Lucitone Digital Print Denture™ System

Scientific Manual

Dentsply Sirona

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1.0 Introduction

While the life expectancy is increasing[1], the number of dental labs and skilled technicians able to meet patient needs is declining[2]. As a result, the demand for denture production that does not rely on advanced technical skills, complex assembly methods or long processing times has never been greater. Additive manufacturing (AM) or 3D printing allows for the creation of perfectly customized quality products in a fraction of the time and with less workers in comparison to traditional methods. By using 3D printing, dental professionals can produce dentures with speed, quality, accuracy, and esthetics that are better than those made using traditional methods. From the patient's perspective, 3D-printed dentures fit better and require fewer clinical visits. The typical traditional denture requires the patient to make five clinical visits. In some cases, with new digital workflows and printed dentures, the number of clinical visits can be reduced to two.

The Lucitone Digital Print Denture™ (LDPD) System has been developed by Dentsply Sirona to help dental professionals utilize digital technologies to thrive in this changing landscape. With the LDPD system, denture production can be converted to printing, and in so doing, better serve dentists and patients.

LDPD is built on Dentsply Sirona's legendary high-impact Lucitone 199 Denture Base Resin, which came to the market in 1968. LDPD is a family of resin formulations comprising:

- Lucitone Digital Print™ 3D Denture Base (LDP)
- Lucitone Digital IPN™ 3D Premium Tooth (LDI)
- Lucitone Digital Value™ 3D Economy Tooth & Trial Placement
- Lucitone Digital Fuse™ Step 1 3D Conditioning Agent
- Lucitone Digital Fuse™ Step 2 3D Denture Bonding Resin
- Lucitone Digital Fuse™ Step 3 Total 3D Sealer

The innovations from the LDPD family provide more efficient workflows, faster patient delivery , superior performance, better fit , and premium esthetics featuring a natural-looking denture with natural-looking denture teeth. All are delivered while still upholding the quality credentials that Dentsply Sirona has spent over a hundred years building, promoting safety and efficacy for edentulous patients, with predictable and repeatable results for dental professionals.

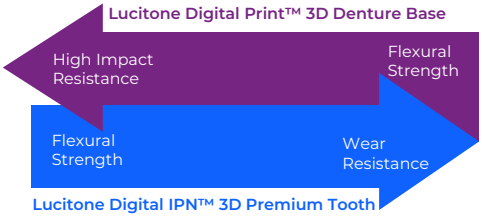
Design of a Body-Activated High Impact Printed Denture Base

Balanced mechanical properties are essential for denture base materials. Flexural modulus and strength are indicative of the hardness and rigidity of a material. A harder and more rigid material allows for improved mechanical integrity under biting force and overall better dimensional stability.

However, typically high modulus materials tend to be brittle, less flexible, and dentures made of such materials tend to be uncomfortable . This is clearly an undesirable feature of high modulus materials, and, as a result, some degree of elasticity within the denture matrix is desired. This additional elasticity will provide high impact and fracture resistance minimizing the potential for denture breakage through normal, everyday patient handling and use. This resistance to fracture is manifested by stress intensity factor and Work of Fracture (Wf), which are key performance indicators for high impact 3D-printed dentures.

Designing denture base materials is complex and the final formulation requires a unique balance of specific monomers, oligomers, polymers and reinforcing agents to generate materials with the desired mechanical and physical properties. Three-dimensional printing also adds more to the complexity of this formulation, as it requires an ideal balance of the formulation's components with fine-tuned initiator concentration and resin viscosity, which are also key to the performance of resin formulations. Printing strategy and printing parameters, including light intensity, layer irradiation time, printing angle and speed, etc. should all be optimized to provide the desired final product performance. In addition, factors such as post-processing procedure, washing, tooth bonding, post curing, and finishing, etc. need to be optimized to achieve the desired mechanical and physical properties.

Significant formulation effort was spent to develop Lucitone Digital Print denture and teeth resins. Hundreds of formulations were evaluated for baseline mechanical and physical properties and for the development of the structure-property-performance relationship. Various monomers, oligomers, polymers, crosslinking agents, initiators, antioxidants, and impact modifiers were evaluated, and custom resins were developed in-house to achieve our desired properties. A novel 3D printed microphase interpenetrated polymeric network was developed in final cured dental devices, such as denture base and denture teeth. Various printing and post processing parameters were optimized through a series of experimental designs. Three-dimensional printing parameters (light intensity, printing time, printing angle, part orientation, shrinkage factors, exposure times and intervals, slice thickness, etc.) and post-processing procedure and curing condition (post-wash solvents and times, post-cure light intensity and curing zone, temperature profile and duration) were fine-tuned. As a result, the desired overall mechanical and physical properties, biocompatibility, and dimensional accuracy were achieved.



Smart polymers or stimuli-responsive polymers are materials that change according to their environment. During the development of the formulation, one important objective was to design a material behaving as smart polymers. Our goal was to develop a material featuring: a) sufficient flexural strength to hold denture teeth in place for dimensional stability and effective function; b) sufficient strength to withstand masticatory forces; c) superior toughness and wear resistance for durability, and; d) resistance to abrasion and chipping during use. The discovery was made when a formulation containing a proprietary resin monomer and an oligomer dramatically increased its fracture toughness when moved from room temperature to body temperature. Dentsply Sirona describes this phenomenon as a “body-activated process” and the overall material as a “body-activated-material (BAM)”.

Once the denture is placed under physiological temperature, the material is “activated” and undergoes a thermally induced change that results in a twofold increase in Wf. Figure 1 shows the relationship between Wf and test temperature. As it can be seen, the LDP resin results in a twofold increase in Wf when exposed to body temperature. It is important to note that control test bars were also prepared and tested using Dentsply Sirona’s commercially available heat-cured denture base resin Lucitone 199 , and cold-cured denture base resin Lucitone HIPA. With these samples, Wf is about the same at room and body temperatures.

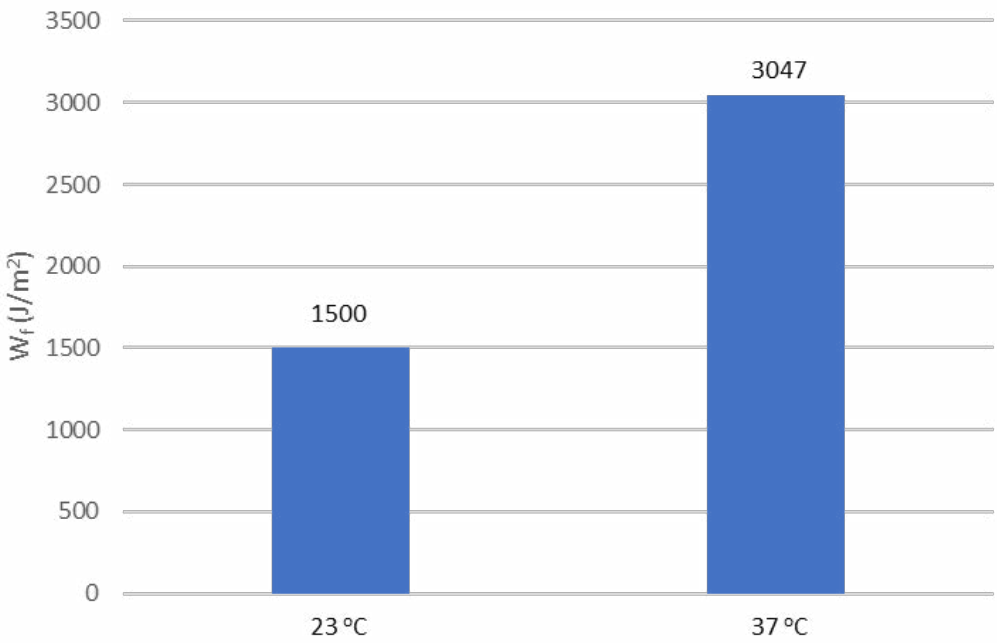


Fig. 1 – LDP Wf according to temperature.

