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Can Specular Gloss Measurements Predict the Effectiveness of Finishing/Polishing Protocols in Dental Polymers? A Systematic Review and Linear Mixed-effects Prediction Model

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Clinical Relevance

A clear and dependent relationship was found between specular gloss and roughness in resin composites. A reference value of >55 GU was found to be correlated with well-polished samples. This value can thus be used to objectively determine effectiveness of polishing and may serve as a starting point for future *in vivo* gloss measurements.

SUMMARY

Purpose: The current gold standard measure to assess polishing efficacy is surface roughness (SR) assessed in laboratory research. Specular gloss (SG) has been negatively correlated to SR, which raises the following question: Can SG be used to accurately

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determine the effectiveness of a finishing/polishing procedure in direct resin composites?

Methods: A systematic approach and search strategy, following Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines, was developed and conducted in five electronic databases: PubMed/Medline, Scopus, Web of Science, EMBASE (Ovid), and SciELO/LILACS to identify laboratory studies that assessed SR and SG, simultaneously, of resin composites, without date or language restriction. Risk of bias assessment was carried out by two reviewers, independently. From the extracted quantitative data of SG/SR, regression analyses were performed, and a linear mixed-effects prediction model was derived using the nimble package in R (v4.0.3).

Results: A total of 928 potential studies were found, out of which, 13 were eligible after criterion screening. Experimental groups featured 31 resin composites of six different filler types, with the most common being microhybrids followed by nanohybrids. More than half of the studies initially reported a linear correlation between SR and SG, which ranged from r^2 = 0.34-0.96. Taking into account the regression analysis and prediction model posteriorly performed, the corresponding SG threshold for 0.2 μm is estimated to be >55 GU. Most of the evidence was classified as moderate or high risk of bias.

Conclusion: SG is universally correlated to SR in polymers, and a reference value of >55 GU is proposed, above which samples are considered well polished.

INTRODUCTION

Specular gloss (SG), like color, opalescence, translucency, and fluorescence, is a crucial parameter in dental aesthetics and is linked to the nature of the material, its surface properties, or external factors such as illumination and the observer itself.[1] Gloss is a parameter that comes from the geometrical distribution of light reflected on the surface of a material.[2] The distinction between a natural tooth and a restorative material can be found by measuring the difference in SG. This highlights the importance of gloss as a biomimetic parameter in restorative dentistry.[1,3] SG is capable of altering color perception.[4] Loss of gloss results in aesthetically unpleasant restorations, which makes them noticeable when adjacent to natural teeth.[5] Gloss variability also exists in restorative materials and especially in the natural tooth due to anisotropic texture in dental surfaces.[6]

Previous studies that determined SG in resin composites correlated it with surface properties such as SR.[4,7-10] This correlation is usually established in studies where different finishing/polishing systems are tested in order to assess the one which is the most efficient. A decrease in SR is linked with an increase in gloss in a correlation that some authors report as linear and inversely proportional.[9,11] SR of a tooth or restorative material has a direct impact on other important factors, such as dental plaque accumulation, by increasing the potential of microbial adhesion.[12] Thus, a smooth surface is crucial in maintaining periodontal health and avoiding events such as caries recurrence.[13,14]

A well performed finishing and polishing procedure is essential for the overall aesthetics of a direct restoration. It allows the manufacture of mirror and shadow areas, responsible for the way light is reflected by the enamel, playing a role in size and contour perception.[1,7] The existence of a reproducible, well-defined, simple, and predictable polishing sequence is therefore required to achieve acceptable smoothness and gloss, mimicking a natural tooth.[15] Great variability is present in polishing protocols, and evidence shows that systems that appear similar do not achieve comparable SR values.[8,16] Additional valid methods for polishing effectiveness are required.

Currently, the gold standard method to evaluate the effectiveness of a finishing/polishing protocol of a resin composite is the measurement of its SR. *In vivo* perception of roughness and visual gloss perception can be highly subjective and innacurate.[1,16] Both depend on the observational ability of the clinician and the patient's self-perception. The aim of this systematic review was to find whether gloss determination can be a valid alternative to evaluate the effectiveness of a polishing procedure of direct restorations and whether a minimum threshold gloss value can be determined to assess if samples are well polished. This review also seeks to examine the different types of SG measurements that have been conducted to assess finishing/polishing of resin composites, to investigate the variability in SG determination protocols, its correlation with SR, and what is still lacking in the evidence.

