Refraction and reflection

When light passes through an interface and enters a different material, eg, from air to glass, the direction of light propagation is changed, which is called refraction. Depending on the incidence angle, light might also be completely reflected as if hitting a mirror (Fig 1-1-8). These effects lead to a scattering of the light. Interfaces in a material (ie, particles incorporated for strengthening) add to the optical properties by scattering the light as well (Fig 1-1-9).

Diffraction and opalescence

At obstacles smaller than the wavelength, the light will be refracted and scattered in all directions. By diffraction white light is split into the spectral colors. The short blue wavelength will be more deflected than the long red one. If the light source is behind the observer, mainly the blue light is seen; if the light source is behind the object mainly yellow and red colors are seen (Fig 1-1-10). The effect is visible in the sky: small water drops scatter the light. If the sun is in front of us, we mainly see yellow and red light; if the sun is behind us, we can see the azure blue sky.





Figs 1-1-4a to 1-1-4c Fractured zirconia framework 42 x x 32. **(a)** Framework after sintering, fracture occurred between 41 and 31. **(b)** Light microscopy image of the fractured area. The area was cut in the white state in order to separate the two pontics. Thus a crack was initiated, which was not sealed during sintering. **(c)** Scanning electron microscopy (SEM) of the fractured surface after sintering. The formation of grains at the surface indicates that the fracture occurred before sintering.

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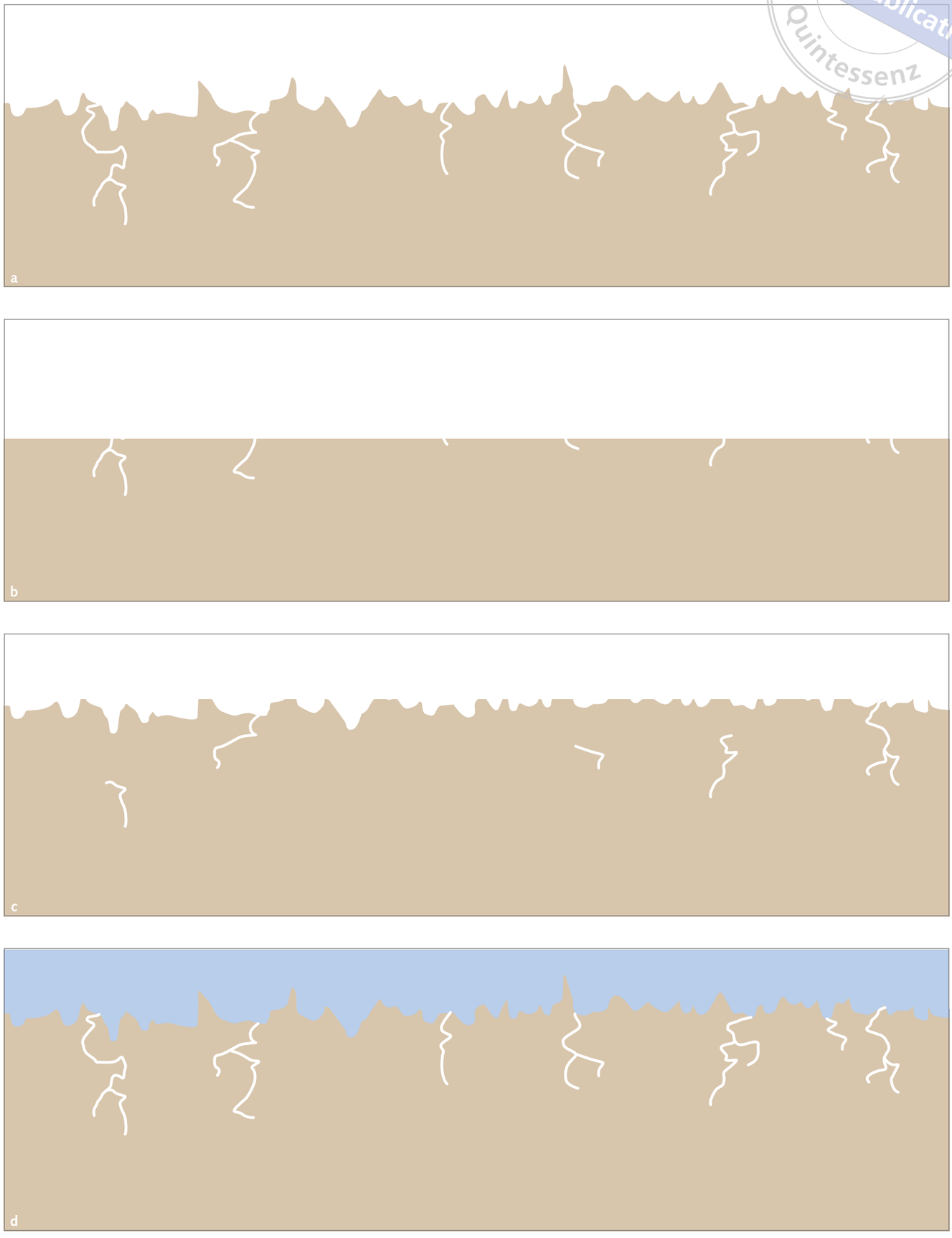

Figs 1-1-5a to 1-1-5d Schematic representation of the effect of polishing, glaze firing, or glazing on the surface quality. **(a)** Microcracks at the surface after processing. **(b)** Surface after polishing. **(c)** Surface after glaze firing. **(d)** Surface after glazing.

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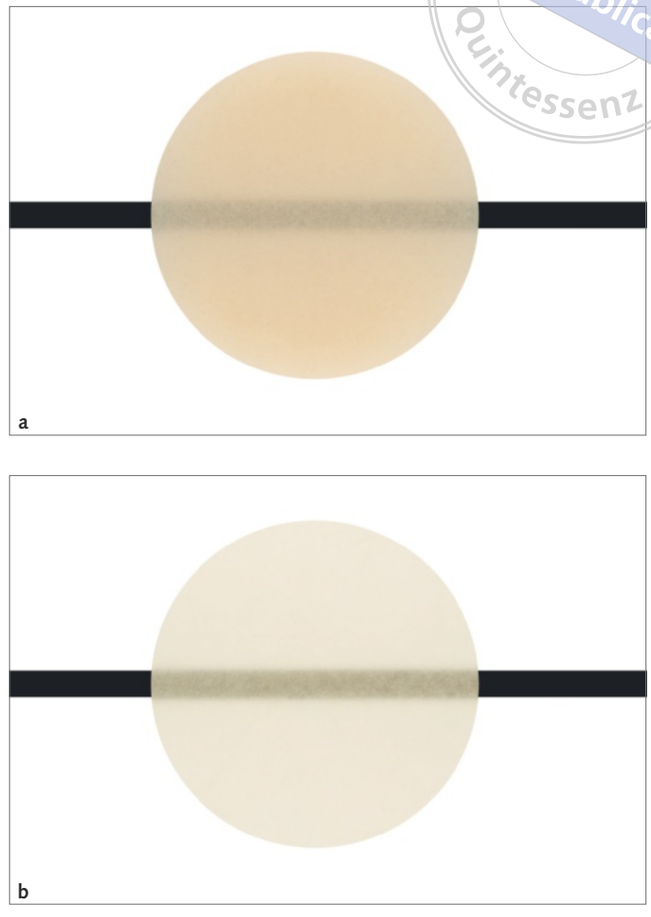
Fig 1-1-6 Pigments used to produce the appropriate shades.



Figs 1-1-7a and 1-1-7b Translucency of different ceramic shades. **(a)** Dentin layer. **(b)** Enamel layer.

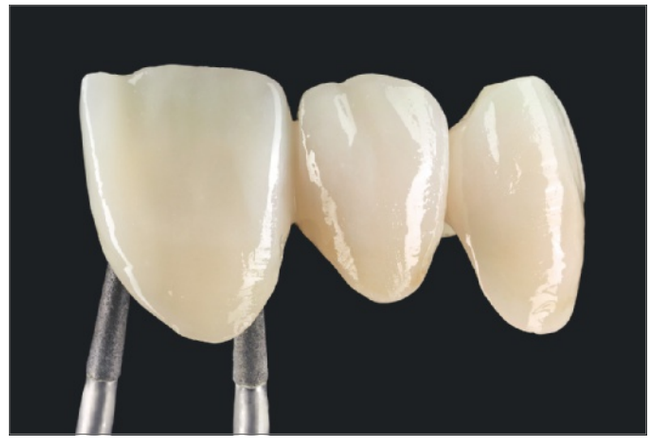


Fig 1-1-8 Reflection of light at the ceramic surface. Depending on the surface roughness and the incidence angle, reflection is more or less pronounced.

Fluorescence

The teeth glow when illuminated with ultraviolet light. Electrons are stimulated by the ultraviolet light and give off the energy by emitting visible light (Fig 1-1-11). Materials for esthetic restorations must show a similar effect. The name originates from the mineral fluorite, where this effect was first observed.

Blending quality

Blending quality ("chameleon effect") is the perception that color differences between esthetic dental materials and dental hard tissues appear smaller when the materials are viewed side-by-side than would be expected when viewed in isolation[12].