[1]Villias, A., Karkazis, H., Yannikakis, S., Artopoulou, I. I., & Polyzois, G. (2022). Is the Number of Appointments for Complete Denture Fabrication Reduced with CAD-CAM? A Literature Review. Prosthesis, 4(1), 91-101.
[2]Wang C, Shi YF, Xie PJ, Wu JH. Accuracy of digital complete dentures: A systematic review of in vitro studies. J Prosthet Dent. 2021 Feb;125(2):249-256. doi: 10.1016/j.prosdent.2020.01.004. Epub 2020 Feb 27. PMID: 32115218.
[3]Acrylic Teeth Market Size is Projected to Reach USD 1.1 billion, Advancing at an 8.4% CAGR by 2034: Transparency Market Research Inc. An increase in the prevalence of periodontal disorders and dental cavities is driving opportunities in the acrylic teeth market. October 07, 2024 08:10 ET | Source: Transparency Market Research
[4]Acrylic Teeth Market Size is Projected to Reach USD 1.1 billion, Advancing at an 8.4% CAGR by 2034: Transparency Market Research Inc. An increase in the prevalence of periodontal disorders and dental cavities is driving opportunities in the acrylic teeth market. October 07, 2024 08:10 ET | Source: Transparency Market Research

Highly Esthetic Wear Resistant Denture Teeth

LDI teeth, when paired with LDP denture, enable dental professionals to meet the accelerating demand for premium denture teeth with esthetics built into the workflow.

- Premium wear resistance built from Dentsply Sirona's long history of denture teeth expertise
- Translucency and esthetic detail expected in premium denture teeth
- Available in 16 A-D shades , plus two bleach shades
- Portrait and Genios Denture Tooth mould families for CAD software

The majority of preformed artificial teeth sold in the United States are made of acrylic. As it might be expected, the majority of resin teeth are based on poly(methyl methacrylate) (PMMA). PMMA resins used in the fabrication of prosthetic teeth are very similar to those used in denture base construction. Nevertheless, the degree of cross-linking within prosthetic teeth is greater than that within polymerized denture bases.

In the development of LDI, the primary focus was to achieve high wear resistance while retaining uncompromised esthetics, balanced mechanical strength, and fracture resistance. Some key proprietary monomer resins in denture base formulation are incorporated in tooth formulation. One proprietary monomer was selected from several dozens of candidate monomers synthesized in Dentsply Sirona's laboratory to achieve superior wear resistance and high flexural strength, as well as good fracture toughness. As in LDP, a novel 3D-printed microphase interpenetrated polymeric network (IPN) is formed in the final cured LDI.

The esthetics of printed LDI denture teeth are amplified through Dentsply Sirona's conversion of the Portrait IPN and the Genios denture tooth mould families into digital libraries for use in CAD design software. Intricate mould family conversion modeling was developed for the printing process to create incisal translucency, mimic mamelon effects, as well as light refraction and reflection on the surface of the teeth. The digital libraries include both anatomical and semi-anatomical posterior denture teeth, pre-occluded in either balanced or lingualized set-ups.

Accuracy Designed into the LDPD Workflow

The development of accuracy in the LDPD system is of vital importance. It enables predictable and repeatable outcomes for dental professionals, and most importantly it helps provide patients better fitting dentures. Accuracy is uniquely integrated into each step of the LDPD workflow. Starting with Dentsply Sirona's proprietary CAD software designs, in the printing step unique platform angulations for LDP and LDI were developed for every validated printer system to ensure the integrity of the printed parts and that they fit together to precise micron standards. In the curing step, intense heat and light requirements are balanced with denture positioning in the curing oven and continued t-bar utilization to eliminate warping. The accuracy standards developed for the LDPD system cannot be matched by traditional denture processes.

[5]The A1-D4 designations correspond to the VITA classical A1-D4®shade guide which is meant to be a guide, not a match. VITA classical A1-D4 is a registered trademark of VITA Zahnfabrik H. Ratuer GmbH & Co.
[6]Acrylic Teeth Market Size is Projected to Reach USD 1.1 billion, Advancing at an 8.4% CAGR by 2034: Transparency Market Research Inc. An increase in the prevalence of periodontal disorders and dental cavities is driving opportunities in the acrylic teeth market. October 07, 2024 08:10 ET | Source: Transparency Market Research

Simple Workflow to Achieve Optimal Bonding of Denture Teeth to Base Resin

The LDPD system establishes that the printed base and the printed teeth are bonded in their green state, that is, before the final post-curing step. In the green state, both the printed denture base and the printed teeth are only partially polymerized and there is appreciable amount of residual double bonds. Lucitone Digital Fuse Step 2 3D Denture Bonding Resin is used to cohesively combine the denture base and denture teeth. Fuse Step 2 has some of the same resins as in LDP base and LDI teeth. Thus, Fuse Step 2 can readily diffuse into the green state denture base and teeth, strongly joining them together after light curing to form an integral denture.

In addition, no mechanical roughening or soaking of teeth/base with bonding agent for extended duration at warm temperature is needed. The bonding workflow is finalized with the application of Lucitone Digital Fuse Step 3 Total 3D Sealer to the denture teeth (and base if desired). Fuse Step 3 Total is a completely clear liquid that, like Step 2, creates an integral bond to the teeth and base after final light curing. The addition of Fuse Step 3 Total to the denture teeth chemically polishes the denture teeth, greatly simplifying the finishing and polishing of the final cured denture.

In conclusion, combining LDP base (high impact resistance, enhanced with BAM), LDI teeth (high wear and stain resistance) with a simplified workflow positions dental professionals to meet growing demand for dentures, driven by aging populations. The LDPD System enables dental professionals to convert all of their denture production to printing, capitalizing on the system's increased capacity, throughput, and simplicity. Denture production efficiency is improved all the while using stronger materials, and without sacrificing esthetic standards established with traditional products. Process consistency and product confidence deliver accuracy, efficacy, and repeatable results. Dental labs can deliver greater choice and new possibilities - print single arch dentures, partial dentures, implant overdentures, and treat complex cases.

[7]Carbon is a registered trademark of Carbon, Inc.
Asiga, Asiga MAX, Asiga PRO 4K are trademarks of Asiga.
HeyGears® UltraCraft A2D and UltraCraft A2D 4K are trademarks of HeyGears® , Inc.

2.0 Vitro Studies

Impact Resistance by Fracture Toughness Test

As a company with more than 100 years of history in dental material innovation, Dentsply Sirona leverages industry-leading testing know-how with the highest fidelity to the International Standards such as ISO 20795-1:2013 Dentistry — Base polymers — Part 1: Denture base polymers[3], ISO 22112:2017 Dentistry — Artificial teeth for dental prostheses[4], and ISO 10477:2020 Dentistry — Polymer-based crown and veneering materials[5].

Per ISO 20795-1:2013[3], for a denture base material to qualify as having "improved impact resistance" or commonly known as high impact resistance, it must satisfy both conditions of:

(1) total work of fracture $W_f \geq 900$ J/m^2 at 23°C, and
(2) maximum stress intensity factor $K_{max} \geq 1{,}9$ MPa m$^{1/2}$ at 23°C

Together, K_{max} and Wf define the impact resistance of a prosthesis. Adequate values of these properties assure that the prosthesis can withstand the forces of mastication and resist fracture from dropping. Following ISO 20795-1:2013[3], Dentsply Sirona internal tests showed that Lucitone Digital Print™ 3D Denture Base (LDP) has a W_f = 1000 - 1650 J/m^2 and K_{max} = 2.1 - 2.8 MPa m1/2 at 23°C, qualifying as a high impact denture base.

These two parameters, K_{max} and Wf are derived from the fracture toughness test. In this test, a sharp notch is introduced to the middle of a specimen after which a three-point bending procedure is conducted to force the specimen to fracture from the notch. The peak stress of the resultant stress-strain curve and the area under the curve determine, respectively, K_{max} and Wf,after adjusting for each specimen's geometrical parameters.

The impact resistance of LDP is comparable to traditional high impact denture base materials. Dentsply Sirona internal tests show that the K_{max} and Wf of LDP, Lucitone 199 Denture Base Resin (poured acrylic denture), and Lucitone 199 Denture Base Disc (milled acrylic denture) are in the same range when measured according to ISO 20795-1: 2013[3] (Fig. 2a).

The literature corroborates these results. An in vitro analysis investigated the Wf and a KIC (mode I critical stress intensity factor) of Lucitone Digital Print™ 3D Denture Base resin, Lucitone 199 Denture Base Resin, and Lucitone 199 Denture Base Disc, after 7 and 90 days of artificial aging. For that, the authors produced 20 samples per material per time point (120 in total) and submitted them to the notchless triangular prism (NTP) specimen KIC test. **Results show all tested Dentsply Sirona materials to meet the criteria of a high impact denture base, with Lucitone Digital Print™ 3D Denture Base resin presenting the highest K_{IC} and W_f, both after 7 and 90 days of ageing[6]. Mean ± standard deviation values can be found in the table below.**

Table 1 - Fracture Toughness and Work of Fracture per Material per Timepoint

Material	K_{IC}(MPa x $m^{1/2}$)		W_f(J/m^2)	
	7 d	90 d	7 d	90 d
Lucitone Digital Print™ 3D Denture Base	2.23 ± 0.11[a]	2.24 ± 0.17[a]	8700	6300
Lucitone 199 Denture Base Resin	2.09 ± 0.13[b*]	1.82 ± 0.19[b*]	2300	1700
Lucitone 199 Denture Base Disc	1.96 ± 0.14[b*]	1.96 ± 0.27[c*]	2700	1800

Different superscript letters indicate a statistically significant difference ($p < 0.05$) between means in a same column, whereas asterisks denote significant differences between 7 d and 90 d groups.

