Dentaurum – Dental technologies

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50 years Orthocryl® – Acrylics for removable orthodontic appliances

Just think of products still available today which you can remember from your childhood or adolescent days! Could you think of any? If the third digit of your year of birth is ≤6, these products are approximately 50 years old, depending on the fourth digit on your birth certificate. For those who were born later, there are bound to be a few product names from their early years which are still around today. Now make the same exercise for the dental market. Which products are still available today that you already know from your training in dentistry and/or dental prosthetics? Quite possibly the fingers of one hand would be enough to count them. The number becomes even more limited when you begin to consider the current product range in the field of orthodontics. Hopefully your list will also include Orthocryl®. This acrylic – a cold-polymerizing polymethyl methacrylate (PMMA) - for the production of orthodontic appliances entered the market in 1963! And is still one of the most important products today for this purpose. The success was and is perhaps less due to the material itself, as it has been available as a cold-curing resin since 1949 and still is. What was revolutionary at the time was the processing made possible by the so-called salt-and-pepper technique.

And by the way, this is still the most widely used technology for producing orthodontic appliances today. You will therefore certainly understand that we at Dentaurum are proud of our Orthocryl®. Acrylics are en vogue. Millions of times in physical terms and often only verbally. The spectrum of opinions on dental acrylics – in other words also Orthocryl® – on the part of patients, medical personnel and the uninvolved media ranges from unreserved acceptance to monomer alarmists, phobics and patients with allergies. Opinions range between being a blessing and the utmost concern for artificial substances made by industry. Removable orthodontic appliances are an important component in the treatment of dysgnathia and are no longer conceivable nowadays without the use of acrylics. For more than half a century, Orthocryl® has proven itself not only an easy to process acrylic, but also as being well tolerated. As with all dental materials, there are pros and cons that need to be considered before using them on patients.

And if one looks back in time, some of the problems that are associated with this material originate from a different perspective. And of course, there are material-specific characteristics of PMMA that one should be aware of. Their effects can be controlled or also avoided.

Salt-and-pepper technique with Orthocryl®

Fig. 1 Retention by means of a cast silver splint from 1902.

Why was the salt-and-pepper technique with Orthocryl® revolutionary? To answer this question, one must take a look into the past. Initially, orthodontic appliances only consisted of soldered metal structures (Fig. 1). The introduction of rubber plates opened up new possibilities for the production of removable appliances in orthodontics (Fig. 2). Charles Goodyear discovered and developed the vulcanization of natural rubber into rubber, patented in 1844.

The first dental use of rubber was proposed in 1851.[16, 56] This and the invention of celluloid (Hyatt brothers, 1870) were also important milestones in orthodontics.[33, 58]

In 1924, the celluloid preparation Hekolith was launched on the market. Selected Egyptian cotton was used for this purpose, which was converted into nitrocellulose with nitric acid and kneaded with camphor and alcohol to form a uniform, viscous compound. Hekolith contained 30-40% fillers and pink aniline dye.[33, 56, 58] All these materials were supplied as sheets, which acquired their individual shape through thermoplastic processes and pressure. The terms plate prosthesis and orthodontic plate, which are still used today, presumably originated at this time.

Fig. 2 Jaw expansion according to Coffin using piano wire and rubber plate from 1882 (both images: Collection of the Clinic for Orthodontics and Pediatric Dentistry at the Center for Dental Medicine at the University of Zurich).

Introduction of PMMA

1928 marked an important development in the field of acrylics - acrylic glass (Plexiglas). A group of materials that has played an important role in dentistry up to the present day and will continue to do so in the future. From 1933 onwards, there were cast panes made of acrylic glass (Dr. Otto Röhm). Initially (around 1938), prefabricated sheets of acrylic or methyl methacrylate (Plexiglas) were processed. These could be reversibly formed at 180°C. The softened material had to remain under pressure until it solidified. Another variant was to process the polymer in powder form. The dough was formed into a plastic strand by heating and pressed into a flask (Bauer, 1930).[16, 64] The shrinkage that occurred during cooling was up to 50 percent.[9, 58] This technique, known as injection molding, has regained a certain importance in today's production of dental restorations, albeit with other acrylics.

Gottfried Roth made an important discovery for dentistry. He discovered that the polymer (PMMA) in Plexiglas is soluble in the monomer (MMA). He was the first person to mix both components of Plexiglas (acrylic glass) into a rubber-like mass, which was then pressed and polymerized under the effect of heat - in other words, it hardened again. This was the genesis of the wet plastic process (Paladon process) for the production of dentures and orthodontic plates in 1936.[9, 16, 58, 64] Ernst Schnebel became known for his attempts to fabricate acrylic teeth. He spent the last years of his life until his death working on the development of self-polymerizing PMMA acrylics.

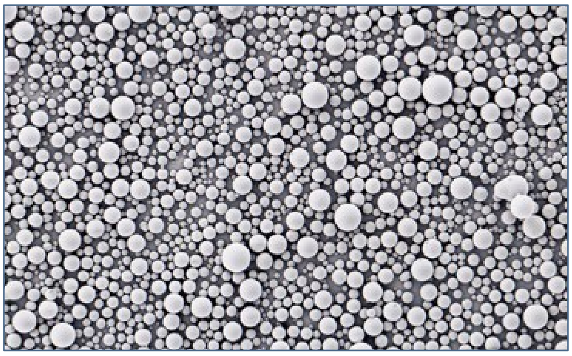


Fig. 3 Spherical PMMA powder (bead polymer) at 50x magnification. The different diameters of the particles enable high material density and thus reduce shrinkage and the release of residual monomer.

