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Comparative Analysis of Mechanized Versus Conventional Polishing Protocols for Denture Base Acrylic Resins

Margarida Martins Quezada [1,*], Carlos Fernandes [2], Javier Montero [3], André Correia [1] and Patrícia Fonseca [1]

1 Centre for Interdisciplinary Research in Health (CIIS), Faculty of Dental Medicine, Universidade Católica Portuguesa, 3504-505 Viseu, Portugal; andrecorreia@ucp.pt (A.C.); pafonseca@ucp.pt (P.F.)
2 Faculty of Engineering (FEUP), Universidade do Porto, 4099-002 Porto, Portugal
3 Faculty of Medicine, Department of Surgery, University of Salamanca, 37008 Salamanca, Spain; javimont@usal.es
* Correspondence: s-mmquezada@ucp.pt

Abstract: Surface roughness is primarily determined by the inherent characteristics of a material, the specific polishing protocol and the manual operator's dexterity. This research intends to conduct a comparative analysis between a conventional and mechanized polishing protocol concerning surface roughness and its impact on surface topography. Thirty samples were included in this in vitro study: six samples for each type of acrylic resin. All specimens underwent a polishing protocol by a conventional method and a mechanized approach with a controlled polishing tool (CPT). Profilometric measures were extracted: arithmetic mean height (Pa), skewness (Psk) and kurtosis (Pku). The Pa values acquired through both the mechanized and conventional polishing techniques are significantly lower compared to the control group. The mechanized polishing notably yielded higher roughness compared to the control group. Relatively consistent skewness and lower-to-moderate values of kurtosis were found across resin types. Differences in the dispersion and pattern for Pa were not detected between the polishing protocols. The CPT protocol reliably maintains consistent skewness and kurtosis values. The conventional protocol remains significant due to the variations observed in the Pa values obtained.

Keywords: dental polishing; polymers; polymethyl methacrylate; prosthodontics; surface properties

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1. Introduction

Acrylic resin, mainly constituted of polymer poly(methyl methacrylate) (PMMA), predominates as the most extensively employed material in the development of denture bases due to its capacity to deliver satisfactory aesthetics, ease of manipulation, biocompatibility and cost effectiveness [1–4]. Nevertheless, its characteristics can experience several modifications due to both intrinsic and extrinsic factors, such as residual monomer presence and absorption.

PMMA is a synthetic polymer formed through the addition of free radicals and the polymerization of methyl methacrylate ($C_5O_2H_8$) into poly(methyl methacrylate) $(C_5O_2H_8)_n$ [5]. The polymerization reaction is initiated and activated by N, which generates either a free radical through chemical means (agent as dimethyl-p-toluidine) or energy input (such as heat, light or microwaves) and origin free monomers. These act at the vinyl group of MMA, opening the carbon double bond and forming a new carbon–carbon single bond. During the propagation stage, the activated polymerization progresses by the binding of monomers, followed by termination through the relocation of free electrons to the chain end [5,6].

As per Specification No. 12 of the American Dental Association (ADA), prosthetic base polymers undergo classification based on their polymerization reaction activation and composition [7]. The surface processing method of PMMA has a direct influence on surface behavior. The surface topography constitutes a random structure comprising microscopic peaks and valleys created during the manufacturing process where macro- and micro-roughness appear [8]. A significant difference ($p < 0.001$) was detected in the surface roughness mean (Pa), highlighting that its distribution varies depending on the technique employed to obtain the PMMA.

To ensure the extended durability of a denture base and optimize the oral health of patients, effective control of biofilm is essential. The combination of mechanical and chemical methods is widely recommended. The surfaces of dentures should be gradually polished to eliminate rough layers, resulting in a smoother surface and a reduction in surface free energy [2,9]. Originally, Bollen et al. [10] described a surface roughness threshold of 0.2 mm as appropriate to facilitate biofilm control and minimize microorganism adhesion.