It must be noted, however, that Mann et al.[6] performed a non-ISO fracture toughness test, in which non-ISO notchless triangular prism specimens were used, and KIC was reported instead of maximum stress intensity factor (K_{max}). Nonetheless, both studies clearly indicate that LDP's impact resistance is at least on par with the gold standard of traditional denture base resin, Lucitone 199.

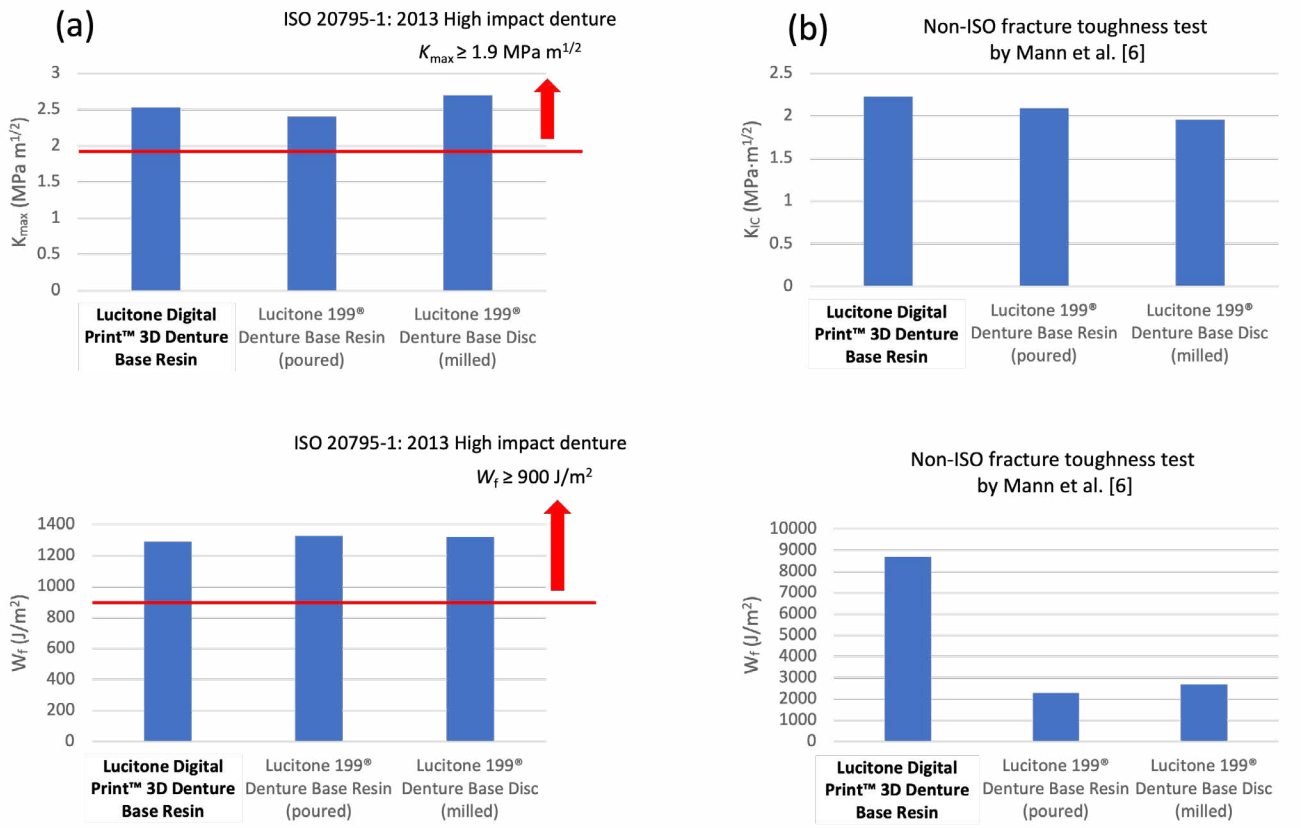
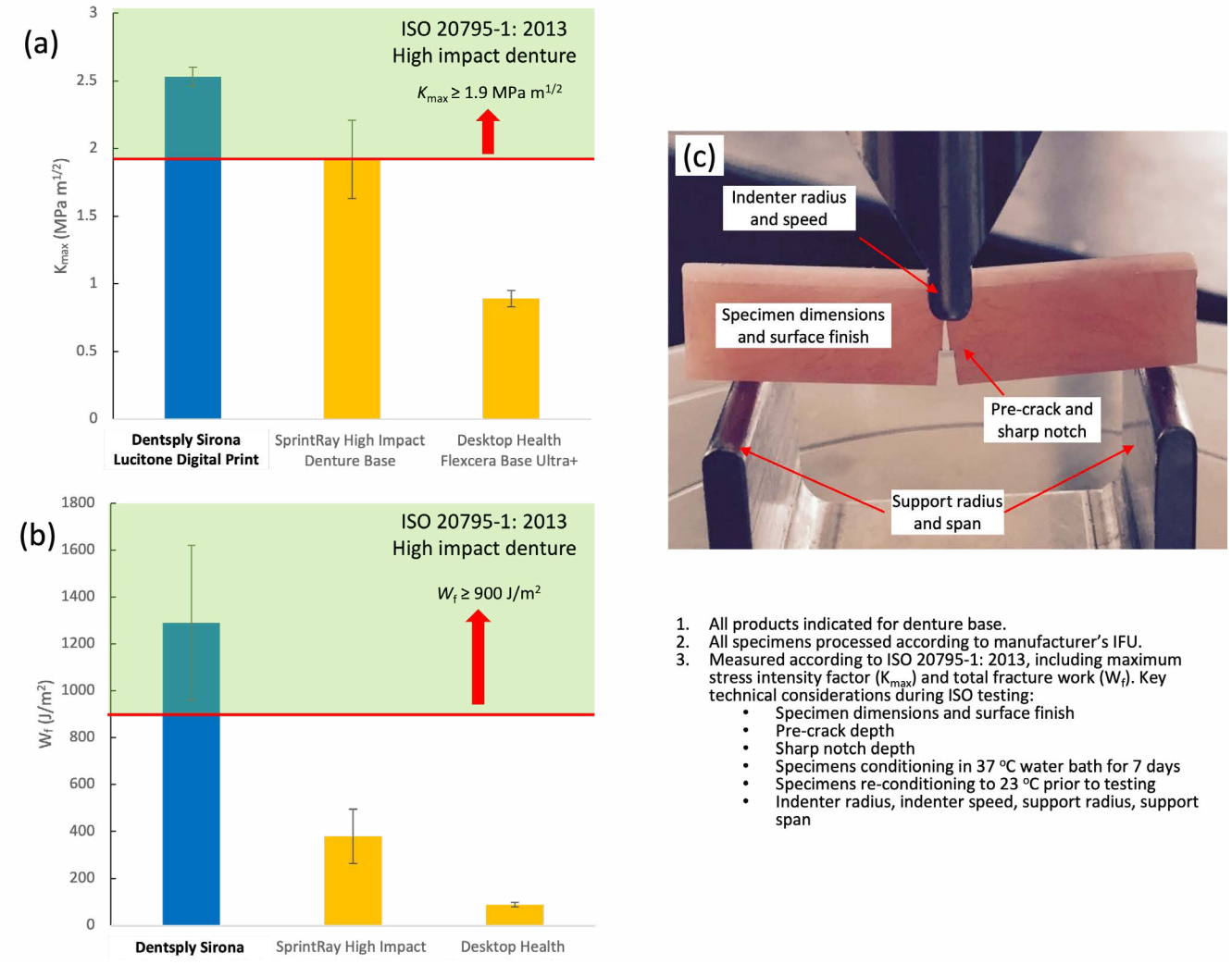


Fig. 2 - (a) K_{max} and W_f of LDP, Lucitone 199 Denture Base Resin, and Lucitone 199 Denture Base Disc according to ISO 20795-1: 2013 fracture toughness test by Dentsply Sirona; (b) K_{IC} and W_f of the same denture base materials according to Mann et al.[6].

The above-mentioned non-ISO fracture toughness test should serve as a reminder that caution must be taken when evaluating fracture toughness data from various sources and publications. Moreover, due to the complexity of specimen preparation, the ISO 20795-1[3] fracture toughness test itself can be technique sensitive and consequently caution is also advised when evaluating data from less experienced labs.