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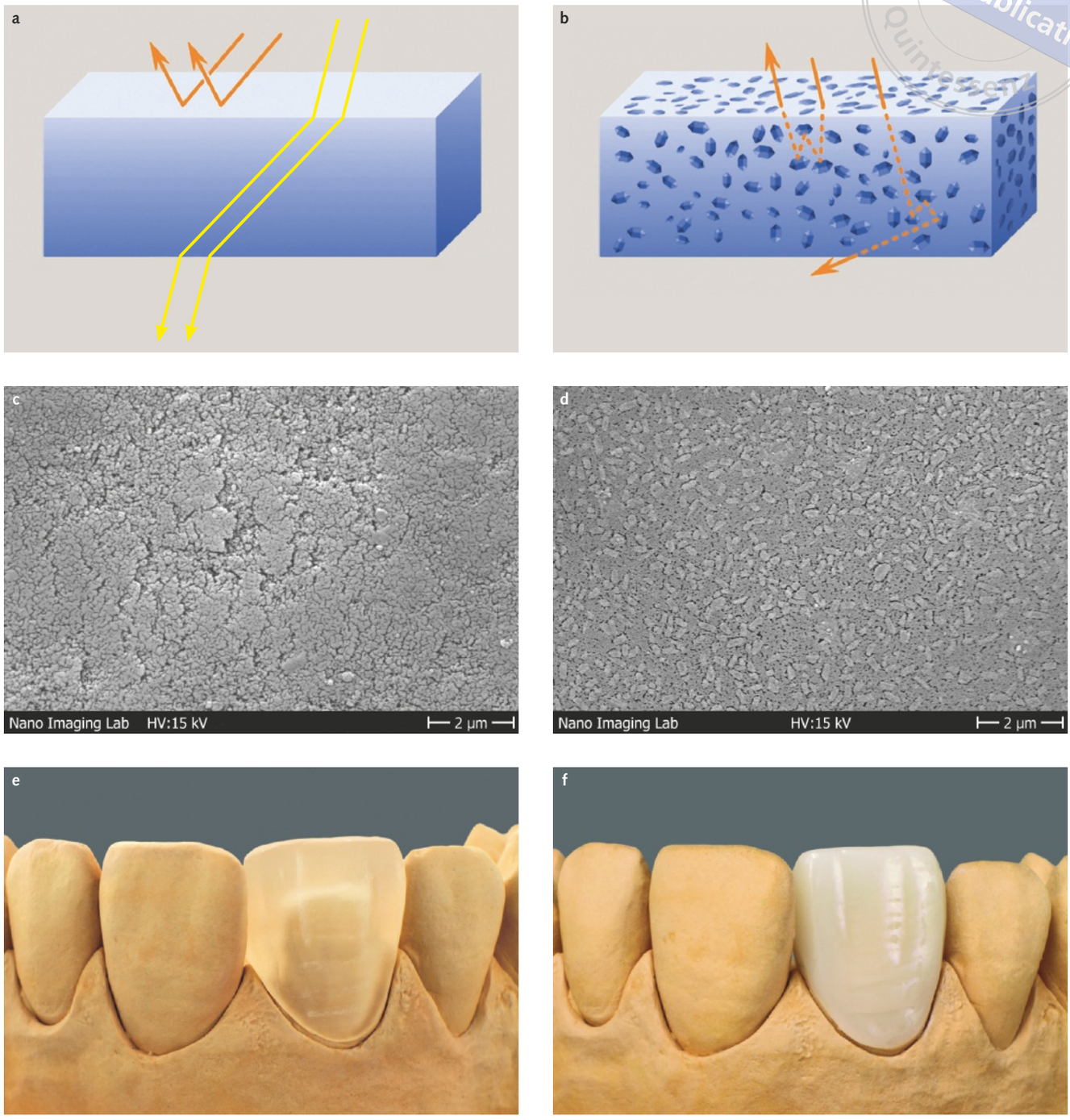

Figs 1-1-9a to 1-1-9f Refraction of light in a glass-ceramic (Vita Suprinity PC) before and after crystallization. **(a and b)** Schematic representation of light refraction. In the glassy state **(a)** the material is translucent. Light passes through the material without being refracted. After crystallization **(b)** light is scattered at the interfaces between glass matrix and crystals. The light is partially refracted and the material thus appears whitish. The surface is slightly etched with hydrofluoric acid to demonstrate the transition from the glassy state to the typical microstructure of glass-ceramic characterized by a glass matrix and incorporated crystals. **(c and d)** Microstructure before **(c)** and after **(d)** crystallization. **(e and f)** Appearance before **(e)** and after **(f)** crystallization.

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PART II
CLINICAL PROCEDURES STEP-BY-STEP

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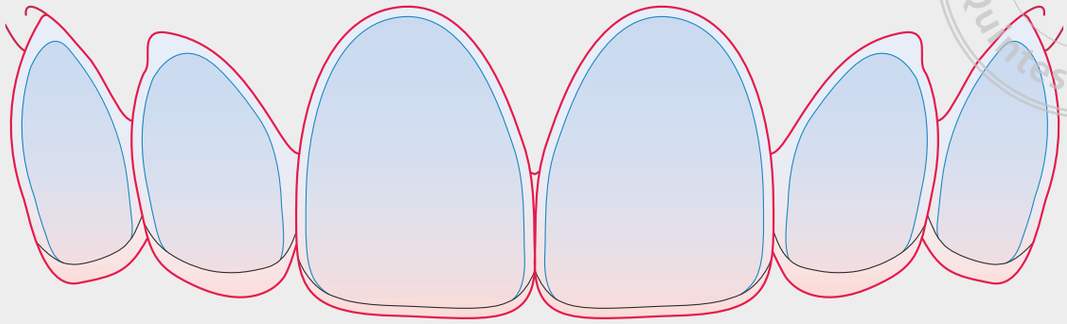

Amelogenesis imperfecta

(traditional veneers)

2.1.3 Traditional veneers for restoration of amelogenesis imperfecta (six maxillary anterior teeth)

The following section describes the minimally invasive rehabilitation of a patient with amelogenesis imperfecta.

Assessment and treatment planning

A 27-year-old healthy and almost caries-free woman presented at the clinic seeking treatment for her dark spots on the maxillary incisors and unesthetic gingival margin. A history of trauma, tetracycline staining, or fluorosis could be excluded. The clinical examination did not fully reveal the severity of the amelogenesis imperfecta nor the depth of the staining. In agreement with the patient, a step-by-step treatment plan was established. The first step consisted of a home bleaching procedure. If the stains were still present in the deeper layers of the tooth, a microabrasion technique would be applied. This procedure implies the removal of a 0.03 mm thin layer of enamel. Depending on the result of microabrasion, the third step would be undertaken: preparation of the teeth for ceramic veneers or crowns. The latter option would be considered if the enamel could not be etched due to the hypoplasia. Since the patient did not like the appearance of her gingival margin, a crown-lengthening procedure was planned (Fig 2-1-13). The step-by-step approach is described as follows.

Diagnostics

The patient's chief complaint was the dark and white-opaque staining of the maxillary incisors and canines. However, she was also bothered by the asymmetrical gingival margin and the difference between the incisal edges of tooth 11 and 23. Furthermore, the patient requested a correction of the overlapping of teeth 21 and 11.

Initially, all corrections were performed digitally by means of an image editing software, Photoshop Elements (Adobe Systems, San Jose, CA, USA), to visualize the patient's treatment. Thereafter, all the planned changes were transferred into a wax-up. The position of the two incisors was adjusted to better fit into the arch. At teeth 11 and 23, the gingiva on the plaster cast was modified in order to simulate future crown lengthening (Fig 2-1-14).

Mock-up

In order to transfer the simulations into the patient's mouth, the incisal edge of tooth 23 and the cusp of tooth 24 had to be shortened. A resin cap served as a reference for the amount of incisal reduction required (Acryline clear, Anaxdent, Stuttgart, Germany). Following preparation, the enamel was smoothened with fine-grit diamond burs (Universal Prep Set, Intensiv, Montagnola Switzerland).

A silicone index of the wax-up was prepared in order to directly fabricate a mock-up in the patient's mouth (Memosil 2, Kulzer, Hanau, Germany). This silicone index was filled with a chemically curing composite material, in shade Vita A1 (Protemp, 3M, Rüschlikon, Switzerland) and placed over the teeth. The resulting mock-up served as a communication tool, and the prospective treatment

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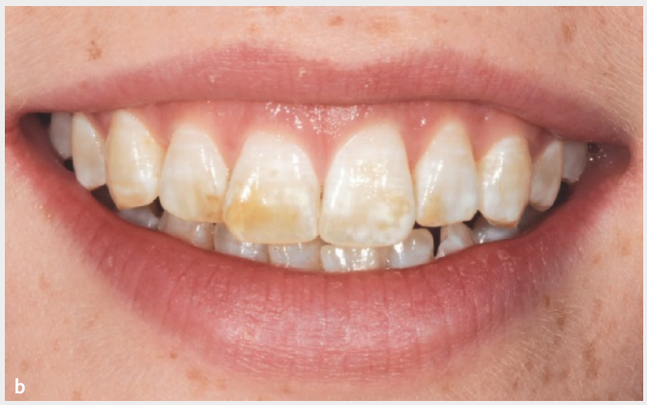

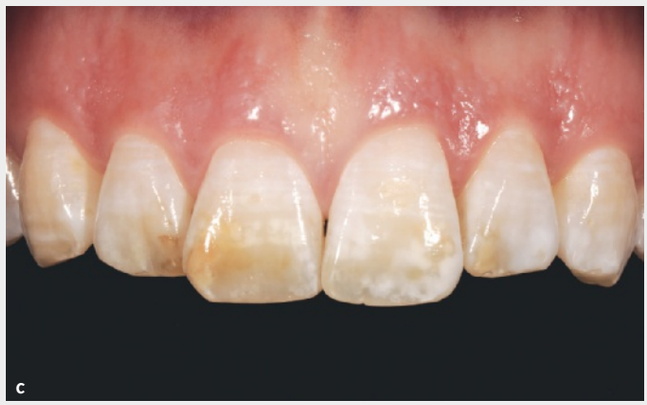

Figs 2-1-13a to 2-1-13c Pretreatment photographs (Figs 2-1-13a and 2-1-13b reproduced with permission from Büchi et al[1]).

