

## Article

# A Different Approach to Analyzing the Surface Roughness of Prosthetic Dental Acrylic Resins

Margarida Martins Quezada <sup>1,\*</sup>, Carlos Fernandes <sup>2</sup>, Javier Montero <sup>3</sup>, André Correia <sup>1,\*</sup>, Helena Salgado <sup>1</sup>  
and Patrícia Fonseca <sup>1</sup>

<sup>1</sup> Centre for Interdisciplinary Research in Health (CIIS), Faculty of Dental Medicine, Universidade Católica Portuguesa, 3504-505 Viseu, Portugal

<sup>2</sup> Faculty of Engineering (FEUP), Universidade do Porto, 4099-002 Porto, Portugal

<sup>3</sup> Faculty of Medicine, Department of Surgery, University of Salamanca, 37008 Salamanca, Spain

\* Correspondence: s-mmquezada@ucp.pt (M.M.Q.); andrecorreia@ucp.pt (A.C.)

**Abstract:** (1) Introduction: Apart from the polishing method, conventional or mechanized, the arithmetic mean roughness (Ra) is the most common metric to evaluate the surface roughness of denture base acrylic resins. An overview of the constraints related to this roughness parameter is highlighted in this study. This research introduces new parameters for accessing a functional analysis of surface roughness. (2) Materials and Methods: Five samples of CAD/CAM 3D-printed acrylic resins were prepared. Two polishing techniques, manual and mechanical, were applied. Surface roughness parameters were extracted from a profilometer reading: arithmetic mean height (Ra and Pa), skewness (Rsk and Psk), and kurtosis (Rku and Pku). (3) Results: Significant differences ( $p < 0.001$ ) were found in the Ra distribution among the study samples, in contrast with the lack of significance in Pa values. Surface roughness parameters revealed an increased coefficient of variance (CV) value due to mechanized polishing across the specimens analyzed. Skewness and kurtosis indicate a more pronounced distribution with the manual polishing technique. (4) Conclusion: This preliminary study exhibits the influence of different polishing protocols on surface roughness parameters. The primary profile, skewness, and kurtosis should be assessed for the surface characterization of acrylic resins.

**Keywords:** polymethyl methacrylate; 3D printed resin; prosthodontics; surface roughness; functional properties



**Citation:** Quezada, M.M.; Fernandes, C.; Montero, J.; Correia, A.; Salgado, H.; Fonseca, P. A Different Approach to Analyzing the Surface Roughness of Prosthetic Dental Acrylic Resins. *Appl. Sci.* **2024**, *14*, 619. <https://doi.org/10.3390/app14020619>

Academic Editor: Joseph Nissan

Received: 16 December 2023

Revised: 6 January 2024

Accepted: 9 January 2024

Published: 11 January 2024



**Copyright:** © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 1. Introduction

Acrylic resins are used for various applications in dentistry, such as denture base materials. The most common material used for denture base is poly (methyl methacrylate) (PMMA) [1].

Among PMMA properties, surface roughness emerges as a clinically significant factor, directly or indirectly impacting microbial plaque retention in tissues in contact with the denture base. A clinical threshold, devoid of statistical relevance to microbial colonization, was established at 0.2  $\mu\text{m}$  [2]. Beyond this value, the potential for pathological conditions, such as prosthetic stomatitis and oral candidiasis, rises due to microbial accumulation. To counteract this, mechanical and chemical polishing processes on the prosthetic base surface are recommended to enhance the material's biocompatibility [3–5].

The surface roughness of dental acrylic resins is mainly affected by acrylic resins' inherent features, the polishing technique, and the operator's manual skills [1,4,6]. The authors of the present study propose a mechanical device for polishing acrylic resins, regardless of the individual operator's skills. When assessing surface roughness, this variable should be excluded [1].

Different surfaces exhibit different tribological properties, with surface roughness performing a major role [7]. Functional performance is significantly correlated with surface

finish, encompassing surface texture, and the mechanical characteristics of the surface [8,9]. Manipulating surface roughness affects the mechanism and structure of acrylic resins, not only from the visual aspect but also from a clinical perspective, since it extends to properties such as fatigue life, wear resistance, corrosion resistance, and micro-organism deposit formation or colonization on acrylic resins [9].

To characterize and classify different surfaces, surface roughness parameters were developed and standardized through the American National Standard Institute (ANSI) and the International Organization for Standardization (ISO) [10]. ISO 4288:1996 [11] has presented rules and procedures to assess surface texture.

In general, profilometers are the most used contact instrument for measuring surface roughness, quantifying it based on the recorded surface height. The operating principle of the device consists of a diamond tip in contact with a surface that performs a straight-line scan, where height variations are converted into electrical signals, referred to as micrometric magnitudes. The measurements obtained only represent two dimensions (2D), considering that the tip only moves vertically and horizontally along a central line [12,13]. From a graphical perspective, surface roughness corresponds to variations in height on a surface relative to a reference plane [10,14,15]. However, profile graphs do not provide the quantitative data required to estimate the functional value of a surface [14,16]. Such data can be extracted from surface profile graphs by analyzing statistical parameters. These parameters measure the vertical (amplitude), the horizontal deviations (spatial), or a combination of both amplitude and spatial aspects [12–14].