Dentsply Sirona has been performing ISO 20795-1[3] fracture toughness test since the era of traditional dentures. Critical factors such as specimen dimensions and surface finish, pre-crack depth, sharp blade, sharp notch depth, specimen conditioning sequence, indenter radius, indenter speed, support radius, support span, etc. are all rigorously inspected to ensure compliance. Shown in Fig. 3 are the fracture toughness results of selected 3D-printed denture base materials when tested by Dentsply Sirona following ISO 20795-1: 2013[3].



1. All products indicated for denture base.
2. All specimens processed according to manufacturer's IFU.
3. Measured according to ISO 20795-1: 2013, including maximum stress intensity factor (K_{max}) and total fracture work (W_f). Key technical considerations during ISO testing:
   - Specimen dimensions and surface finish
   - Pre-crack depth
   - Sharp notch depth
   - Specimens conditioning in 37 °C water bath for 7 days
   - Specimens re-conditioning to 23 °C prior to testing
   - Indenter radius, indenter speed, support radius, support span

Fig. 3 - (a) maximum stress intensity factor of selected denture base materials; (b) total fracture work of the same materials; (c) exemplary image of a post-fracture specimen with some key technical considerations of the fracture toughness test highlighted.

Moreover, LDP is a body-activated material (BAM) thanks to its smart polymer technology. That is, LDP doubles its Wf (in comparison to 23°C ± 1°C, as specified in ISO 20795-1:2013[3]) when exposed to body temperature (Fig. 4). This strengthening of the appliance is imperceptible to the patient and has no effect on the fit or function of the denture, while making it more resistant to breakage and aggravation of existing cracks or fractures.

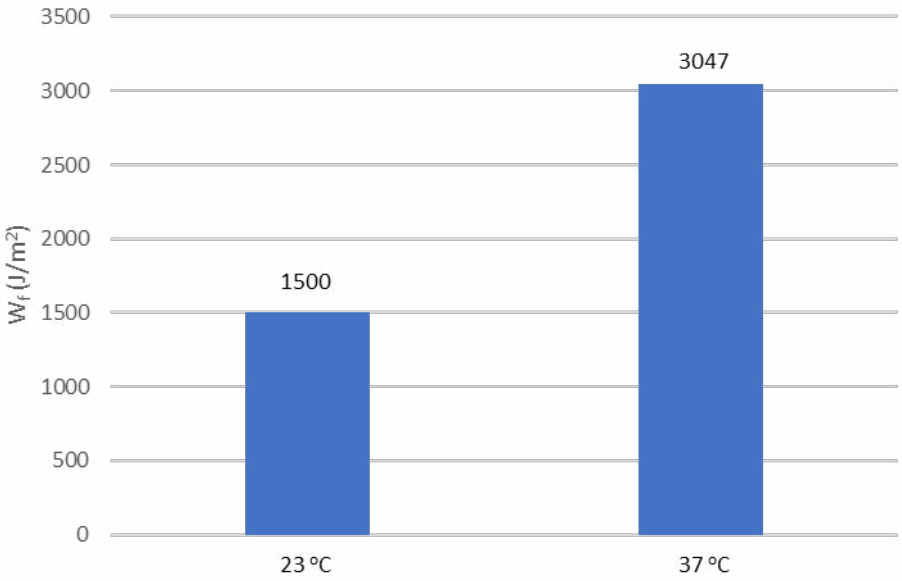


Fig. 4 Mean Wf of LDP doubles when temperature changes from 23 °C to 37 °C.

Flexural Strength and Flexural Modulus

Flexural strength is the ability of a material to resist bending or fracturing under load, whereas its flexural modulus stands for its stiffness. Together, these properties affect the durability and stability of a denture. If these values are too low, the denture base may break or deform under stress, which can lead to tooth debonding. However, if these values are too high, the denture base may be too rigid and uncomfortable for the patient. High rigidity also increases the risk of a fracture in the midline during mastication or when the denture is accidentally dropped. The denture base provides support for the denture teeth and serves as an interface between these and the alveolar bone and gingival tissues. To withstand the functional forces and to prevent tooth debonding and irregular resorption of the alveolar bone, the denture base must present an optimal flexural strength and flexural modulus.

ISO 20795-1:2013 specifies a minimal flexural strength of 65 MPa and a minimal flexural modulus of 2000 MPa for denture base polymers[3]. In the ISO 20795-1 flexural test, a specimen is brought to the specified dimensions and surface finish with grinding paper, conditioned in 37 ± 1°C water bath for 50 ± 2 hours, and then subject to a three-point bending procedure in a 37 ± 1°C water bath. The peak stress from the resultant stress-strain curve and the initial slope of the curve give rise to the flexural strength and flexural modulus, respectively, after adjusting for the specimen's geometrical parameters. Deviation from the ISO in the final testing environment (e.g., 37°C water bath) can lead to substantially inflated false flexural strength and modulus, whereas other deviations such as in specimen dimensions and surface finish can lead to inaccuracy in the final results as well.

Following the methods laid out in the standard [3], forty five specimens of Lucitone Digital Print™ 3D Denture Base resin were tested internally. All of them showed values above these thresholds, with a mean Flexural Strength of 68 MPa and a mean Flexural Modulus of 2193 MPa, resulting in a well-balanced denture base that is both durable and comfortable.

Optical Properties

Good shade match, high translucency, even distribution of pigments and color stability are key features to achieve overall esthetics and customer satisfaction for a denture. Five Lucitone Digital Print™ 3D Denture Base resin shades (Original, Light, Light Reddish Pink, Dark Reddish Pink, and Original Opaque) were evaluated by Dentsply Sirona's Research & Development team. Specimens were prepared for each shade according to the instructions for use and inspected for shade match, overall translucency and distribution of pigments. All shades met both internal DS standards, as well as the criteria defined in ISO 20795-1:2013-Denture Base Polymers [3].

For color stability, samples and control specimens were prepared and incubated at 37°C for 24 hours. Control specimens were wrapped in aluminum foil and stored away from light, while test specimens were exposed to UV light for 24 hours in accordance with ISO 7491:2000 — Dental materials — Determination of colour stability[7]. After exposure, the samples were evaluated by three qualified observers per ISO 7491[7]. In turn, Lucitone Digital IPN™ 3D Premium Tooth's color stability was also assessed internally, following the instructions laid out in ISO 22112:2017 — Dentistry — Artificial teeth for dental prostheses[4]. Our results show both materials present no perceptible color change.

Furthermore, denture base materials should resemble the tissues they replace. The appearance of a dental prosthesis is determined in part by its translucency (the relative amount of light transmission) or diffuse reflection from a substrate surface through an opaque medium. It is also determined by the reflectance of underlying substances, like the inner dentin or opaque substrate layer, through the outer translucent layer. Translucency provides a vivid appearance to a denture base. However, in prostheses with a translucent base and low color-masking ability, underlying metal frameworks can cause gray shadows. This is clinically relevant, for many implant-retained and implant-supported removable dentures have metal components under or within their bases, which could cause such gray shadows and lead to patient dissatisfaction.

With that in mind, Wang, Chu and Lin assessed the transparency and color-masking ability of denture bases of varying thickness (1, 2, and 3 mm) fabricated with 8 different materials. Heat-polymerized Lucitone 199 Denture Base Resin was used as control, while experimental groups included two milled prepolymerized pink PMMA denture base materials (Lucitone 199 Denture Base Disc, Light Shade, and IvoBase CAD, Pink Shade (Ivoclar Vivadent, Amherst, NY), and five 3D-printed denture base materials (Lucitone Digital Print™ 3D Denture Base, original shade; Formlabs Denture Resins, Light Pink Shade (Formlabs, Somerville, MA); Dentca Denture Base II, Light Pink Shade, and Original Pink Shade (DENTCA Inc, Torrance, CA); and dima Print Denture Base, Original Pink Shade (Kulzer GmbH, South Bend, IN)). In total, 240 samples (10 per material per thickness) were fabricated. Using a spectrophotometer, the color coordinates (L*, a*, b*, according to the CIELab color space) of all specimens were obtained against a white, black, and metallic background.The translucency parameters (TP00) at each thickness and the color differences between 1 mm and 2 mm (dE00M1-2) and between 2 mm and 3 mm (dE00M2-3) against the metallic background were calculated with the CIEDE2000 color matrix. **Results show that, from all the 3D-printed resins, tested Lucitone Digital Print™ 3D Denture Base has color-masking abilities comparable to heat-polymerized and milled denture base materials[8]. Mean values ± standard deviation can be found in the tables below.**

[8]Alqutaibi AY, Baik A, Almuzaini SA, Farghal AE, Alnazzawi AA, Borzangy S, Aboalrejal AN, AbdElaziz MH, Mahmoud II, Zafar MS. Polymeric Denture Base Materials: A Review. Polymers (Basel). 2023 Jul 31;15(15):3258. doi: 10.3390/polym15153258. PMID: 37571151; PMCID: PMC10422349.