This work was perfected by the Kulzer company, which launched Rapid-Paladon on the market in 1949.[58] Today, the worldwide annual consumption of PMMA amounts to several hundred tons.[64] This makes it the most widely used non-metallic material for the fabrication of dental restorations and removable orthodontic appliances today. Starting from the liquid monomer methyl methacrylate, the double bonds are split to form long chains or networks, which then form the polymer PMMA.

This type of polymerization cannot be realized in the dental laboratory. In addition, shrinkage of approx. 25 % occurs. For this reason, a powder (polymer)-liquid (monomer) system has been used since the introduction of the Paladon process. In this process, the liquid monomer (methyl methacrylate = MMA) and the solid polymer powder (poly- methyl methacrylate = PMMA) are mixed together and shaped. The desired denture or orthodontic appliance is then created through polymerization.

There are two processes for producing the powder: block polymerization and dispersion. In the former, a primary polymer block is produced from the monomer, which is then broken down into splinters (splinter polymer). Production using the dispersion process is considerably faster. This results in polymer beads with diameters between 0.001 and 0.2 mm (Fig. 3).

Depending on how the composition and size of the particles are selected, the properties of the acrylic can be influenced.[63] Splinter and bead polymers exhibit different properties due to their different shape, despite having the same chemical structure of the polymer. Splinter polymers are of high molecular weight. In other words, they release less residual monomer and have lower water absorption.[52] Mixtures of bead and splinter polymers were used to optimize the properties. Today, almost only bead polymers are used as they allow more efficient production.

The salt-and-pepper technique

A new era in the production of removable orthodontic appliances began in 1963 with the introduction of Orthocryl® by the Dentaurum company.

Fig. 4 Orthocryl® was the first PMMA acrylic for producing orthodontic appliances using the salt-and-pepper technique in 1963.

Both in terms of material properties as well as processing. You can read up on the product history of this material in the interview with Jochen Peter Winkelstroeter at the end of the article.

The well-known and widely used scattering technique (salt-and-vinegar technique / salt-and-pepper technique)[41, 46, 55, 60] represented an enormous advance (Fig.5).

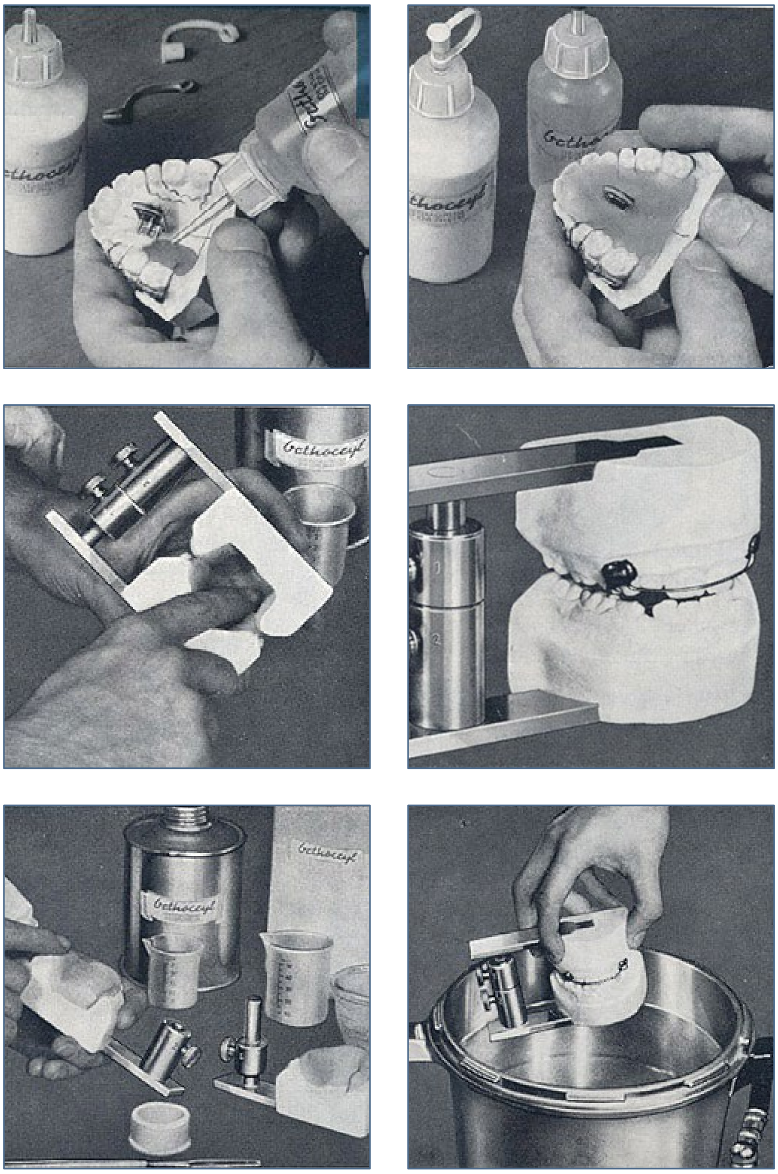


Fig. 5 The first illustrated processing instructions for the salt-and-pepper technique with Orthocryl® dated 1963.

Modelling the plates from wax, embedding and devesting, and thermal polymerization were cumbersome and associated with numerous risks. The clasps and archwires could bend, the hollow mold could only be filled incompletely or the plate could break during devesting.[1, 57] These risks could be avoided with the salt-and-pepper technique or spray-on technique[41, 46, 60.] This, together with the time savings, were the main reasons for the rapid popularity of this method. Orthocryl® and other comparable cold-curing acrylics can also be used in the classic doughing or modelling technique[46, 60] in addition to the salt-and-pepper technique.