This challenge emerges from the need to select suitable surface parameters for monitoring whether the desired functional surface properties are met [17]. The most common metric to analyze surface roughness is Ra (the arithmetic average of the absolute values of the profile height deviations from the mean line, recorded within the evaluation and length). Although this parameter provides a good overall description of height variations, it does not provide information relative to the shape of the surface and does not provide information about the frequency and regularity of their occurrence [1,7,14]. It also lacks details about wavelengths and is not responsive to minor changes in the profile. For example, different authors [10,14] describe the possibility of the same Ra value for a surface with profiles of different shapes and frequencies. A correlation between the cutting parameters and surface finish can be established when the valleys transform into peaks or the opposite. This argument cannot be established using Ra [9,16].

A single roughness parameter is insufficient to analyze surface texture or recognize patterns [17]. The amplitude parameters skewness (Rsk) and kurtosis (Rku) assess surface structure, surface defects, and wear conditions, offering a more comprehensive surface characterization [10,14,16]. Skewness (Rsk) [7,14] is an effective parameter to characterize the symmetry level within the distribution function. It is particularly responsive to occasional deep valleys or high peaks, allowing us to differentiate between asymmetrical profiles that might otherwise share the same Ra value [7]. Kurtosis (Rku) quantifies the sharpness of the probability density distribution within the profile by measuring the extent of pointedness or flatness in a distribution function [7,14]. The conjunct analysis of Rsk and Rku can precisely determine the surface condition and elucidate whether it exhibits excessively high peaks or valleys [17].

Considering the constraints highlighted in prior investigations, the present authors propose an analytical comparison between two different polishing methods, manual and mechanical, to establish a different approach for analyzing the surface roughness height parameters in dental acrylic resins.

## 2. Materials and Methods

### 2.1. Materials

#### 2.1.1. Samples Preparation

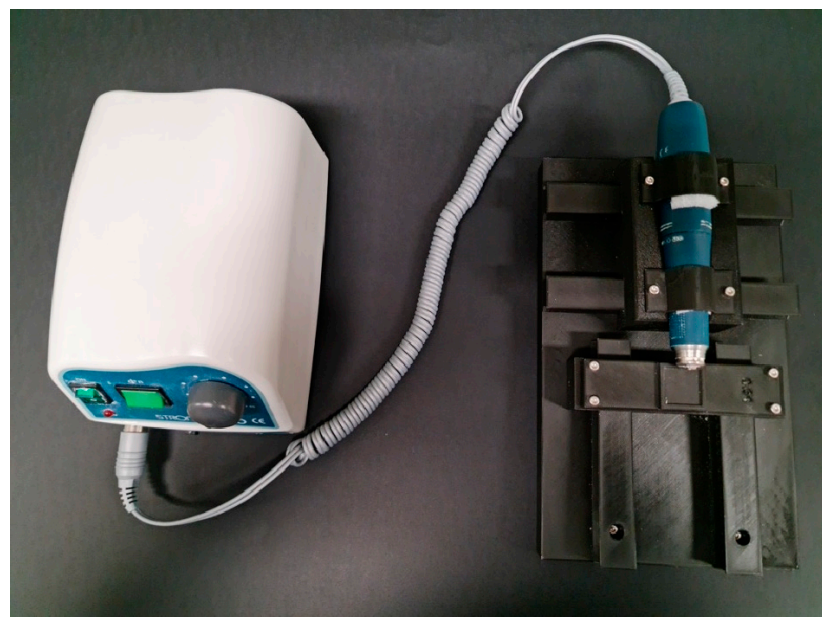
Six samples of a CAD/CAM 3D printed resin (V-Print dentbase, VOCO GmbH, Cuxhaven, Germany), each measuring 20 × 20 × 3 mm, were tested. Table 1 describes the process, resources, and method, used to prepare the samples

**Table 1.** Sample preparation process.

Process	Resources	Method
Design	CAD <i>Asiga Composer 2.0</i> (Asiga Composer, ASIGA, Erfurt, Germany)	STL file
Impression	<i>Asiga Max UV 3D Printer</i> (ASIGA, Erfurt, Germany)	Digital Light Processing (DLP)
Cleaning	<i>Sonorex Super, RK 102H</i> (Bandelin, Berlin, Germany)	Isopropyl alcohol
Post-Processing	<i>Otoflash G17 G171, Flashing Unit</i> (NK-Optik GmbH, Baierbrunn, Germany)	$\lambda_{(\text{wavelength})} = 580 \text{ nm}$

#### 2.1.2. Polishing Protocol

Five specimens were subjected to two polishing protocols: manual and mechanized. A prototype of a mechanical polishing device (Figure 1), previously developed and published by the author [1], was used in this investigation. A sixth specimen was not submitted to any polishing protocol and served as a control.



**Figure 1.** Mechanized polishing device [1].

All samples were polished following traditional steps described in ISO standard 20795-1:2008 [18] using a tungsten carbide bur with a thin crosscut followed by a JOTA<sup>®</sup> Kit 1877 DENTUR POLISH (Jota AG, Rüthi, Switzerland) sequence with a handpiece coupled to a micro-motor (STRONG 206, SAESHIN<sup>®</sup>, Daegu, Republic of Korea) at 5000 rpm. The manufacturer's instructions recommend using a bullet-shaped drill for acrylic prosthetic bases. In both methods, each drill (coarse grain, medium grain, and fine grain) was applied for 30 s. To reduce the wear effect of the drill upon contact with the samples, the polishing methods were applied sequentially.

The same five samples were used for both polishing techniques to ensure consistent processing conditions and reduce their impact on surface roughness. The manual technique was applied on one side, while the mechanized technique was applied on the opposite side, randomly determined.