Table 2 - Translucency parameter (TP00) of each material at different thicknesses (mean ± standard deviation)

Material	Manufacturing method	Thickness 1 mm	Thickness 2 mm	Thickness 2 mm
Lucitone 199 Denture Base Resin (light shade)	Heat-polymerized (control)	20.46 ± 0.64[a]	13.72 ± 0.27[a]	10.55 ± 0.23[a]
Lucitone 199 Denture Base Disc (light shade)	Milled	22.49 ± 0.30[b,c]	14.79 ± 0.26[b]	9.86 ± 0.13[b]
IvoBase CAD (pink shade)	Milled	22.30 ± 0.34[b]	15.09 ± 0.18[c]	9.52 ± 0.24[c]
Lucitone Digital Print™ 3D Denture Base (original shade)	**3D-printed**	**22.84 ± 0.36[c]**	**14.32 ± 0.22[d]**	**10.25 ± 0.18[d]**
Formlabs Denture Resin (light pink shade)	3D-printed	31.67 ± 0.49[d]	26.39 ± 0.26[e]	21.89 ± 0.31[e]
Dentca Denture Base II (light pink shade)	3D-printed	31.54 ± 0.32[d]	27.09 ± 0.44[f]	23.21 ± 0.38[f]
Dentca Denture Base II (original pink shade)	3D-printed	30.00 ± 0.73[e]	23.13 ± 0.38[g]	17.66 ± 0.41[g]
Dentca Print Denture Base (original pink shade)	3D-printed	30.39 ± 0.69[e]	23.51 ± 0.44[h]	16.60 ± 0.30[h]

Different superscript letters indicate a statistically significant difference ($p < 0.05$) between means in a same column.

[9]Internal data on file. For more information, contact Consumables-Data-Requests@dentsplylsirona.com

Table 3 - The color difference between 1 mm and 2 mm (dE_{00M1-2}) and between 2 mm and 3 mm (dE_{00M2-3}) samples against the metal background (mean ± standard deviation)

Material	Manufacturing method	dE_{00M1-2}	TdE_{00M2-3}
Lucitone 199 Denture Base Resin (light shade)	Heat-polymerized (control)	6.30 ± 0.92[a]	4.19 ± 0.88[a]
Lucitone 199 Denture Base Disc (light shade)	Milled	8.26 ± 0.68[b]	3.98 ± 0.57[a]
IvoBase CAD (pink shade)	Milled	7.52 ± 0.33[c]	4.31 ± 0.23[a]
Lucitone Digital Print™ 3D Denture Base (original shade)	**3D-printed**	**6.40 ± 1.35[a]**	**3.88 ± 1.31[a]**
Formlabs Denture Resin (light pink shade)	3D-printed	7.67 ± 0.45[c]	6.01 ± 0.40[b]
Dentca Denture Base II (light pink shade)	3D-printed	6.90± 0.26[a]	5.78 ± 0.25[b]
Dentca Denture Base II (original pink shade)	3D-printed	9.52 ± 0.32[d]	6.61 ± 0.39[c]
Dentca Print Denture Base (original pink shade)	3D-printed	9.38 ± 0.94[d]	7.04 ± 0.84[c]

Different superscript letters indicate a statistically significant difference ($p < 0.05$) between means in a same column.

Bonding between denture base and teeth

Lucitone Digital Print™ 3D Denture Base and Lucitone Digital IPN™ 3D Premium Tooth work seamlessly together to address a major cause for concern of patients, dentists, and lab technicians: denture teeth debonding.

To test the bond strength between Lucitone Digital Print™ 3D Denture Base and Lucitone Digital IPN™ 3D Premium Tooth, a modification of the test described in ISO 20795-1:2013[3] and ISO 22112:2017[4] was used in internal tests. Both ISOs reference each other for the exact same test for tooth bond testing, as both base and teeth are required for testing. ISO 22112:2017[4] establishes that at least 5 out of 6 teeth must meet the criteria of the bond and shall be considered acceptable if the mode of fracture is cohesive within the tooth or the denture base polymer. Only pure adhesive interfacial fracture is considered a failure[4]. However, the sample preparation for the above-described tooth bond testing per the ISOs pertains to traditional dental materials and is not suitable for printed denture materials. Hence, a modification to the sample preparation had to be developed to create a tooth bar sample containing a printed denture base with computer-assisted designed tooth pocket features to accommodate the basal / ridgelap surface of the printed teeth. When this specimen was submitted to testing, the 6 teeth (100%) presented a cohesive fracture, which shows an excellent bond between Lucitone Digital Print™ 3D Denture Base and Lucitone Digital IPN™ 3D Premium Tooth.

These results find support in the work of Alfadhli, who conducted an in vitro evaluation on the shear bond strength (SBS) and mode of failure (MoF) of denture teeth materials bonded to denture base materials, with and without artificial aging (thermocycling). Combinations tested were LDP and Lucitone Digital Value™ (Dentsply Sirona, York, PA) (DSDP), Ivotion Base and Ivotion Dent (Ivoclar Vivadent AG, Schaan, Liechtenstein), Formlabs Denture Base OP and Formlabs Denture Teeth (DENTCA, Inc., Torrance, CA), and Lucitone HIPA and Portrait IPN denture teeth (Dentsply Sirona, York, PA). Plates (15 mm × 15 mm × 2 mm) of denture base materials were bonded to cylinders (3.5 mm × 6 mm) of denture teeth materials according to manufacturers' instructions. For each material combination, 24 specimens were prepared and divided into two groups: control and thermocycled. SBS was determined through shear bond test using a universal testing machine (Instron, Norwood, MA)[9].

Alfadhli's results show the LDP assembly to present the highest SBS of all material combinations in both test scenarios (26.59 ± 5.26 MPa or 255.69 ± 50.58 N, and 22.93 ± 4.63 MPa or 220.50 ± 44.52 N, control and thermocycled, respectively), being statistically significantly higher ($p < 0.0001$) than Formlabs' (14.22 ± 5.05 MPa or 136.74 ± 48.56 N, and 23.07 ± 9.03 MPa or 2.40 ± 0.94 N, control and thermocycled, respectively). Regarding the poor performance of the thermocycled Formlabs assemblies, it should be noted that only 3 specimens were submitted to the SBS test, as 9 failed prematurely due to debonding after thermocycling. As for MoF, LDP was the only material to show 100% cohesive failure in both test scenarios, while Formlabs was the only material to show 100% adhesive failure in both test scenarios[9].

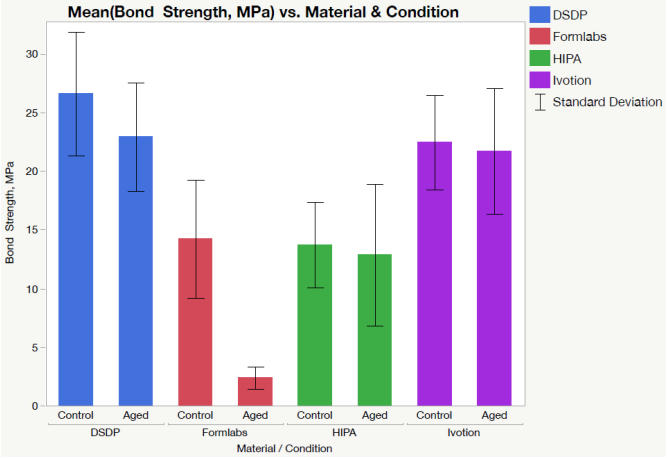


Fig. 5 - Mean SBS (MPa) of all material groups comparing control and aged groups. (Reprinted with permission from the authors.)