The suitability of a polishing protocol relies on the processing technique employed. Intrinsic factors such as polymerization temperature and pressure and PMMA composition exert direct influence on surface topography, consequently requiring an appropriate polishing protocol [8]. Mechanical polishing methods involve the use of polishing wheels, felt cones and rubber and silicone polishers in conjunction with different abrasive pastes like aluminum oxide and pumice [1,2,11]. In contrast to chemical polishing techniques such as surface sealants or immersion in heated monomers, mechanical methods reduce surface irregularities through controlled abrasion. The efficacy of mechanical methods compared to chemical alternatives has been documented [1]. Linke B.S. [11] emphasized the significance of selecting and utilizing appropriately abrasive tools. Variations in abrasive grain sizes and grain size distributions can alter surface roughness and impact functionality. Secondary roughness has been described consequently to an inadequate polishing protocol [9].

The surface roughness of these materials primarily depends on inherent material characteristics, the polishing method employed and the manual skill of the operator [2,3,12–14]. The authors suggest a mechanical device for polishing acrylic resins, irrespective of the individual operator's skills. Its effectiveness has been proven with arithmetic roughness mean (Ra) values lower than those of the samples not submitted to polishing [3,12,13].

Despite the effectiveness of mechanical polishing having been studied, the purpose of this technique is to perform consistent and uniform polishing compared to the conventional protocol (human dependent). To date, only Corsalini et al. [12] has described a mechanized method in industrial terms rather than chairside.

Several parameters should be considered to analyze the effect of polishing on surface topography. The most common parameter used for the analysis of roughness is Ra [3,12,13]; however, it only represents height variation and does not consider surface shape [15–17]. In addition, it is insufficient in analyzing surface texture or identify patterns. Amplitude parameters such as skewness and kurtosis evaluate surface structure defects and wear conditions, providing a more comprehensive surface characterization. The combined analysis of skewness and kurtosis can accurately determine the surface condition and elucidate surface topography [18]. The authors proposed a different approach to surface roughness by including these parameters [17].

The present research aims to apply the new approach for roughness evaluation to compare two polishing techniques (conventional and mechanized) and to assess its influence on surface topography.

2. Materials and Methods

2.1. Denture Base Acrylic Resins

Five denture base acrylic resins (Table 1), obtained by different processing techniques, were evaluated in this research.

Table 1. Evaluated acrylic resins.

Conventional		Composition	CAD/CAM		Composition
Heat cured	Probase® Hot, Ivoclar Vivadent, Schaan, Liechtenstein	P: PMMA Dibenzoyl peroxide Li: MMA 1–4 butanediol dimethacrylate	Milled	CediTEC DB, VOCO® GmbH, Cuxhaven, Germany	PMMA
Self cured	Probase® Cold, Ivoclar Vivadent, Schaan, Liechtenstein	P: PMMA Dibenzoyl peroxide Li: MMA	3D printed	V-Print dentbase, VOCO® GmbH, Cuxhaven, Germany	Li: UDMA Bis-EMA TEGDMA
Injected molded	iFlex™, tcs® Dental Inc., Signal Hill, CA, USA	Polyolefin			

P—powder; Li—liquid; PMMA—poly methyl methacrylate; UDMA—urethane dimethacrylate; Bis-EMA—bisphenol-A-ethoxylate dimethacrylate.

Each resin was prepared according to the manufacturer's instructions. The conventional processing technique for PMMA involves a powder–liquid system (P/Li). Heat-cured and self-cured resins were obtained by a flasking technique at 100 °C and 23 °C, respectively. Injected-molded resin was produced through an injection technique. Regarding the CAD/CAM technique, the milling process of the pre-polymerized PMMA block directly yields the milled resins, and 3D printing was achieved through the digital light processing (DLP) method (Table 1).

For each material, six samples—each measuring 20 × 20 × 3 mm—were prepared: five samples were polished (study group), and one did not undergo any polishing protocol (control group). A total of 30 samples were considered in the "in vitro" study. All samples were subjected to a comprehensive quality assessment to ensure the absence of fractures or visible surface irregularities. This evaluation was conducted through both visual inspection and precise measurement of predefined dimensions using an analog caliper (ROSTFREI GEHARTET caliper, Brütsch/Rüegger Tools Ltd., Urdorf, Switzerland).

