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REPORT

Research and Development Ivoclar Vivadent AG, 9494 Schaan / Liechtenstein

DIGITAL DENTURE

THE FAST MONOLITHIC PROCESS

ivoclar digital®

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The path to high quality and accurately fitting dentures involves many labour-intensive and time-consuming tasks if conventional denture manufacturing methods are used. This is at odds with the necessity for technicians to fulfil the patients' demands for "function", "esthetics" and "durability" efficiently, reliably and effectively in line with the ever increasing economic exigencies.

Against this backdrop, the introduction of the digital workflow for complete dentures and the accompanying materials from Ivoclar Vivadent at IDS 2015 ushered in a new era in the manufacturing of removable denture prosthetics. The experiences and user feedback gathered since then inspired us at Ivoclar Vivadent to implement substantial enhancements to the process and outcome.

In doing so, we prioritized the needs of dentists, dental technicians and patients and endeavoured to optimize aspects of reliability, economic efficiency, esthetics and durability in equal measure. The result of our efforts is an efficient and effective end-to-end process that begins by taking an anatomical impression in conjunction with the Centric Tray and UTS CAD in the practice, continues by the digitalization of the patient data in the dental lab to generate a 3D Bite Plate for functional impression taking and ends by inserting the complete denture in the patient at the third appointment without the need for a try-in beforehand. All this can be achieved in a quality that is comparable to that provided by a conventional process.

Several enhancements of the technology and procedure were incorporated into the digital workflow to enable dentists and dental technicians to achieve even better results faster, more easily and more efficiently. The workflow features the software tools "Full Denture" (3Shape), "CAM 5.0" and "Ivoclar Digital Denture Tooth Library", which are a joy to work with because they all offer a range of coordinated CAD/CAM processes. The entire workflow has been optimized for use with denture bases made of IvoBase CAD and tooth segments milled from SR Vivodent CAD discs. Dental labs will be pleased to see that, among other things, the SR Vivodent CAD discs, together with the Smile Composer, enable them to considerably lower their storage costs for prefabricated teeth. In addition, customizations are more easily achieved and the effort required for durable bonding of the teeth and denture base is reduced to a minimum. We also focused on providing optimally integrated, highly reliable processes in conjunction with the new PrograMill PM7 milling unit.

Patients benefit from tooth replacements that offer them an excellent accuracy of fit, functionality and occlusion due to the profiling process developed by Ivoclar Vivadent and 3Shape. The unique oversize milling procedure inherently eliminates all errors occurring during the bonding process. High process reliability makes it possible to accomplish dentures in only two, instead of the three appointments required if a conventional procedure is used. Furthermore, digital dentures can be easily reproduced – i.e. if they are lost or become damaged.

The complete workflow, equipment, software and materials were put to extensive testing in the dental lab and clinic at Ivoclar Vivadent AG and their functionality has been confirmed by external experts. Digital dentures by Ivoclar Vivadent AG meet all the requirements of the applicable dental medical standards. The quality and durability that they offer is in every respect comparable to those of conventionally produced dentures.

We are confident that the new Digital Denture process and the accompanying devices, software programs and materials represent a milestone in the digital design and manufacture of complete removable dentures. The end-to-end process creates value for dentists, dental technicians and patients alike. We hope that you too will enjoy using these products. We are looking forward to hearing from you about your experiences, results and suggestions.

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Development and testing of SR Vivodent® CAD (Multi)

Introduction

Conventional prosthodontics is an area of dental technology that involves a multitude of time-consuming manual steps. Unsurprisingly, efforts to streamline the time-intensive process and make the procedures more user-friendly have been ongoing for some time now. Digitalizing as many of the procedures as possible is an essential step in achieving this.

However, digitalizing the esthetically demanding field of complete prosthetics poses tough challenges to developers. Although elaborately layered, esthetic denture teeth can be produced with appropriate acrylic material, they are difficult to integrate into a digital process. The reason for this is that prefabricated teeth tend to extend beyond the denture base and require shortening. To find a way around this problem, IvoclarVivadent developed a patented process, called "Glue & Mill"[1], to facilitate the integration of highly esthetic teeth into the digital workflow. With this method, the teeth are integrated into the denture base and then reduced (if and as required) by recontouring the basal surface of the denture. Yet, prefabricated denture teeth entail additional problems: for instance, they cannot be customized, involve a complicated cementation process, require the use of a transfer template (normally a dental positioning device) for securing in the correct position and they necessitate a large number of tooth sets of different shapes, shades and sizes to be kept in stock.

Against such a backdrop, our task was to develop a material disc that could be processed using digital technology – and in this case milling tools – without diminishing the physical qualities or esthetics of the teeth.

Chemical structure

Proven DCL material was employed to develop the monochromatic SR Vivodent CAD discs. DCL is short for "double cross-linked" and refers to the high chemical resistance provided by the high degree of polymeric cross-linking. The form and size of the highly cross-linked organic fillers have been tailored for optimum gloss retention and polishing properties. In addition, the fillers are designed to feature a significantly reduced susceptibility to wear. Thus, the DCL polymer formed a reliable basis to develop a material that was able to meet the stringent requirements placed on a material in permanent use.

Some cunning was necessary to design a monochromatic material that could be used to provide esthetic tooth replacements. For this purpose, the existing relationships between pigment-based shading, scattering effect of the translucent fillers and the opacity of the resin matrix were examined in detail. The findings were used to create an optimally balanced variant, for which a patent application was filed[2]. This formulation makes it possible to mill denture teeth and entire tooth segments that feature a translucent incisal area and yet demonstrate the required chroma emanating from the depth of the tooth.

The fillers used in the material provide special gravel-like contours, which distinguishes them from the spherical fillers typically used in dental materials. The uneven shape prevents the filler grains from becoming dislodged if the softer matrix material surrounding them is eroded.

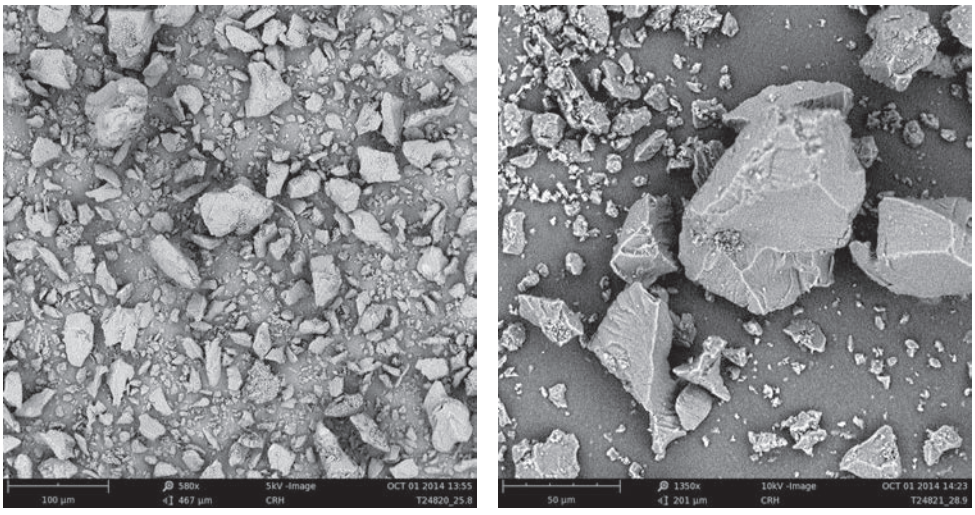

Fig. 1 DCL filler particles
The filler particles shown in the SEM images (at 580 x and 1,350 x magnification) exhibit the desired gravel-like shape. The fillers are structurally intact.

Materials testing

To date, no specific test methods have been defined for testing material discs designed for milling prosthetic teeth. In the light of this fact, the current standard for artificial teeth materials (ISO 22112:2017) served as a guide to test the material in ways that are commensurate with its field of application. In essence, the following material-specific tests, among others, were deemed relevant:

- Bonding to denture base polymer
- Resistance to blanching, distortion and crazing
- Colour stability
- Dimensional stability

For these tests, we first milled teeth, in the appropriate geometry, from the discs and then we tested them in the same way as we would have tested prefabricated denture teeth. The values typically obtained with prefabricated teeth were employed as reference values. In addition, we devised methods to test entire tooth segments. To assess the static benefit of bridged tooth segments, bonded tooth segments and bonded individual teeth were tested under identical conditions. These investigations were extended to test the IvoBase CAD Bond bonding system in conjunction with specified denture geometries (see page 16 onwards).

The manufacturing process has been fundamentally changed by the introduction of the 20-mm material disc. When conventional teeth are manufactured, the resin material is built up in very fine layers, resulting in correspondingly low-volume final moulds that are then polymerized (prefabricated teeth often have a volume of less than 1 ml). By contrast, when discs are manufactured, a bulk-polymerization process is involved with different exigencies: a smooth and homogeneous polymerization and cross-linking process is required to obtain a good material quality and avoid possible material defects, such as porosities or inhomogeneities. While porosities are normally detected in the course of in-process checks, different test methods are required to assess the homogeneity of the material. The chipping test has been especially developed for this purpose and has proven to be one of the most useful methods. In the process, teeth are milled from discs in various configurations and loaded until they break. The fracture pattern and the load-to-fracture value provide a good picture of the quality of the polymerization and the level of homogeneity within the material. They also indicate if the material is too brittle.

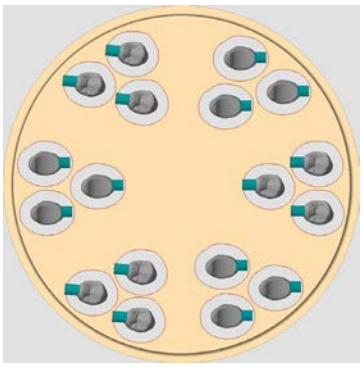

Fig. 2 Teeth arranged on a material disc to perform a chipping test:
the specimens are placed in groups of three that are arranged identically in terms of height and direction. Tooth geometries were milled alternatively from an upward facing and downward facing direction and positioned at three different levels of height on the disc.

Fig. 3 The tooth shown on this image (NU5 Tooth 5) broke at a load significantly exceeding 1000 N (i.e. approx. 100 kg). Typically, the fracture occurred in the buccal area by large-scale chipping. If intrinsic tension had been present in the material, an even fracture pattern at a low load would have occurred.

Material shading of SR Vivodent CAD

Our attention focused on a decisive question: To what extent, if at all, can a monochromatically shaded material match the highly esthetic qualities of prefabricated denture teeth? Having put every effort into working out an elaborate process, we can now with confidence say that **the expectations can be met**. The SR Vivodent CAD material features several unique properties that endow it with extraordinary esthetic qualities, of which the following are key features:

- Monochromatic shading in combination with
- multiple optical effect with intrinsic chroma effect based on an appropriate selection of fillers, and
- proven, sound tooth material

The existing monochromatic disc can be processed in any milling machine that is equipped with a suitable 98.5-mm disc holder. Intuitive software enables users to define any position on the disc to configure the geometries of the teeth. The especially adjusted optical effects of the monochromatic discs provide esthetic results that by far surpass the expectations placed on so-called "mono" materials. This is mainly because the material shows an increase in the shade effect (= chroma) in deeper and thicker layers due to the filler and opacity used in it. At the same time, a sufficient amount of light can pass through the thinner areas to create the required incisal effect.

Material shading of SR Vivodent CAD Multi

Once the SR Vivodent CAD with its favourable esthetic qualities had become available, the call for an additional enhancement of the material's shade effect rose. In response, a multi-chromatic disc was developed and is now available in the form of the SR Vivodent CAD Multi disc.

While individual teeth or tooth segments can be positioned more or less randomly on the disc, solutions involving 3D geometries (e.g. dentin bodies in the shape of elevations) had to be excluded. In other words, a rotational symmetrical arrangement – and in the simplest case a plane layering pattern – was the only feasible solution. And this concept was implemented, albeit in a greatly improved form. The idea was to allow only one height positioning and, at maximum, only a slight tilting of the teeth or tooth segments, while a few essential general conditions had to be met:

- Multilayer optical effect (i.e. clearly distinguishable incisal area)
- Every tooth must contain all layers.
- Transitions between layers must be invisible.
- Maximum variation of shade and opacity in the layers

In view of these requirements, we had to break new ground. It was inevitable to design a new layering scheme from scratch. An incisal and dentin material exhibiting the relevant optical effects (opacity and chroma) were required in order to achieve a multi-tiered effect. The fact that teeth of any size – big or small – always have to contain all layers to ensure a uniform esthetic appearance made it necessary to limit the number of layers to three or four at maximum. The challenge, then, was to achieve a clear change in opacity and colour intensity across a very few layers, without causing perceptible transitions – an occurrence often observed in plane-parallel layered multi-chromatic discs. Straight transitions often result in very noticeable interruptions in the curvy contours of the teeth and these discontinuities can often be seen from a distance, severely impairing the esthetic outcome.

We tackled this challenge by developing an elaborate three-dimensional stratification of the transition zones between the layers, using a technique known as microstructuring. Miniscule flattened cup-shaped structures (0.7 mm in height) emerge from the interface into the lighter stratification above them, creating a horizontal permeation of the normally plane boundaries between the layers. These cup-shaped structures are spaced at a distance of 2.5 mm from each other along lines and are shifted by half a space in relation to the structures arranged above and below them.

Fig. 4 The image on the left shows a graphic visualization of a tooth segment positioned on a Multi disc. The incisal area, shaded in blue, can be clearly seen. Every tooth incorporates all three stratifications. The image on the right shows a thin cut through a disc whose stratifications had been dyed in different shades to examine the layers.

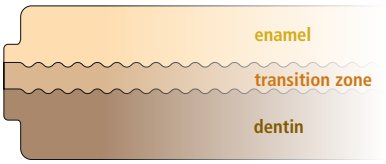

Fig. 5 This image shows the stratification scheme of the disc.
Dentin material makes up the largest part of the disc. The 2.75-mm layer in the middle creates an optically smooth transition towards the significantly lighter and less opaque incisal layer. The cup-like structures that extend into the lighter stratum above them are clearly discernible. Only a (fictional) parallel cut through the disc shows the regular transition structure depicted. The curved outer contours of the teeth result in varying degrees of elevations.