The polishing protocol was standardized by a single operator. The mechanized technique involved a mechanized device. The intention behind this device was to standardize and control the polishing method by reducing the operator's associated variables. In the mechanized device, the handpiece is fixed on a support that glides over the sample surface. In the case of manual polishing, the operator holds the handpiece.

The repeatability of the polishing protocol between techniques was ensured by fixing the samples on the same support to ensure parallelism with the bur. The polishing direction was maintained.

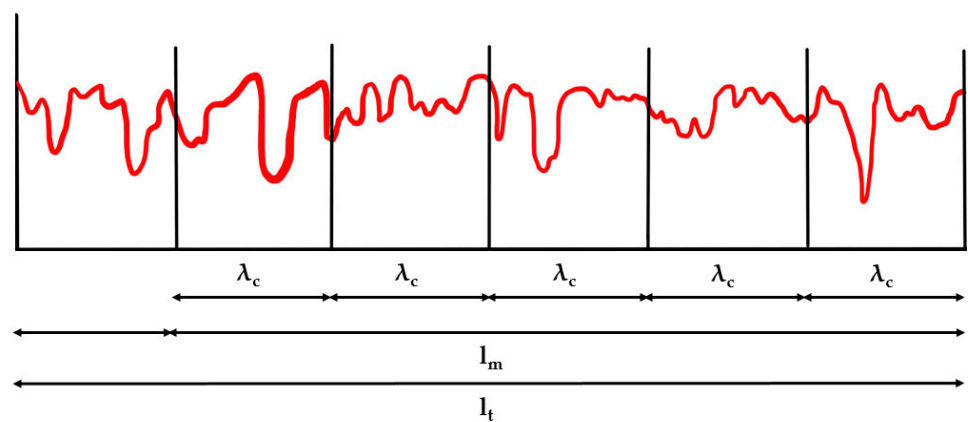
Following the polishing process, the samples were immersed in distilled water and placed in an oven (EHRET BK 4106, EHRET GmbH, Mahlberg, Germany) at a constant temperature of 37 °C for 24 h to replicate the acrylic rehydration process for denture bases.

## 2.2. Methods

Surface roughness evaluation was performed using a contact profilometer (Hommelwerke with a linear unit LV-50 and T8000 controller, Hommelwerke, Germany).

The surface of the specimen was traversed by a diamond tip (length of 4.8 mm) with a constant load of 10 s and a constant speed of 0.5 m/s. Three measurements were taken from each test specimen on randomly selected measurement lines.

Surface roughness parameters and profilometric profiles were extracted. A primary profile was obtained (Profile P), unfiltered with a length  $l_t$ . Per definition, Profile P corresponds to the curve that appears when the actual surface of the material is cross-sectioned. A Gaussian filter was applied to the primary profile, resulting in a roughness profile (Profile R) with a length  $l_m$  used to calculate roughness parameters (Figure 2). Profile R refers to the curve in which only high-frequency components of the primary profile are recorded through a high-pass filter (cutoff value  $\lambda_c$ ).



**Figure 2.** Primary profile ( $l_t$ ); Roughness profile ( $l_m$ ); Gaussian filter with a cut-off length ( $\lambda_c$ ).

A Gaussian filter with a cut-off length ( $\lambda_c$ ) was chosen according to the expected roughness threshold for microbial colonization ( $R_a = 0.2 \mu\text{m}$ ) [2,19], as recommended by ISO 4288 [20]. Transverse ( $l_t$ ) length was directly selected through the cut-off length selected (Table 2) (Figure 2) [15].

**Table 2.** Relationship between cut-off and transverse lengths (ISO 4288; 1997) [20].

Cut-Off ( $\lambda_c$ ) mm	Transversing Length ( $l_t$ ) mm
0.8	4.8

Selecting the correct filter parameter is important to the significance [20] of the measurement [15].

### 2.3. Surface Roughness Parameters

The authors propose the following approach to evaluate surface roughness in dental acrylic resins.

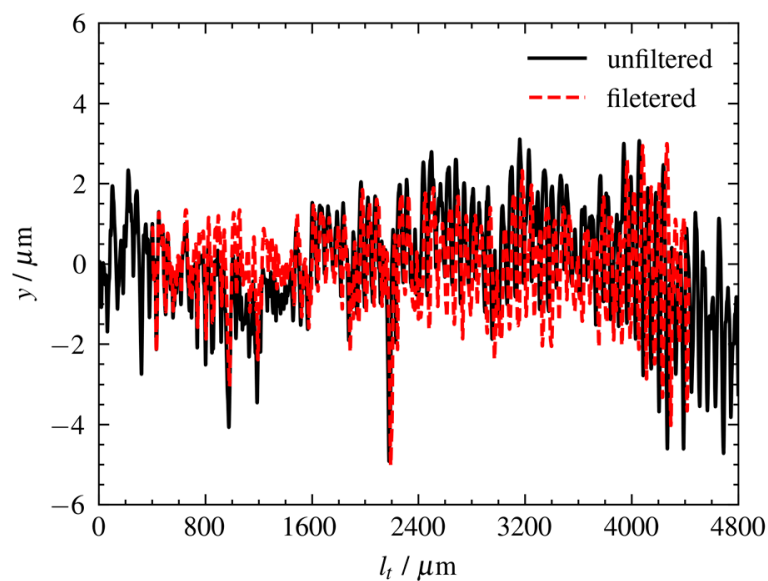
#### 2.3.1. Arithmetical Mean Height

Arithmetical mean height describes the average of the absolute values along the sample length. Arithmetic mean roughness (Ra) refers to the filtered profile ( $l_m$ ) and arithmetic mean height (Pa) refers to the primary unfiltered profile ( $l_t$ ). Table 3 demonstrates the corresponding mathematical formulation described in ISO 4287 (1997)-surface texture [11].