2.2. Polishing Protocol

The study group followed the polishing protocol described by the authors [3]. All specimens underwent polishing following the conventional steps outlined in ISO standard 20795:2008 [19]. The process involves using a tungsten carbide bur with a thin crosscut followed by a JOTA® KIT 1877 DENTUR POLISHING (Jota AG, Rüthi, Switzerland) sequence (Table 2) with a micro-motor coupled (STRONG 206, SAESHIN®, Daegu, Republic of Korea).

Table 2. JOTA® KIT 1877 DENTUR POLISHING: selected burs for the "in vitro" study.

Code	Grain	Shape	Length (mm)	Diameter (mm)	Revolutions Per Minute (rpm)
9572G	Green	Bullet	23.00	10.00	5000
9572M	Grey	Bullet	23.00	10.00	5000
9572F	Yellow	Bullet	23.00	10.00	5000
1164	-	Wheel	-	-	10,000

The protocol recommends selecting bullet-shaped burs for polishing denture base acrylic resins.

JOTA® KIT 1877 DENTUR POLISHING was applied on the study group under two different techniques described by the authors [3,17]: a conventional technique, dependent on the human operator, and a mechanized technique, with a controlled polishing tool (CPT), not human dependent [3].

Control Polishing Tool (CPT)

The CPT consists of two platforms. The first platform secures the handpiece, ensuring consistent pressure is applied to the samples during polishing. The second platform stabilizes the sample on a support with predefined dimensions (20 × 20 × 3 mm). A track mechanism enables the movement of the first platform across the sample, maintaining a parallel alignment between the handpiece and the base of the prototype (Figure 1). The design ensures that the sample's surface is polished uniformly along its support. By employing this device, the polishing process is standardized and controlled, effectively eliminating operator-dependent variables.

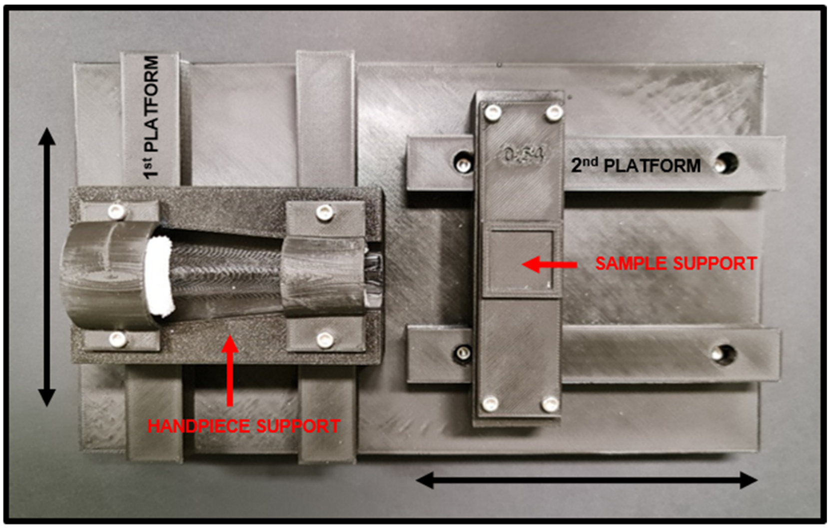

Figure 1. Kinematics of the CPT.

Both polishing techniques were applied to each sample, with each technique being used on one side of the sample. The selection of the polishing technique for each side was determined randomly.

The polishing direction of the samples was maintained. The operator was calibrated to perform 30 movements along the platform containing the samples. The polishing protocol was performed by a single operator to avoid inducing variability and to simulate the procedure executed chairside/in the laboratory uniformly and independently of the tested resin.