The effect of this arrangement is easy to explain: if teeth are milled from a material that is structured in this way along the interfaces, the cut is performed at an arbitrary site in the transition layer due to the curved shape of the geometry. Valleys or elevations (= cups) are cut completely at random, resulting in completely randomly curved micro-transitions on the outside surfaces of the milled teeth. In view of the fact that the elevations behind the transition line are shifted by half a space, the transitions appear blurred in an imperceptible layer of a thickness of approx. 0.7 mm. This results in a harmonious blend between the differently shaded strata. In effect, this stratification scheme results in two extra layers in the transition zones in addition to the actual three layers. This was fundamental to achieving a sufficiently pronounced gradation in the shade and opacity of the material to provide the esthetic qualities required.

Conclusion

Purpose-designed shade concepts – and, in the case of the multi disc, additional stratification schemes – were essential to develop milling blanks that fulfil the high esthetic expectations placed on a material for artificial teeth in removable denture prosthetics. The high-quality tried-and-tested DCL polymer was the material of choice. It offers a combination of good esthetics and high-performance, showing off its strengths against other PMMA discs available on the market.

Literature

[1] Ivoclar Digital "Glue & Mill Process": Patent EP 2 742 907 B1
[2] Ivoclar "Colour Strategy Mono Disc": Application EP 3 375 429 A1

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Development and testing of IvoBase® CAD

Introduction

In clinical use, denture bases are exposed to high mechanical loading. Stress can build up at the interface between the denture base and the individual teeth. As a result, the risk of material failure rises. The overall load can be reduced by reproducing the dental arch in segments using CAD/CAM technology. This spreads the load among the different parts. Nevertheless, it is of utmost importance for a denture base material to exhibit high fracture toughness. Therefore, it is advisable to use an impact-resistant PMMA acrylic resin for this purpose.

The property of fracture toughness describes the ability of a material to resist crack propagation. Cracking can develop due to a minute flaw on the surface or within the material. The most commonly used impact resistance modifiers in acrylic resins include elastomers and other rubbery components. PMMA-based denture materials generally contain elastic particles in the form of what are known as core-shell bead polymers (Fig. 1). The rubbery core of these bead polymers is surrounded by a hard polymerized PMMA matrix. When the polymer comes in contact with the methyl methacrylate (MMA) liquid, the matrix expands. It polymerizes in the subsequent curing process and thus structurally encapsulates the core. As a result, crack propagation is reduced due to the compensation of the arising stress peaks. The forces are redistributed and the risk of complete failure or fracture of the denture base decreases significantly. Ivoclar Vivadent has developed advanced materials preparation and automated production processes for the reproducible manufacture of high-quality impact-resistant IvoBase CAD denture base discs.

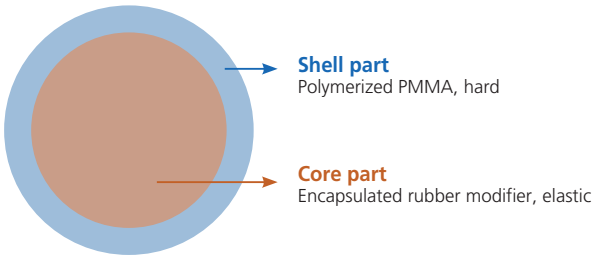
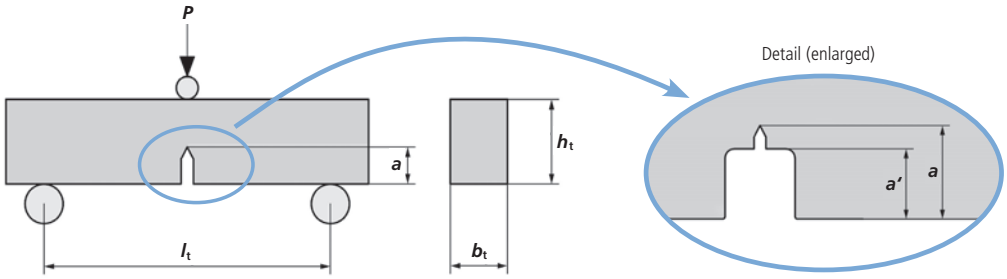


Fig. 1 Diagram of the structure of a core-shell bead polymer

Testing method

The denture base material was examined in a classical 3-point flexural test: a fracture load test set-up with two supporting pins (Fig. 2). Comparisons of various testing methods[1] have shown that fracture toughness tests using a 3-point flexural set-up are more accurate in detecting the effects of changes within denture base materials than impact toughness tests using the Charpy V-notch (pendulum) method. Therefore, fracture toughness is usually expressed in terms of the maximum factor of the loading intensity (K_{max}) and the fracture work (Wf). The latest version (2013) of the corresponding dental standard ISO 20795-1 does not contain any typification or classification of prefabricated milling discs such as IvoBase CAD. In order to establish the physical parameters, the test specimens were digitally designed according to the standard and milled from the discs using special templates. This ensured reproducible data. Furthermore, it allowed comparisons to be made with conventionally used denture base resins.



Hight	h_t	(8.0 ± 0.2) mm	Crack length	a	(0.1 – 0,4) mm longer as a'
Width	b_t	(4.0 ± 0.2) mm	Span	l_t	(32.0 ± 0.1) mm
Pr-crack	a'	(3.0 ± 0.2) mm	Load plunger	P	Point load

Fig. 2 Test specimen with notch in 3-point flexural test set-up

K_{max}: The maximum factor of the loading intensity, denoted as K_{1c}, expresses the intensity of the stress field around the crack tip and it characterizes the required crack opening force perpendicular to the crack surface. Crack growth depends on the level of the stress intensity factor (Fig. 3).

Wf: Fracture work describes the energy required for fracturing a test specimen after crack opening (K_{max}).

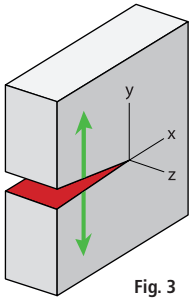


Fig. 3

Testing procedure

For the fracture toughness testing, the test specimens were produced using digital methods. They were directly machined starting from the vertical centre of the disc using specially created templates (Fig. 4). This ensured that the machining parameters of the milling machine (rpms, feed rate, path distance) would be the same as in the clinical fabrication of denture bases. Due to the precise milling parameters and the excellent surface quality of the discs, reproducible test specimens were produced. After the final preparation stage in which a razor blade cut (crack length a) was made as the predetermined breaking point, the test specimens were immersed in demineralized water at 37 °C for one week and then inspected when they were dry.

Fig. 4 Positioning of the test specimens within the disc

The differences in the appearance of the fractures of impact-resistant and non-impact-resistant denture base resins are discussed below on the basis of SEM (Scanning Electron Micrographs) and stereomicroscope images showing comparable magnification.

Figures 5 a + b show a glassy fracture in a non-impact-resistant denture base material (e.g. ProBase Hot). Figures 6 a + b show the crack structure of a high-impact modified acrylic, which is usually referred to as stress whitening. This phenomenon is produced by the material's viscoelastic behaviour during its overexpansion as a result of the elastomeric components.

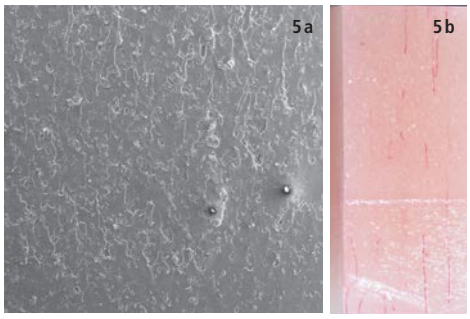


Fig. 5 a + b Glassy fracture of a non-impact-resistant material

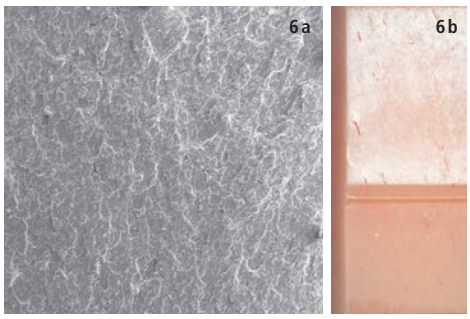


Fig. 6 a + b Stress whitening in a high-impact material

Comparison of materials

CAD/CAM discs:	**IvoBase CAD**	Ivoclar Vivadent AG
	Lucitone 199 Denture Base Disc	Dentsply Sirona
	VITA VIONIC Base	VITA Zahnfabrik

Conventional denture base acrylic:	**IvoBase High Impact**	Ivoclar Vivadent AG
	SR Ivocap High Impact	Ivoclar Vivadent AG
	Lucitone 199	Dentsply Sirona
	PalaXpress Ultra	Kulzer

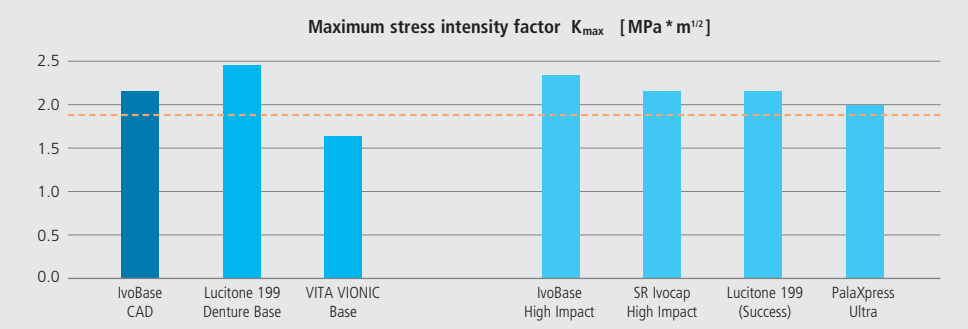


Fig. 7 K_{max} value measured according to ISO 20795-1: 2013, internal data. The graph shows sample values. The orange line represents the minimum requirements (≥ 1.9 MPa*m$^{1/2}$) as stipulated by the standard.

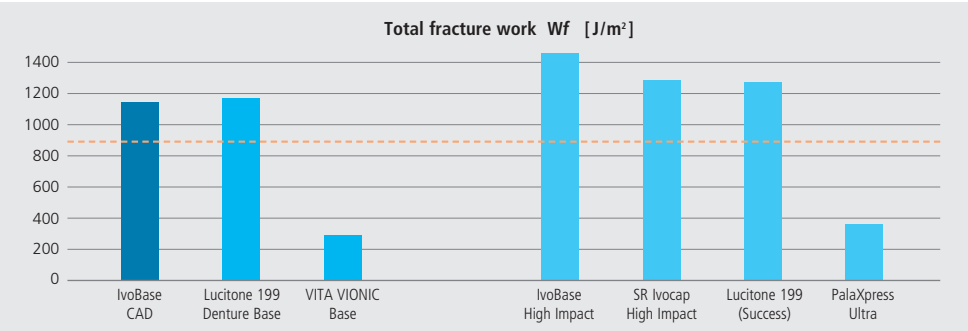


Fig. 8 Wf measured according to ISO 20795-1: 2013, internal data. The graph shows sample values. The orange line represents the minimum requirements (≥ 900 J/m^2) as stipulated by the standard.

The fracture toughness data of the IvoBase CAD milling discs clearly fulfils the minimum requirements according to the applicable ISO standard and are comparable to the values of well-known high-impact denture base resins.

Conclusion

IvoBase CAD represents the successful transfer of the expertise and knowledge gained in the development of market-leading denture base acrylics to the new technological segment of subtractive manufacturing. Apart from many outstanding features, the high-impact characteristics of IvoBase CAD provide a sound basis for digitally manufacturing dentures of exceptional clinical quality.

Literature

[1] Zappini G., Comparison of fracture tests of denture base materials, The Journal of Prosthetic Dentistry, Vol 90/6_2003

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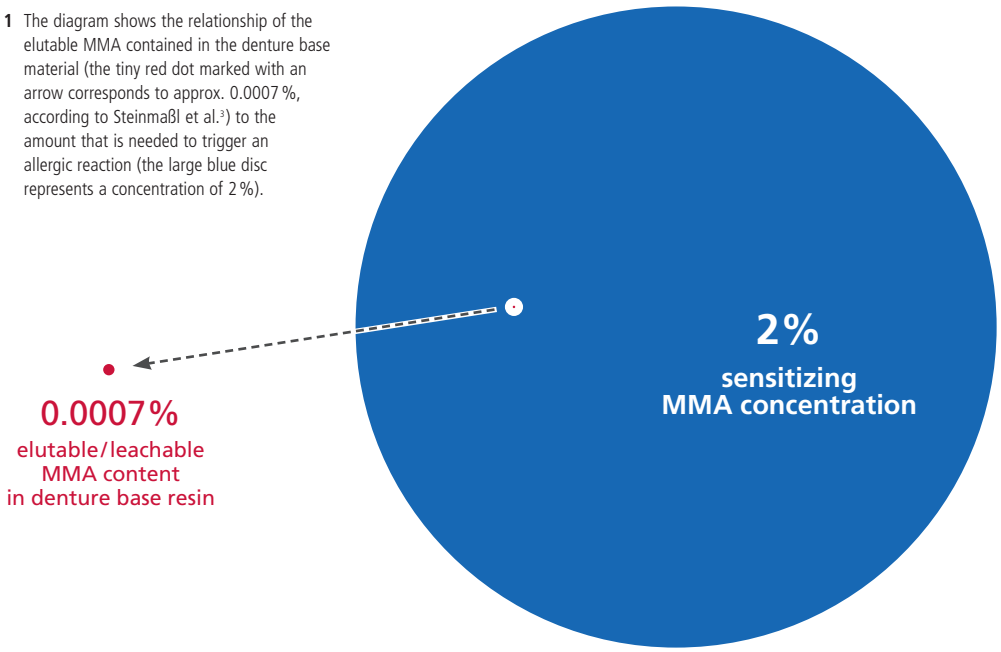
Residual monomer content in IvoBase® CAD

Summary

Residual content of methyl methacrylate (MMA) in polymethyl methacrylate (PMMA)-based denture base materials cannot be avoided. Generally, these residues do not pose any danger to the patient, neither when the denture base materials are processed conventionally nor when they are machined with CAD/CAM systems. The concentration of leachable MMA is much too low for a biological effect to occur. The amount of MMA that can be eluted from denture bases is several thousand times smaller than the amount that would be needed to trigger an allergy.