METHODS AND MATERIALS

Systematic Search

This systematic review followed Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines,[17] and the protocol, submitted to PROSPERO, was published as a preprint in

OSF open platform, following recommendations for protocols pertaining to *in vitro* studies that cannot be registered. The resulting protocol can be found at https://osf.io/4kvcb/ The systematic search was performed independently by two reviewers (TPM and AD). Search strategies were employed in the following five electronic databases: PubMed (MEDLINE), Scopus, EMBASE, ScieLO/LILACS, and Web of Science. The systematic search strategy included both Medical Subject Headings (MeSH) terms and free keywords. No language restrictions or publication date restrictions were applied in this review. The search included articles from inception until October 2020. The full electronic search strategy for PubMed/Medline was as follows: ((((((composite resins[MeSH Terms]) OR (resin composite)) OR (composite)) OR (restoration)) OR (dental resin[MeSH Terms])) AND ((((polish*) OR (finish*)) OR (dental polishing[MeSH Terms]) AND (((gloss*) OR (shin*)) OR (bright*)). The last search was conducted on November 5, 2020.

A hand search was also performed in the reference list of the papers that were eligible. Where full-text records could not be retrieved online, researchers were contacted via e-mail or digital platforms (researchgate.net).

Selection Criteria

Inclusion criteria—

- Laboratory, preclinical studies
- Studies with at least one experimental group that features direct resin composite as a restorative material
- Studies that have evaluated SG and SR simultaneously
- Studies that include finishing/polishing protocols that are clinically applicable and reproducible
- Studies that feature a control group (positive or negative) OR a baseline measurement before the polishing protocols
- Studies that evaluated SR using profilometer or AFM methods

Exclusion criteria—

- Studies that evaluated indirect materials such as ceramics, Computer-aided Design-Computer-aided Manufacturing (CAD-CAM) polymers, or indirect resin composite
- Studies that have evaluated other direct materials such as glass ionomer cements (GICs), resin-modified glass ionomer cements (RMGICs), or compomers
- Studies that have performed abrasion protocols (ie, with toothbrushes)
- Studies that used only standard laboratory polishing protocols (ie, SiC abrasion carbide paper) that are not clinically applicable
- Clinical studies

The defined intervention for this review were studies that evaluated finishing and polishing procedures with different systems in at least one experimental group with direct resin composite as a restorative material. The primary outcome evaluated was SG measurement [in gloss units (GU)], usually assessed by means of a glossmeter. The secondary outcome was SR determination—R_a (in µm or nm).

Screening of Primary Studies , Data Extraction, and Synthesis

Careful screening of the title/abstract from the references retrieved from the databases was carried out by two researchers (TPM and AD), independently, using Mendeley Desktop (v1.19.4). Papers that respected the inclusion criteria were considered eligible. After this stage, the full-text was acquired and evaluated. Disagreements were debated, and consensus was reached by seeking other review members (AMA and LL). At the full-text reading stage, reasons for exclusion were documented. As mentioned above, the primary studies also underwent a reference hand search.

A data extraction spreadsheet was developed and validated by five reviewers (TPM, AD, LL, SG, and PV). This form contained key information such as author/date, intervention type, experimental groups, sample size, material and classification, finishing/polishing system, how SR was measured (equipment/parameters), if a correlation of gloss with SR was found, and the study conclusions. Quantitative data such as SR and SG measurements were also extracted, in the form of means and standard deviations. Authors were contacted to provide access to datasheets when these were not available online. When this failed, bar charts were uploaded onto a digital platform for mean and standard deviation extraction (https://automeris.io/WebPlotDigitizer/). Data extraction was conducted independently by two reviewers (TPM and AD). When discrepancies existed, consensus was reached by consulting another review team member (LL, AMA and PV).

Quality Assessment—Risk of Bias

To assess the quality of the laboratory studies included, a risk of bias measurement was undertaken, following the method of prespecified risk of bias tools published in laboratory studies in dentistry.[18] The following criteria were assessed: Randomization of samples, sample size calculation, presence of a control group, materials used according to manufacturer's instructions, appropriate outcome assessment, blinding of the outcome assessment, and correct reporting of outcomes. A YES/NO scale was used for classification. Classification was based on the number of "No" scores, with moderate risk being three parameters and high risk being more than three. The risk of bias plot was built using an online visualization tool - RoBvis 2.0 (https://mcguinlu.shinyapps.io/robvis/).