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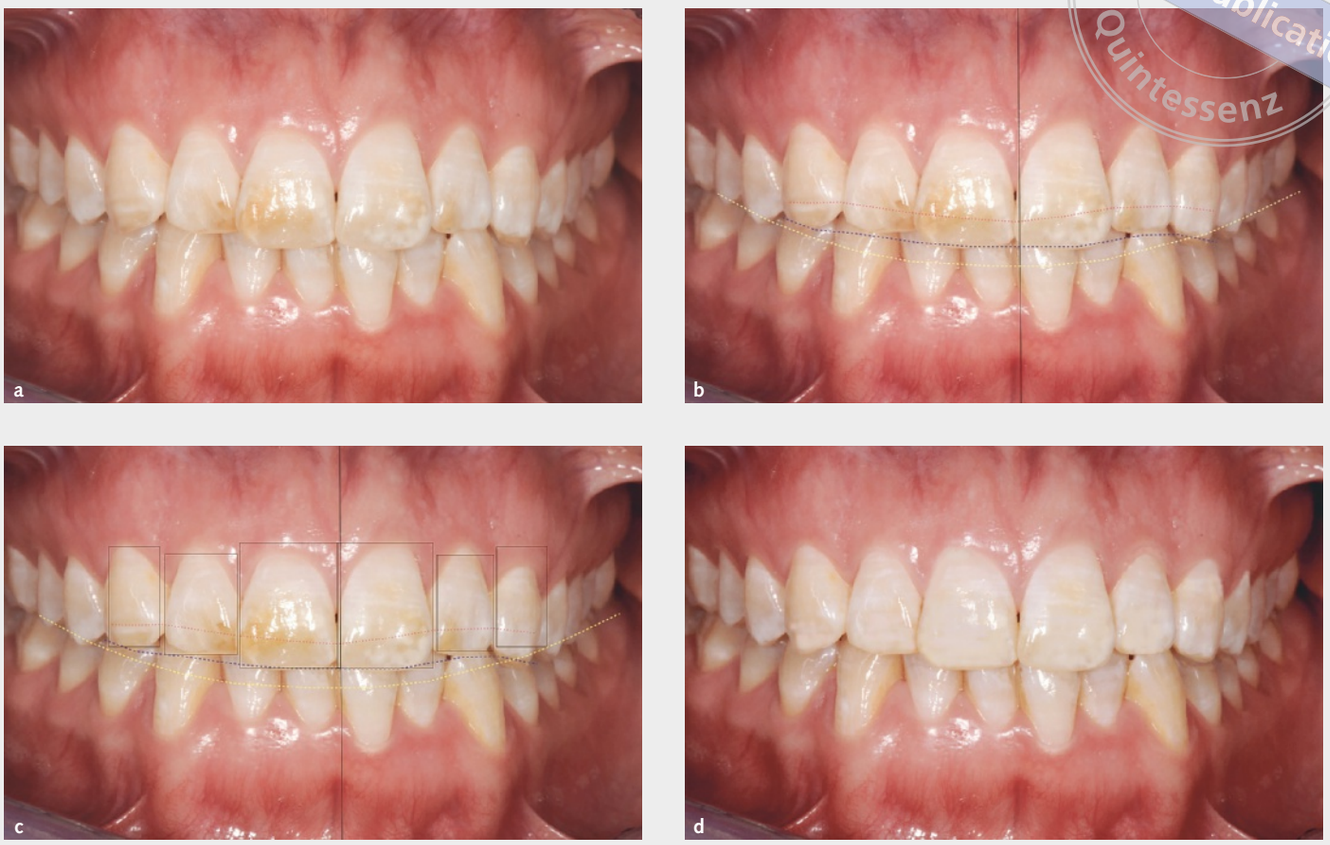
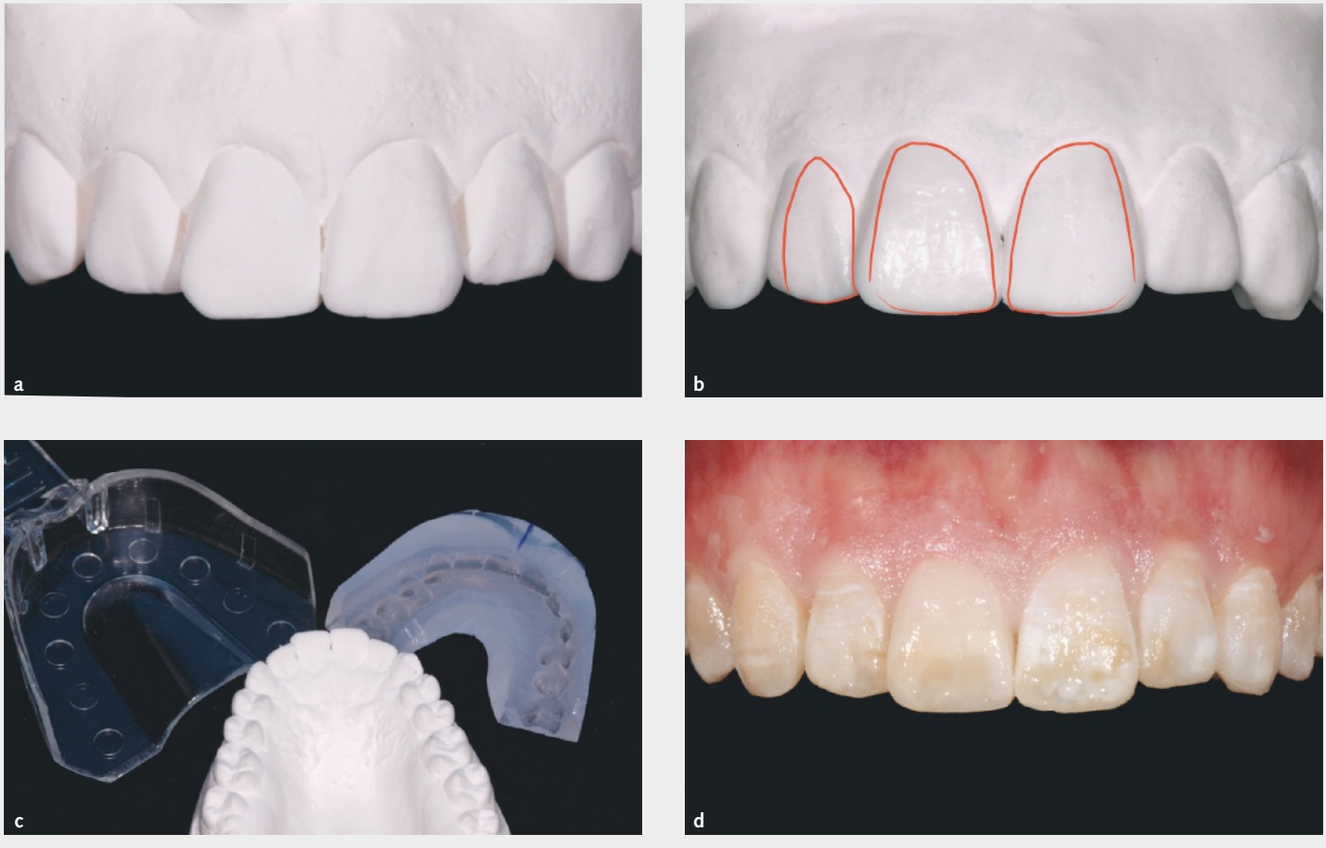


Figs 2-1-14a to 2-1-14d Treatment planning (reproduced with permission from Büchi et al[1]).



Figs 2-1-15a to 2-1-15d Creation of mock-up (reproduced with permission from Büchi et al[1]).

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result could now be discussed with the patient. The mock-up also helped to estimate the extent of the crown lengthening that would be necessary (Fig 2-1-15).

Crown lengthening

On tooth 11, the gingival level had to be moved about 1 mm apically and on tooth 23, about 1.5 mm apically. The periodontal examination revealed that both teeth had pseudo pockets. The vertical distance to the bone was around 4 mm. A gingivectomy was carried out without violating the biological width. The mock-up was used to verify the total prospective crown length. To ensure the success of the crown lengthening, the treatment plan now foresees a healing and stabilizing break of 2 months (Fig 2-1-16).

Home bleaching

For the home bleaching procedure of all teeth, bleaching trays were fabricated in the dental laboratory (Erkodur, Pfalzgrafenweiler, Germany). A carbamide peroxide bleaching gel with a concentration of 15% (Opalescense, Ultradent Products, South Jordan, UT, USA) was administered to the patient to be used for 2 hours a day for the following 3 weeks. At the follow-up visit 1–2 weeks after the last bleaching, a major improvement in the color was observed. The patient became more and more aware of dental esthetics, noticed a positive change, and was motivated to seek further improvement.

Microabrasion

The next stage of the treatment plan was the application of the microabrasion technique (Opalustre, Ultradent Products). The most superficial enamel layer was etched and subsequently removed with an abrasive paste and a rubber cup. Again, in the follow-up visit, a clear improvement was noticed, but the stains could not be fully removed. Moreover, the patient wanted to continue in order to correct the position and shape of her anterior teeth (Fig 2-1-17).

Veneer preparation and impression

A silicone index was fabricated based on the wax-up to facilitate the correct preparation of the teeth. The teeth 13–23 were prepared in a minimally invasive way to receive veneers. With an epigingival course solely in the enamel, the final impression was taken using two retraction cords. In order to avoid traumatization of the gingiva and to minimize the risk of recessions, a surgical suturing material (size 4-0, Vicryl Ethicon, Johnson & Johnson, New Brunswick, NJ, USA) was used as the first retraction cord. The second retraction cord was the thinnest cord available on the market (000 Ultrapak, UP Dental, Cologne, Germany). The preparation margins could be sufficiently exposed with this technique (Fig 2-1-18).

Fabrication of the veneers in the laboratory

Before the dental technician initiated the fabrication of the final restoration, all the information gathered during the diagnostic phase was reviewed in order to ensure that the prospective shape, position, and shade of the teeth would fulfill the patient's and the dental team's expectations.

The first step for the final restoration was the fabrication of an alveolar cast. This cast offers a big advantage in comparison with conventional saw-cut casts because it preserves all the information on gingival morphology. Refractory dies were manufactured (anaxVest, Anaxdent, Stuttgart, Germany) to guarantee the best possible fit of the veneers.