Fig. 1 The diagram shows the relationship of the elutable MMA contained in the denture base material (the tiny red dot marked with an arrow corresponds to approx. 0.0007 %, according to Steinmaßl et al.[3]) to the amount that is needed to trigger an allergic reaction (the large blue disc represents a concentration of 2 %).



Why do denture base materials contain residual monomer?

In conjunction with a radical polymerization process such as that occurring in polymethyl methacrylate and methyl methacrylate mixtures (PMMA-MMA), a residual content of non-cross-linked monomer molecules inevitably remains. In general, this is referred to as non-ideal kinetics[1]. During polymerization, the reaction rate and degree of polymerization significantly increase at the same time.

This auto-acceleration (Trommsdorff-Norrish effect or gel effect) gets all the more pronounced, the more viscous the system becomes. As polymerization progresses, the system solidifies to a solid mass. Consequently, the diffusion of free monomers is prevented and chain growth is terminated. Once the glass effect sets in, the reaction rate will drop to zero. Therefore, not all the monomer will polymerize completely.

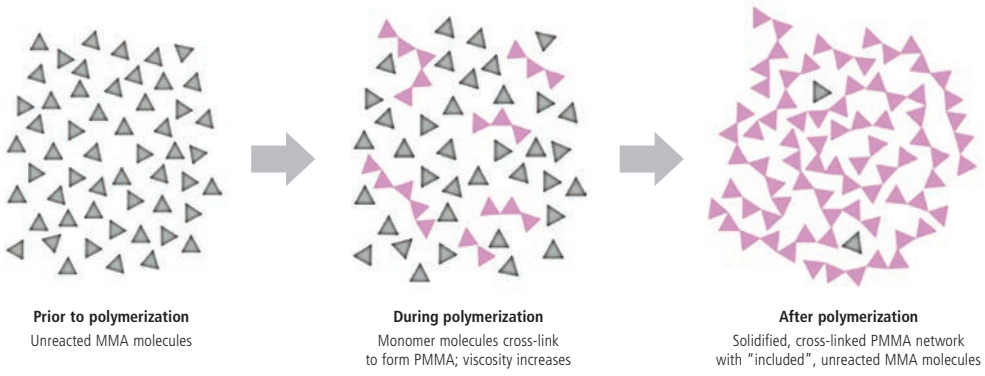


Fig. 2 Polymerization reaction scheme showing the inclusion of unreacted MMA molecules

Why is it impossible to further reduce the residual monomer content even when using industrial production procedures?

The production of 2–5 mm thick denture bases in the fabrication of conventional partial or complete dentures is completely different from the production of up to 30-mm thick discs for CAD/CAM processing. An everyday example provides a suitable analogy: It is easier to evenly bake a 5-mm thick cookie than one that measures 30 mm in thickness. A low layer thickness supports controlled polymerization and the dissipation of the produced heat by means of an exothermic reaction. Therefore, the production of bulky discs can be extremely challenging due to the kinetic energy as described in the previous section. The temperature and pressure used in the procedure need to be optimally adjusted.

Ivoclar Vivadent has succeeded in developing an ingenious process for the industrial production of the high-quality, long-lasting denture base material IvoBase CAD. However, due to the reasons mentioned on the previous page, the product still contains a certain amount of unreacted methyl methacrylate. While the residual MMA content in conventionally fabricated dentures will vary depending on the polymerization time and temperature as well as the geometry of the workpiece, the residual monomer content will always be the same when industrial production procedures are followed and it will remain below the regulatory threshold value. The applied technology in the production of IvoBase CAD discs is of course confidential internal company know-how and will not be disclosed. Apart from their highly appreciated esthetic shading, the industrially produced discs feature proven high impact strength. These attributes make them unique in the market. In combination with the Digital Denture workflow from Ivoclar Digital, IvoBase CAD offers a consistent material performance for reproducible, high-quality results.

At this point, we would like to emphasize that the product complies with the comprehensive physico-chemical requirements of ISO standard ISO 20795-1:2013[2]. Several well-known competitors are unable to provide evidence of conformity regarding these normative references for their products in this segment.

How is the residual monomer content determined?

The methods described in the following section are used to determine and compare the concentration of elutable monomer residue in a material. They represent two different approaches and therefore they cannot be directly compared.

Method A, in accordance with the guidelines of ISO 20795-1:2013 for denture base polymers, involves a chemical separating process (extraction) in which a solvent (acetone) is used to completely dissolve a component (methyl methacrylate, MMA) from a mixture of materials (denture base acrylic). This allows the maximum number of unpolymerized MMA molecules to be established in the acrylic material.

Method B, which was used in a study at the University of Innsbruck, involves a process that simulates the conditions within the patient's mouth. Therefore, it provides a realistic picture of the unpolymerized MMA molecules that could be released from the denture base.

The actual diffusion of monomer represents a decisive criterion when evaluating the criticality of the residual monomer content. As previously discussed, verifying the presence of MMA molecules is essentially a question of method. The valid dental standard for conventional denture base materials, ISO 20795-1:2013[2], requires the chemical extraction (method A) of unreacted monomer by means of a solvent (acetone), which ensures effective detection. However, the result in no way reflects the clinically leachable percentage that would be relevant for allergic sensitization. It is conceivable that saliva or possibly liquids contained in food could leach out the monomer in the patient's mouth. Nevertheless, these fluids are much less effective in extracting MMA from denture bases than acetone.

What is the difference between CAD/CAM-fabricated and conventionally made denture bases in terms of the residual monomer content?

A recent study conducted by researchers from Innsbruck/Austria[3] explored the issue of residual monomer in denture base materials intended for CAD/CAM processing. Four different CAD/CAM materials were compared with a conventional, heat-curing denture base material. The following products were investigated:

- **Baltic Denture System** (Merz Dental),
- **Whole You Nexteeth** (Whole You Inc.),
- **Wieland Digital Denture** (Wieland Dental + Technik)
  This product corresponds to IvoBase CAD from Ivoclar Vivadent.
- **VITA VIONIC** (VITA Zahnfabrik)

The conventional, heat-curing Aesthetic Red denture base material from Candulor served as the reference

As opposed to the customary method according to ISO standard 20795:2013, this study involved the analysis of the residual monomer content of finished dentures in a clinically relevant geometry. The standard, however, stipulates standardized test specimens. Instead of extracting unreacted monomer by means of the effective solvent acetone as required by the standard test (see above), the Innsbruck research team used water. The standard test determines how much residual monomer a denture base material contains. However, the test set-up in Innsbruck allowed the residual monomer that leached out in an aqueous medium to be established. Therefore, this test set-up more reliably reflects the actual clinical situation than the standard test.

The residual monomer content was expressed in ppm, with the acronym ppm standing for "parts per million". One ppm corresponds to 0.0001%. Overall, the dentures tested showed a very low residual monomer content. In three of the conventional dentures as well as one Wieland denture, the residual content was so low that it could not be detected. The lowest content (averaged over 9 test dentures) was found in the dentures made with the Baltic Denture System (0.6 ppm). However, the difference between these and the conventional dentures, which showed a residual monomer content of 1.6 ppm, was not statistically significant. Whole You Nexteeth released 6.2 ppm of MMA, which was statistically significantly higher than the amount leached by Aesthetic Red dentures. The residual monomer content of Wieland dentures was 4.4 ppm. As far as the VITA system is concerned, only 4 dentures were tested. The average value measured was 6.8 ppm.

How relevant is the measured residual monomer content for patients?

Is a concentration of several ppm of MMA in the mouth of the patient clinically relevant? A value of 7 ppm (the highest value that was measured across all the systems) corresponds to 0.0007 %. In allergy tests that involve triggering a reaction to MMA, a 2% solution is normally used. In their publication, Steinmaßl et al. cite a threshold value of 1 – 3 % MMA, which means that materials with lower values are considered to be biocompatible. In the European Risk Assessment Report on methyl methacrylate[4], formulations with a MMA content higher than 1% are considered to have a potential sensitizing effect. This means that the residual monomer contents patients are exposed to when wearing recently made dentures are many times (almost 1500 times) lower than what is generally considered to be sensitizing or allergy provoking. In this respect, there is hardly any difference between conventional and CAD/CAM-fabricated dentures.

Moreover, it should be noted that the tests carried out in Innsbruck deliberately did not involve the immersion of the dentures in water. In real life situations, however, this would be the case, so that even lower concentrations are to be expected[5,6]. It is also assumed that MMA will only leach out at the beginning. After a few days or weeks, the amount of MMA that can leach out is expected to be significantly reduced[7].

In summary, a residual content of MMA in denture bases cannot be avoided. However, these residual monomer contents do not pose any risk to the health of patients, independent of whether the dentures are produced conventionally or using CAD/CAM systems. The concentrations of leachable MMA are much too low to have a biological effect.

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Development and testing of IvoBase® CAD Bond

Introduction

When we set out to develop the digital denture process, we first employed the highly esthetic prefabricated denture teeth from Ivoclar Vivadent in our initial tests. These efforts led to the development of the patented Ivoclar Digital Glue & Mill Process [1], which continues to be available as part of the Digital Denture Professional module. When we were working on finalizing the process, we were looking for a method that would allow us to bond the denture teeth to the milled denture base in a reliable and lasting fashion. In the process, we defined essential new requirements for a future bonding system:

- accurately coordinated consistency over an extended period of time
- capability of being suitable for both narrow and wide bonding gaps
- good swelling properties
- sufficiently long working time
- easy removal of surplus material
- reduced evaporation when unpolymerized
- complete polymerization at low temperatures
- good storage stability without colour drift

These requirements precluded the use of a standard cold-curing polymer. Hence, it was necessary to develop a new material from scratch. One of the priorities was to ensure that the consistency of the material remained suitable for a sufficiently long period of time whilst it would also polymerize reliably.

Chemical structure

The dual challenge of developing a material that, on the one hand, features good storage stability without colour drift and, on the other, offers high responsiveness to ensure a fast polymerization reaction and reliable adhesive bond foreclosed the possibility of developing a single-component material system. To meet the demand for a material that is also suitable for "grouting" wide bonding gaps, we decided to develop a solid-fluid material system,

which, by definition, results in less polymerization shrinkage and thus counteracts stresses in the system. Like other cold-curing systems, the material system selected was based on PMMA polymer as the solid component and methyl methacrylate (MMA) as main monomer component. In addition to the customary crosslinking agents, the monomer component also contained a low-volatile monofunctional monomer and a speciality polymer. These compounds were added to reduce the volatility of the mixture. They are also instrumental in preventing desiccation effects that may lead to whitish discolourations. Proven benzoyl peroxide (BPO), encapsulated in the polymer, and a special amine accelerator, were employed in the material as initiators to trigger the polymerization reaction. We deliberately decided against using dimethyl-p-toluidine (DMPT) as accelerator because of the concerns surrounding its toxicity[2] and its severe susceptibility to staining. A barbituric acid/copper system was used as co-initiator to ensure a reliable depth of cure even at low temperatures. Finally, high-stability pigments, like those used in denture base materials, were added to the material to give it a universal shade.

As expected, initial testing confirmed that conventional cold-curing polymers – such as the ones used in denture base materials – are suitable to only a limited extent for bonding teeth and tooth segments in denture bases. There are two reasons for this: first, cold-curing polymers, such as the ProBase Cold system from Ivoclar Vivadent, are too fast-reacting, and second, the types of polymers used in these polymers quickly dissolve in the monomer and lead to a rapid thickening of the mixture. To ensure a long working time, other suitable types of pearl polymers were selected and the initiator system was amended accordingly. The resulting material featured a significantly extended working time.

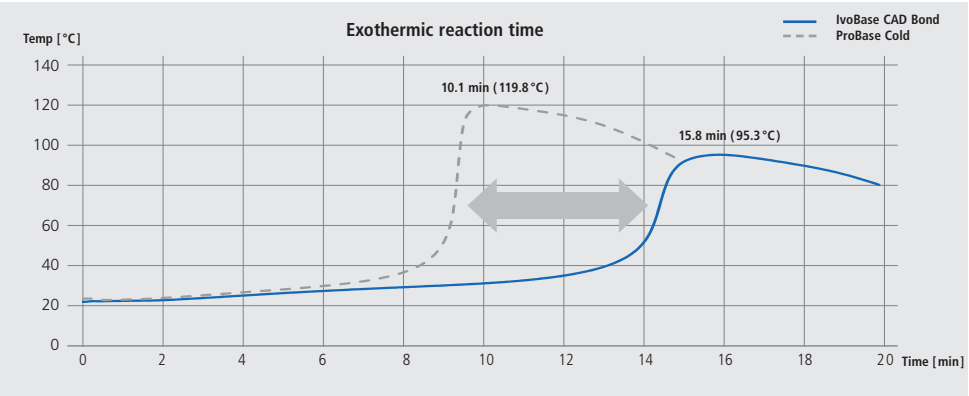

Fig. 1 Exothermic reaction time – Comparison with cold-curing denture base material
The graph shows the time-temperature change in freshly mixed samples of a conventional cold-curing polymer (ProBase Cold, grey) and the newly developed IvoBase CAD Bond system (blue). While the conventional cold-curing polymer begins to set after about 9 min, the newly developed material allows an additional 4 to 5 minutes before the curing reaction starts to kick in (see double-pointed grey arrow), giving users somewhat more time to remove surplus material, make corrections, apply additional materials to contour the papillae and, if desired, smooth the surfaces. The bonding material in the bonding gap is gradually becoming thicker as increasingly more polymer is being dissolved. Unlike with conventional polymers, however, frothing does not occur. The polymerization reaction only begins after approx. 14 min but can be accelerated by applying heat (pressure pot).