**Table 3.** Comparison between arithmetic mean roughness and arithmetic mean profile [15].

Parameter	Description	Formula
Ra	Arithmetic mean roughness	$\frac{1}{l_m} \int_0^{l_m}  y(x)  dx$
Pa	Arithmetic mean profile	$\frac{1}{l_t} \int_0^{l_t}  y(x)  dx$

Figure 3 represents the differences between a filtered and an unfiltered roughness profile of a sample used in the present study. The filtered profile corresponds to a 4000  $\mu\text{m}$  measuring length ( $l_m$ ) while the unfiltered profile reaches a 4800  $\mu\text{m}$  measuring length ( $l_t$ ). The difference between both measuring lengths corresponds to the cut-off length selected ( $\lambda_c$ ) (Table 2).



**Figure 3.** Roughness profile ( $y/l_t$ ).

#### 2.3.2. Skewness (Rsk)

Profile skewness describes the symmetry of the amplitude distribution curve at the profile mean line, as shown in Table 4.

**Table 4.** Amplitude of the distribution curve skewness [15].

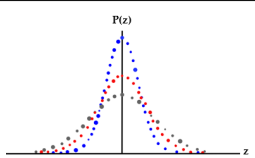
Value	Meaning	Graphic Representation [10]
Rsk < 0	Longer tail on the left of the distribution (red curve) Symmetrical Gaussian distribution (blue curve)	
Rsk > 0	Longer tail on the right of the distribution (gray curve)	

A Gaussian distribution of the roughness profile is reflected by zero skewness. A surface characterized by negative skewness displays an increased number of local maxima above the mean, deviating from the symmetric pattern of a Gaussian distribution. For positive skewness, the converse occurs [9,10,17].

### 2.3.3. Kurtosis (Rku)

Kurtosis quantifies the sharpness of the probability density distribution within the profile being classified, as shown in Table 5.

**Table 5.** Amplitude of the distribution curve—Kurtosis [15].

Value	Meaning	Graphic Representation [10]
Rku < 3	Flat amplitude distribution (gray curve)	
Rku = 3	Symmetrical Gaussian distribution (red curve)	
Rku > 3	Sharp amplitude distribution (blue curve)	

A Gaussian distribution of the roughness profile is reflected in a kurtosis value of 3. A surface with lower probability of occurrence of extreme values compared to Gaussian distribution is reflected in a kurtosis < 3. The opposite occurs for a kurtosis > 3 [9,10,17].

### 2.4. Statistical Analysis

The surface roughness values obtained from the profilometric reading were subjected to a descriptive and inferential statistical analysis of the data using IBM® SPSS® version 25.0 (IBM, Berlin, Germany) with  $p < 0.05$ . Arithmetic mean roughness values (Ra and Pa) were represented using the mean and standard deviation and 95% confidence interval of the mean. Skewness (Rsk and Psk) and kurtosis (Rku e Pku) were also represented. High kurtosis values indicate a sharp amplitude distribution with large peaks and valleys. Negative skewness suggests a concentration of material near the top of the profile and a plateau-like surface. In addition, the variation coefficient (CV), defined as the ratio between standard deviation and average value, was utilized. The two-way analysis of variance (ANOVA) with Bonferroni and the Games–Howell post-hoc test were used to compare the distribution of surface roughness Pa and Ra between polishing techniques.

## 3. Results

Table 6 shows the mean and standard deviation roughness parameters measured for the unfiltered (Pa) and filtered (Ra) groups.

**Table 6.** Dispersion measures of roughness for different polishing techniques.

Measure	Sample			ANOVA	
	Mechanized	Manual	Control	F	p-Value
Pa (µm), mean ± SD	1.49 ± 0.50	1.49 ± 0.50	11.11 ± 4.18	90.139	<0.001
Ra (µm), mean ± SD	0.89 ± 0.32 *	0.52 ± 0.17 *	2.13 ± 0.14 *	53.028	<0.001

\* significant differences between groups on post-hoc analysis; F, ANOVA F-statistic.

In terms of Pa, the mechanized technique demonstrated the lowest mean value at 1.49 µm, followed closely by the manual technique at 1.49 µm. The control technique exhibited the highest mean value at 11.11 µm (Table 6). The ANOVA F-statistic of 90.139, along with the associated p-value of <0.001, underscores a statistically significant difference in Pa distribution among the three techniques. However, the lack of homogeneity among variances between the samples precluded the identification of significant differences in the post-hoc analysis, as revealed by the Games–Howell test.

Similarly, for Ra, the mechanized technique displayed the lowest mean value at 0.89 μm, followed by the manual technique at 0.52 μm, and the control technique at 2.13 μm. The ANOVA F-statistic of 53.028, coupled with a *p*-value of <0.001, indicates a statistically significant difference in the Ra distribution among the three techniques. Post hoc analysis further corroborated noteworthy differences in Ra between all three techniques, with both the mechanized and manual techniques surpassing the control technique in performance.

The coefficient of variation (CV) for Pa displayed relatively similar values across the three techniques, ranging from 0.334 for mechanized to 0.377 for control (Table 7).