For the fabrication of the veneers, a reverse planning concept was applied. The laboratory work was guided by the information from the wax-up and mock-up, which was transferred with the aid of silicone indexes (Matrix Form 60, Anaxdent). The ceramic masses were then applied (Creation Classic, Willi Geller, Meiningen, Austria) according to the custom shade that was developed by the dental technician in collaboration with the patient, and re-adjusted after the evaluation of the preparation. After two dentin firings, the surface texture and the final shape was done with diamond burs. Gold powder was used to highlight the microstructure of the surface and make the texture clearly visible. The glaze firing was followed by a mechanical polishing procedure. The polished veneers were removed from the refractory dies by airborne-particle abrasion and cleaned in an ultrasonic waterbed (Fig 2-1-19).

Integration of the restoration

A try-in session was carried out where the veneers were inserted with glycerin gel in order to improve color assessment. Both the patient and the dental practitioner expressed their satisfaction with the esthetic result. Subsequently, in a dry environment (rubber dam) the fragile ceramic veneers were cemented. The abutment teeth were etched with 35% phosphoric acid (Ultra-Etch, Ultradent Products) and bonded with a multistep adhesive

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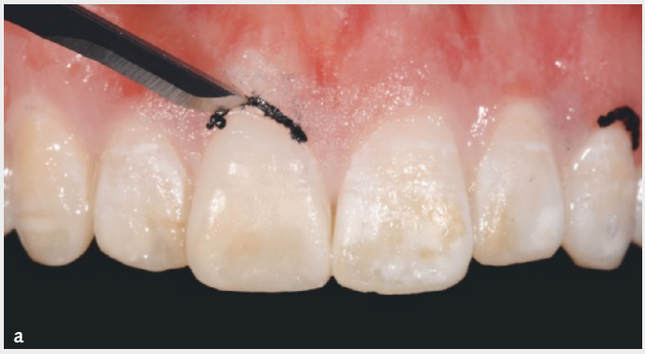
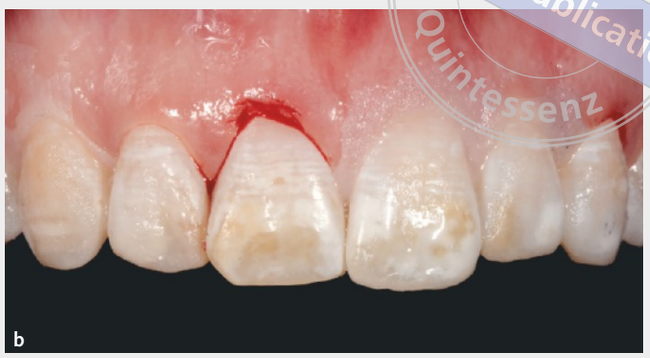
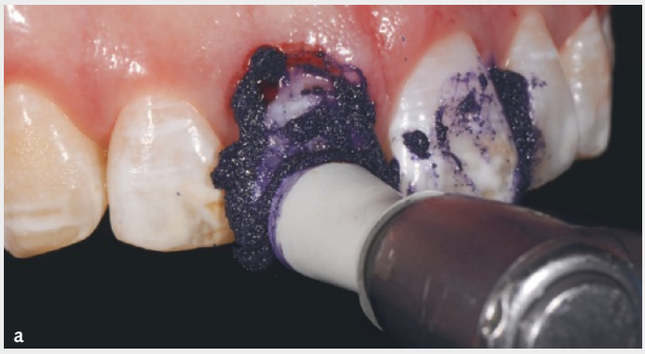
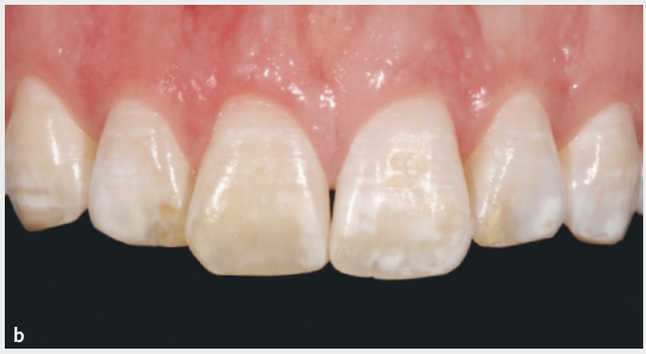


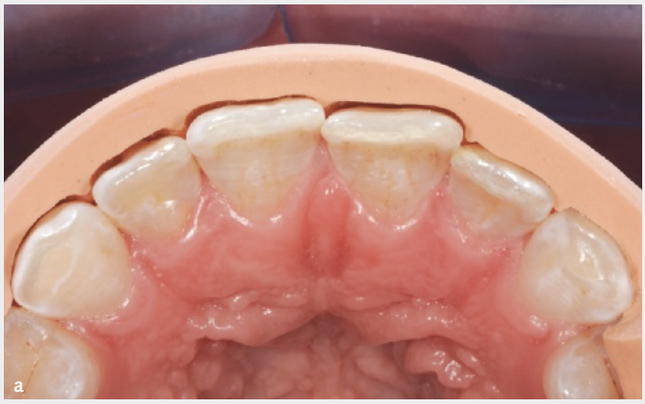


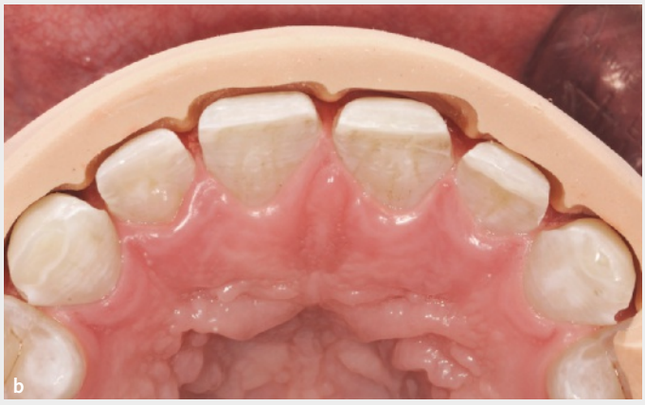
Figs 2-1-16a and 2-1-16b Crown lengthening (reproduced with permission from Büchi et al[1]).

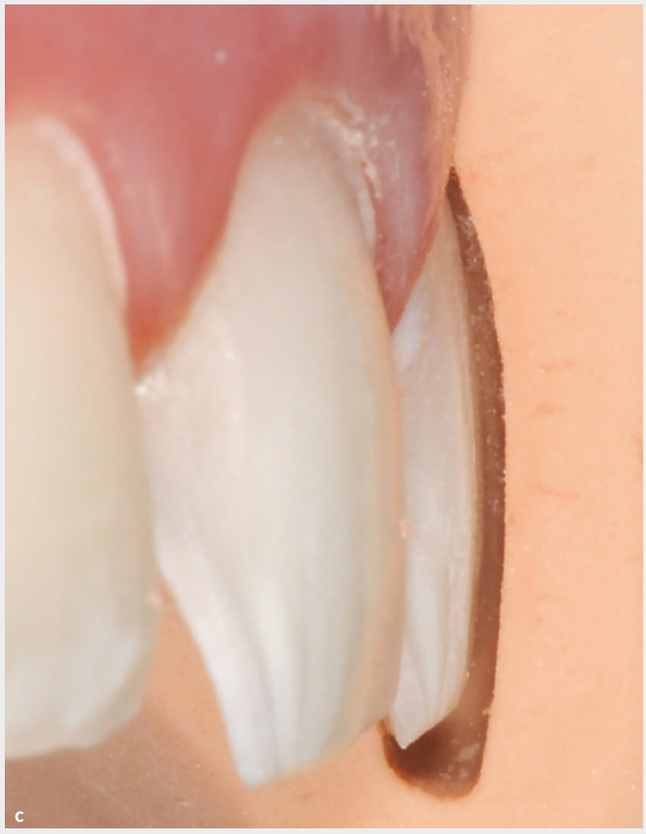




Figs 2-1-17a and 2-1-17b Bleaching (reproduced with permission from Büchi et al[1]).







Figs 2-1-18a to 2-1-18c Veneer preparation and impression (reproduced with permission from Büchi et al[1]).