2.3. Oral Conditions Simulation

The samples were submerged in distilled water and placed in an EHRET BK 4106 oven (EHRET GmbH, Mahlberg, Germany) at a constant temperature of 37 °C for 24 h to simulate the rehydration that the acrylic of the prosthetic bases undergoes after the surface polishing procedure, according to ISO 20795-1 [20].

2.4. Surface Roughness Assessment

A surface roughness evaluation was performed using a contact profilometer (Hommelwerke with a linear unit LV-50 and T8000 controller, Hommelwerke GmbH, Germany). The authors proposed a new approach to evaluate surface roughness in dental acrylic resins: Pa (mean profile height), skewness (Psk) and kurtosis (Pku) [17]. Pa is a parameter directly extracted from the primary profile of a surface, and it is considered an extension of Ra within the profile. Both metrics represent the deviation of each point's height from the arithmetical mean in different profiles. From a clinical perspective, Pa is relevant, as it specifically characterizes the actual profile of the resin surface [15,17,21]. Considering that the value of Pa represents an arithmetic mean, it is possible for distinct surfaces to present the same value, despite displaying different textures.

Parameters such as skewness (Psk) and kurtosis (Pku) are precisely employed to allow this distinction [15]. Per definition, skewness describes the symmetry of the amplitude distribution curve at the profile mean line, and kurtosis quantifies the sharpness of the probability density distribution within the profile [15,17,21].

The surface of the specimen was transversed by a diamond tip with a constant load following a straight measuring length of 4.8 mm for 10 s. A TK300 pick up with a vertical range of measurement of ±300 µm, a tip radius of 5 µm and a cone angle of 90° was used. Three measurements were obtained on each specimen on randomly selected measurement lines. The mean roughness value (Pa), skewness (Psk) and kurtosis (Pku) derived from the average of these three measurements were then determined.

This study employs descriptive statistics to summarize skewness (Psk) and kurtosis (Pku). Non-parametric tests (Mann–Whitney U and Kruskal–Wallis (H)) were selected to compare differences between groups. Pa roughness values (mean and standard deviation), skewness (Psk) and kurtosis (Pku) were represented using mean and standard deviation. High kurtosis values indicate a sharp amplitude distribution with large peaks and valleys. A negative skewness suggests a concentration of the material near the top of the profile and a plateau-like surface. Pairwise comparisons were conducted using the Mann–Whitney U test to compare Pa values across different resin types within each polishing technique. The Kruskal–Wallis (H) test was utilized to assess the significance of disparities in mean Pa values between mechanized polishing, conventional polishing and the control group. Statistical analyses were conducted using IBM SPSS® Statistics software, version 27. A significance level of $p \leq 0.05$ was employed for all statistical inferences.

3. Results

Table 3 illustrates the mean Pa values for the study group (mechanized polishing (6.04 ± 5.45 µm) and conventional polishing (4.27 ± 4.74 µm)) and for the control group (7.72 ± 5.86 µm), revealing a significant difference ($p = 0.003$, Kruskal–Wallis test). While the mechanized polishing yields higher roughness compared to the conventional polishing and the control group, both mean Pa values obtained from the mechanized and conventional polishing are significantly lower than those of the control group (Figure 2).

Table 3. Roughness data for polishing techniques and resin types (Pa/µm).

Mechanized Polishing	Conventional Polishing	Control	*p*-Value
6.04 ± 5.45	4.27 ± 4.74	7.72 ± 5.86	0.003

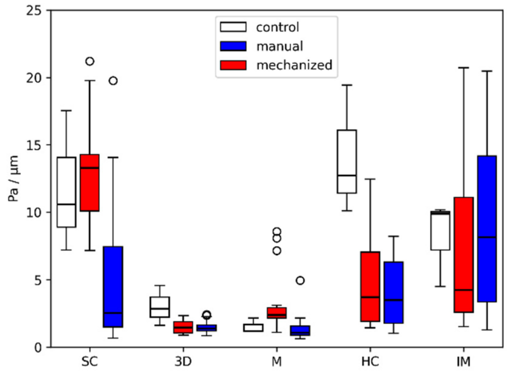

Figure 2. Distribution and dispersion of Pa/µm with control group (SC—self cured, 3D—3D printed, M—milled, HC—heat cured, IM—injected molded).