**Table 7.** Coefficient of variation (CV) for different polishing techniques.

Coefficient of Variation (CV)	Sample		
	Mechanized	Manual	Control
Pa (μm)	0.334	0.337	0.377
Ra (μm)	0.362	0.323	0.067

By contrast, the CV for Ra exhibited a distinct pattern, with the control group registering a lower value of 0.067 compared to 0.362 for mechanized and 0.323 for manual.

Tables 8 and 9 show the filtered and unfiltered groups for skewness (Rsk/Psk) and kurtosis (Rku/Pku), respectively.

**Table 8.** Skewness data for two groups of specimens.

Statistics	Psk	Rsk
Control	−0.452	−0.282
Mechanized	−0.893	−1.153
Manual	−0.416	−1.365

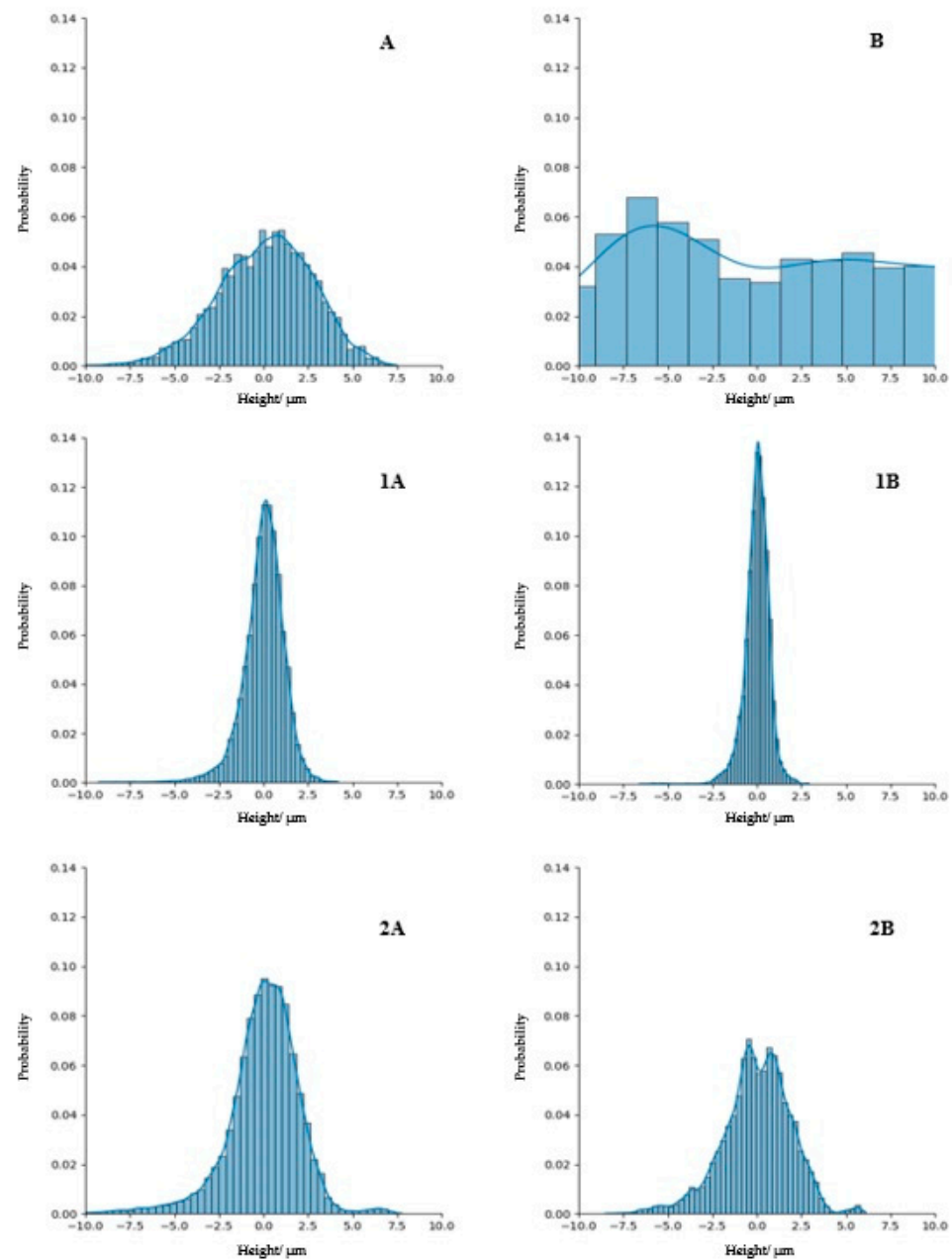
**Table 9.** Kurtosis data for two groups of specimens.

Statistics	Pku	Rku
Control	0.461	−0.032
Mechanized	3.348	4.921
Manual	0.819	8.267

The skewness values indicate a leftward tendency for the three categories, aligning with the text’s observation of heightened skewness heterogeneity in this category. The mechanized and manual categories exhibit a larger magnitude value compared to the control. A more pronounced distribution with lower values is found in the manual category (Table 7).

The kurtosis values indicate a platykurtic distribution ( $Pku/Rku < 3$ ) for the control category. After the polishing procedures (mechanized and manual), the probability of occurrence of extreme values increased with a distribution tendency for leptokurtic ( $Pku/Rku > 3$ ). On the other hand, a platykurtic distribution ( $Pku = 0.819$ ) is found on the profile of kurtosis for manually polished samples (Table 9).