Statistical Analysis

Quantitative results from primary studies were pooled to originate datasets for SR and SG measurements of resin composites. These were used to model the relationship between both the variables. A sensitivity analysis excluded quantitative data from Lolita and others (2020)[19] due to significant outliers, Kamonkhatinkul and others (2014)[20], and Lopes and others (2018).[8] The estimates were derived using Markov chain Monte Carlo (MCMC) methods within the nimble package (v0.10.1) in R (4.0.3).

Bayesian Linear Mixed Effects Model

A normal hierarchical regression model, also called a linear mixed effects model, was used to describe the within-study heterogeneity of observations followed by the between-study heterogeneity, using a sampling model for the study-specific regression parameters.

The within-study model is:

$$y_{i,j} = \gamma_j^{\mathrm{T}} \boldsymbol{x}_{i,j} + \epsilon_{i,j}, \quad \epsilon_{i,j} \overset{iid}{\sim} N(0, \sigma_j^2) \quad (1)$$

where $x_{i,j} = (1, x_{i,j,1}, x_{i,j,2,\ldots})$ is a design vector representing the observed SR and other possible covariate values for the observation i in study j; where $j \in = \{1,2,_{\ldots, N=10}\}$ and $i \in = \{1,2,_{\ldots, nj}\}$.

The heterogeneity among the regression coefficients, $y_1,\ldots, y_N$, will be described with a between-study model. Studies were modeled as exchangeable, assumed to be independent and identically distributed (iid) from some distribution representing the sampling variability across studies. Studies were modelled as exchangeable, ie considered as iid from some distribution representing the sampling variability across studies. The between-studies sampling model can be rewritten as:

$$\gamma_{\mathrm{j}} = \boldsymbol{\beta} + \boldsymbol{b}_j \quad (2)$$

$$\boldsymbol{b}_j \sim N_2\,(\boldsymbol{0}, \Sigma) \quad (3)$$

which, transferred to the within-study regression model gives:

$$y_{i,j} = \beta_1 + \beta_2\, x_{i,j,1} + b_{j,1} + b_{j,2}\, x_{i,j,1} + \epsilon_{i,j}. \quad (4)$$

In this parameterization, β is referred to as a vector fixed (population) effect as it is constant across studies, whereas b_j are called random effects, as they vary and are study-specific. "Mixed effects model" means the regression model that contains both fixed and random effects.

Given a prior distribution for $\beta_j, \sigma^2, \Sigma$, and having retrieved the SR and study, the observed data for the jth study are $D_j = \{(y_{i,j}, x_{,i,j})\}_{i=1}^{n_j}$, the Bayesian analysis proceeds by computing the posterior distribution $p(\beta, \boldsymbol{b}, \Sigma, \sigma^2|D)$, where D is the set of all data. This posterior distribution is approximated quite easily with Markov chain Monte Carlo (MCMC) methods within the nimble package in R. The prior distributions used are given in Table 1.

Bayesian Inverse Regression

Taking into account lower SR translates into polishing success, to correlate with SG, this problem, in its simplest form is one of inverse regression.[21] Rather than predicting SG values for a given SR, the aim was to invert this relationship to provide a prediction of SR to a specified SG value. The distributions required are for the entire population (10 studies).

Dropping the subscripts in the model, writing of the mean SG value is possible as $E[Y_0]$ at roughness x0 as $E[Y_0] = \alpha_0 + \alpha_1 x_0$. Inversion of this relationship produces the desired roughness for a specified $E[Y_0]$; that is $x_0 = (E[Y_0]\ \alpha_0)/\alpha_1$. Such distributions were summarized in terms of quantiles. Posterior features for the population parameters can be seen in Table 2.

Exploratory Analysis

To deal with the small values of the roughness and to be able to consider a normal distribution for the gloss values, a logarithmic transformation of both variables was undertaken.[22] In Figure 1, it is possible to discern

Table 1: *Prior Distributions Considered for Each Parameter in the Application*[a]

Parameter	Prior Distribution
β_1	$N(0, \sigma_{\beta 1})$
β_2	$N(0, \sigma_{\beta 2})$
$\sigma_{\beta 1}, \sigma_{\beta 2}$	$U(0.001, 100)$
$b_j\Sigma$	$N_p \geq 2(0, \Sigma)$
Σ^{-1}	*Wish*(diag(100), 2)
σ_j	$U(0.001, 100)$

[a] *The notation considered for each distribution is N (., .), N_p(., .), Wish(., .) and U (., .) standing respectively, for univariate normal,* p-*variate normal, Wishart, and uniform.*