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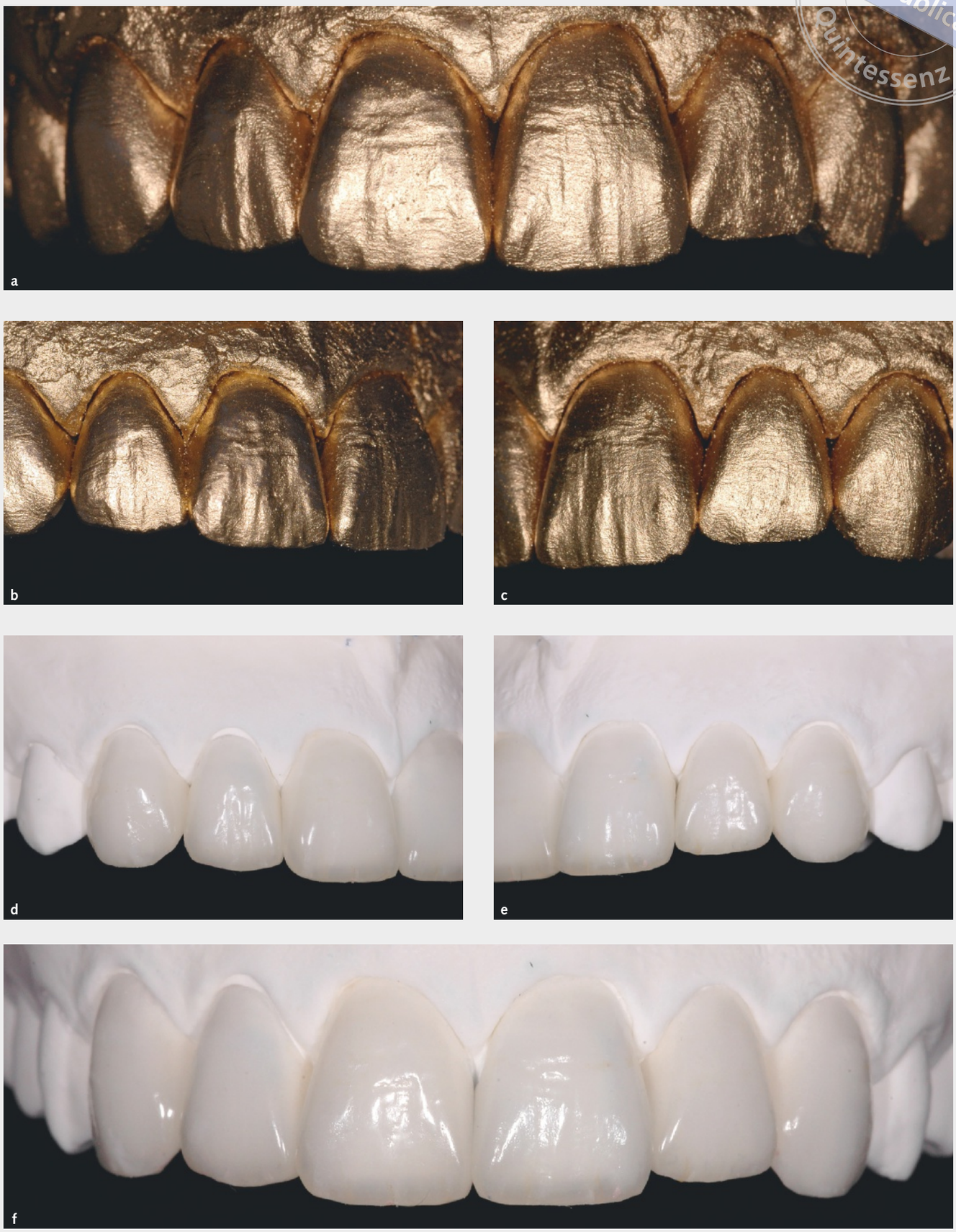

Figs 2-1-19a to 2-1-19f Fabrication of the veneers (Figs 2-1-19a and 2-1-19b reproduced with permission from Büchi et al[1]).

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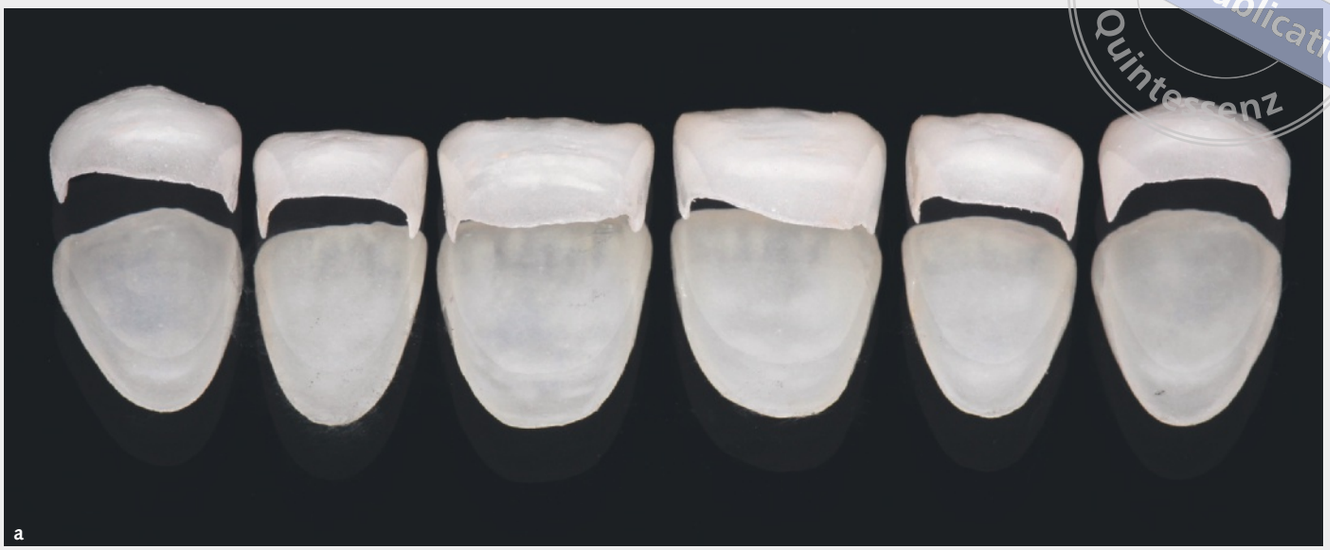

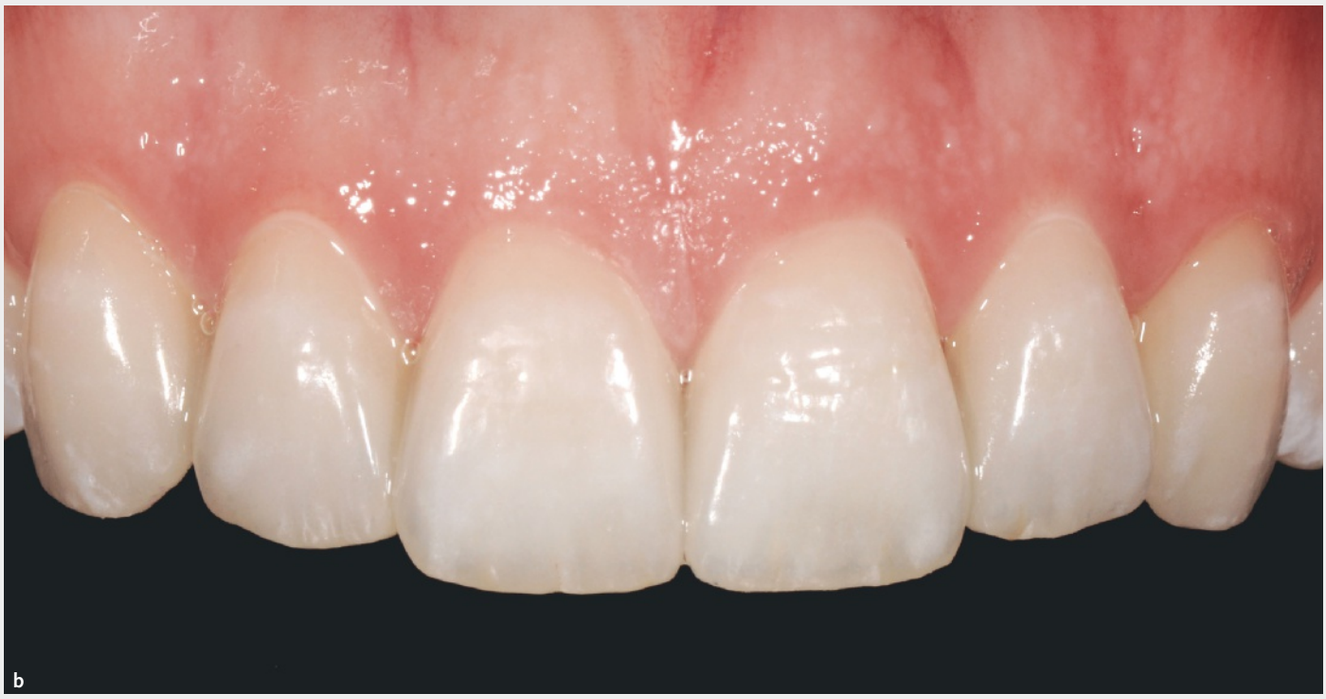

Figs 2-1-20a and 2-1-20b Cementation of the veneers (reproduced with permission from Büchi et al[1]).

system (Syntac Classic, Ivoclar Vivadent, Schaan, Liechtenstein). The bond was not light-cured in order not to compromise the fit of the veneers. The veneers were etched with hydrofluoric acid (9% concentration for 1 min) (Porcelain Etch, Ultradent Products). A primer (Monobond S, Ivoclar Vivadent) and a bonding system (Heliobond, Ivoclar Vivadent) were applied. Then the veneers were cemented with a dual-curing resin cement (Variolink transparent, Ivoclar Vivadent). Excess cement was removed with rotating diamond instruments. The occlusal and functional contacts were analyzed and no adjustments were necessary (Fig 2-1-20).

All participants were very satisfied with the final treatment outcome. At a follow-up visit 18 months post-insertion, all the veneers looked well integrated without any discoloration of the margin or chipping and fractures of the ceramic (Fig 2-1-21). (Dental practitioner: Dr D Büchi; Technician: MDT V Fehmer.)