Figure 4 represents the height distribution curve for the filtered and unfiltered profiles: control (A, B), mechanically polished (1A, 1B), and manually polished (2A, 2B).



**Figure 4.** Height distribution curve—filtered profile ((A) Control sample; (1A) Mechanized polished samples; (2A) Manually polished samples); unfiltered profile ((B) Control sample; (1B) Mechanized polished samples; (2B) Manual polished samples).

#### 4. Discussion

PMMA remains the predominant choice for denture base materials. Additives such as polymerization initiators, accelerators, bonding agents, and colorants have been incorporated into the base composition. These additives play a crucial role in shaping the physical and chemical properties of these materials. Among these properties, surface roughness influences the retention of microbial plaque in tissues in contact with the denture base [1,6,19].

The inherent physical characteristics of surface roughness are influenced by factors such as the operator's manual dexterity, the polishing protocol employed, and the inherent composition of the material itself.

In the literature [4,21], there is a lack of knowledge concerning the development of an effective mechanical protocol for polishing acrylic resin surfaces. To overcome this

deficiency, a prototype was developed [1]. The authors proved its validity by determining significant differences between resin groups polished with the prototype ( $p = 0.031$ ) [1]. Nevertheless, only differences in average roughness values (Ra) between the groups were assessed. One limitation was the absence of other height parameters to compare both polishing techniques (mechanized and manual).

Selecting the most suitable and pertinent surface roughness parameters to monitor desired surface properties is challenging. The need to promptly identify a subset of parameters that correlate with surface functionality has been emphasized [17].

As studied for other materials, the present authors propose the introduction of a primary profile to the analyses of a surface. The primary profile is the most critical aspect of evaluating surface roughness because it directly represents surface details, including peaks and valleys and all height variations [10,14,15]. The main parameter used to characterize the surface roughness of acrylic resins is Ra. It is an optimal value for evaluating the effect of surface polishing and finishing protocols because it considers variations in height and depth roughness [4,9,15,19,21]. However, it only addresses the profile's vertical deviation, failing to offer insights into the slopes, shapes, asperity sizes, or the frequency and regularity of their occurrence [15,16]. These features directly define the functionality of a surface in relation to bacterial adhesion, microbial growth, and stress [17,22].

Pa, directly extracted from the primary profile, can be considered an extension of Ra to the profile, as shown in Table 3. Both represent the deviation of each point's height from the arithmetical mean in different profiles [23]. From a clinical perspective, the significance of Pa is relevant because it addresses the actual profile of the resin surface. Pa represents the average of unfiltered peak and valley distances from the mean surface profile. The observed differences are comparable to the Ra results of the filtering operation, eliminating the deepest asperities of the surface [21]. Significant differences were found in three groups ( $p < 0.01$ ) for Ra; however, the heterogeneity among samples for Pa makes it difficult to determine these significant differences. Specific parameters, such as skewness and kurtosis, are described to differentiate surfaces with different shapes and the same value for Pa [14], as described in the values for the mechanical and manual techniques ( $1.49 \pm 0.50 \mu\text{m}$ ) (Table 5). Figure 4(1B,2B), show differences between the distribution curves, respectively.

Height distribution is indicated by height probability density, which compares the probability of having a given surface height relative to the centerline for each group, and is shown in Figure 4. Beyond the average roughness values, skewness (Rsk/Psk) and kurtosis (Rku/Pku) should be considered to provide information about the distribution of irregular heights on the surface [14,17]. Previous studies [4,21] showed a quasi-normal Gaussian distribution for mechanically polished specimens and a clearly asymmetric distribution for manually polished specimens. By contrast, after the polishing procedure (manual or mechanized), the present authors verified that the height distribution displayed an increase in kurtosis and a leftward skewness tendency, signifying asymmetry in height data and extreme values associated with valleys (Tables 8 and 9). Negative skewness describes a significant number of local maxima below the mean, as compared to a Gaussian distribution [10,14,24], which corresponds to areas with deep valleys and a lack of high peaks. A parameter  $Sk_u > 3$  (leptokurtic) describes surfaces with high peaks and deep valleys. By combining both parameters, a plateau-like smooth surface with deep valleys is observed, similar to the mechanized samples (Figure 4, 1A and 2A).

In terms of CV, the control group registered the lowest CV value of 0.067 compared to the polishing techniques, exhibiting a height distribution with lower kurtosis (Table 9) and a skewness near zero (Table 8).

This finding implies that the control group, directly resulting from the processing technique, produces a more uniform surface finish for Ra than the other two techniques, which increases the dispersion of surface roughness values. The literature also describes that surface height distribution features are contingent on the processing method used [6]. The ultimate shape of surfaces generated through cumulative processes, such as 3D printed resin, results from the aggregation of numerous random local events, displaying a cumula-

tive effect that follows a Gaussian form ( $R_{sk} = 0$  and  $R_{ku} = 3$ ) (Figure 4) [10,14]. Similar values were obtained for  $P_a$ , and a distinctive pattern was seen for  $R_a$ . Surface roughness parameters revealed an increased CV value for mechanically polished specimens (Table 7). Measurements of  $P_a$  and  $R_a$  for manual polished resins reflect not only the intrinsic roughness characteristics of the surface, but also the influence of the operator’s factors, such as the technician’s skill, wrist stability, attention level, and other relevant considerations associated with the manual polishing process. In contrast to the results obtained by Corsalini [21], mechanized polishing exhibited significantly higher  $R_a$  dispersion values. The efficiency of mechanized over manual protocols is questionable since it did not have the most reliable process for value dispersion or the  $R_a$  and  $P_a$  values obtained in relation to the control group.