Yet progress has its price. The downside of using cold-curing acrylics are the different properties of this variant of PMMA acrylic. Compared to the hot polymers used until now, the polymer chains are shorter and therefore the proportion of residual monomer is higher. As will be shown, these drawbacks can be compensated for and make their use acceptable from a medical point of view.

Basically, the method has not changed during the last few decades.

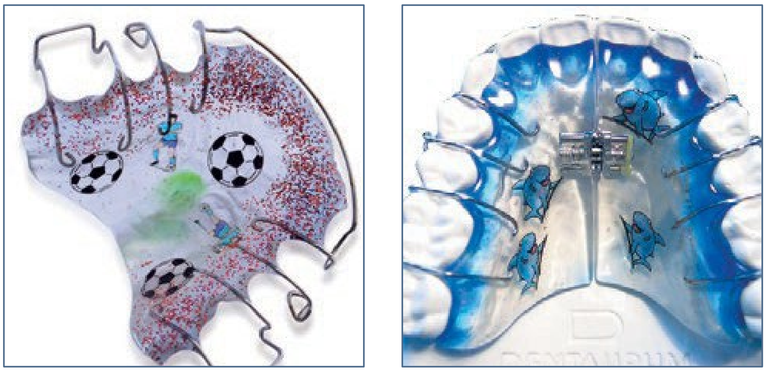


Fig. 6 Different colors, glitters and decals offer endless design options for the production of removable orthodontic appliances.

Fig. 7 Orthocryl® black & white.

However, numerous variants are available for the design of removable orthodontic appliances. For example, next to various plastic colors, glitter elements (Orthocryl® Disco glitter) and decals are available (Fig. 6). With Orthocryl® black & white, there is another variant which offers interesting creative freedom (Fig. 7). The individual design of appliances is extremely popular with children and adolescents. Dentaurum offers patients the opportunity to design their own plate in terms of color, glimmer and decals with the brace configurator (Fig. 8). This then forms the template for the dental technician to fabricate the removable appliance.

PMMA – the material

These days, PMMA is generally used for removable orthodontic appliances. Compared to the acrylics used for prosthetics, they are softer and less rigid.[50] The acrylic is supplied in two components (see Table 1).

Fig. 8 The Dentaurum braces configurator allows patients to design their own plate per iPhone or Android app.

Tab. 1 Composition of Orthocryl® (Dentaurum).

Substance	Function	Proportion
Polymer powder		
Polymethylmethacrylate	Plastic compound	98 %
Benzoyl peroxide	Initiator component	0.5%
Dyes	Color scheme	< 0.5%
Monomer		
Methyl methacrylate	Plastic compound	> 90%
Ethylene glycol dimethacrylate (diacrylate)	Cross-linking monomer	< 10%
N,N-Dihydroxyethyl-p-toluidine	Accelerator	≤ 0.5%
Hydroquinone monomethyl ether	Stabilizer	50 ppm
Dyes	Color scheme	< 0.5%

The powder largely consists of bead polymer (Fig. 3) as well as dyes and control substances. The liquid contains approx. 90 % MMA monomer, which is unstable in aqueous solutions[3] and has a high vapor pressure. This explains the potent odor. Add to this the control substances and dyes. The dyes in the polymer or monomer enable the well-known variety of colors of orthodontic appliances.

The mixing ratio of powder and liquid depends on the type of primary polymer (bead, splinter or mixed polymer) and a necessary surplus. To obtain a processable plastic dough (mash), the monomer must fully moisten the powder and coat all the polymer particles. Additives such as dibutyl phthalate improve the solubility of the high molecular weight MMA.[21]

Polymerization

Polymerization takes place in three stages[8]:

- *Starting phase*

After mixing the components (MMA+PMMA), the swelling phase begins. Here, the monomer diffuses into the primary polymer particles and dissolves them on the surface. By supplying energy (heat, light, pressure, initiators/catalysts), the carbon double bond of the MMA is split and the first monomers react with one another and form growth nuclei. In the case of orthodontic cold-curing acrylics, the dibenzoyl peroxide is excited to decay by the presence of the tertiary amine in the monomer and a small heat supply (40-65° C.). Benzoyl radicals are formed which provide the necessary energy for starting the polymerization reaction of the monomer.

- *Growth phase* (exothermic)

The flowability of the mixture and thus the respective variant of the processing (e.g. salt-and-pepper technique, wet and injection processing) are influenced by the average molecular weight and the degree of crosslinking of the polymer particles. This produces a mass which first becomes thin, then viscous and then plastic. In this "mash", the monomer polymerizes and forms chains or networks with one another and forms the primary, almost completely intact polymer particles. As a reactive filler, these have the object of reducing the unavoidable polymerization shrinkage from more than 20% to 1-2%. [64] Only the monomer shrinks during curing.

- *Termination*

Polymerization ends when all achievable monomer molecules have been used up or have been incorporated into the network. The chain length determines the quality of the product and the release of residual monomer. One indicator of this is the degree of polymerization, this gives information on how much monomer has been converted to polymer. At 100%, all monomer molecules would be used up, i.e. polymerized. Such a state is not achieved in any chemical reaction, so there will always be unreacted monomers (residual monomers) which remain in each polymerization reaction.

Cold-curing acrylics contain porosities, which lead to the absorption of water or saliva and thus also of microorganisms.[38] At 19 and 25 µg/mm, orthodontic acrylics have a slightly higher water absorption than hot polymerizates and thus still lie below the specified threshold of 32 µg/mm for denture acrylics and orthodontic acrylics (DIN EN ISO 20795).[3, 13, 6]

Formaldehyde

PMMA powder and monomer do not contain formaldehyde. However, it has been shown in vitro that formaldehyde can be formed during polymerization by oxidation, the amount of which depends on the polymerization conditions.[35, 45] Cold-curing acrylics have a higher proportion of formaldehyde than hot polymers.