Surface Roughness and C. albicans adherence

The surface roughness (Ra) of a denture base material is important, as it correlates well with microbial adherence. **In vitro studies show Lucitone Digital Print™ 3D Denture Base has a very smooth surface, performing similar to dentures fabricated by traditional methods and outperforming its 3D-printed competitors [10, 11].**

Anderson et al. evaluated the impact of fabrication method (technology and material) on surface roughness. For that, six groups were established, according to fabrication method (CM – compression molding - Lucitone 199 Denture Base Resin; IM- injection molding - IvoCap High Impact, (Ivoclar Vivadent AG, Schaan, Liechtenstein); CNC - Computer Numerical Control milling - Ivotion Base (Ivoclar Vivadent AG, Schaan, Liechtenstein); and additive manufacturing - Lucitone Digital Print™ 3D Denture Base and Carbon M2 printer (Carbon Inc., Redwood City, CA) (AM-LD), Dentca Denture Base II (DENTCA Inc, Torrance, CA) and SprintRay Pro55 S printer (SprintRay Inc., Los Angeles, CA) (AM-DB), and Flexcera Base (Desktop Health, Burlington, MA) and Envision One printer (Envisiontec US LLC, Dearborn, MI) (AM-FB). For each group, 10 disks of diameter 10 × 2 mm were fabricated and analyzed using a noncontact laser confocal microscope (VK-X1000 Series; KEYENCE) at ×5 magnification. Next, images were imported into a multifile analyzer, horizontal and vertical roughness profiles were inserted into each scan, and Ra values were calculated and averaged according to ISO 4287[10]. **Their results show LDP has a surface roughness comparable to traditional methods and superior to its 3D-printed counterparts, specially in relation to Dentca Denture Base II, which showed more than double the Ra value of the other groups[10].**

Table 4 - Mean ± standard deviation (SD) of surface roughness (Ra) in µm of tested materials and statistical comparison

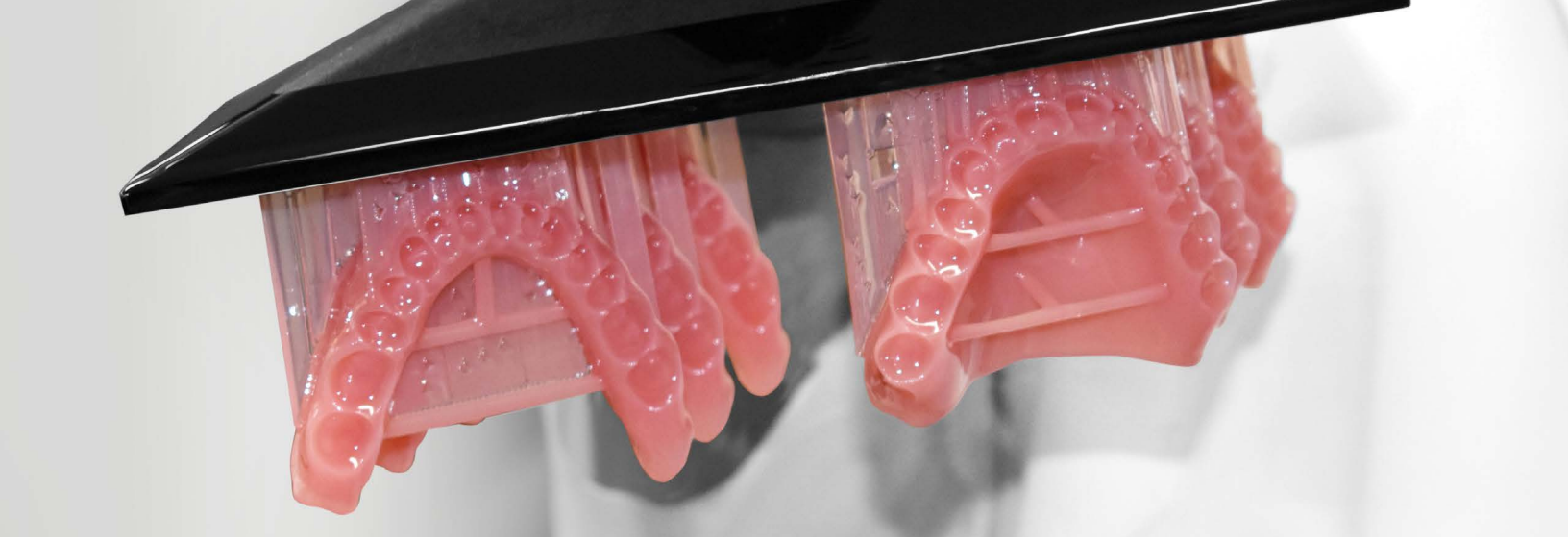
Tukey Multiple Test	Comparisons	Mean ± SD of LDP	Mean ± SD of Competitors	Mean Difference	Adjusted p value
AM-LD	**AM-DB**	1.21 ± 0.26	3.64 ± 0.95	-2.43*	<.001
	AM-FB		1.49 ± 0.42	-0.27	.775
	CNC		0.91 ± 0.07	0.31	.682
	CM		1.03 ± 0.32	0.18	.953
	IM		0.84 ± 0.22	0.37	.496

* statistically significant difference (p<.05) between compared materials.

In a similar study by the same group, disks were produced in the same manner as described above, using the same materials and technologies. This time, however, the authors looked not only into surface roughness, but also into C. albicans adherence. In this study, at ×100 magnification, LDP (AM-LD) had the smoothest surface of all CAD-CAM materials. At ×2000 magnification, LDP (AM-LD) and IvoCap (IM) exhibited the smoothest surfaces of all materials, whereas Flexcera Base (AM-FB) and Dentca Denture Base II (AM-DB) presented some of the roughest surface characteristics. The two latter groups also showed the highest values of C. albicans adherence[11].

Table 5 - Mean ± standard deviation (SD) of Log10 transformed data of CFU/ml after planktonic suspension for 48 hours

Group	Log10 CFU/ml (Mean ± SD)
AM-LD	2.465 ± 0.332
AM-DB	3.117 ± 0.233
AM-FB	2.672 ± 0.156
CNC	2.483 ± 0.689
IM	1.568 ± 0.827



Dimensional Accuracy of denture base and teeth

High dimensional accuracy of the printed denture base enable optimal fit, function, and comfort for the patient, reducing the potential for pressure sores, bone resorption and poor retention. In turn, high dimensional accuracy of the printed teeth translates into optimal occlusion, function, and esthetics. Thus, it is paramount that the printed denture accurately matches the computer-assisted design. Lucitone Digital Print™ 3D Denture Base and Lucitone Digital IPN™ 3D Premium Tooth reproduce the dimensions of the computer-assisted design with impressive accuracy, as internal and external data show.

To measure the accuracy of printed denture bases fabricated from Lucitone Digital Print™ 3D Denture Base resin, the intaglio surface of 20 specimens was scanned and compared to the original STL files using color mapping in internal tests. Dentures to print were selected from a database of real patients' scans to include different types (upper / lower jaw) and sizes (small / medium / large).

Additionally, cases with a range of palate geometries were chosen (flat / normal / deep / asymmetric). This was done to ensure that all shapes of dentures could be printed and post-cured and that the original scans of the patients' mouths would match the scans of the dentures. Dentures were fabricated following Lucitone Digital Print™ 3D Denture Base resin's Instructions for Use (IFU), including the washing and post-cure procedure. Then, they were sprayed with the centric occlusion spray and scanned using the InEos X5 optical scanner (resolution ≈ 0.012 mm), generating a new .STL file. Finally, using a color mapping software, this new .STL file was compared to the original that had been used to fabricate the dentures. Results were generated as a percentage of the scanned tissue surface area within a set tolerance of ± 0.13 mm. **Denture bases fabricated from Lucitone Digital Print™ 3D Denture Base resin showed a mean accuracy of 90%.**

Similarly, to measure the accuracy of printed denture teeth fabricated from Lucitone Digital IPN™ 3D Premium Tooth, 6 full arches (with 14 teeth) were scanned and compared to the original STL files using color mapping. Arches to print were selected from a database of real patients' scans to include different types (upper / lower jaw) and sizes (small / medium / large). Arches were fabricated following Lucitone Digital IPN's IFU. Scanning and color mapping were performed as described above. **Arches fabricated from Lucitone Digital IPN™ 3D Premium Tooth showed a mean accuracy of 95%.**

These results find support in the literature. An in vitro analysis on the trueness and precision of denture bases compared Lucitone Digital Print™ 3D Denture Base resin to Dentca Denture Resin (DENTCA, Inc., Torrance, CA)[12]. Trueness and precision are measures of a method's accuracy. The ISO 5725-1:2023 Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions[13] defines trueness as the closeness of agreement between the arithmetic mean of a large number of test results and the true or accepted reference value, while precision is the closeness of agreement between test results. To assess these outcomes, the authors scanned a master model and used a computer- assisted design (CAD) software to generate the design of the denture base. Then, they fabricated five specimens per material using a Carbon 3D printer.