Notably, surface polishing influences the features of height data distribution [7,24]. Improvements to the polishing device and the present protocol should be implemented. As previously mentioned [4,21], a protocol not dependent on the operator is more reliable. Obstacles to clinical usage of the proposed mechanical polishing system include the curvature exhibited on a denture base surface and the shape irregularity of removable prostheses [21].

This is a preliminary and analytical study. Studies analyzing this specific approach are not described in the literature for prosthetic acrylic resins. However, the integration of skewness and kurtosis has already been studied in other dental materials. For example, the authors performed a functional analysis on the shear bond strength of prosthetic rehabilitations in zirconia ceramics and resorted to these parameters [22].

Table 10 summarizes the differences between both approaches and clarifies the importance of analyzing additional parameters.

**Table 10.** Comparison between the conventional and proposed approach.

<b>Ra:</b>	<b>Pa:</b>
<ul style="list-style-type: none"> <li>• Result of a filtering operation that excludes information from a surface;</li> <li>• Only addresses surface irregularities in a vertical direction;</li> <li>• Height average deviation to the mean line (does not differentiate peaks and valleys);</li> <li>• Same <math>R_a</math> value with different tribological performances.</li> </ul>	<ul style="list-style-type: none"> <li>• Direct extraction of the primary profile.</li> </ul>
	<b>Skewness and Kurtosis</b>
	<ul style="list-style-type: none"> <li>• Height distribution and tip geometry of peaks and valleys;</li> <li>• Describes how the roughness is distributed along the profile;</li> <li>• Differentiates between different tribological performances.</li> </ul>

Future studies should emphasize the clinical context of the presented parameters when assessing surface characteristics and applications.

PMMA exhibits relatively low hardness, and its surface is prone to daily wear. Roughness parameters undergo continuous changes over time.

The functional performance of a surface is closely linked to the surface finish, including the surface layer’s texture and mechanical properties. These properties accompany daily use and consequent wear in the oral cavity [8]. As studied in other materials [8,9,17], skewness and kurtosis in surface roughness are critical parameters for clinically assessing retention and fit, fatigue life, corrosion, resistance, wear resistance, tissue response, aesthetics, cleaning, and maintenance of dental prostheses made of acrylic resins. For example, Das et al. [17] emphasize the importance of selecting abrasive grain sizes, as they can directly modify surface roughness and functionality, such as susceptibility to microbial contamination or the accumulation of fluid/debris. Grzesik (2016) [8] exhibited a strong correlation between skewness and kurtosis with the grit size of abrasive tools. With the additional influence of the primary profile, professionals can make informed decisions to optimize the surface finishing process of acrylic resins.

## 5. Conclusions

One significant challenge in surface-related research is selecting meaningful roughness parameters that exhibit a fundamental correlation with surface formation mechanisms and behavior, which are crucial for bacteria adhesion.

The conventional approach using Ra does not address the actual profile of the resin surface and only assesses vertical deviations. The proposed approach enriches the understanding of how these parameters influence the overall performance and functionality of acrylic dental resins within clinical scenarios. The primary profile (Pa) serves as the foundation for assessing and characterizing surface roughness. Parameters such as skewness and kurtosis were presented to provide information relative to the shape of the surface and differentiate between tribological surface behaviors.

**Author Contributions:** Conceptualization, M.M.Q., A.C., C.F., P.F. and J.M.; Methodology, M.M.Q., H.S. and C.F.; Software, C.F.; Validation, M.M.Q. and C.F.; Formal analysis, A.C., P.F. and J.M.; Investigation, M.M.Q. and C.F.; Resources, M.M.Q., C.F. and A.C.; Data curation, M.M.Q.; Writing—original draft preparation, M.M.Q. and C.F.; Writing—review and editing, M.M.Q., C.F., A.C., P.F. and J.M.; Visualization, A.C., P.F. and J.M.; Supervision, A.C., P.F. and J.M.; Project administration, A.C., P.F. and J.M.; Funding acquisition, A.C. and P.F. All authors have read and agreed to the published version of the manuscript.

**Funding:** This work was financially supported by National Funds through FCT—Fundação para a Ciência e a Tecnologia, I.P., under the project UIDB/04279/2020. Carlos Fernandes is grateful for funding through LAETA, Portugal, in the framework of project UID/50022/2020.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding authors.