The initiators

The polymerization process is started by the reaction of the initiators. These require energy to start their reaction. Sources for this are heat, chemical reactions (redox systems) or light. The initiators and temperature control determine the polymerization process and have a decisive influence on the quality of the acrylic and the proportion of residual monomer.[64] Modifications to the initiator-accelerator complex and the monomer liquid resulted in acrylics that could be used in salt-and-pepper technique.[43]

Hot polymers

Hot polymers contain dibenzoyl peroxide in the polymer. The liquid consists exclusively of a mixture of different monomers, but mainly methyl methacrylate. Heating provides the starting energy. The result is high molecular weight acrylics.

Orthodontic acrylics

Orthocryl® and other comparable products are low-molecular cold-curing resins. Dibenzoyl peroxide (BPO)-based systems are used as initiators in salt-and-pepper acrylics.[30, 45, 64] The energy required to start polymerization is also applied by heat, but at much lower temperatures (approx. 45°C). Cold-curing resins also contain similar levels of dibenzoyl peroxide in the polymer as do hot polymers. The difference lies in the composition of the liquid. In addition to the monomer mixture, it contains tertiary amine. The amine lowers the decomposition temperature of the dibenzoyl peroxide present in the polymer from > 100°C to < 50°C. The radical polymerization reaction is only initiated through the decomposition of benzoyl peroxide. It is only the difference in reaction temperature that is responsible for the higher content of residual monomer in the orthodontic acrylics compared to the hot polymers[59].

Barbiturate-based catalyst systems are used for denture acrylics. However, dibenzoyl peroxide is always present in the polymer. The advantage of these systems is said to be the lower residual monomer content and the lower discoloration tendency of the polymers. This hardness system can be applied to orthodontic and denture acrylics.

Light-curing acrylics

In these acrylics, photoinitiators are stimulated to react by light of a certain wavelength (nowadays usually 460 nm). Camphor quinone decomposes into energy-rich radicals.[23] The energy released by these highly reactive radicals starts the actual polymerization. In the case of light-curing materials, the monomer vapors known from the scattered plastics are dispensed with. In light-curing acrylics, when compared with cold-curing resins, relatively high molecular weight monomers, i.e. larger monomers, such as, for example: urethane dimethyl acrylate (UDMA), are used.[43] Their odor is barely perceptible due to the lower vapor pressure. Depending on the consistency, they have a better shape behavior and different mechanical properties. Their processing is much simpler and time-saving.[43]

The controllable risk of PMMA cold-curing acrylics

If problems occur in individual patients, a "material intolerance" is regularly inferred. However, practice has shown that only a very small number of complaints are attributable to a direct chemical effect of the materials. Instead, the main focus is on the wearing style, the mechanical stimuli emanating from the plate, occlusion errors and mouth and denture care.[4] Erythema of the oral mucosa is the first visible and at the same time most unspecific sign of every inflammation. If this redness is in congruence with the plastic plate, there is suspicion of directly or indirectly material-related problems. Allergy to PMMA is much less common than thought. Such reactions do occur[20], but the prevalence of confirmed cases lies well below 1%.[51, 59] As such a contact allergy is not possible due to the compact acrylic plate, but only to the acrylic eluates (dissolved substances), the best prophylaxis is to minimize them. Specifically, it concerns the elution of residual monomers and inhibitors or catalysts. The same applies to any toxic reactions by methyl methacrylate, which is known to be a respiratory and cellular poison.[34, 38, 61] The bottles are also labeled accordingly. On the other hand, the polymerized PMMA is highly biocompatible.[47]

Residual monomer

Unbound monomer is left over in every polymerization. Its amount depends on various factors, for example the choice of bead polymer, splinter polymer or copolymer. For each type of polymer and processing (salt-and-pepper or dough technique) there is an optimum quantity of monomer in order to achieve complete polymerization on the one hand and to limit the residual monomer content on the other hand.

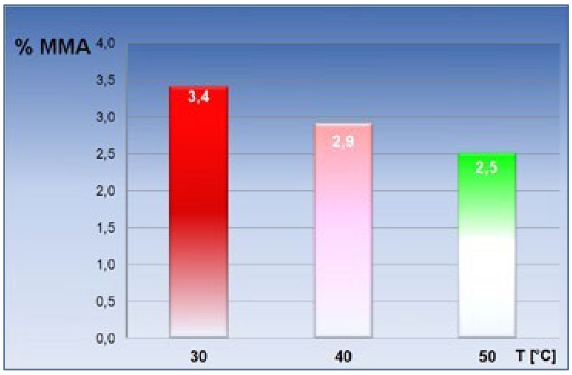


Fig. 9 The quantity of residual monomer also depends on the temperature during polymerization (t = 25 min., p = 2.2 bar).

In this respect, the manufacturer's instructions must be strictly adhered to.[64] In the case of Orthocryl®, the mixing ratio of PMMA to MMA is 2 : 0.8 for the salt-and-pepper technique and 2.5 : 1 for the doughing technique.

Hot, cold and autopolymers are optimized by catalysts and inhibitors for the respective area of application and thus have a different degree of polymerization. The higher the temperature, the less residual monomer remains (Fig. 9). In the study by Lamb et al.[36], the proportion was 1.6% at 55° C (15 min). At a temperature of 22° C (30 min), on the other hand, it was 4.4%. A prolonged polymerization process (7 hours) leads to a high degree of polymerization and thus to less residual monomer and correspondingly less mucosal reactions.[2] In the case of hot polymers, the residual monomer content usually lies well below 1 %.[43] The cold-curing acrylics used to produce orthodontic plates have the highest content of residual monomer due to the material.