Table 2: *Posterior Features for the Population Parameters (Means and 95% Credibility Intervals Shown)*

Parameter	Mean	95% Credibility Interval
β_1	2.326	(1.536, 2.986)
β_2	-0.690	(–0.953, –0.469)
$\sigma_{\beta 1}$	30	(1, 100)
$\sigma_{\beta 2}$	20	(10, 100)

that within each study, the higher the log(*SR*) the lower the log(*SG*). However, there is some common trend able to be retrieved by considering the Bayesian hierarchical model defined in (4). Note the high within- and between-study variability, and a clear indication of a decreasing trend. There are indications that the studies produce very different results whether looking at SR or SG.

RESULTS

Systematic Search and Data Retrieval

The systematic search retrieved 928 references in total from the five databases in which the search was conducted. After title and abstract screening, 460 references were excluded and 1 additional reference was found during manual searching. 32 final references were eligible for full-text access. Out of these, 19 studies were excluded: 12 did not have a control group or a baseline measurement of SR, and/or SG, 4 did not use finishing/polishing systems with clinical applicability, and 3 did not directly measure and determine gloss. A summary of the PRISMA flowchart can be seen in Figure 2.

The remaining 13 studies were eligible for synthesis in this systematic review, and extracted data are shown in Table 3. All the studies included measured SG and roughness in direct resin composites, with different intervention aims, using a laboratory study design. Only the experimental groups containing resin composites were featured for data synthesis and are shown in the table.

Experimental Groups: Resin Composite

A total of 31 resin composites was evaluated in the 13 studies included in this review. Only 2 studies evaluated individual materials, by varying only the finishing/polishing protocol,[10,19] while the remaining 11 studies compared different resin composites with distinct filler classifications.[8,20,23-31] Regarding filler classification, the preferred filler type studied was microhybrids (15/31 groups): ceramX, Clearfil AP-X, Clearfil Posterior, Enamel Plus HFO, Esthet X, Grandio, Filtek Silorane, Filtek Z250, FZ-Dentin, FZ-Enamel, Premise, Prisma APH, Tetric EvoCeram, Tetric Ceram, Venus; followed by nanohybrids (9/31): Brilliant Everflow, Clearfil Posterior, Estelite Asteria, IPS Empress Direct, Kalore, Sonic Fill 2, Tetric EvoFlow, Venus Diamond, Venus Pearl; nanofilled (3/31): Filtek BulkFill, Filtek Supreme XTE and Filtek Z350; and finally microfilled (3/31):