**Acknowledgments:** VOCO dental, Jota AG.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Quezada, M.M.; Salgado, H.; Correia, A.; Fernandes, C.; Fonseca, P. Investigation of the Effect of the Same Polishing Protocol on the Surface Roughness of Denture Base Acrylic Resins. *Biomedicines* **2022**, *10*, 1971. [[CrossRef](#)] [[PubMed](#)]
2. Bollenl, C.M.; Lambrechts, P.; Quirynen, M. Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: A review of the literature. *Dent. Mater.* **1997**, *13*, 258–269. [[CrossRef](#)] [[PubMed](#)]
3. Alammari, M.R. The influence of polishing techniques on pre-polymerized CAD\CAM acrylic resin denture bases. *Electron. Physician* **2017**, *9*, 5452–5458. [[CrossRef](#)] [[PubMed](#)]
4. Corsalini, C.M.; Carella, M.; Boccaccio, A.; Lamberti, L.; Pappalettere, C.; Catapano, S.; Carossa, S. An alternative approach to the polishing technique for acrylic resin surfaces. *Int. J. Prosthodont.* **2008**, *21*, 409–412. [[PubMed](#)]
5. Swaney, A.C.; Paffenbarger, G.C.; Caul, H.J.; Sweeney, W.T. American Dental Association specification No. 12 for denture base resin: Second revision. *J. Am. Dent. Assoc.* **1953**, *46*, 54–66. [[CrossRef](#)] [[PubMed](#)]
6. Oravcová, J.; Labašová, E. The analysis of surface roughness of the samples produced by 3D printing. *J. Phys. Conf. Ser.* **2022**, *2413*, 012010. [[CrossRef](#)]
7. Sedláček, M.; Podgornik, B.; Vižintin, J. Correlation between standard roughness parameters skewness and kurtosis and tribological behaviour of contact surfaces. *Tribol. Int.* **2012**, *48*, 102–112. [[CrossRef](#)]
8. Grzesik, W. Prediction of the functional performance of machined components based on surface topography: State of the art. *J. Mater. Eng. Perform.* **2016**, *25*, 4460–4468. [[CrossRef](#)]
9. Ba, E.C.T.; Dumont, M.R.; Martins, P.S.; Drumond, R.M.; Martins da Cruz, M.P.; Vieira, V.F. Investigation of the effects of skewness R sk and kurtosis R ku on tribological behavior in a pin-on-disc test of surfaces machined by conventional milling and turning processes. *Mater. Res.* **2021**, *24*, e20200435. [[CrossRef](#)]
10. Bhushan, B. Surface roughness analysis and measurement techniques. In *Modern Tribology Handbook*; CRC Press: Boca Raton, FL, USA, 2000; pp. 79–150.
11. ISO 4287:1997; Geometrical Product Specifications (GPS)—Surface Texture: Profile Method—Terms, Definitions and Surface Texture Parameters. International Organization for Standardization: Geneva, Switzerland, 1997.

12. Fort, R.; Álvarez de Buergo, M.; Vázquez-Calvo, C.; Gómez-Villalba, L.S. Análisis de la microrugosidad mediante técnicas portátiles: Aplicaciones y casos de estudio en patrimonio. *Cienc. Y Arte IV Minist. De Educ. Y Cult. Madr.* **2013**, *198–216*.
13. Alves, M.L.; Ferreira, B.B.; Leta, F.R. Evaluación de parámetros de rugosidad usando análisis de imágenes de diferentes microscopios ópticos y electrónicos. *Inf. Technol.* **2011**, *22*, 129–146. [[CrossRef](#)]
14. Stout, K. Surface roughness~measurement, interpretation and significance of data. *Mater. Des.* **1981**, *2*, 260–265. [[CrossRef](#)]
15. Mummery, L. *Surface Texture Analysis: The Handbook*; Hommelwerke GmbH: Villingen-Schwenningen, Germany, 1992.
16. Shi, R.; Wang, B.; Yan, Z.; Wang, Z.; Dong, L. Effect of Surface Topography Parameters on Friction and Wear of Random Rough Surface. *Materials* **2019**, *12*, 2762. [[CrossRef](#)] [[PubMed](#)]
17. Das, J.; Linke, B. Evaluation and systematic selection of significant multi-scale surface roughness parameters (SRPs) as process monitoring index. *J. Mater. Process. Technol.* **2017**, *244*, 157–165. [[CrossRef](#)]
18. *ISO 20795-1:2008; Dentistry—Base Polymers—Part 1*. International Organization for Standardization: Geneva, Switzerland, 2008.
19. Al-Dwairi, Z.N.; Tahboub, K.Y.; Baba, N.Z.; Goodacre, C.J.; Özcan, M. A comparison of the surface properties of CAD/CAM and conventional polymethylmethacrylate (PMMA). *J. Prosthodont.* **2019**, *28*, 452–457. [[CrossRef](#)] [[PubMed](#)]
20. *ISO 4288:1996; Geometrical Product Specifications (GPS)—Surface Texture: Profile Method—Rules and Procedures for the Assessment of Surface Texture*. International Organization for Standardization: Geneva, Switzerland, 1996.
21. Corsalini, M.; Boccaccio, A.; Lamberti, L.; Pappalettere, C.; Catapano, S.; Carossa, S. Analysis of the performance of a standardized method for the polishing of methacrylic resins. *Open Dent. J.* **2009**, *3*, 233–240. [[CrossRef](#)]
22. Wongsue, S.; Thanatvarakorn, O.; Prasansuttiporn, T.; Nimmanpipug, P.; Sastraruji, T.; Hosaka, K.; Foxton, R.; Nakajima, M. Effect of surface topography and wettability on shear bond strength of Y-TZP ceramic. *Sci. Rep.* **2023**, *13*, 18249. [[CrossRef](#)] [[PubMed](#)]
23. Kara, D.; Tekçe, N.; Fidan, S.; Demirci, M.; Tuncer, S.; Balcı, S. The effects of various polishing procedures on surface topography of CAD/CAM resin restoratives. *J. Prosthodont.* **2021**, *30*, 481–489. [[CrossRef](#)] [[PubMed](#)]
24. Lee, S.; Rasoolian, B.; Silva, D.F.; Pegues, J.W.; Shamsaei, N. Surface roughness parameter and modeling for fatigue behavior of additive manufactured parts: A non-destructive data-driven approach. *Addit. Manuf.* **2021**, *46*, 102094. [[CrossRef](#)]

**Disclaimer/Publisher’s Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.