The thickness of the acrylic also has an influence on the release of residual monomer.[2, 36] In particular, the unpolymerized, i.e. free monomer molecules on the surface can be extracted by diffusion[36] As a result, local toxic effects[24, 52] on the mucosa are also conceivable. When MMA comes into contact with molecular oxygen, formaldehyde can form and act as an allergen.[45] However, sensitization or allergic reaction to MMA is a rare event.[3, 38] PMMA-based bone cements were used to cement hip joints. In such cases, MMA can enter the bloodstream but is broken down within a few hours.[10]

However, the crucial question is not how much residual monomer is present in the plate, but how much of it is released![34, 59] In vitro studies on this topic were conducted as early as 1966, and further articles have been published regularly to this day.[28, 34, 40] Recent studies, too, have only confirmed known facts and have not identified any dramatic changes.

Depending on the examination method and the production of the orthodontic plates, residual monomer eluations of between 0.15% and 4.7% were found.[34, 35, 38, 55] Depending on the results, the authors assessed this release as being non-toxic or slightly toxic.[43] These results, which are always determined in vitro, must be interpreted in a clinical context.

Elimination of residual monomer

Within the first 24 hours, most of the residual monomer is released in the water. Further release is a very slow process.[3, 35, 55] If the plates are not incorporated immediately after production, but are initially stored in water for at least one day, the risk to the patient, which is only present latently in any case, can be significantly reduced.[3, 55] In the oral cavity, the plate is repeatedly rinsed with fresh saliva. Water from saliva and the contained oxidative enzymes such as myeloperoxidase and temperature lead to faster decomposition of MMA and thus to accelerated elimination of residual monomer. When monomer enters the digestive tract, it is broken down by stomach acid. No residual monomer could be detected in either blood or urine shortly after fitting an appliance.[3] The mucus layer on the surface of the orthodontic appliance forms a barrier for the diffusion of the residual monomer into the oral cavity. On the other hand, on the side of an appliance facing the mucosa, a concentration of monomer four times higher is present in the saliva layer than in the free saliva. This could be a cofactor in inflammation of the mucosa.[3]

From a toxicological point of view, polymerized PMMA is harmless and of minor allergological relevance.[61] Local toxic reactions of the residual monomer have only been reported for fixed dental restorations[52] and not for removable orthodontic appliances. The effect is short-lived because the concentration of the residual monomer rapidly drops below the irritation threshold.

Dibenzoyl peroxide & Co.

Other problematic substances are the stabilizers, inhibitors, organic and mineral dyes and catalysts contained in the acrylic.[59] Dibenzoyl peroxide can be detected in the plate body, but did not dissolve when stored in artificial saliva. In addition, dibenzoyl peroxide has a very short temperature-dependent half-life. The remaining dibenzoyl peroxide can also be removed by post-polymerization.[7, 59] Dibenzoyl peroxide has a highly irritating effect on the skin, which is often misinterpreted as an allergic reaction in the epicutaneous test (ECT).

Dermatologists are increasingly advising against testing this substance at all in the ECT because the frequently occurring false positive test results lead to unnecessary treatment cascades.

Orthodontic plates are manufactured in a wide variety of colors and with glitter. The powder Orthocryl® is neutral in color. The monomer contains a wide variety of dyes (anthraquinone), which neither impair the biocompatibility[49, 62] nor the mechanical stability[31] of the end product.

As a prophylaxis, many authors [28, 34, 40, 43, 44, 52] recommend that the removable plates be stored in (distilled) water for at least 24 hours before being fitted. As a result, a large part of the residual monomer and of the unbound ingredients is already eluted. When scheduling appointments, one should remember to allow the laboratory time for storage in the water. If the patient stores the appliance in water, the tendency of the metal inserts to gap corrosion is reduced.

Processing

Damaging factors can be reduced or even eliminated even during the production of a plate (see Table 2). This starts with mixing, which must always take place strictly according to the Instructions for use. The dosage cannot be measured with the salt-and-pepper technique. Only as much monomer should be used here as is necessary to moisten and shape the PMMA powder. Underdosing leads to porosities and powder inclusions in the appliance, to inhomogeneous curing and thus to poor material properties. Overdosing of the liquid results in the mash flowing away and in a higher content of residual monomer in the appliance.

After scattering the plate, complete polymerization must be performed in the pressure vessel (e.g. Polyclav, Dentaurum) with warm water (45°C).[36] A heating plate keeps the water temperature in the pressure vessel constant (Fig. 10). The warm water is not primarily used to accelerate the process: More important is the higher degree of polymerization that can be achieved. For Orthocryl® and Orthocryl® EQ the polymerization time is 25 or 20 min at 2.3 bar. An extension of these times increases the degree of polymerization and thus lowers the content of residual monomer. Falling short of the specified minimum times causes exactly the opposite and worsens the material properties.

Increasing the temperature by 10° C. leads to a doubling of the reaction rate and to a halving of the reaction time. An increase by 20° C quadruples the values. The start-up phase is an endothermic process. After the start of polymerization, heat is released by an exothermic reaction. This can increase under ambient pressure into regions which lie above the boiling point of methyl methacrylate.