Testing with ISO-based methods

Functional testing and defining valid acceptance criteria posed a particular challenge in the development of the bonding material. There were no specific standard tests for systems designed for bonding prefabricated teeth or tooth segments in milled denture bases at the beginning of the development. For this reason, we turned to the existing DIN standards for denture base materials, C&B and tooth materials and adapted the methods to digital applications. Maximum attention was given to fracture testing to evaluate the bond strength between denture base and tooth material. The aim was to generate fractures across the tooth or denture base material (cohesive fracture) rather than generate fractures at low loads caused by a failing bond (adhesive fracture). We decided not to use any tooth geometries in the pilot test. The bond strength of cylindrical tooth material samples on plane denture base bodies was investigated (Figs 3 and 4). This enabled us to assess additional features of the prospective material, such as its consistency, "stickiness" in the unpolymerized state and clean-up properties.

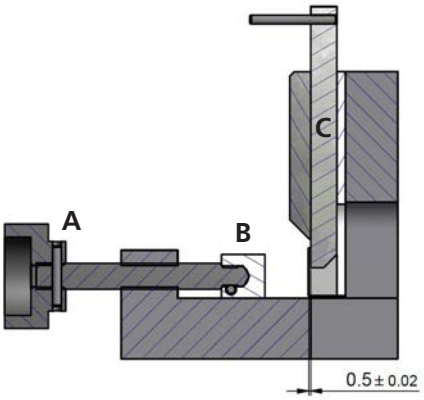

Fig. 2 Experimental design for shear bond strength testing
The image on the left shows the experimental set-up designed in accordance with the specifications of the relevant standard: the bonded block-cylinder assembly is secured with the screw (A) and the positioning guide (B). The slider (C) positioned at a clearly defined distance from the plate is shearing off the bonded cylinders while the loads are gradually increased. Eventually, this results in one of two types of fractures:

Fig. 3 Adhesive fracture due to the bonding material

Fig. 4 Cohesive fracture with loss of denture base material

After a few favourites emerged from the formulations tested, the scope of the testing was extended to include the bond strength tests described in the standard for denture base materials. The material proved again strong enough to last until a cohesive fracture occurred.

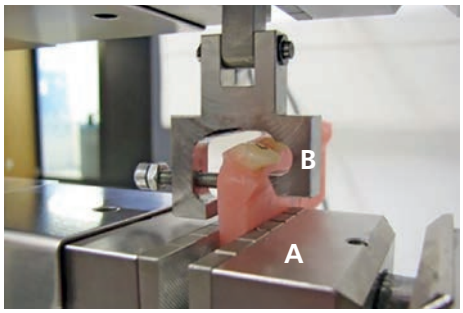

Fig. 5 Experimental design for bong strength testing
The image above shows the set-up for bond strength testing. A denture base sample is secured with a clamping jaw (A) and a bonded denture tooth (upper anterior moulds) is pulled off by a hook (B) secured with a clamping jaw. The resulting fracture pattern is then assessed.

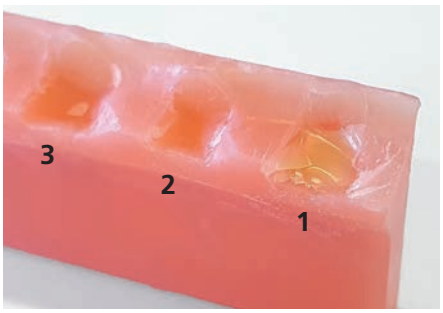

Fig. 6 The sample illustration shows a cohesive fracture (no. 1), where some denture material remained in the denture base body, and two adhesive fractures (no. 2 and 3) where the bond failed.

After optimizing and finalizing the final formulation, we tested the material's tolerance to handling errors. In the process, we found out that the performance of the system is hardly impaired if the bonding surfaces are not wetted with monomer. By contrast, correct sandblasting prior to applying the system turned out to be a must. Even "freshly" finished objects that had just been removed from the milling unit did not bond properly if they had not been carefully sandblasted beforehand.

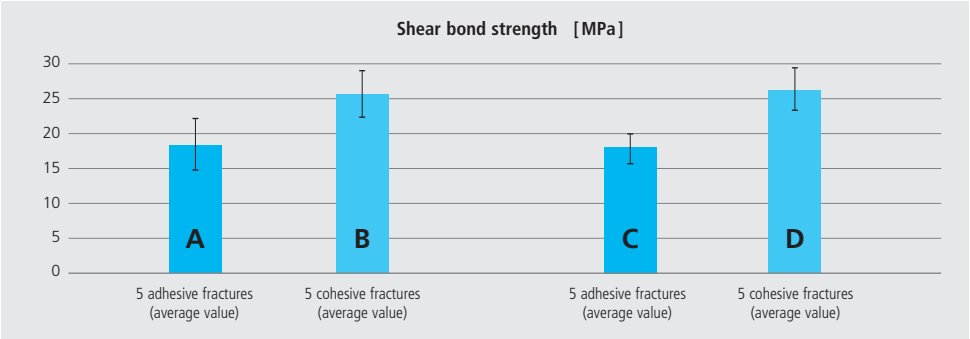

Fig. 7 The graph shows the effect of conditioning the substrates on the shear bond strength. Both version A and C showed adhesive fractures at a selected average load of less than 20 MPa. Both versions were not sandblasted, but conditioned with monomer. Cohesive fractures occurring at higher loads can be seen in versions B and D (25 MPa on average), regardless of whether the bonding surfaces had been wetted with monomer (version B) or not wetted (version D).

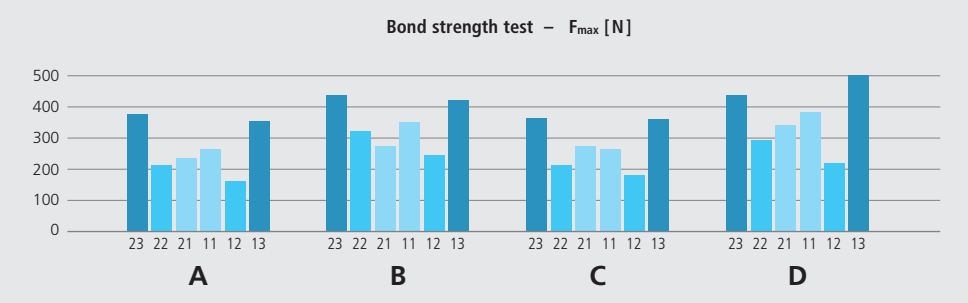

Fig. 8 The graph above shows the load-to-fracture obtained for single bonded teeth (upper anterior moulds). The tests revealed that the tooth geometry and the thereof resulting lever have a certain effect. The canines only fractured when exposed to the highest loads, followed by the central incisors. The lateral incisor 12 and 22 fractured at the lowest loads. The sandblasted teeth of version B (wetted) and D (not wetted) clearly stood out against group A and C, which were not sandblasted.

Computer calculations

In the process of developing the IvoBase CAD Bond system, we turned not only to proven methods of analytics but we also employed advanced computer technology to simulate the fracture behaviour of bonded materials. For this purpose, the physical properties of the assembled materials (denture base, denture tooth and bonding material) were determined in detail. The data was then employed for model simulation using ANSYS® (Version 15).

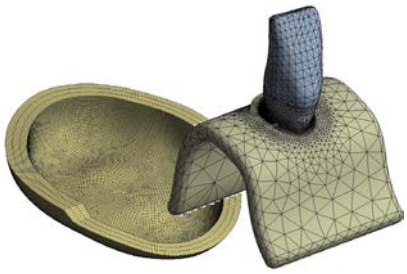

Fig. 9 Setup to test torsional loads
The graph shows a test sample consisting of denture tooth, a cementation gap with bonding material and a denture base in a triangle mesh.

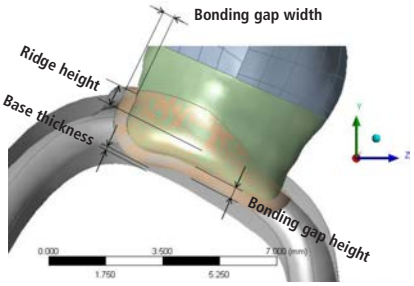

Fig. 10 Bonding parameters
It was especially interesting to define recommendations for the minimum ridge height and bonding gap height based on the simulations and calculations implemented.

The calculations that we carried out clearly showed that a reduction in the ridge height had the most severe effect on weakening the system. Circular socketing of the tooth (reducing the basal surface in the case of protrusion) leads to a loss of resilience that is within an absolutely tolerable range.

Denture strength testing

The ISO-based physical tests and the simulations carried out provided a sound scientific basis to assess the suitability of the material for use as a bonding system. Various configurations of dentures were designed and subjected to especially designed fracture testing methods to gain additional information on the material's suitability for use in the manufacture of digital dentures. Talks with dental technicians and dentists revealed that torsional loading – or twisting in opposite directions – is seen as one of the most dominant mechanical strains to which dentures are exposed. Torsional forces occur especially if the dentures are only loaded on one side during chewing or if the dentures are poorly fitting. To carry out the investigation, the outer contours of the dentures were left unaltered in all the tests, but the tooth arch was segmented into various groups. A monoblock denture, milled from fracture-resistant IvoBase CAD Pink, was used as the reference.

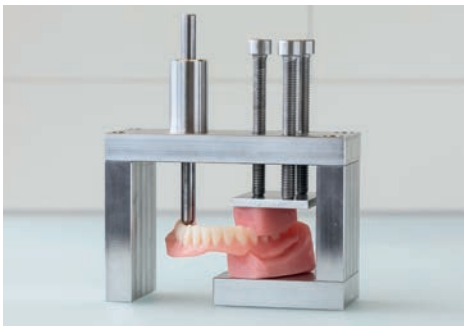

Fig. 11 Study setup for torsion loading
The study setup depicted above shows a denture base body secured on one side with suitable clamps made from denture base material. Torsional forces were generated in conjunction with tooth 46 with the help of a rounded metal punch.

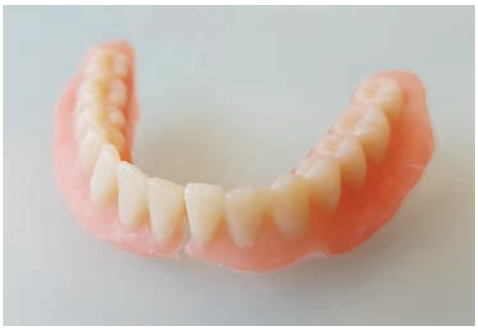

Fig. 12 Fractured test specimen consisting of two bonded tooth segments (31–37 and 41–47) after fracture testing.
The samples fractured already at 70 % of the loading threshold of the unsegmented dental arches (14 teeth) and they did so exactly in between the two bonded segments.

An analysis of the fracture loads (see Table 1 on the following page) clearly showed that creating removable dentures in a single arch (14 teeth) is preferable over any other form of segmentation. If no segmentation is implemented, the dentures can withstand 84 % of the load required to break the monoblock denture made of the fracture-resistant IvoBase CAD Pink material. An uninterrupted arch stabilizes the system and was able to withstand the highest torsional loads of all the bonded configurations.

Denture base	Tooth material	Bonding material	Segments	Load to fracture (N)	Load to fracture (%)
Monoblock dentures made of IvoBase CAD Pink			none	**75**	100
IvoBase CAD Pink	SR Vivodent CAD	IvoBase CAD Bond	full dental arch	**63**	84
			2 segments (31–37, 41–47)	**44**	59
			3 segments (33–43, 34–37, 44–47)	**51**	68
	Pre-fabricated teeth		none	**35**	47

Table 1 Analysis of load-to-fracture values

Conclusion

A combination of existing ISO-inspired test procedures and newly developed physical tests allowed us to develop a new bonding system that meets all the requirements placed on the bonding of digitally manufactured denture parts. With the help of additional computational methods, we were able to generate computer simulated fractures. The results allowed us to define basic requirements regarding the thicknesses of the tooth materials being used and recommendations for the geometry of the bonding surfaces.

If used correctly, the IvoBase CAD Bond system provides a reliable bond between SR Vivodent CAD (Multi) and the IvoBase CAD denture materials. The mechanical resistance of the dentures is the result of the minimum material thicknesses used in designing them, provided that the bonding surfaces are adequately sandblasted prior to carrying out the bonding procedure. The design software is programmed to point out any areas where the minimum material thicknesses defined in the process of developing the IvoBase CAD Bond system are not observed.

References

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Scientific Service

External studies and investigations involving CAD/CAM manufactured dentures

Laboratory and in-vitro investigations

Cyclic fatigue testing of the bonding interface between denture teeth and denture base materials in an aqueous environment at 37 °C

Place of the study: Department of Dental Prosthetics, Justus Liebig University, Giessen, Germany

Time: 2015/2016

Author(s): Dr Thomas Niem, Prof. Dr Bernd Wöstmann

Method:
Ten test specimens per group were subjected to a cyclic stress test (2 Hz, 50,000 cycles in an aqueous environment at 37 °C) to determine the maximum force that caused the test specimen to fracture. The reference groups included test specimens fabricated with conventional procedures (IvoBase High Impact injection system) and test specimens produced with a CAD/CAM procedure (pre-fabricated denture teeth bonded to milled denture bases). In this context, various surface treatment methods (removal of wax with steam, sandblasting, wetting with monomer) were investigated. Moreover, it was possible to analyze the fracture surfaces of one specimen each by means of light microscopy and to document the results.

Fig. 1 Test specimen

Results:
The bond strength achieved with IvoBase CAD Bond between conventional denture teeth and milled denture bases was comparable to that achieved in conjunction with conventionally polymerized dentures. The recommended pre-treatment had a significant influence on the resistance of the bond between the denture teeth and the acrylic resin. Both in conjunction

with digital and conventional processing procedures only cohesive fractures within the denture tooth were observed, provided that the procedure was carried out correctly. This confirms the excellent bond between the denture tooth and the denture base acrylic. Without pre-treatment, the CAD/CAM produced dentures showed adhesive fracture, whereas the conventionally fabricated dentures showed mixed fractures along the bonding interface.