Significant disparities emerged in the overall Pa values between the mechanized and conventional polishing techniques, with the mechanized polishing notably yielding higher roughness compared to the control group (6.04 ± 5.45 µm vs. 4.27 ± 4.74 µm; $p = 0.004$). Notably, the Pa values exhibited variations across different resin types, with self-cured and injected-molded resins generally manifesting higher values, while the 3D-printed and milled resins demonstrated lower values.

Figure 2 allows an analysis of the distribution and dispersion of the roughness values. Neither the conventional nor the mechanized polishing techniques exhibited symmetrical distribution for any of the resin types. In terms of dispersion, the conventional polishing exhibited slightly higher dispersion compared to the mechanized technique, in contrast with the self-cured resin, where the mechanized polishing showed a slightly higher variability in Pa values. There is no discernible pattern, indicating that one polishing technique consistently showed higher dispersion across all resin types.

Specifically, the self-cured ($p < 0.001$) and milled ($p = 0.001$) mechanized polished resins demonstrated significantly higher Pa values compared to the conventionally polished resins. However, no significant differences in irregularity Pa values were discerned in the subgroup analysis for the 3D-printed, injected-molded and heat-cured resins (Table 4).

Table 4. Roughness data (Pa/µm) for polishing techniques and resin types.

Polishing Technique	Overall Pa (µm), Mean ± SD	Resin-Specific Pa (µm), Mean ± SD				
		Self Cured	3D Printed	Milled	Injected Molded	Heat Cured
Mechanized	6.04 ± 5.45	13.12 ± 4.00	1.49 ± 0.50	3.32 ± 2.47	7.17 ± 5.95	5.11 ± 3.61
Conventional	4.27 ± 4.74	5.46 ± 5.51	1.49 ± 0.50	1.44 ± 1.08	8.93 ± 6.23	4.01 ± 2.58
U statistics	2051.500	28.500	111.000	29.000	223	93.000
p-value	0.004	<0.001	0.950	0.001	0.443	0.419

The analysis of roughness dispersion across various polishing techniques and resin types is presented in Table 5 and Figure 2.

Table 5. Skewness and kurtosis for polishing techniques and resin types.

Group	Resin Type	Skewness	Kurtosis
Mechanized	Self cured	0.51	0.07
	3D printed	0.52	−1.04
	Milled	1.49	0.83
	Injected molded	1.04	0.13
	Heat cured	0.75	−0.62
Conventional	Self cured	1.54	2.16
	3D printed	0.84	−0.24
	Milled	2.75	8.71
	Injected molded	0.44	−1.08
	Heat cured	0.41	−1.46
Control	Self cured	−0.28	−0.03
	3D printed	−0.10	2.23
	Milled	−0.85	2.04
	Injected molded	3.17	18.92
	Heat cured	0.66	2.10

The mechanized polishing demonstrates relatively consistent skewness values across resin types, ranging from 0.51 to 1.49, suggesting a moderate concentration of material near the top of the profile and a plateau-like surface. However, the conventional polishing exhibits greater variability in skewness, with values ranging from 0.41 to 2.75.

Particularly noteworthy is the conventionally polished milled group, which shows significantly higher skewness (2.75), indicating a more pronounced distribution of material with a longer tail towards higher amplitudes compared to other conventional techniques.

Regarding kurtosis values, the mechanized polishing techniques generally exhibit low to moderate values, ranging from −1.04 to 0.83, indicating a relatively balanced amplitude distribution with smaller peaks and valleys. In contrast, the conventional polishing techniques display significantly higher kurtosis values, ranging from −1.46 to 18.92. The conventional milled group stands out with an exceptionally high kurtosis of 8.71, suggesting a sharp amplitude distribution with large peaks and valleys.