Tab. 2 Errors in the processing of salt-and-pepper

Problem	Cause	Remedy
Air bubbles in the appliance	Boiling bubbles, insufficient watering	Optimum pressure and temperature in the pressure vessel, sufficient watering, no opening of the pressure vessel during
Pores / snowflakes / white spots	Cool room temperatures, strong air suction	Higher room temperatures, use of EQ-polymer
Discolorations on wire elements and expansion screws	Gap corrosion	Storage in water
Curing of monomer	Storage too hot	Shelf life is extended by storing in a cool place.
Accuracy of fit	Wrong separating medium, unfavorable conditions for polymerization	Use thin-flowing alginate insulation, allow to stand longer before placing in the pressure vessel

This inevitably leads to boiling bubbles in the plate (Fig.11). For this reason, polymerization must be performed in the pressure vessel at 2.3 bar. Furthermore, the monomer and water form an azeotropic mixture with a boiling temperature of 78° C. If the specified temperature is not maintained, polymerization is not complete after the regular time has elapsed.

The pressure during the polymerization has further functions. It compresses the mash and prevents boiling bubbles. Here too, the properties deteriorate due to underdosing.

Fig. 10 A heating plate allows the water in the pressure vessel (Polyclav, Dentaurum) to be kept constant for the entire polymerization period.

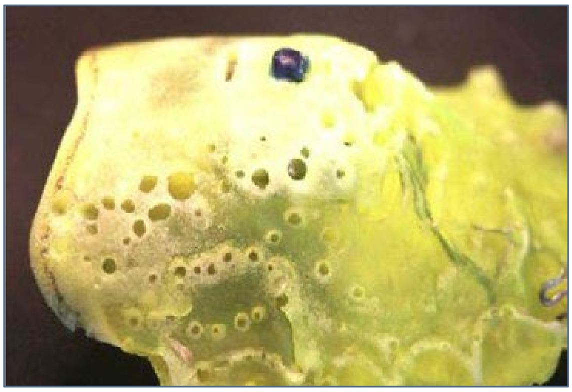


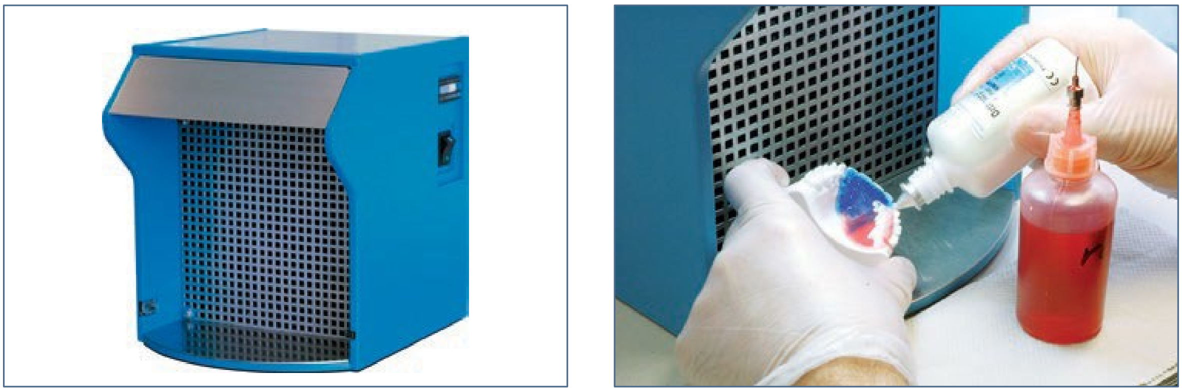
Fig. 11 Bubble formation in the acrylic due to processing errors. The model was not watered and boiling bubbles appeared.

Postpolymerization

The entire polymerization process can take up to 500 hours.[55] This gradually reduces the proportion of residual monomer.[36, 59] This effect can be exploited by targeted postpolymerization, for which various procedures have been described.[15, 18, 43] For patients with a known allergy to critical ingredients of the cold-curing acrylics, a classic hot polymer[43] could also be used, or, for example Orthocryl® LC (see also Section Orthocryl® LC).

Staff problems

Compared to the affected patients, the exposure of the practice team, in particular the dental technician, to MMA and PMMA is significantly higher in terms of frequency and intensity.[29] Inhalation of MMA vapors is questionable from a toxicological and allergological point of view and must be expressly prevented.[61] Appropriate extraction devices with activated carbon filters (Dentaurum, Fig. 12) are available for this purpose. In the case of inhalation of MMA vapors, the threshold is 410 mg per m^3 per 8 h (Health and Safety Executive, 1986)[3]. But it is not only MMA vapors that are dangerous for the dental technician. MMA is a highly effective solvent that destroys the protective barriers of the skin. If the contact frequency is appropriate, non-allergic contact dermatitis and later allergic contact dermatitis may occur. Therefore, direct skin contact with the MMA should be avoided, e.g. by wearing appropriate gloves (Fig. 13) or by consistent skin protection management with various creams.[29, 42, 61] The end product PMMA, on the other hand, is harmless.



Figs. 12 a and b Extraction units with activated carbon filter (Dentaurum) (a) should be the standard for processing (b) to avoid monomer vapors in the laboratory.

Fig. 13 When processing MMA, direct skin contact must be avoided by wearing suitable gloves.

Future

The era of salt-and-pepper acrylics is certainly far from over. New developments promise interesting additions or alternatives to a technology that is more than 50 years old.

Orthocryl® LC

There have been repeated attempts to produce orthodontic plates from light-curing acrylics.[43] In 1990, Triad Gel VLC (DENTSPLY) and Wil-o-dont (Wilde), two acrylics designed for this purpose, entered the market. However, they did not prove to be optimal for this indication.

The main problems with these acrylics developed for prosthetic use are the limited color range, insufficient viscosity of the paste, light units that are too small, the very high strength and insufficient elasticity of the polymerized material.[30] This can result in fine chipping of the acrylic, particularly at the emergence points of the wires (Fig. 14).