Fig. 2 Test chamber

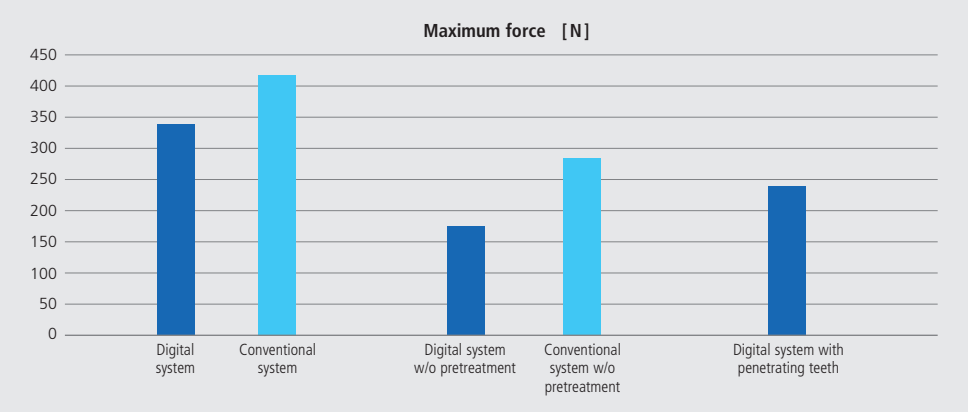

Fig. 3 Results of the bond strength test:
The maximum force is indicated at which both groups survived 50,000 cycles.

Conclusion:

Denture teeth that are bonded to milled denture bases are capable of withstanding the same forces as denture teeth that are conventionally polymerized into the denture base. The bonding strength is higher than the innate strength of the denture teeth in both cases. In the case of excessive stress, the fracture of the tooth is more likely than a failure of the adhesive bond. Appropriate pretreatment (above all sandblasting with abrasive media) is essential to achieve an optimum bond.

Do CAD/CAM-dentures really release less monomer than conventional dentures?

Place of the study: Department of Prosthetic Dentistry, Medical University of Innsbruck, Innsbruck, Austria

Time: 2016

Author(s): Patricia-Anca Steinmaßl, Verena Wiedemair, Christian Huck, Florian Klaunzer, Otto Steinmaßl, Ingrid Grunert, Herbert Dumfahrt

Method:
Complete dentures manufactured with four different CAD/CAM systems were compared to dentures fabricated conventionally using a heat-curing denture base material.

The following CAD/CAM systems were used in the study:

- **Baltic Denture System** (Merz Dental),
- **Whole You Nexteeth** (Whole You Inc.),
- **Wieland Digital Denture** (Wieland Dental + Technik)
  This product corresponds to IvoBase CAD from Ivoclar Vivadent.
- **VITA VIONIC** (VITA Zahnfabrik)

The conventional material used for comparison was the heat-curing Aesthetic Red denture base material from Candulor.

Ten upper dentures each were produced with three different CAD/CAM systems for ten patients. Four dentures were produced with the VITA system. Denture bases of minimal thickness were milled and the prefabricated denture teeth were then bonded to the denture bases according to the directions of the manufacturer. Subsequently, the denture bases were polished manually, an exception being the Whole You Nexteeth denture bases which had already been supplied in a finished and polished state.

The conventional dentures used for comparison were fabricated using a heat-curing denture base material. A long polymerization cycle was chosen (water bath at a temperature of 75 °C for 8.5 hours and subsequent cooling phase of 6 hours). They were then finished and polished. In contrast to the usual process, the dentures were not immersed in water to prevent the residual monomer from washing out prematurely. In order to determine the residual monomer content, the dentures were stored in water for six days at a temperature of 37 °C. Then the organic phase containing the MMA was separated from the aqueous phase and analyzed using HPLC (High-Performance Liquid Chromatography). Moreover, the volume and weight of the dentures was determined and their density calculated based on the values obtained.

Results:
Overall, only very small amounts of residual monomer were found in all the dentures. The residual monomer level detected in three of the conventionally produced dentures as well as one of the digital dentures produced with the Wieland system was so low that it could not be measured. The dentures produced with the Baltic System (average of nine test dentures) showed the lowest residual monomer content (0.6 ppm). However, the difference between them and the conventionally fabricated dentures, which showed a residual monomer level of 1.6 ppm, was not statistically significant. The Whole You Nexteeth dentures were found to release 6.2 ppm of MMA. The difference between this value and the residual monomer level of conventionally fabricated Aesthetic Red dentures was statistically relevant. The value measured for Wieland digital dentures was 4.4 ppm. Only four of the dentures manufactured with the VITA Zahnfabrik system were analyzed. The average value measured was 6.8 ppm.

The volume and weight of the Wieland Digital Dentures and the Whole You Nexteeth dentures was significantly lower than that of the conventionally fabricated dentures. The authors considered this to be a clear advantage for the patient, as dentures with a lower weight are more comfortable to wear.

Conclusion:
The amount of residual MMA that could be extracted from the tested dentures was very low, irrespective of whether they were manufactured digitally or conventionally. Please also refer to the chapter "Residual monomer content in IvoBase CAD" in this context.

Clinical cases and clinical trials

Fabrication of dentures for ten edentulous patients

Place of the study: Department of Dental Prosthetics, Justus Liebig University, Giessen, Germany

Time: 2015/2016

Author(s): Dr Nicole Toth, Dr Ghezal Asef, Dr Anke Podhorsky, Prof. Dr Bernd Wöstmann

Method:
Ten edentulous patients aged 47 to 81 years were provided with dentures fabricated with the Digital Denture 4-step process. First, an anatomical impression was taken in conjunction with the Centric Tray and UTS CAD. The impression material used was Virtual 380 Heavy Body. It was applied in Schreinemakers impression trays. Following this step, 3D Bite plates were fabricated based on the data collected. The functional impression was taken using Virtual Heavy Body (border moulding) and Virtual Light Body as well as putty-type material (seal area and posterior border elevation). A bite registration was obtained using the needle-point tracing method. Then, the midline, width of the nose and smile line was marked on the bite registration that had previously been secured with plaster. At the next appointment, the patients tried in the CAD/CAM milled trial dentures. If necessary, adjustments of the vertical dimension of occlusion, the occlusal plane and/or esthetic features were noted down and the information was passed on to the dental laboratory. Based on this information the final dentures were manufactured. Immediately following incorporation and after 7 to 14 days in situ, the occlusion was checked and adjusted if required. Any existing pressure points could be evaluated at that point in time.

Results:
At the time of incorporation, all the denture bases showed a good accuracy of fit. Only the denture outline and borders were suboptimal in some cases. This already became apparent at the time of the functional impression taking. It could have been due to a lack of experience of the operators in working with the impression material chosen (Virtual 380°), as normally other impression materials (Xantopren function, Xantopren medium/light) are used in the Department of Dental Prothetics at the University of Giessen.

As the bite registration was made at an early stage, only minimal adjustments of the occlusion were required. The authors of the study considered this to be an essential advantage of the procedure. They further pointed out that they found the separation of the procedure into different working steps to be very user friendly.

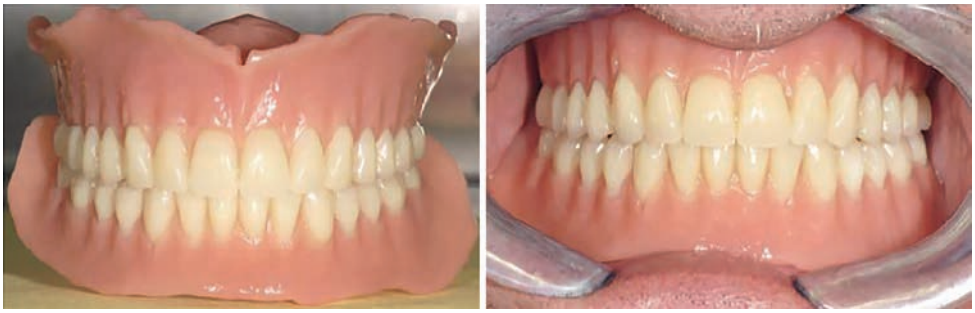

Fig. 1 View of one of the ten dentures outside the mouth and in situ

Conclusion:

The digital manufacturing process allows laboratory professionals to manufacture high-quality complete dentures in a very user-friendly and patient-friendly way.

A comparison of two digital techniques for the fabrication of complete removable dental prostheses: A pilot clinical study

Place of the study: Polyclinic for Dental Prosthetics, University Hospital Heidelberg, Heidelberg, Germany

Time: 2015/2016

Author(s): Dr Franz Sebastian Schwindling; PD Dr Thomas Stober

Method:
The objective of this study was to evaluate the integration of the CAD/CAM process for the manufacture of removable dentures into daily practice routines (feasibility study) and compare this approach to the conventional fabrication procedure. Digitally constructed dentures with a similar design were either produced with a CAD/CAM system or conventionally fabricated using the IvoBase Injector (control group). For this purpose, the dentures designed in CAD software were milled from wax and reproduced in the IvoBase Injector using the denture base material IvoBase High Impact.

Five patients (one woman and four men) aged 60 to 89 years were treated. They each received one complete denture produced with the 4-step Digital Denture process (including try-in) and one produced conventionally. All the working steps were assessed with the help of a questionnaire and documented. The clinical parameters were rated on a scale of 1 to 6. Upon completion of the study, the patients received the CAD/CAM fabricated dentures.

Results:
The clinical steps of the digital manufacturing process were smoothly integrated into the daily practice routine after a certain familiarization period. Only minor difficulties were observed during the process, which were mainly related to the implementation of the esthetics required by the patient. Nevertheless, the esthetic appearance of the final dentures received very positive ratings. The parameters of fitting accuracy, suction effect, esthetics, jaw relation, speech and occlusion of the digitally manufactured dentures were similar to those of the conventionally fabricated dentures. No clinically relevant difference between the two types of dentures was detected.

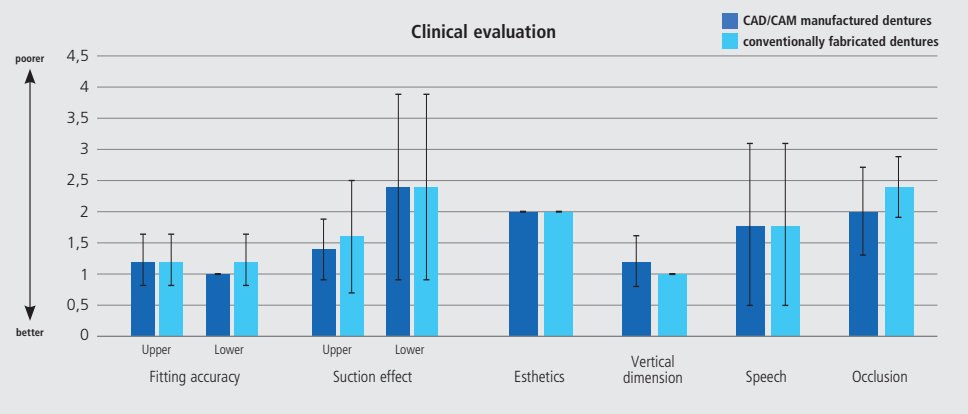

Fig. 1 The mean values of the five dentures are shown. The assessment scale ranged from 1 (excellent) to 6 (inadequate).

Conclusion:

The CAD/CAM production of dentures was easy to integrate into routine clinical procedures. The milled dentures proved equal in quality compared with conventionally fabricated dentures.

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Clinical Practice

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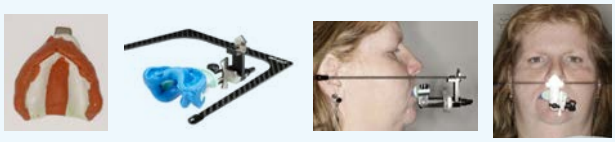
Clinical application

An overview of the Digital Denture oversize procedure:

➔ Clinician

- Anatomical impressions
- Bite registration using Centric Tray, documenting the Camper´s plane and the bipupillary line with the UTS CAD

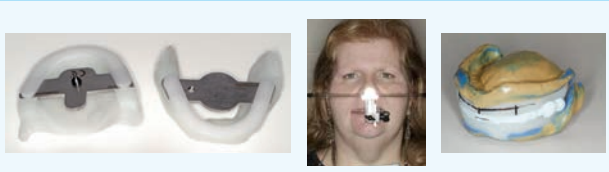


➔ Dental Technician

- Scan of the impressions
- Production of 3D Bite Plates

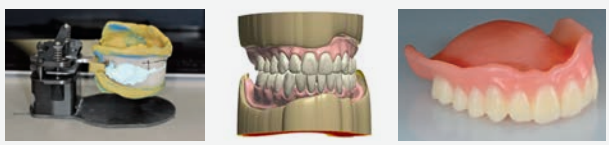
➔ Clinician

- Functional impressions
- Intraoral Gothic arch registration
- Alignment of the occlusal plane to the Camper´s plane and bipupillary line



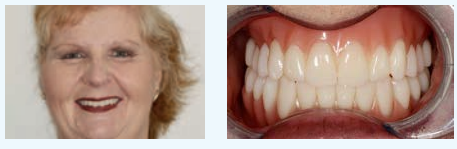
➔ Dental Technician

- Scan of the functional impressions
- Production of the Digital Dentures with the oversize procedure (optional: monoblock try-in dentures)



➔ Clinician

- Insertion of the dentures



1st treatment step

Anatomical impressions, Centric Tray and UTS CAD

The anatomical impressions (Fig.1.1) are taken with the Centric Tray together with the UTS CAD (Fig.1.2). The Centric Tray is a bimaxillary impression tray for taking a preliminary intraoral bite registration. This impression tray allows the scan software to precisely align the digitalized models and/or impressions (Fig.1.1) in relationship to one another. In addition, extraorally it is possible to use the UTS CAD to align the occlusal plane parallel to the bipupillary line (BP, Fig.1.3) and Camper's plane (CP, Fig.1.4). The acquired correction values can later be transferred to the CAD software.