4. Discussion

The surface roughness is the variable used to describe the quality of a surface [22]. Surface roughness is directly related to plaque accumulation, discoloration, material degradation and increased patient dissatisfaction [9,23]. Polishing protocols have a significant impact on the surface roughness of denture base materials with the intention of a gradual removal of rough layers from the surface [14]. The aim of these procedures is to achieve a sufficient smooth and glossy surface to prevent bacterial plaque formation [11,14,24].

A problem related to the polishing protocols resides in their reliance on operator-dependent variables that directly influence the resulting surface roughness outcomes. In 2008, Corsalini et al. [12] addressed the first standardized method of polishing acrylic resins that would effectively ensure operational repeatability, facilitating the comparative assessment of various resins on a more homogeneous basis. The efficacy of a mechanized polishing protocol was established [12,13], revealing significant differences between the control group and the corresponding study samples, similar to the results obtained by the present authors ($p = 0.003$).

Nevertheless, in comparison to the conventional protocol, the Pa values of the mechanized protocol exhibited higher values. Hence, while its efficacy has been substantiated, conventional polishing emerges as noteworthy. The abrasion process involves traversing a series of abrasive particles (varying in fineness) over the surface. The hardness of the abrasive particles must be higher than the polymeric matrix being abraded. The pressure exerted by the abrasives, as well as the shape, size, rate and duration of the movement, may influence the efficacy of the polishing system [22,25,26]. To minimize the impact of the variables, a single operator executed all polishing procedures, and the rate (rotation per minute) and duration of treatment were standardized. The only difference presented between the two polishing techniques was the pressure exerted by the handpiece on the samples. The fact that the mechanized protocol presupposes the movement of the handpiece on the platform where the test piece is inserted may not exert sufficient pressure to produce the same polishing level in comparison to the conventional technique [3]. Milled resins present significant differences because of the higher degree of PMMA polymerization. As a result, their surface pressure resistance increases, leading to the appearance of secondary roughness (3.32 ± 2.47 µm vs. 1.44 ± 1.08 µm; $p = 0.001$) [27,28]. Furthermore, when a single operator applies the same polishing protocol, variations in the Pa values are directly influenced by the processing techniques of acrylic resins. The polymerization temperature and time affect the content of the resins [28,29]. In the polymerization reaction of self-cured resin, the degree of conversion to a polymethyl methacrylate polymer is reduced; in consequence, higher values are associated with it. Another possible explanation is that the self-cured polymer precursor has a bead size larger than the other resins [29] (13.12 ± 4.00 µm vs. 5.46 ± 5.51 µm; $p < 0.001$). Pa values identified as outliners were presented in self-cured and milled resins and potentially regarded as infrequent occurrences resulting from the polishing protocol. Moreover, a relevant outlier can be detected in the group undergoing mechanized polishing for milled resins, as the higher degree of polymerization could be the explanation for the increased surface pressure resistance and the appearance of secondary roughness (Figure 2) [28,30].

A symmetrical distribution and a pattern for Pa values for any of the resin types and between polishing techniques was not detected. This is evident from the varying lengths of the box plots, where the length represents the spread of the data. Data regarding the mechanical polishing exhibited significantly lower dispersion, primarily because the effectiveness of the protocol is no longer reliant on human factors [12,13]. The distribution tends to have lower kurtosis, suggesting flatter peaks and moderate tails, reflecting the more consistent roughness observed in the box plots, except for the milled resins. On the other hand, the conventional polishing exhibited more variability and higher skewness and kurtosis for several resin types, indicating more variability and extreme values, which aligns with the wider spread and more outliers seen in the box plots and tends to produce a broader distribution of roughness values, reflecting higher irregularities compared to mechanized polishing. The hypothesis proposed by Corsalini et al. [13] that the mechanized protocol would result in more consistent surfaces was substantiated.