The fractured surfaces are always sharp-edged. Light-curing acrylics exhibit a higher surface hardness than Orthocryl®.[11] Although less residual monomer is eluted from them due to the significantly larger molecules, some products have in the past demonstrated cytotoxic effects in in vitro tests.[47, 48, 62] The problem was probably due to reaction products from an incompletely removed oxygen inhibition layer.[23]

Fig. 14 In the case of light-curing acrylics with increased brittleness, cracks may occur at the exit points of the clasps.

With Orthocryl® LC, a light-curing acrylic is now available for the first time whose properties largely correspond to those of the classic Orthocryl® (s. Table 3) and which meets the special mechanical requirements of expansion plates, occlusal splints, bimaxillary and other orthodontic appliances.[22, 32, 39] In addition, the material can also be used for the production of anti-snoring appliances and surgical stents.

Like all light-curing acrylics, the single-phase Orthocryl® LC consists mainly of urethane dimethacrylate (see Table 4). The acrylic, which is always ready-to-use, can be easily dispensed with the injector and applied with pinpoint accuracy. Since the monomer is present in a gel form with low vapor pressure, the problems caused by the monomer of the salt-and-pepper acrylics (allergenic or irritative potential, flammability, respiratory and skin protection for technicians, etc.) are eliminated here.

Tab. 3 Comparison of the physical properties of Orthocryl® and Orthocryl® LC

	DIN ISO 20795-2	Orthocryl®	Orthocryl® LC
Viscosity(23°C) [Pas]	_	_	85
Flexural strength [MPa]	50	88	80
Modulus of elasticity [MPa]	1500	1905	1898
Compressive strength [MPa]	_	150	139

Tab. 4 Main constituents of Orthocryl® LC (Dentaurum)

Substance	Function
Aliphatic urethane dimethacrylate	Plastic compound
PEG-400 dimethacrylate (polyethylene glycol dimethacrylate)	Plastic compound
Butanediol dimethacrylate	Plastic compound
Pyrogenic silica	Improvement of consistency
Photoinitiators	
Stabilizers	
Color pigments	

The gel-type Orthocryl® LC is characterized by an optimum balance between sufficient viscosity and high stability (Fig. 15). The different colors (Fig. 16) allow for very individual patterns that are not possible with a salt-and-pepper acrylic. When designing such patterns, one has considerably more time, as polymerization only starts with the application of light (wavelength 400-500 nm). In a sufficiently dimensioned light polymerization device, this takes between three and nine minutes, depending on the appliance. Compared to the salt-and-pepper technique, the technician only needs to adjust minimally, but saves time (see Table 5). Material shrinkage is very low, as a result the expansion plate fits the teeth perfectly (Fig. 17).

Fig. 15 Orthocryl® LC from Dentaurum (right) has a significantly higher stability than the Triad gel (left) when applied.

Fig. 16 Color spectrum of Orthocryl® LC

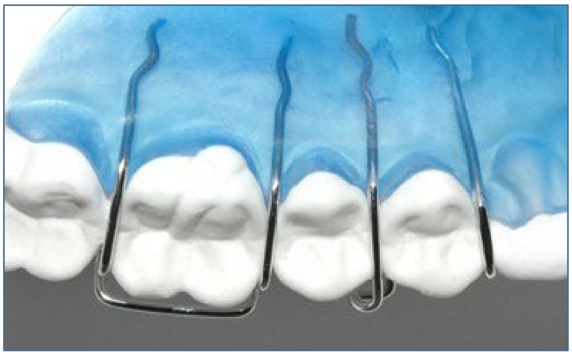


Fig. 17 Orthocryl® LC has little shrinkage and thus achieves an outstanding fit.

Tab. 5 Time savings when processing Orthocryl® LC using an expansion plate as example

	Orthocryl® LC [min]	Salt-and-pepper technique [min]
Watering the models	Not applicable	10-30
Separating medium	1	1
Material application	<2	3-4
Polymerization	6	20-25
Finishing & Polishing	6	7
Sum:	15	41-67

All light-curing acrylics which have not been polymerized under vacuum form a 25 to 100 µm thick oxygen inhibition layer. Part of the acrylic in this greasy layer is not polymerized and has a toxic effect. Therefore, the lubricating layer must be removed in the laboratory. Without this layer, the polymerized material has no or a very low toxic effect.[43, 47, 62]

Therefore, Orthocryl® LC may not be applied directly in the mouth, where the inhibition layer cannot be removed completely. In the case of light-curing acrylics, UDMA is eluted. However, the percentage share is lower than the MMA from the cold-curing acrylics. As already indicated, this is due to structural reasons. The UDMA molecule is substantially larger and thus more immobile, i.e. difficult to elute. The difference in vapor pressure probably also plays a role. The largest proportion of both monomers is eluted in the first three days.[43]

Antimicrobial additives

Acrylics that contain antimicrobial agents (nano-, micro-silver, triclosan) or are coated with nanoparticles are currently at an experimental stage. Their effects are not yet known in all details.[6] All additional substances in the base material may also have undesirable adverse reactions in addition to the desired effects. The question then arises as to whether such additives are necessary, as the consequences of microbial colonization can be minimized with adequate care.

CAD/CAM

Digitization in the production of dental restorations is well advanced, regardless of whether this involves additive (e.g. selective laser melting, printing, stereolithography) or subtractive (e.g. milling technique) processes. Plate prostheses can also be produced digitally. In principle, these procedures are also conceivable for the production of orthodontic appliances. However, the integration of clasps and expansion screws is problematic. Here, there is still not a more efficient method than the salt-and-pepper technique or the use of light-curing acrylics.