Next, they scanned the denture bases using the optical scanner inEos X5 (Denstply Sirona, Bensheim, Germany) at high-resolution to create an STL file. For trueness evaluation, the scanned file of the master model was superimposed on the STL file of the intaglio surface of each denture base, whereas for precision evaluation, the scanned file of each denture base was superimposed on each other denture base within the group. Finally, 3D inspection software (Geomagic Control X v.18.1 - OQTON) was used to superimpose files and analyze the fit discrepancies of the overall surface and 5 different locations: palatal floor, palatal slope, ridge crest, flange, and posterior palatal seal. Results are presented as root mean square (RMS) values, which indicate the discrepancy between the master model and the intaglio surface of the denture base. The deviation thresholds are shown in the color maps with a tolerance of 100 micrometers.

The authors found LDP's trueness to be outstanding (0.174 ± 0.025 mm) and better than Dentca's (0.291 ± 0.010 mm) (Figs.6 and 7). With regards to precision, both materials performed similarly well (LDP 0.244 ± 0.043 mm, Dentca 0.235 ± 0.143 mm) (Table 6)[12].

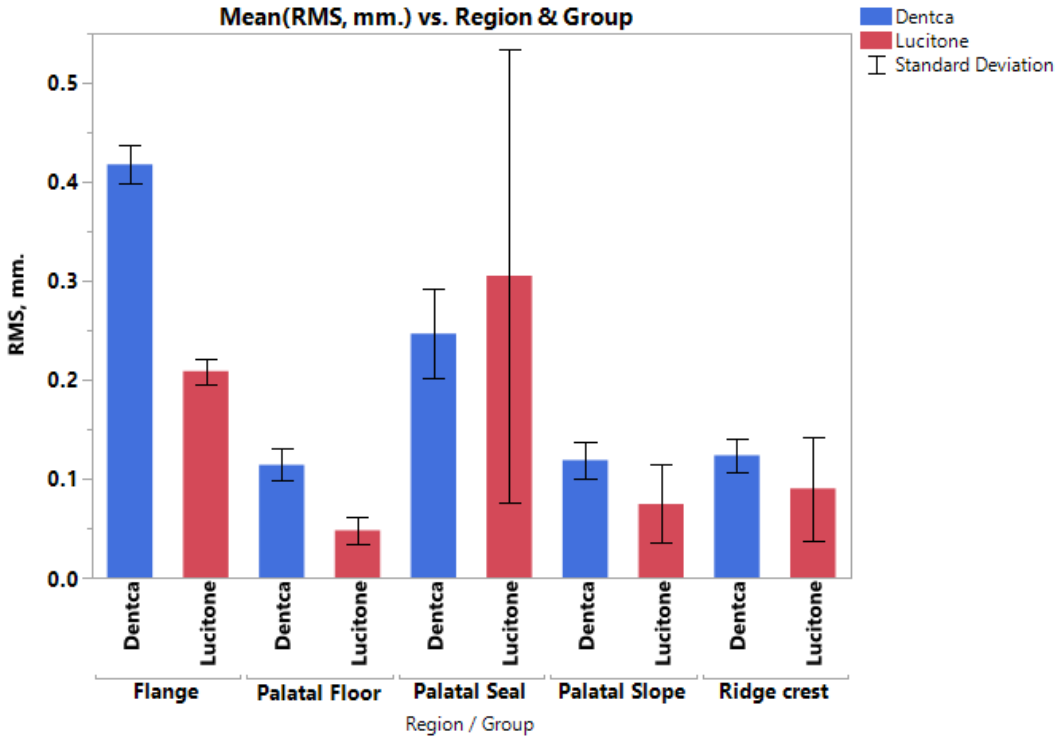


Fig. 6 - Mean RMS values in comparison of the trueness between group and region (Reprinted with permission from the authors.)

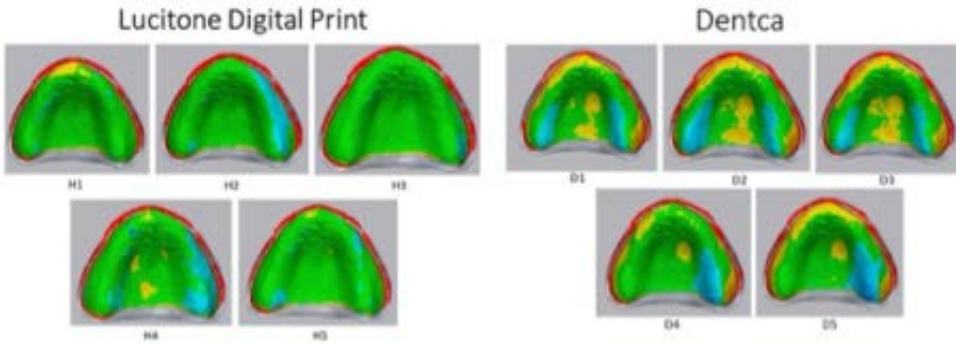


Table 6 - Precision of each material, expressed as RMS values (mean ± standard deviation, in mm) [1]

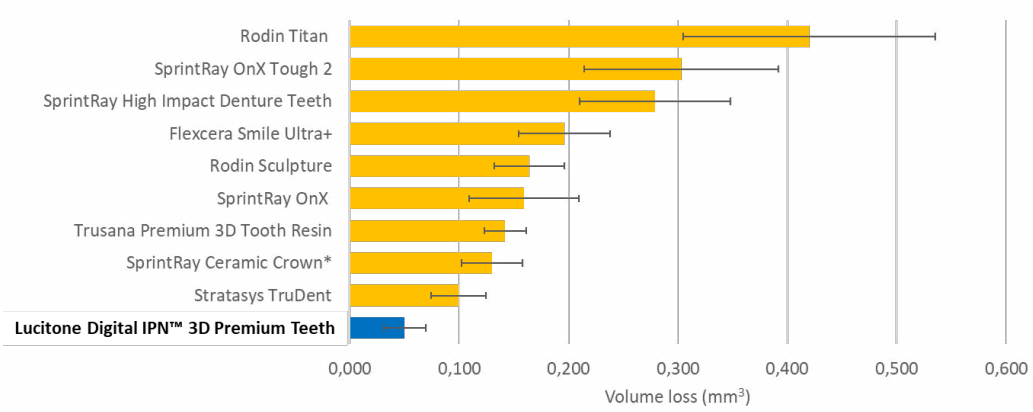
Location	Lucitone Digital Print™ 3D Denture Base	Dentca Denture Resin
Flange	0.110 ± 0.076[b]	0.046 ± 0.013[b]
Palatal Floor	0.036 ± 0.014[c]	0.056 ± 0.018[b]
Palatal Slope	0.057 ± 0.035[c]	0.034 ± 0.014[b]
Posterior Palatal Seal	0.406 ± 0.132[a]	0.359 ± 0.318[a]
Ridge Crest	0.113 ± 0.093[b]	0.049 ± 0.018[b]
Overall Precision	0.244 ± 0.043	0.235 ± 0.143

Different superscript letters indicate a statistically significant difference ($p < 0.05$) between means in a same column.

Wear Resistance of Printed Denture Teeth

The wear resistance of denture teeth is an important factor for the longevity of a rehabilitation, as progressive wear of the chewing surfaces will result in insufficient tooth support, leading to functional and esthetic impairments. To determine the wear resistance of Lucitone Digital IPN™ 3D Premium Tooth material, an in-house test was conducted to compare it to other commercially available 3D printable tooth resins. The printable tooth resins were cured according to the respective IFUs. The specimens (n≥8 per material) were subjected to 400,000 cycles of loading according to the Alabama localized 3-body wear simulation using a stainless steel ball antagonist. Wear resistance (volume loss in mm^3) was then measured using a contact profilometer.

The results show Lucitone Digital IPN™ 3D Premium Tooth material presents a superb wear resistance with only minimal volume loss (0.050 ± 0.019 mm^3), outperforming other 3D denture tooth materials.