The polishing protocol must be correctly adapted to the surface characteristics of each resin depending on the processing techniques. The correlation between skewness (Psk) and kurtosis (Pku) offers a valuable insight into the height distribution of surface roughness [16,31–33]. Per their definitions, skewness quantifies the symmetry of the height distribution within the surface topography and kurtosis quantifies the sharpness of the height distribution [16,34]. The JOTA® KIT 1877 DENTUR POLISHING protocol assumes surface polishing with three sequential milling burs, from coarsest to finest grain (green to yellow). It is expected that the height profile would exhibit a pronounced negative skewness and a reduction in the kurtosis values due to the removal of more high peaks compared to valleys [25,32,33]. Both the mechanized and conventional protocols contributed to the increase in the skewness and kurtosis values in the overall acrylic resins, which presupposes that the polishing kit selected has a greater tendency to develop more peaks in the surface topography and it is not effective in its removal. However, the mechanized polishing protocols revealed consistent skewness values and generally lower-to-moderate kurtosis values across resin types. Only the influence of polishing protocols on the surface topography of a surface was assessed; however, their impact on bacterial colonization was not considered. A study revealed that nanostructured surfaces (characterized by skewness and kurtosis) with a greater ratio of peaks to valleys exhibit a resistance against Candida Albicans attachment, as these surfaces act like external stressors. Conversely, surfaces featuring a valley-like nano-architecture were conductive to Candida Albicans attachment and proliferations [35]. Understanding the topography will facilitate the recognition of surface typology more conducive to the development of microorganisms, such as Candida albicans, as the leading cause of denture-related stomatitis [10,35].

The current study's limitations encompassed its "in vitro" and analytic design, failing to replicate the clinical conditions accurately. A notable characteristic of poly(mehtylmethacrylate) denture bases is their inherently low hardness. The surfaces are constantly exposed to daily wear, leading to ongoing alterations in surface roughness. To ensure durability, regular polishing is critical. Das et al. [18] underscored the importance of selecting the appropriate abrasives, as these significantly influence surface roughness and the overall functionality of the denture, including aspects such as the denture's resistance to microbial contamination and the accumulation of fluids and debris. Only five commercial brands of acrylic resins for prosthetic bases and a single polishing protocol were tested. The CPT was planned to reduce the influence of the operator's skill. The absence of calibration for the CPT warrants consideration, particularly given its status as a prototype. It introduced additional sources of variability, including the type of milling machine used, the rotation speed and the type and dimensions of the polishing tool. Enhancements should be implemented, such as the calibration of the pressure exerted by the handpiece on the sample. However, these aspects are more controllable than the variability introduced by human factors. As a result of discrepancies in the composition of denture base acrylic resins polymerized through different methods, the efficacy of polishing may diverge within the tested conditions. A significant challenge to the clinical implementation of the proposed mechanized system relies in the complex three-dimensional geometry of a denture base. The CPT is constrained to perform polishing exclusively in the transverse direction. The irregular surface of a complete denture should be assessed by incorporating a pulley system in the prototype that travels along the surface of the prosthesis with constant pressure. Moreover, the clinical implication should focus on the development of a portable device with a pressure control system (similar to an electric toothbrush) associated with the torque control of the handpiece that would allow wearers of a removable dental prosthesis to perform the polishing at home by accessing a different program for each type of acrylic resin [1] and to reduce the variability reported in our research.

5. Conclusions

This research highlights that polishing protocols present a direct effect on the surface roughness topography of acrylic resins. While comparative assessments indicate that the mechanized protocol maintains consistent skewness and kurtosis values, the conventional protocol remains noteworthy due to differences in the Pa values obtained. The CAD/CAM surfaces achieved lower roughness values, suggesting that these resins are responsive to both polishing protocols. The narrower interquartile ranges identified consistent skewness and kurtosis values for the 3D-printed, milled and heat-cured resins on the CPT protocol. Mechanized polishing protocols like CPT should be refined to develop standardized approaches that are needed to promote better denture base outcomes.

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J.M.; funding acquisition, A.C. and P.F. All authors have read and agreed to the published version of the manuscript.

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