General problems with plates

Despite all the progress made with the introduction of rubber and later of various acrylics for prosthetic dentistry and orthodontics, similar problems were observed time and again. These related primarily to irritations of the mucosa. Whereby it is irrelevant for the pathophysiological processes whether it is a mucosa-covering dental restoration or an orthodontic plate. Insofar as this is the case for both therapeutic agents, only plates are referred to in the following. The covering of natural hard and soft tissue by the plates leads to completely new conditions in the biotopes of the oral mucosa and tooth surface. Among other things, this causes disruptions or pathological changes to the physiological processes of the mucosa. The disorder is primarily caused by four factors:

- impaired self-cleaning of the mucosa by covering the bacterial
- colonization
- the mechanical irritation of the plates
- the physico-chemical characteristics of the plate materials.

All of these known problems with PMMA can be eliminated or minimized by appropriate processing and wearing techniques.

Depending on the individual anatomical, physiological and pathological conditions[53], the flexibility and disposition of the patient, the consequences of wearing plates resp. the plate-related disorder vary between absolute tolerance and local or general intolerance. In orthodontics, the former is the rule and the latter the very rare exception.

Covering the mucosa

Covering the mucosa creates completely different conditions for this microbiotope.[17, 38] Depending on the daily wearing time of the plate, removal of the desquamated epithelial cell remnants, for example, is temporarily impeded. These cell remnants break down between the plate and the mucosa, producing a bad taste and bad breath. Wetting of the mucosa and temperature conditions change. A suspected build-up of heat under the plates is also discussed repeatedly.[5, 17, 34] It is well established that "round-the-clock" wearing of mucosa-covering plates is the classic predictor of prosthetic stomatitis.

Colonization by germs

The germ colonization of plates is a well-known problem. The more or less rough surface of removable plates, the microstructure of PMMA-based cold-curing acrylics and the resulting comparatively high water absorption allow plaque and microorganisms per se to adhere well.[14, 26, 27, 52] Yeast fungi in particular love the slightly more acidic environment under the plate.[12, 19] Wire elements and expansion screws provide additional retention surfaces. The microorganisms can also penetrate through the porosities together with the water into deeper layers of the plate. A clear indication of this is the fetid odor that occurs when grinding worn plates.

Prosthetic stomatitis and gingivitis may result as a consequence of microbial colonization. In addition, the germs settling under the plates are also regularly found in the pharynx, from where they are aspirated.

However, these germs can not only cause damage to the wearer of the plates, but also become the start of an infection chain of the patient/practice team and laboratory.[14] In healthy patients this is not a problem. But caution is advised in the case of impaired immune defense.[25] However, almost all microbially induced problems can be controlled solely by oral and plate hygiene adapted to the respective condition. The simplest measure is a regular plate waiting period. In addition, there are sufficient mechanical and chemical cleaning and disinfection methods.

Plate-related mechanical irritation

Removable prostheses and orthodontic appliances are subject to various force attacks in the oral cavity, which lead to the movement of the plate. In addition, there is the incongruity between the plate and the jaw resp. the teeth. These purely mechanical factors are the most common cause of irritation, hyperemia, and hyperplasia of the mucosa.[17, 37, 54]

The symptoms of mechanical and chemical irritation[53] are very similar, making differential diagnosis difficult. Since the prevalence of mechanical irritations of the mucosa is significantly greater, these things should first be clarified.

Conclusion & tips for the practice

Orthocryl® and comparable cold-curing acrylics for the production of removable orthodontic appliances have been used successfully for more than 50 years. The known risks of PMMA acrylics can be largely avoided by taking appropriate measures. If the appliances are stored in water for at least 24 hours prior to fitting and cleaned regularly, the material poses no risk to the patient. It is quite apparent that chemical and physical irritation from the plates is overrated. Nonetheless, intolerance to individual components of the acrylic cannot be ruled out completely. In relation to the more than 250 million plates produced worldwide, the cases described are exceptions and lie in the per mille range. An alternative is available for such patients with the new light-curing Orthocryl® LC. In addition, removable appliances can be fabricated even more efficiently with this material, which has been specifically developed for the requirements of orthodontics.

In conclusion, the benefits of using acrylics for orthodontic appliances are so great that the potential (and manageable) risks fade into the background. Although both prosthetic and orthodontic plates can be partially replaced by fixed solutions, they still have an important role to play.

If the indication is given and the removable appliance is the most efficient individual solution, it would be contrary to any medical responsibility not to use such appliances.

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Abstract:

Orthocryl® and comparable cold-curing acrylics for the production of removable orthodontic appliances have been used successfully for more than 50 years. The known risks of PMMA acrylics can be largely avoided by taking appropriate measures. If the appliances are stored in water for at least 24 hours prior to fitting and cleaned regularly, the material poses no risk to the patient. It is quite apparent that chemical and physical irritation from the plates is overrated. Nonetheless, intolerance to individual components of the acrylic cannot be ruled out completely. In relation to the more than 250 million plates produced worldwide, the cases described are exceptions and lie in the per mille range. An alternative is available for such patients with the new light-curing Orthocryl® LC. In addition, removable appliances can be fabricated even more efficiently with this material, which has been specifically developed for the requirements of orthodontics. In conclusion, the benefits of using acrylics for orthodontic appliances are so great that the potential (and manageable) risks fade into the background. Although both prosthetic and orthodontic plates can be partially replaced by fixed solutions, they still have an important role to play. If the indication is given and the removable appliance is the most efficient individual solution, it would be contrary to any medical responsibility not to use such appliances.

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