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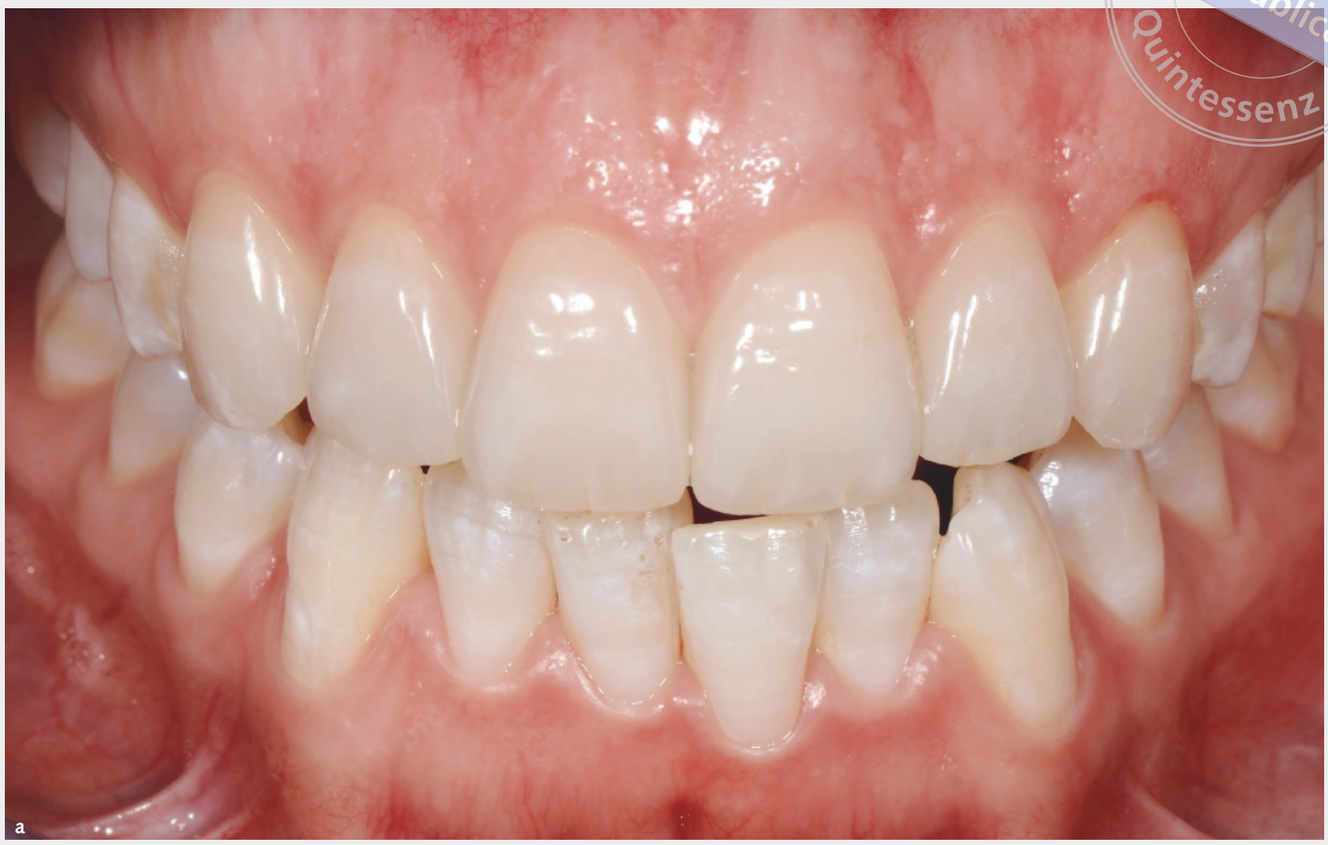

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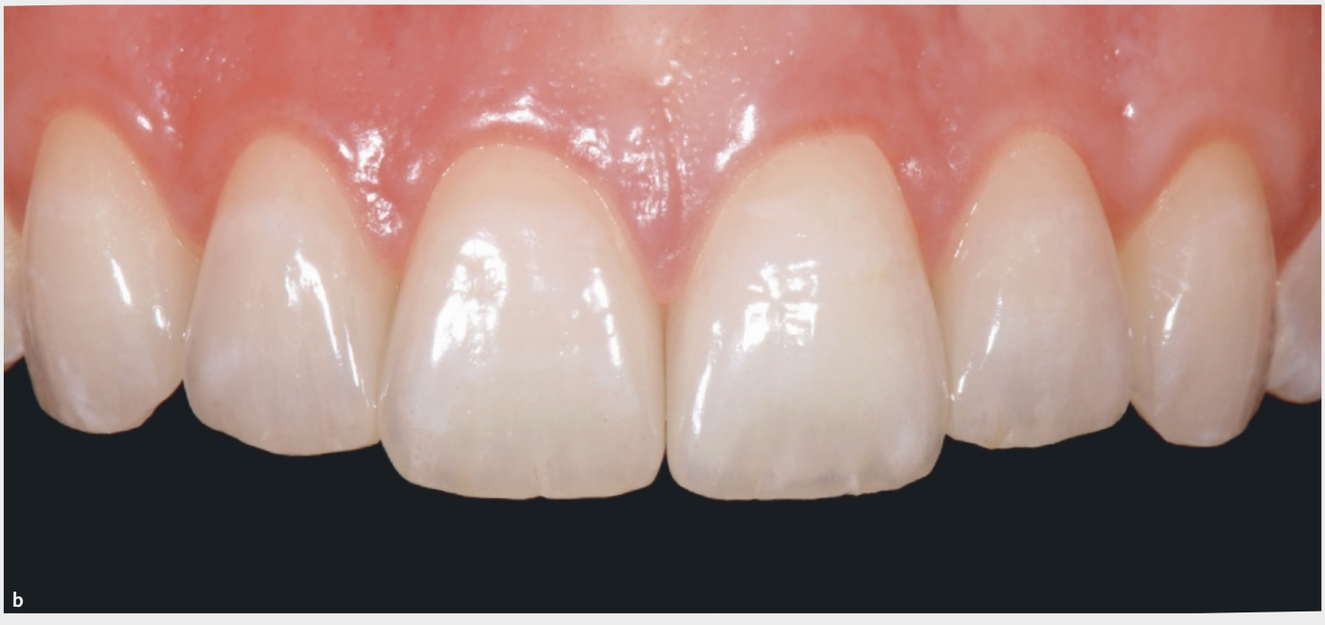

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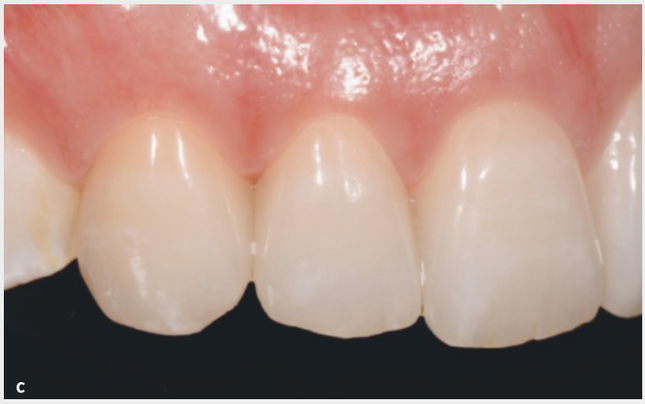
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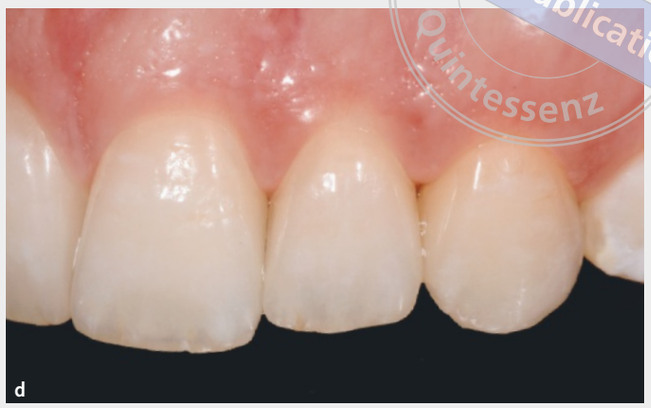
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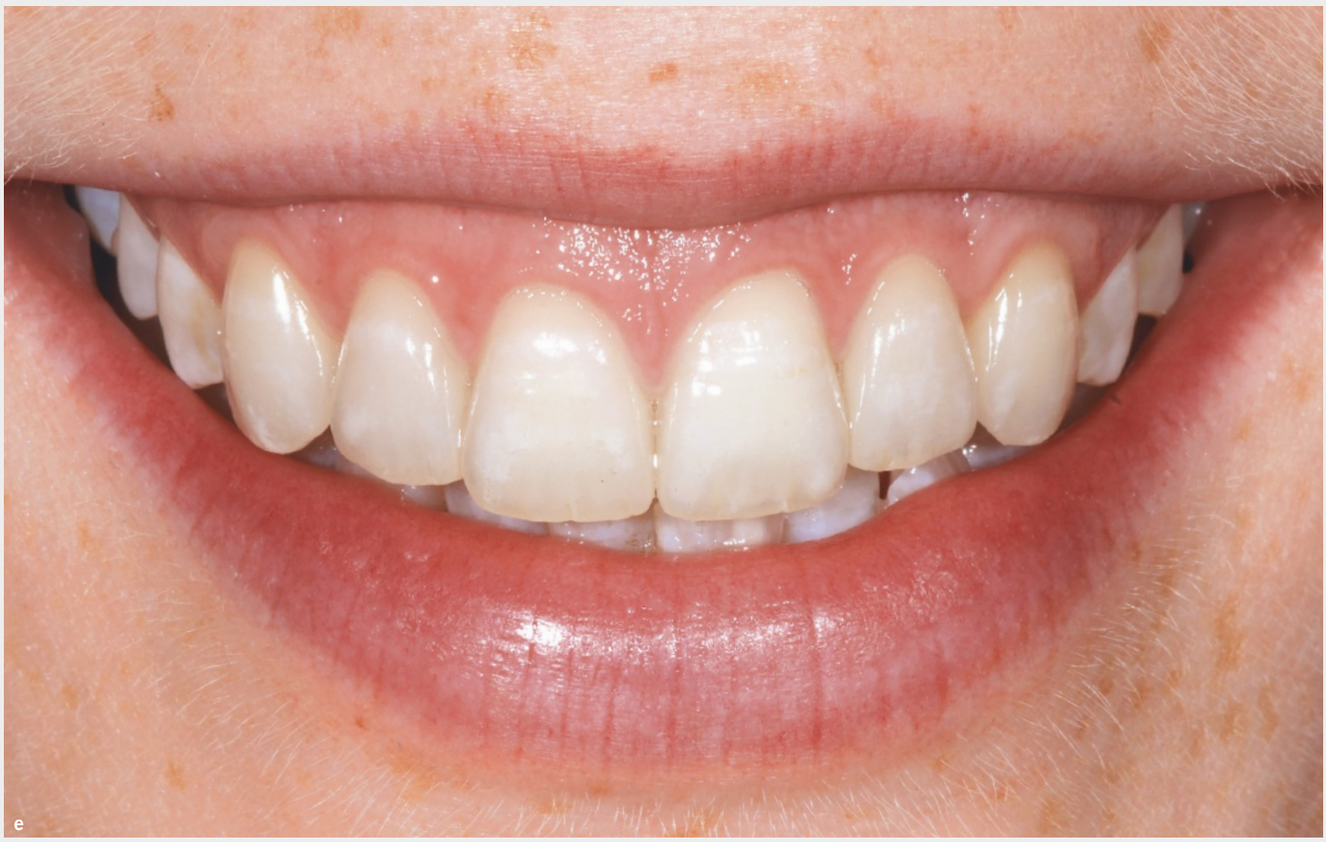
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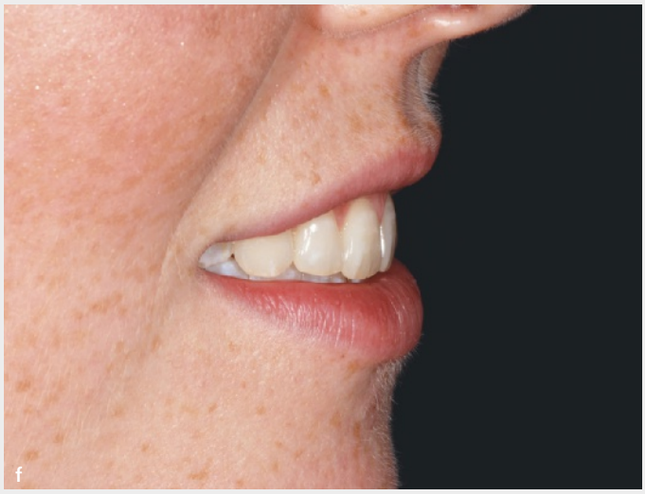
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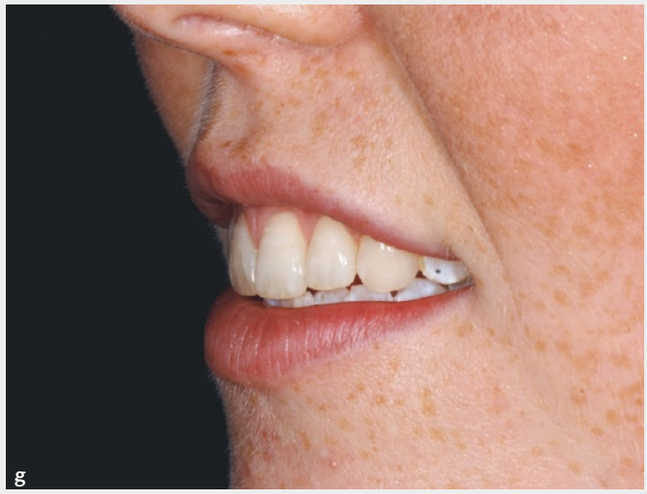
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Figs 2-1-21a to 2-1-21h Final esthetic outcome.