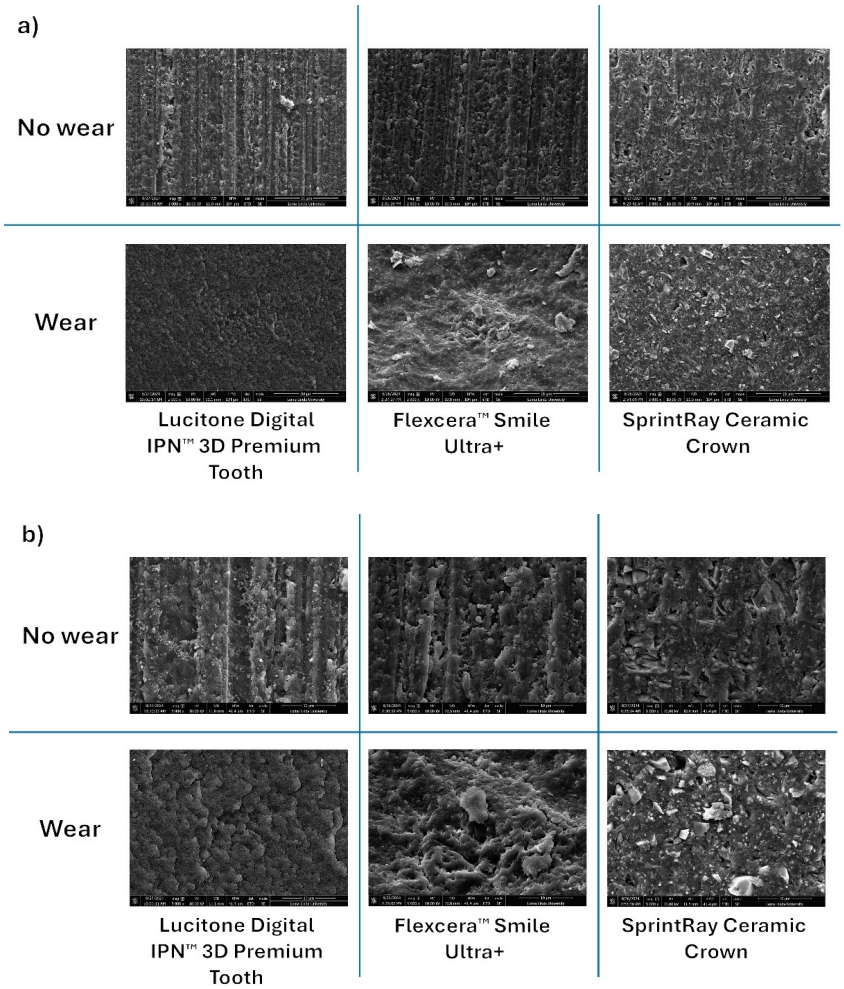
*Despite the product's name, SprintRay Ceramic Crown's indications include "artificial teeth for dental prostheses" according to the product's IFU.
[10]SprintRay. SprintRay Ceramic Crown
Instructions for Use – Valid as of 11/13/2024 [Internet]. Available from: https://sprintray-knowledge-base-public.s3.us-west-2.amazonaws.com/support/IFU/IFU-016_11+-+SprintRay+Ceramic+Crown+IFU.pdf
Accessed 01/31/2025

Fig. 8 - Wear resistance (volume loss in mm^3) of different 3D printable tooth resins

As per request of DS, an external study was conducted by the Center for Dental Research of the School of Dentistry of the Loma Linda University (LLUSD-CDR) to qualitatively evaluate the wear of three 3D-printed teeth resins. The materials tested were Lucitone Digital IPN™ 3D Premium Tooth, SprintRay Ceramic Crown (SprintRay Inc., Los Angeles, CA), and Flexcera™ Smile Ultra+ (EnvisionTEC GmbH, Gladbeck, Germany). Two samples per material were submitted to scanning electron microscopy (SEM) (Quanta 250 FEG - Thermo Fisher Scientific, Waltham, MA) (n=6) to qualitatively evaluate wear. Of these, one sample per group was randomly chosen and submitted to generalized 3-Body Contact Test (n=3) prior to SEM. Samples were mounted onto metallic stubs and sputter-coated with gold (Hummer – Anatech USA, Sparks, NV). Next, they were imaged using 5 kV with an ETD detector in SE mode. Initially, microimaging was taken at ×30 magnification to evaluate the wear region. Then, images of the surfaces were taken at ×2000 and ×5000 magnification.

SEM images from the no-wear group revealed consistent morphology across the samples, characterized by oblique lines throughout the samples, with exception to the SprintRay Ceramic Crown material, which displayed a continuous film on its surface, interspersed with depressions. As for the wear group, distinct characteristics were observed. Lucitone Digital IPN™ 3D Premium Tooth samples revealed a smoother worn surface when compared to the Flexcera™ Smile Ultra+ and SprintRay Ceramic Crown. The latter exhibited a diverse range of particles with various shapes distributed across the surface. From smoothest to roughest, the materials were ranked as follows: Lucitone Digital IPN™ 3D Premium Tooth → Flexcera™ Smile Ultra+ → SprintRay Ceramic Crown. Comparing between the no-wear and wear surfaces, Lucitone Digital IPN™ 3D Premium Tooth samples appear smoother after wear. The same was not observed for the other materials. This is clinically relevant, as a **smooth surface ensures a higher gloss and a more natural look, less microbial accumulation, greater color stability, and less antagonist wear.**

Fig. 9 - a) SEM images at ×2000 magnification; b) SEM images at ×5000 magnification



Residual Monomer

The cytotoxic effects of denture base acrylic resins are mainly caused by leachates, especially unreacted residual monomer. Constant contact of saliva with the material causes the openings between the polymer chains to expand, allowing the unreacted monomer to diffuse out. As a result, substances leached from the denture bases into the saliva are transferred to the oral structures, which can lead to adverse effects, such as mucosal irritation and allergic reactions. Therefore, it is important to reduce the residual monomer content in the processed denture by using appropriate curing methods and post-curing treatments.

Lucitone Digital Print™ 3D Denture Base was tested internally according to ISO 20795-1:2013[3], which establishes that 7 out of 9 specimens of the material must present < 2.2% residual methyl methacrylate (MMA). All specimens (9 out of 9) showed values below that threshold, with an average of 0.02%.

References:

[1]R. Martinez, P. Morsch, P. Soliz, C. Hommes, P. Ordunez, and E. Vega, “Life expectancy, healthy life expectancy, and burden of disease in older people in the Americas, 1990-2019: a population-based study,” Rev Panam Salud Publica, vol. 45, p. e114, 2021, doi: https://doi.org/10.26633/rpsp.2021.114.

[2]R. Elsenpeter. “Dental Labs by the Decade.” https://www.dentalproductsreport.com/view/dental-labs-by-the-decade (accessed November 21, 2024.

[3]ISO 20795-1:2013 Dentistry — Base polymers — Part 1: Denture base polymers, International Organization for Standardization, 2013-03 2013. [Online]. Available: https://www.iso.org/standard/62277.html

[4]ISO 22112:2017 Dentistry — Artificial teeth for dental prostheses, International Organization for Standardization, 2017-08 2017. [Online]. Available: https://www.iso.org/standard/70086.html

[5]ISO 10477:2020 Dentistry — Polymer-based crown and veneering materials, International Organization for Standardization, 2020-10 2020. [Online]. Available: https://www.iso.org/standard/80007.html

[6]R. S. Mann and N. D. Ruse, “Fracture toughness of conventional, milled and 3D printed denture bases,” Dent Mater, vol. 38, no. 9, pp. 1443-1451, Sep 2022, doi: https://doi.org/10.1016/j.dental.2022.06.029.

[7]ISO 7491:2000 Dental materials — Determination of colour stability, International Organization for Standardization, 2000-09 2000. [Online]. Available: https://www.iso.org/standard/26857.html

[8]Y. J. Wang, T. G. Chu, and W. S. Lin, “Translucency parameter and color masking ability of CAD-CAM denture base materials against metal substrates,” J Prosthodont, Aug 5 2022, doi: https://doi.org/10.1111/jopr.13581.

[9]S. F. Alfadhli, “Evaluation of the Bond Strength of Various Denture Teeth Materials to Conventional, CADCAM, and 3D Printed Denture Bases,” Master Thesis, Department of Restorative Sciences and Biomaterials, Boston University - Henry M. Goldman School of Dental Medicine, Boston, 2022. [Online]. Available: https://open.bu.edu/handle/2144/44994

[10]L. N. Anderson, T. Alsahafi, W. A. Clark, D. Felton, and T. A. Sulaiman, “Evaluation of surface roughness of differently manufactured denture base materials,” J Prosthet Dent, Sep 16 2023, doi: https://doi.org/10.1016/j.prosdent.2023.08.028.

[11]W. E. Linder II, “Evaluation of Adherence of Candida albicans to Differently Manufactured Acrylic Resin Denture Base Materials,” Master Thesis, Department of Comprehensive Oral Health (Prosthodontics), University of North Carolina - Adams School of Dentistry, Chapel Hill, 2022. [Online]. Available: https://cdr.lib.unc.edu/concern/dissertations/d791ss027

[12]J. Duangsuwan, K. Kantikosum, Y. Fan, and R. Giordano, “Accuracy Evaluation of Different Denture Bases Fabricated by 3D-Printing Technology,” presented at the 2020 IADR/AADR/CADR General Session, Washington, D.C., USA, 2020.

[13]ISO 5725-1:2023 Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions, International Organization for Standardization, 2023-07 2023. [Online]. Available: https://www.iso.org/standard/69418.html

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