Fig. 1.1 Anatomical impression trays

Fig. 1.2 UTS CAD with the Centric Tray

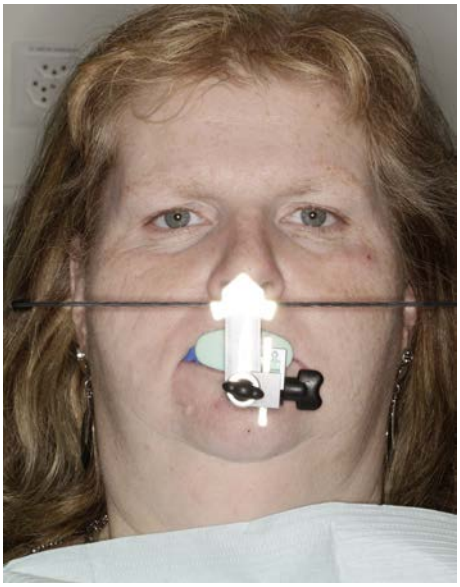


Fig. 1.3 Aligning the occlusal plane parallel to the bipupillary line (BP)

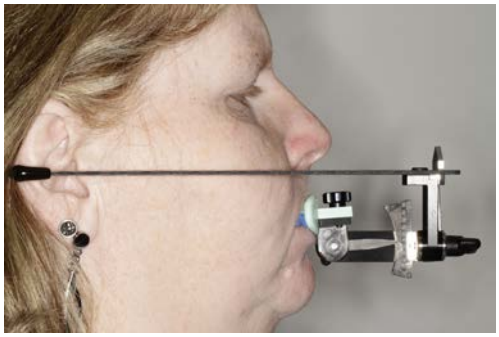


Fig. 1.3 Aligning the occlusal plane parallel to the Camper's plane (CP)

➔ Dental Technician

Transfer of the scan, design, 3D Bite Plate and UTS CAD values into the software
The 3Shape CAD software with the Digital Denture Professional add-on can be used for the design. The operator marks the teeth to be replaced, selects the 3D Bite Plate and the material "ProArt CAD Try-In" under "Appliance" (Fig. 2.1). The software guides the user through the scanning process. The dental technician selects the object to be scanned: either impressions, models or a combination of both.

The workflow is supported by the 3Shape scanner models D710, D750, D800, D810, D850, D900, D900L, and by the new models D1000, D2000, E1, E2 and E3.

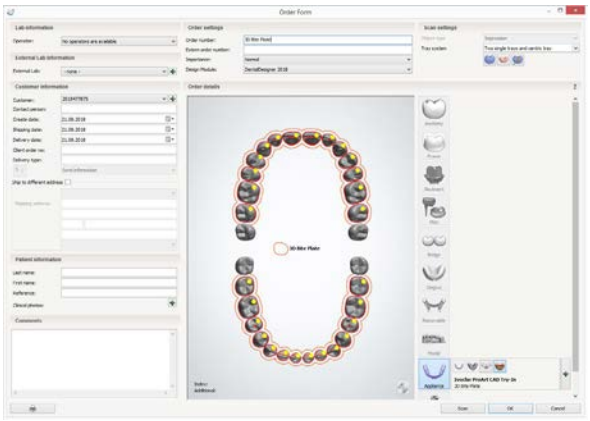


Fig. 2.1 Creating the case in the Order Manager

Fig. 2.2 The 3Shape scanners D2000 (top) and E3 (below)

Fig. 2.3 Impression holder for 3Shape scanners

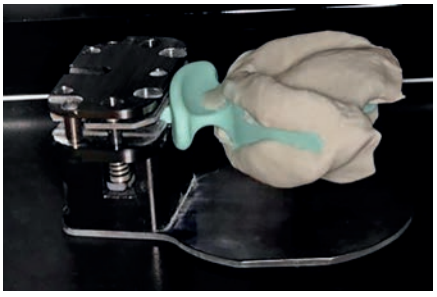


Fig. 2.4 Impression holder with the Centric Tray

The software automatically aligns the virtual models into the correct bite relationship with the help of the Centric Tray. The user can align the Centric Tray scan with a 1 or 3 point allocation option (Fig. 2.5). In the CAD software it is possible to increase or decrease the occlusal dimension using the virtual condylar axis (Fig. 2.6).

Fig. 2.5

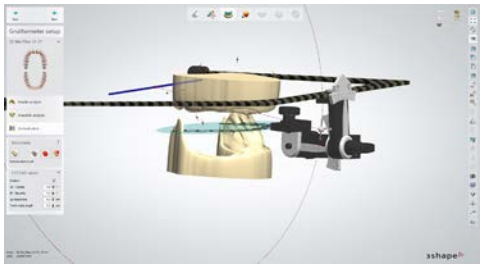


Fig. 2.6

Then both models are analyzed and the upper model reference points, e.g. the maxillary tuberosity, incisive papilla, canine point and the deepest point of the mucolabial fold, are defined and marked. Subsequently, the lower model reference points, e.g. the retromolar pads, centre of the alveolar ridge, canine point and the deepest point of the mucolabial fold, are defined and marked.

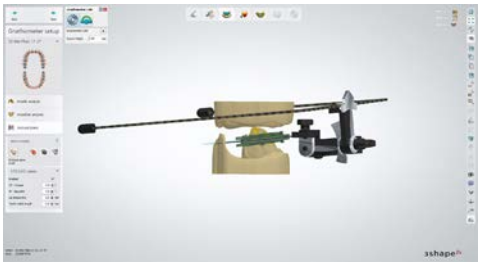


Fig. 2.7

In the next step, the correction values determined with the UTS CAD for the temporary adjustment of the occlusal plane can be transferred to the software. The Gnathometer CAD automatically adjusts to this plane, in preparation for the needle point tracing, which is carried out later on.

Instead of using a 3D Bite Plate, it is also possible to create a conventional bite registration and mill this later from the material "ProArt CAD Wax". In the function "Blocking out", according to the designated path of insertion, all undercut areas are blocked out by the software at an angle of 3 degrees.

Thereafter, the prosthetic base is outlined and subsequently calculated. The software creates an occlusal rim, which is then adapted to the geometry of the Gnathometer CAD (Fig. 2.8).

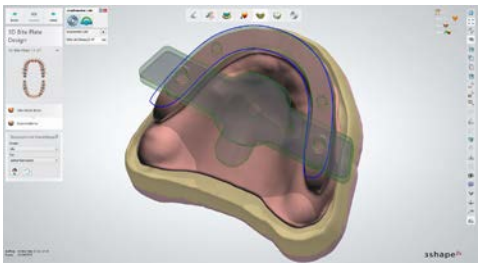


Fig. 2.8

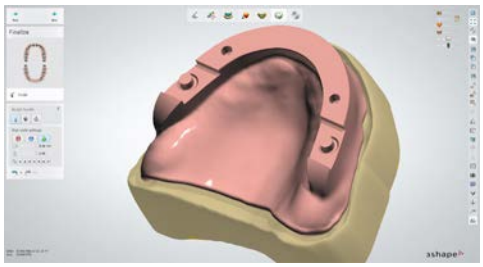


Fig. 2.9

Next, the software automatically calculates the 3D Bite Plates. Any alterations can be made to the base and the bite registration using the free-form tools (Fig. 2.9). The fitting surfaces for the Gnathometer CAD cannot be changed. All surfaces, curves and insertion paths, which are important for processing in the CAM software, are created and written into the CAM 4 output file (Fig. 2.10).

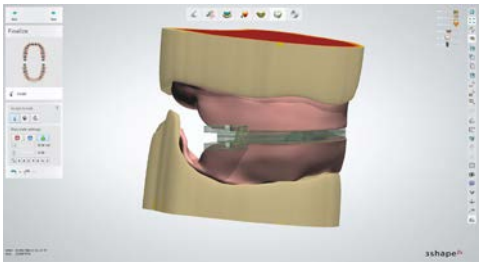


Fig. 2.10

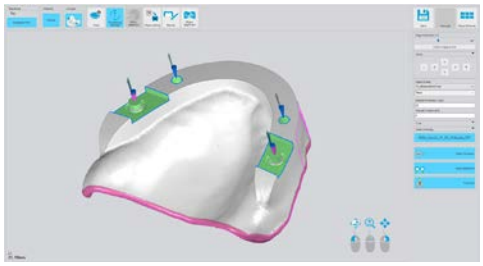


Fig. 2.11 The 3D Bite Plate created by the CAM V4 Software

Both the material (ProArt CAD Try-In) and the indication, as well as all surfaces, curves and insertion paths, are automatically recognized by the CAM V4 software (Fig. 2.11). The software then selects the appropriate milling strategy for manufacture. This makes the procedure more efficient and reproducible for the customer. User errors are reduced.

The 3D Bite Plates (Fig. 2.12) manufactured in the PrograMill PM7 are ready for the functional impression.

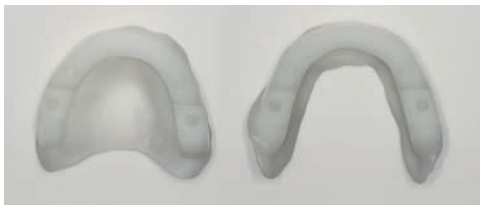


Fig. 2.12 Finished milled 3D Bite Plates

2nd treatment step

Functional impressions, intraoral needle point tracing, UTS CAD and tooth selection
In the second treatment step, the dentist takes the functional impressions of the maxilla and mandible. Thanks to the preliminary bite registration, the upper and lower bite rims lie flush on top of each other in the correct occlusal position, therefore it is possible to take the functional impression whilst the patients have their mouth closed. Using the UTS CAD, the occlusal plane is then aligned according to the bipupillary line and Camper's plane (Figs 3.1 und 3.2). The patient is asked to conduct a speech test, which measures the freeway space and allows the occlusal height to be determined. The results of this procedure are acquired and transferred to the Gnathometer CAD for use with the intraoral needle point registration. Once the centric occlusion has been determined, this is marked with the fixation plate and checked for reproducibility before being secured. If the position is correct, the upper and lower impressions are secured in place with a registration silicone (e.g. Virtual CAD Bite). The lip support and buccal corridor are checked and, if necessary, corrected by removing or applying silicone or wax. In order to position the anterior teeth correctly later, a permanent pen must be used to mark the esthetic lines (midline, smile line, canine position, upper lip length) on the 3D Bite Plates. Finally, the tooth shape and shade are selected by means of the tooth mould chart and the shade guide.

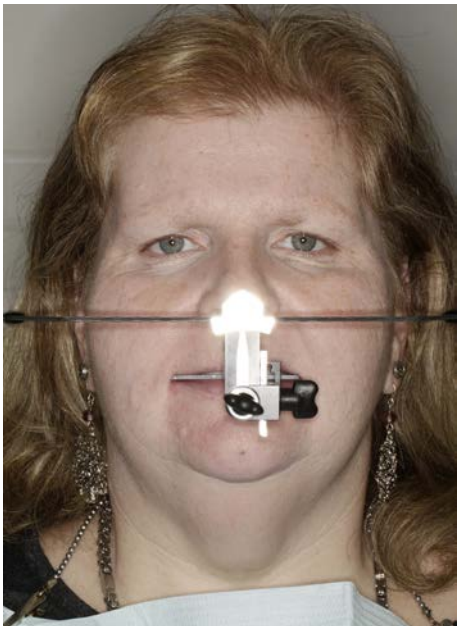


Fig. 3.1

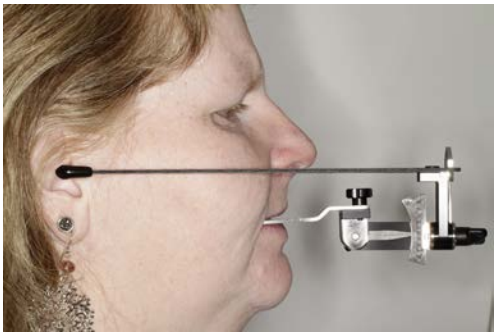


Fig. 3.2

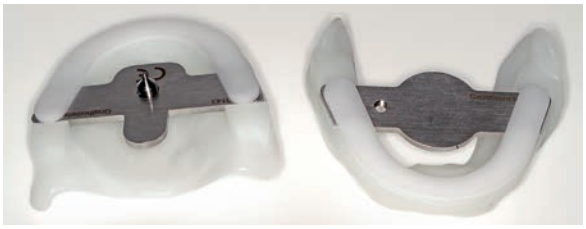


Fig. 3.3 3D Bite Plates with inserted Gnathometer CAD and bite rim supports for checking the fit. Before the impression is taken, the plates are removed.

Fig. 3.4 Secured impressions with marked esthetic lines

➔ Dental technician

In most cases, the denture can now be completely finished. However, it is possible to carry out a try-in with the patient beforehand. For this procedure, try-in dentures made from white PMMA material (ProArt CAD Try In) are milled. The design workflow of the try-in body is no different from the design of the definitive denture. After the try-in, it is only the material which is changed in the existing monoblock order. The software automatically creates the definitive denture.

3rd treatment step

As mentioned before, the try-in procedure with the patient is optional. If the esthetic parameters (lip support, buccal corridor, midline, lip closure line, etc.) are correctly marked on the impression and the reproducibility of the centric occlusal relationship has been checked, the try-in procedure can be omitted in many cases.

If a try-in is carried out, the tooth shape and position, lip fullness, occlusal height, phonetics and fit can be checked with a monoblock try-in body. Any changes can be transferred to the CAD software later. For example, if the occlusal dimension is too high, the dentist can trim the monoblock dentures and then secure them to one another (registration silicone, e.g. Virtual CADBite). The secured monoblock dentures are scanned and digitalized in the CAD software. The models will automatically be adjusted and aligned to the new situation.

If necessary, corrections of the tooth position and tooth direction can be marked on the try-in body or on the patient's photo. Markings on the try-in body will be directly transferred by the texture scan.