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PART III
LONG-TERM OUTCOMES OF FIXED RESTORATIONS

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3.1 Introduction

In this chapter:

- Tooth-supported veneers
- Tooth-supported inlays and onlays
- Tooth-supported SCs
- Endocrowns
- Tooth-supported conventional FDPs
- Tooth-supported cantilever FDPs
- Resin-bonded fixed dental prostheses (RBFDPs)
- Implant-supported SCs
- Implant-supported FDPs
- Implant-supported cantilever FDPs
- Combined tooth-implant-supported FDPs

A group of researchers from the Universities of Iceland, Bern, Geneva, and Zurich in Switzerland, and from the National Dental Center in Singapore have published a broad series of systematic reviews in recent years (see Table 3-11 at the end of Part III)[1–20]. These are based on consistent inclusion and exclusion criteria, methodologies, and a statistical approach summarizing the available information on survival rates of different types of tooth- and implant-supported single crowns (SCs) and fixed dental prostheses (FDPs).

3.2 Tooth-supported veneers

A systematic review[21], aiming to evaluate the 5- and 10-year survival rates of ceramic veneers fabricated of non-feldspathic porcelain, reported an estimated 5-year survival rate of 92.4% based on four studies evaluating the outcomes of approximately 400 veneers. Two studies with a follow-up time exceeding 10 years could be included in the systematic review. The reported 10-year survival rates for these studies were 66% and 94%, respectively[22,23]. A more recent systematic review[24] analyzing the survival of both glass-ceramic and feldspathic porcelain laminate veneers reported survival rates of 94% for the glass-ceramic veneers, based on 676 veneers with a mean follow-up time of 7 years, and of 87% for feldspathic porcelain veneers based on 1283 veneers with a mean follow-up time of 8 years[24]. The difference in survival rates between glass-ceramic and feldspathic porcelain laminate veneers did, however, not reach statistical difference. The most frequent complications were: fracture or chipping (4%); debonding (2%); severe marginal discoloration (2%); endodontic complications (2%); and secondary caries (1%). The authors could not draw any concrete conclusion regarding the influence of preparation depth (limited to enamel or dentin) on the failure rates[24].

3.3 Tooth-supported inlays and onlays

Systematic review and meta-analyses aiming to evaluate the survival rates of both ceramic and resin inlays, onlays, and overlays reported an overall estimated 5-year survival rate of 95% for ceramic inlays and onlays based on the observations of 5811 reconstructions and an estimated 10-year survival rate of 91% based on a sample of 2154 reconstructions[25]. For glass-ceramic inlays and onlays, the 5-year survival rate was reported to be 96% (n = 1579) and the 10-year survival rate was 93% (n = 605). For feldspathic porcelain inlays and onlays the respective survival rates were 92% (n = 661) and 91% (n = 538)[25]. The systematic review indicated that the type of ceramic material (feldspathic porcelain vs glass-ceramic), the follow-up time (5 years vs 10 years), and the study setting (university vs private clinic) did not significantly affect the survival rates. The most frequently observed complications were related to ceramic fractures or chippings (4%), followed by endodontic complications (3%), secondary caries (1%), and debonding (1%). Severe marginal staining was not reported. No studies were available that reported on resin-based inlays, onlays, and overlays, and fulfilled the inclusion criteria of a mean follow-up time of at least 5 years[25].

3.4 Tooth-supported SCs

Recently, Sailer and co-workers[15,16] published a systematic review analyzing the survival and complication rates of all-ceramic and metal-ceramic tooth-supported SCs. The meta-analysis included 17 studies reporting on 4663 metal-ceramic crowns and 55 studies reporting on 9493 all-ceramic crowns (different types of ceramic used). For metal-ceramic SCs the estimated 5-year survival rate was 95.7% (Table 3-1)[26–58] compared with an overall 5-year survival rate of 94.5% for all-ceramic crowns. The survival rates of all-ceramic crowns differed for various ceramic types. The 5-year survival rates were 96.6% for leucite or lithium-disilicate reinforced glass-ceramic SCs (12 studies with 2689 SCs) (Table 3-1), 96.0% for densely sintered alumina SCs (8 studies with 1099 SCs), 94.6% for glass-infiltrated SCs (15 studies with 2389 SCs), 93.8% for densely sintered zirconia SCs (8 studies with 926 SCs) (Table 3-1), 90.7% for feldspathic or sil-

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Table 3-1 Estimated annual failure rate and 5-year survival rate of tooth-supported metal-ceramic, reinforced glass-ceramic, and densely sintered zirconia-ceramic single crowns (SCs)

Study	Year published	Total no. of crowns	Mean follow-up time (y)	No. of failures	Total exposure time (y)	Estimated crown annual failure rate (%)	Estimated 5-y crown survival rate (%)
Metal-ceramic tooth-supported SCs							
Passia et al[26]	2013	100	4.3	9	434	2.07	90.2
Reitemeier et al[27]	2013	190	9.6	10	1832	0.55	97.3
Walton[28]	2013	2211	9.2	83	13,505	0.61	97.0
Rinke et al[29]	2013	50	3.0	1	146	0.68	96.6
Wolleb et al[30]	2012	249	5.3	3	1310	0.23	98.9
Örtorp et al[31]	2012	90	4.5	8	408	1.96	90.7
Vigolo & Mutinelli[32]	2012	20	4.8	0	95	0.00	100.0
Abou Tara et al[33]	2011	60	3.9	1	235	0.43	97.9
Naumann et al[34]	2011	52	3.4	6	176	3.41	84.3
Boeckler et al[35]	2009	41	2.8	2	114	1.75	91.6
Krieger et al[36]	2009	106	17.0	28	1598	1.75	91.6
Näpänkangas & Raustia[37]	2008	100	18.2	21	1820	1.15	94.4
Güngör et al[38]	2007	260	7.0	7	1400	0.50	97.5
Eliasson et al[39]	2007	12	4.3	0	51	0.00	100.0
De Backer et al[40]	2007	1037	10.0	116	10,370	1.12	94.6
Marklund et al[41]	2003	42	5.0	3	190	1.58	92.4
Jokstad & Mjör[42]	1996	43	10.0	0	281	0.00	100.0
Total		**4663**	**7.3**	**298**	**33,965**		
Summary estimate (95% CI)						**0.88 (0.63–1.22)**	**95.7 (94.1–96.9)**

ica-based ceramic SCs (10 studies with 2208 SCs), and 83.4% for composite crowns (1 study with 59 SCs)[15,16]. Compared with metal-ceramic crowns, feldspathic or silica-based ceramic SCs and composite crowns had significantly lower 5-year survival rates. When the outcomes of anterior and posterior SCs were compared, no significant differences in the survival rates were found for metal-ceramic crowns, for leucite or lithium-disilicate reinforced glass-ceramic crowns, and alumina and zirconia-based crowns. Crowns made out of feldspathic or silicabased ceramics, however, exhibited significantly lower survival rates in the posterior region compared with the anterior region[15,16].