Fig. 4.1

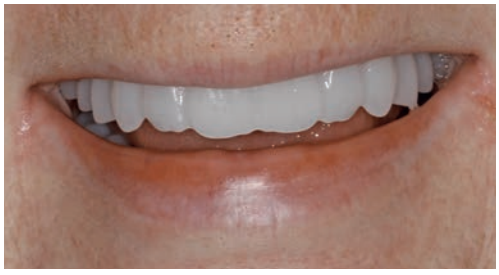


Fig. 4.2

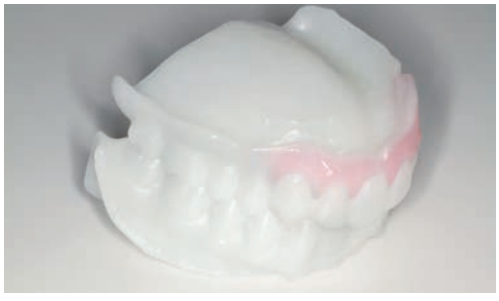


Fig. 4.3

➔ Dental technician

Design of the definitive denture

The teeth which are to be replaced are marked and the material for the dental arch (SR Vivodent CAD) and for the denture base (IvoBase CAD) are selected. All prosthetic teeth must be defined as a bridge, so that the software connects the individual teeth to form a dental arch with defined geometry.

The materials selected when creating the order determine the processing of the data sets in the CAM software and must therefore be executed carefully. Through the information from the CAD software and the CAD output generated from it, all the materials necessary for processing are read and imported into the CAM software and the relevant raw material is selected. Once the data is stored in the CAM software, the software suggests a disc for processing from the material browser.

The next step is to scan the secured 3D Bite Plates. Using the "fork for the impression holder" (Fig. 5.2), they are inserted into the slot of the impression holder (Fig. 5.3). Then, the secured 3D Bite Plates are placed into the scanner and the maxilla and mandible are digitalized (Fig. 5.4).

Fig. 5.1

Fig. 5.2

Fig. 5.3

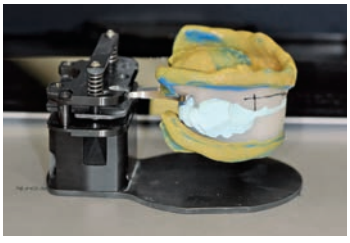


Fig. 5.4

After scanning, digital models are created from the impressions, which are positioned according to the occlusal relationship determined by the bite registration. The dental technician enters the UTS CAD values received from the dentist (Fig. 5.5).

Fig. 5.5

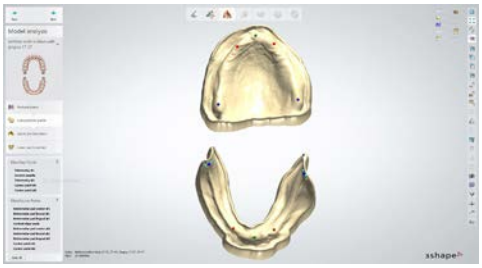


Fig. 5.6

In the following steps, the model analysis (Fig. 5.6) is carried out and the extension of the denture bases is drawn on the models (Fig. 5.7). After this step, the user is in the module, SmileComposer (Fig. 5.8). This includes the tooth moulds SR Phonares II, SR Vivodent S PE/S DCL and Orthotyp S PE/S DCL from Ivoclar Vivadent in the form of digital data sets. These data sets are now available as Full Arch Libraries. This allows the denture to be modelled quickly and efficiently.

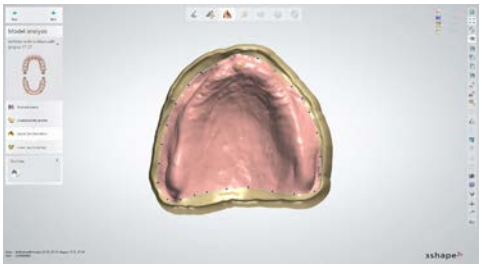


Fig. 5.7

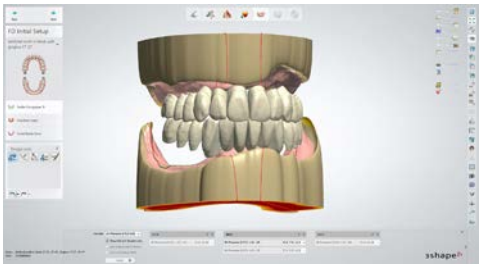


Fig. 5.8

In the SmileComposer, it is possible to upload a 2D image of the patient using the RealView function, and to use this to set-up the teeth (Figs 5.9 und 5.10).

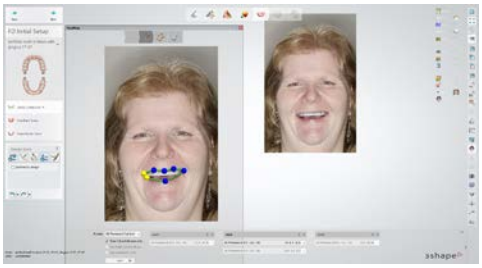


Fig. 5.9

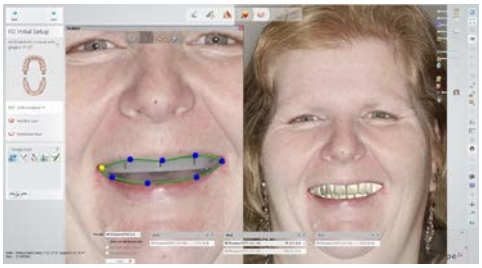


Fig. 5.10

In the next step, the denture bases are calculated (Fig. 5.11) and then the teeth are connected in the form of a dental arch (Fig. 5.12). This dental arch can be virtually ground to fit the antagonist teeth. This option is best used for single dentures.

In the following steps, material can be applied to and removed from the denture base (Fig. 5.13). The software then calculates the definitive geometry beneath the dental arch (Fig. 5.14). This is coordinated with the Ivoclar Vivadent milling tool portfolio. Consequently, optimum processing is ensured. The software calculates the cavity for fitting the dental arch to the denture base. The shape of this cavity is designed in such a way, that it can be efficiently milled from the disc. The denture is now finished. Once the software is closed, the denture will be created according to the designated parameter, which is then saved in the CAM 5 format (Fig. 5.15).

Fig. 5.11

Fig. 5.12

Fig. 5.13

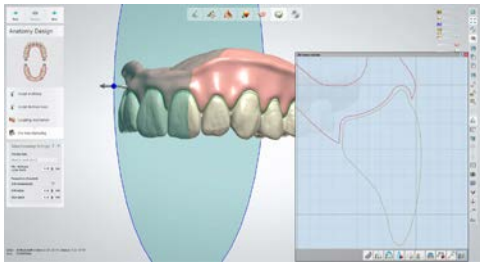


Fig. 5.14

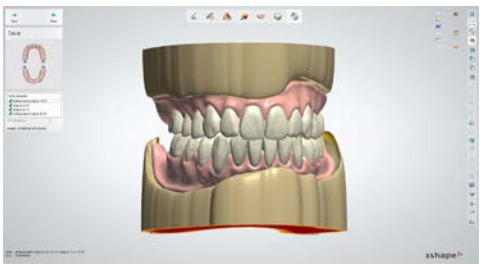


Fig. 5.15

Procedure in the CAM software

Information about the disc is uploaded into the CAM software via an RFID code. This information can be found on every disc. An RFID scanner reads the RFID code and identifies the manufacturer, dimensions, shade and batch number and enters this information into the disc manager of the CAM software.

The CAM 5 task file must be imported into the CAM software in Work Preparation. When the information has been checked and all parameters (materials, shade, milling templates [oversize] or [1 to 1 Standard]) have been accepted or selected (Fig. 6.1), the situation can be saved.

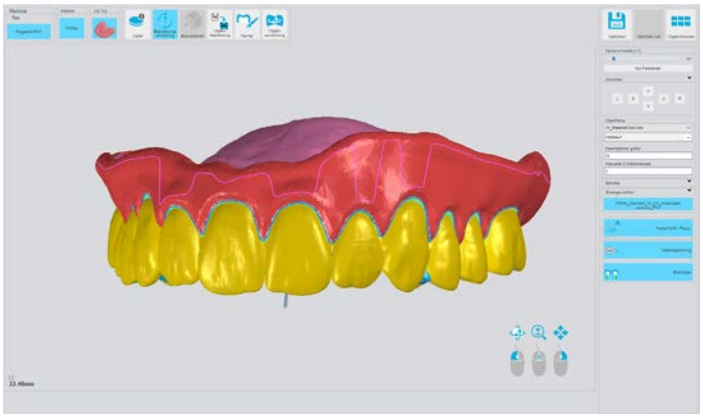


Fig. 6.1 Work preparation in the CAM V4 software

With the information saved from the RFID code, the software automatically filters the appropriate disc for the indication to be milled. This makes the task of selecting the disc from the extensive range of discs in the library much easier for the dental technician. User errors can be largely avoided. When nesting the denture within the disc, it is essential to ensure that the anterior teeth are facing upwards (Fig. 6.2). The advantage: In this area, the milling axis has a higher working angle. This method of positioning means that most of the undercuts in the basal area and in the esthetically important anterior region can be completely milled, which in turn means less rework after processing.

Once the 3 mm bars have been placed (connection between the denture and the disc), the processing offset is set manually to the widest possible marginal extension. This allows the milling tool the most freedom of movement when processing the disc.

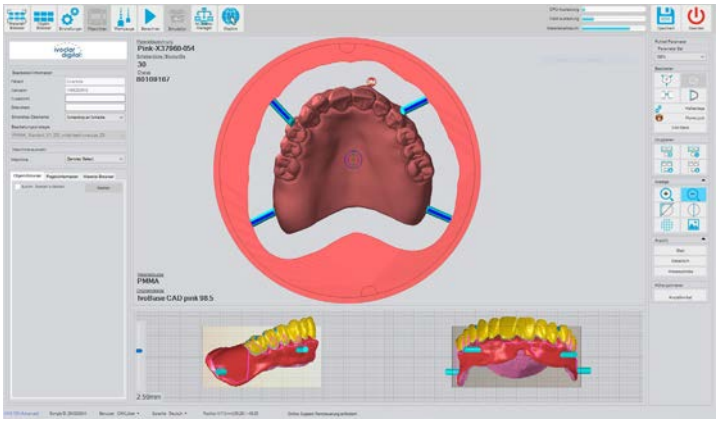


Fig. 6.2 The denture base can be manufactured to a height of 30 mm from IvoBase CAD. Next, the dental arch is bonded to the denture base; together, a maximum height of 40 mm can be achieved.

By clicking on the "calculate" button, the software starts calculating the milling paths. Various parameters are used to calculate the milling paths, all of which can influence the processing accuracy and the speed at which the denture is milled. This balanced ratio allows an optimal milling procedure that is material-friendly (for the disc, spindle and milling tools) and at the same time is efficient and highly reliable. This procedure is verified and validated according to Ivoclar Vivadent's internal guidelines.

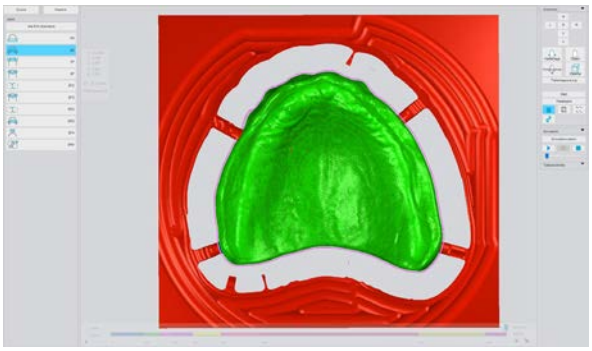


Fig. 6.3

Once the milling path calculation is complete, the fast simulation function checks whether the milling paths have been correctly calculated and ensures that no residual material is left in esthetically visible areas or in areas of the denture which determine the fitting accuracy (Fig. 6.3).

After the calculation, the milling paths are written onto a NC file, which is transferred to the CNC software in the milling machine. The same workflow is also applied to the dental arch, except that this is milled in the material SR Vivodent CAD. In addition to calculating the milling files for the denture base and dental arch, it is also necessary to create a milling file for the rotation protection of the IvoBase CAD. This must then also be sent to the milling machine.

This enables the disc to be replaced into the same position, after adhesive bonding, so that it can be processed in the second milling procedure. The oversize procedure comprises two processing steps for the IvoBase CAD, i.e. two milling data output files (step 1 and step 2). Step 1 is sent to the CNC together with the milling file for the rotation protection. Step 2 remains on hold, as this process will only commence once the base and arch have been adhesively fixed.

The discs can now be clamped into the disc holder and then inserted into the milling machine (Fig. 6.4). The transferred jobs are automatically assigned to the loaded discs in the disc changer. The milling jobs displayed in the middle are the jobs currently being milled by the machine. The user interface shows the progress of the disc currently being milled (Fig. 6.5).

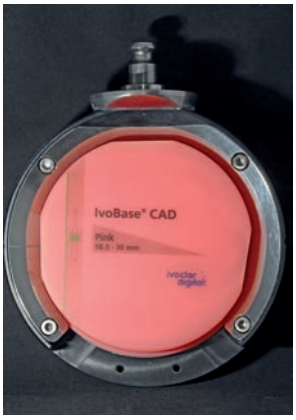


Fig. 6.4

Fig. 6.5

After milling the denture base and dental arch from SR Vivodent CAD (step 1, Fig. 6.6), both parts are bonded together (Fig. 6.8) using IvoBase CAD Bond (Fig. 6.7). Polymerization takes 15 minutes at 50°C and at a pressure of 2 to 5 bar. It is not necessary to meticulously remove excess bond, because in the second milling step, all excess material with be completely removed.

Fig. 6.6 Dental arches milled from SR Vivodent CAD

Fig. 6.7 IvoBase CAD Bond for adhesive bonding

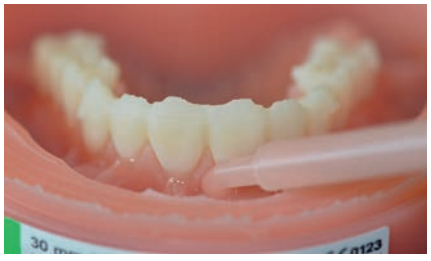


Fig. 6.8 Application of IvoBase CAD Bond

After adhesive bonding, the disc is clamped into the disc holder in the correct position with a special holder ring.