3.5 Endocrowns

Limited data are available on the long-term outcome of endocrowns. A systematic review conducted to evaluate clinical (survival) and *in vitro* (fracture strength) outcomes of endocrowns compared to conventional crowns was able to include three clinical studies, one prospective and two retrospective. The included studies reported on a total of 55 endocrowns inserted in the posterior area. The survival rates ranged between 94% and 100% at a rather short follow-up time of 6–36 months[59]. A recent retrospective analysis of 235 molar endocrowns made with a chairside CAD/CAM method reported a very pos-

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PART IV
AVOIDING AND MANAGING COMPLICATIONS

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4.1 Introduction

In this chapter:

- Success of tooth- and implant-supported restorations
- Tooth-supported restorations
  - Esthetic complications
  - Biological complications
  - Technical complications
- Implant-supported restorations
  - Esthetic complications
  - Biological complications
  - Technical complications

Over the years, several definitions of success have been proposed and used in restorative and implant dentistry[1–3]. Instead of redefining old definitions or inventing new ones over and over again, it would make more sense to move away from success definitions in general. Instead, clinicians should report whether the restorations have remained unchanged and free of any complications over the entire observation period. Hence, a "successful" restoration would be a restoration that did not require any intervention during the entire observation period[4].

4.2 Success of tooth- and implant-supported restorations

In systematic reviews[5,6] addressing the survival and complication rates of tooth-supported fixed dental prostheses (FDPs), only few of the included studies provided information on the number of restorations that remained intact or without complications over the observation period. The 5-year complication rate for tooth-supported FDPs was estimated to be 15.7% (95% CI: 8.5–27.7%)[6,7] and for tooth-supported cantilever FDPs the respective rate was 20.6%[5,7] (Table 4-1).

In the early days of implant dentistry the overall number of biological and technical complications was rarely reported. A former systematic review[4] addressing the survival and complication rate of implant-supported FDPs could only locate three studies that gave the exact number of restorations with complications. The estimated 5-year complication rate was quite high, or 38.7% (95% CI: 33.2–44.7%)[4]. The most frequent complication reported in these studies was loosening of prosthetic screws. A more recent systematic review[8] addressing exclusively implant-supported metal-ceramic FDPs however concluded that 15.1% (95% CI: 11.2–20.4%) of the restorations were affected by biological or technical complications over a 5-year observation period. The reduced number of complications between the older and the more recent studies might represent a positive learning curve in implant dentistry or enhanced components due to developments, causing less technical problems. Another systematic review[9] addressing the survival and complication rates of metal-ceramic and zirconia-ceramic implant-supported single crowns concluded that 13.3% (95% CI: 9.0–19.3%) of the metal-ceramic and 16.2% (95% CI: 6.2–38.4%) of the zirconia-ceramic crowns experienced some kind of esthetic, biological, or technical complications over an observation period of 5 years[9] (Table 4-2). Even though a significant number of studies and meta-analyses[4–20] have presented impressively high survival rates for both tooth- and implant-supported restorations, it must be considered that between 15% and 20% of the restorations were affected by some kind of esthetic, biological, or technical complications. For example, a study evaluating the outcome of implant-supported restorations performed at the University of Bern[21] reported a failure rate of 2.5% but an additional 16.8% of the restorations had some kind of biological and/or technical problems. Comparing the overall complication rates of tooth- and implant-supported restorations, tooth-supported restorations were more frequently affected by biological complications such as caries or loss of pulp vitality, while implant-supported restorations were more affected by technical complications such as screw loosening or material fractures.

4.3 Tooth-supported restorations

4.3.1 Esthetic complications

The incidence of esthetic complications (Fig 4-1), or restorations to be remade due to esthetic reasons, is rarely reported in the dental literature for tooth-supported single crowns (SCs) and FDPs[11,12] (Table 4-1). A recent systematic review[10] evaluating the outcome of tooth-supported resin-bonded fixed dental prostheses (RBFDPs) reported that only 0.3% of the included restorations had to be redone due to unacceptable esthetic appearance[10]. With the materials and technology available today, dental professionals should be able to imitate the natural appearance of a tooth in an acceptable way when manufacturing a tooth-supported restoration.

> The current concept of how to imitate the appearance of a natural tooth with a tooth-supported restoration is presented step by step in Part I, Chapters 6 and 9.

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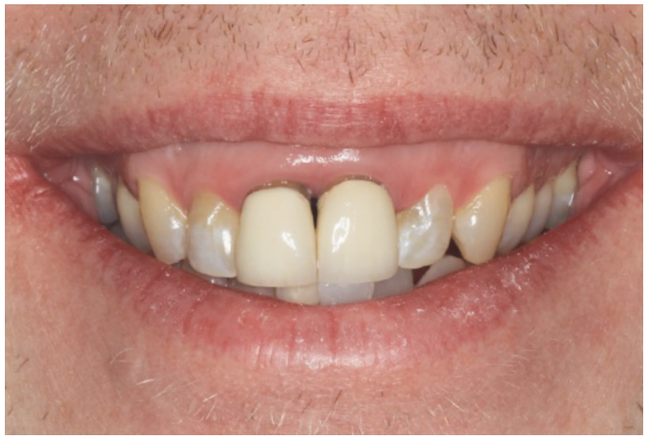

Fig 4-1 Central incisors with tooth-supported SCs with unacceptable esthetic outcome in a patient with a high smile line.

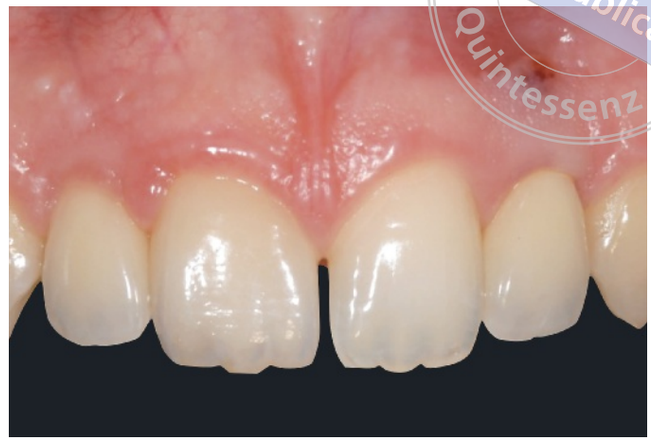

Fig 4-2 The pulp of tooth 22 became necrotic after trauma and a fistula can be detected on the buccal mucosa.

4.3.2 Biological complications

Loss of pulp vitality

One of the most frequent biological complications affecting tooth-supported restorations is the loss of abutment tooth vitality (Fig 4-2; Table 4-1). For tooth-supported SCs, 1.8% of the abutment teeth that were considered to be vital at the time of cementation had lost vitality at an observation period of 5 years[11]. The loss of abutment tooth vitality was less frequent for leucite-reinforced SCs, lithium-disilicate reinforced glass-ceramic SCs, and glass-infiltrated alumina SCs compared with metal-ceramic and zirconia-ceramic SCs[11]. For tooth-supported FDPs loss of abutment tooth vitality was reported in 6.1% of the abutment teeth[5,7]. In the case of cantilever tooth-supported FDPs the respective number of abutment teeth with loss of vitality was 17.9% over a mean observation period of 5 years[5,7]. A study[22] specifically addressing loss of pulp vitality in patients reconstructed with FDPs after successful treatment of advanced periodontitis, reported the highest rate of loss of abutment vitality of 8.2%. Significantly more abutment teeth lost vitality compared with non-prepared control teeth[22]. It must, however, be kept in mind that teeth being restored with SCs, or serving as abutments for FDPs, are often at higher risk of losing pulp vitality due to a significant amount of missing tooth substance or existing large fillings. The clinician should consider that the facial enamel-dentin thickness ranges from 1.8 mm to 3.1 mm depending on the age of the patient. The thickness also varies with tooth type and area of measurement (Fig 4-3)[23]. Histological changes have been detected in the pulpal tissue if the remaining dentin thickness is below 1 mm[24]. It is of great importance to avoid drying-out the dentin during the workflow and pulp capping in general should be avoided for abutment teeth. If endodontic treatment is needed after the restoration has been cemented then a conservative opening preparation should be implemented, leaving as much tooth substance as possible.

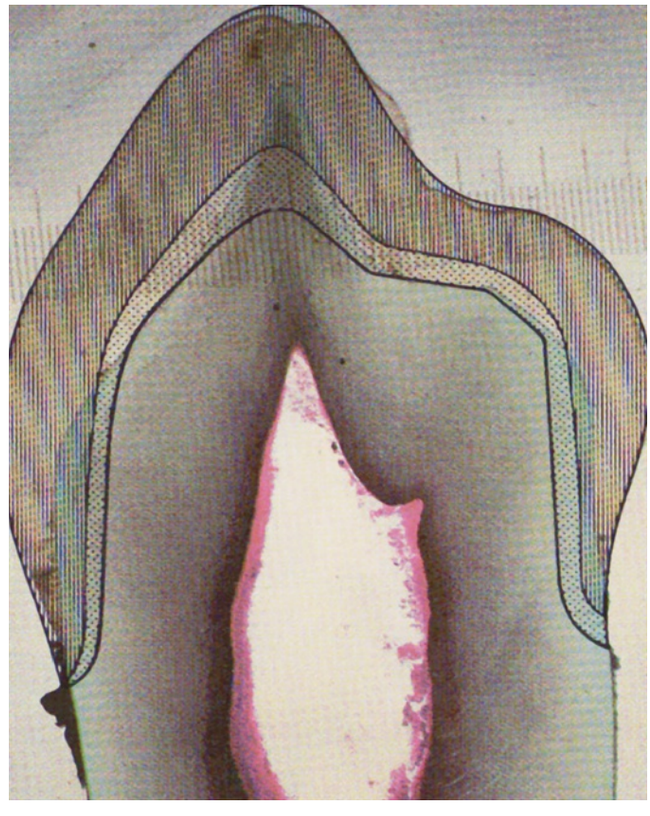

Fig 4-3 A histological section showing the thickness of dentin and enamel in relation to a traditional tooth preparation.