In the next milling procedure (step 2), the oversized dental arch and denture base are milled to their normal dimensions to create the final prosthesis (Fig. 6.9). Once the denture has been separated from the disc (Fig. 6.10), the bars are trimmed using a diagonally cross-cut tungsten carbide bur.

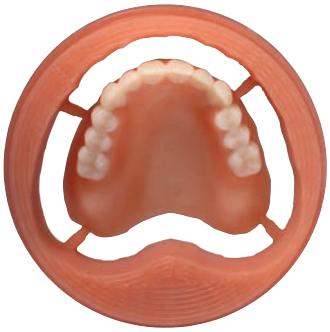


Fig. 6.9 Milled denture

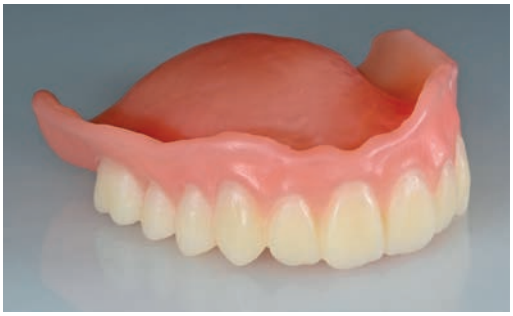


Fig. 6.10 Finished milled denture after the bars have been removed

This type of cutter achieves a sharp cut and removes material quickly without generating heat, leaving a smooth material surface. Characterization of the tooth surface can also be achieved using the same type of tungsten carbide bur. To separate the teeth, a large, fine-grit diamond separating disc is used followed by an ultra-thin diamond separating disc to work on the marginal edges and contact points.

The denture is pre-polished in the handpiece using a goat-bristle brush with fine pumice or a universal polishing paste. First the occlusal areas and then the gingival margins around the neck of the teeth are polished. Finally, the larger surfaces of the denture base and the edges are polished on the polishing lathe. The final polish is carried out with a polishing paste and, depending on the level of gloss required, a cotton buff (for less shine) or a leather buff (for high gloss) is used.

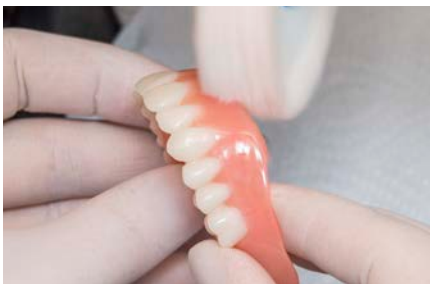


Fig. 6.11 Polishing the denture

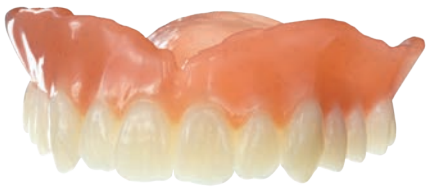
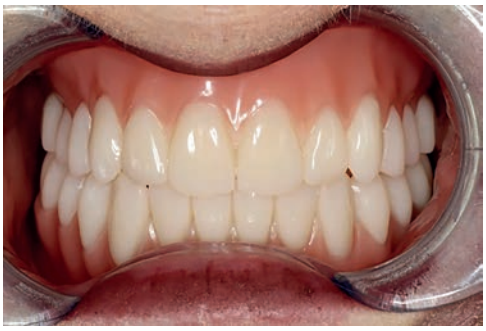
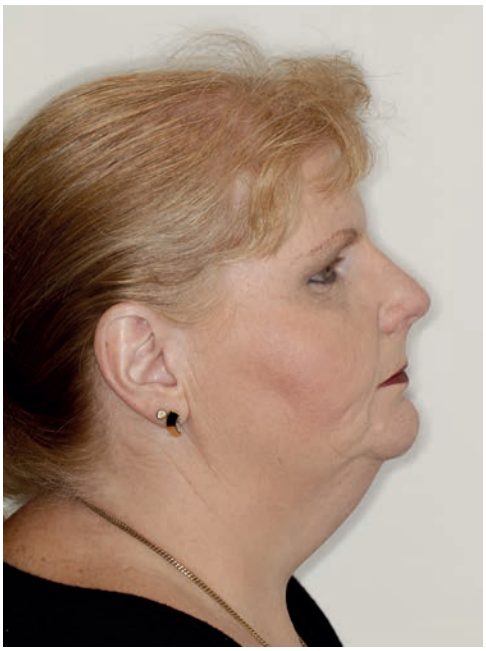


Fig. 6.12 The finished, polished denture

➔ Clinician

When the denture is inserted into the patient's mouth, the usual tests are performed. These include checking the fit, function, esthetics and phonetics. If necessary, corrections are carried out and an appointment is made for the follow-up session. The patient receives exact instructions on denture and oral hygiene.





Verification & validation

The aim of the verification and validation is to guarantee the processing safety of developments for the end-user. This is ensured by an internal testing procedure run by Ivoclar Vivadent AG. During the verification process, the developers focus mainly on the material, milling strategy, etc. whereas the validation process concentrates more on user safety and then release.

Before a product reaches the customer, it is subjected to a specified testing phase. In this phase, the user profile requirements for the end product are tested extensively. Taking the milling strategy as an example, it becomes apparent how comprehensive and how essential this testing phase for the end customer is. Every modification or renewal of a milling strategy includes a tool service-life analysis. Each indication is milled multiple times from different materials, then assessed according to dental technical factors (surface texture, accuracy of fit, misalignment, chipping, etc.) and compared digitally. The values determined are filed later in the user interface of the CNC software. There, the customer receives information when the service-life of which cutter ends and when it should be changed.

This cutter service-life analysis is comparable to new developments. The customer is guaranteed an efficient and economical manufacturing procedure and exact reproducibility in the event of a fractured finished denture.

Processing safety

The oversize milling process, released by Ivoclar Vivadent AG, provides a high level of processing safety. This is possible due to the fact that the software innovations, developed from user requirements and demands, are verified and validated by Ivoclar Vivadent. In addition to the new features, which are introduced into current systems, each new version of an existing system is also tested, providing the user with a modern product, exactly adapted to the current, daily laboratory routine.

All material parameters in the CAD software can be customized and updates can be exchanged by Ivoclar Vivadent AG, then immediately presented to the user via an auto update feature. This makes uncomplicated and fast communication available in a user-friendly way and ensures continuous system optimization.

Reproducibility

All denture information is saved in the laboratory and, in the event of breakage, loss or fracture, can be reproduced in the milling machine. The new denture can be produced and inserted in only one appointment.

In order to compare the accuracy of the reproduced denture, the same denture was produced in the milling machine PrograMill PM7 three times. Digitalization of the top and underside of the denture was carried out in a 3Shape laser scanner (model 900L). Subsequently, the data sets were compared digitally in the software "Geomagic".

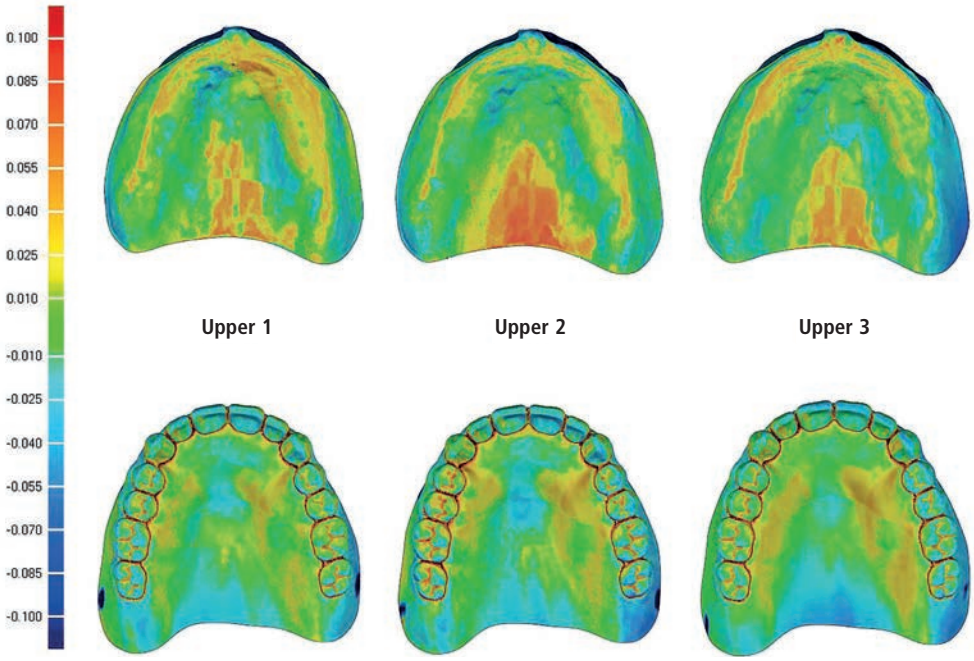
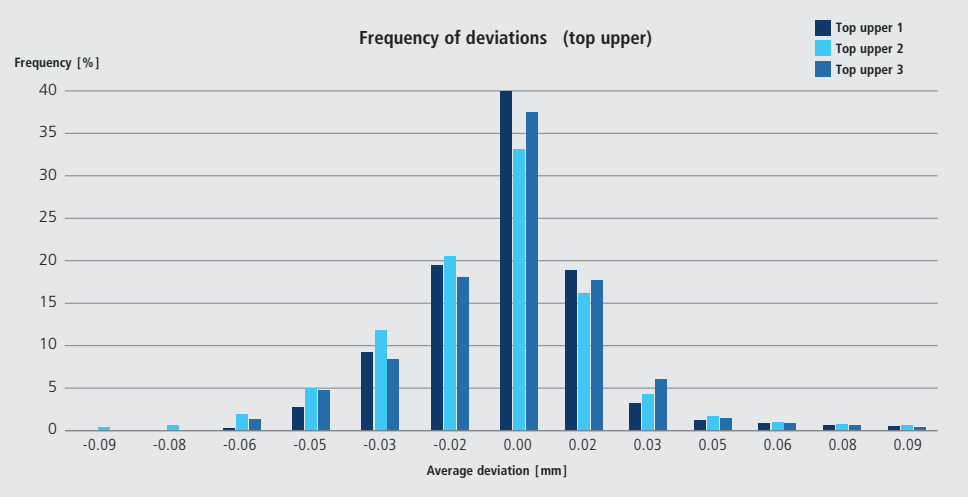
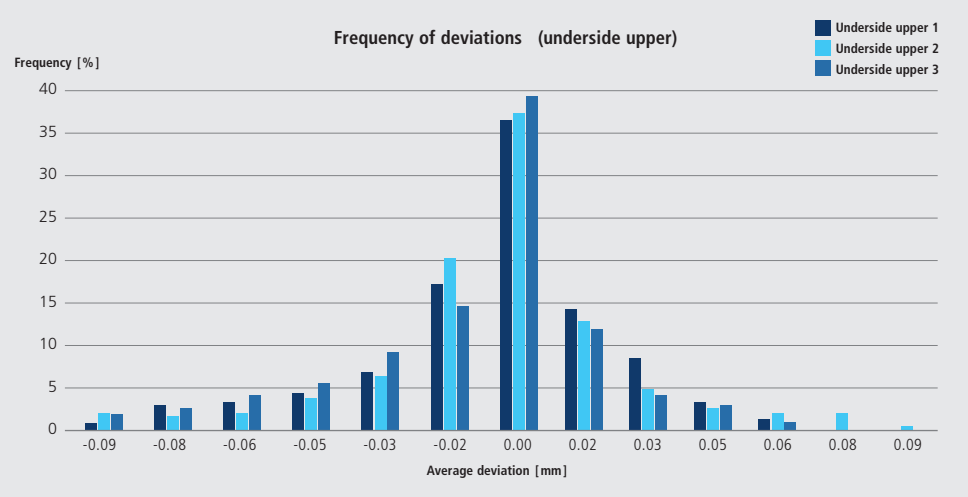


Fig. 7.1 Reproducibility
The overview shows the areas where deviations to a maximum degree of ± 0.1 mm were found.
All results lie within the required tolerance level and have no negative influence on fit, occlusal dimension or esthetics.

The following tables show the frequency (%) in which the average deviations occur on the denture top side and the denture underside.





33 % to 40 % showed no differences between the design and the milled product. In 12 % to 20 % of the cases, there were deviations to a degree of ± 0.02 mm. The other 11 % of the cases showed deviations to the constructed denture to a degree of ± 0.03 to ± 0.10 mm.

Conclusion

Digitization has become indispensable in everyday dental laboratory work. The Digital Denture CAD software from 3Shape allows the dental technician to design and produce a full denture, upper and/or lower, digitally.

The manufacturing method involves milling the denture base (material: IvoBase CAD) and the dental arch (material: SR Vivodent CAD). The advantage: It is possible to create and mill any tooth shape from different denture teeth sets from the "SR Vivodent CAD" disc, which means the laboratory does not have to store an assortment of prefabricated teeth on standby. This increases the range of indications to include single jaw dentures. The fact that the teeth can be modified and virtually trimmed in the CAD software means the dental technician has the option of adjusting the occlusal surface to adapt it to the antagonist teeth. A cross-bite can be achieved in a similar way.

The oversize production compensates for possible user and machine errors – through bonding and re-insertion into the exact position in the holder. This provides a high degree of reproducibility, should the denture become damaged or lost.

The clinician requires one treatment step less to finish the denture. The dental technician has fewer working steps in comparison to the conventional production methods. Due to the fact that data sets of the manufactured dentures are saved, future reproductions can be made (e.g. after "normal" wear) even more efficiently. In most cases, two treatment sessions are sufficient. In the case of loss or large fractures, an exact reproduction of the denture can be produced in only one clinical treatment step. The patients leave the practice with their replacement.

The development of CAD/CAM software in the field of complete denture prosthetics is steadily progressing and is distinguished by efficient, fast and coordinated CAD/CAM and CNC milling processes. The dental technician is kept up-to-date with regular software updates. Continuous further development in this field mean that in future, all areas of indication in removable denture prosthetics will one day be covered.

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