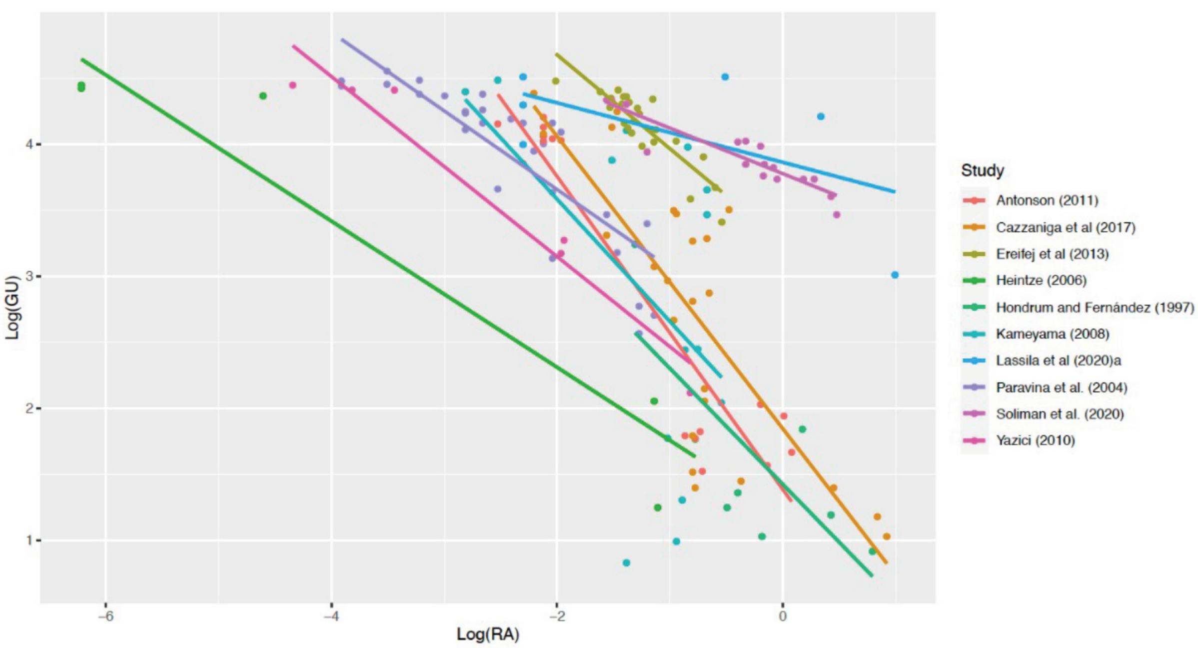

Figure 1. *A linear model fitted to each individual study.*

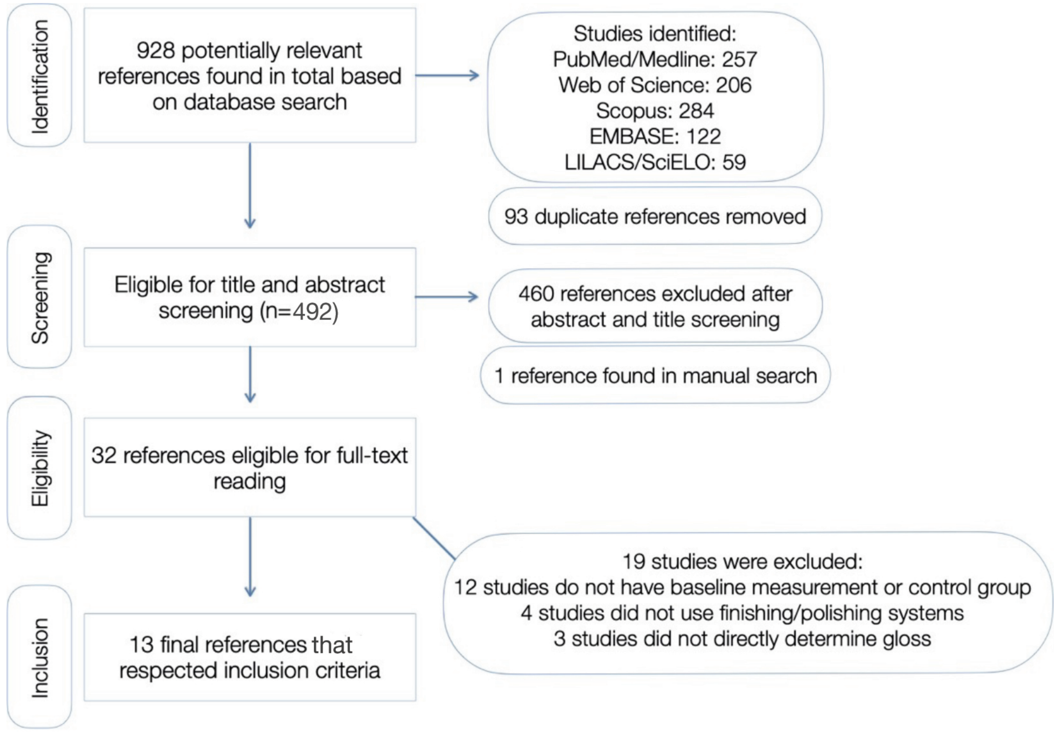

Figure 2. Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) flowchart followed in this systematic review.

Durafill, Heliomolar RO and Renamel Microfill. One submicron resin composite (Estelite Σ) was also studied. Paravina and others (2004) studied two experimental microhybrid composites, while the rest of all studied commercial products.[31]

Experimental Groups: Finishing and Polishing Systems

Most studies compared more than two finishing and polishing systems (11/13), and only two studies compared an individual polishing system.[28,30] A Mylar strip was used in seven studies as a positive control for low SR and high SG.[10,19,23,25,28,31] Sof-Lex discs were the most common polishing system evaluated (8/13), followed by finishing burs (4/13), and the Enhance PoGo system (4/13). Silicon carbide paper was also used to provide varying degrees of roughness, or as a control, in three different studies.[10,20,26] Transversal to all studies, the smoothest and the glossiest surfaces were produced with a Mylar strip when it was used as a control. All the studies support SG and SR as being material dependent and polishing-protocol dependent.

Outcomes

Surface roughness—Surface roughness (SR) was assessed using traditional surface profilometers[19,20,23-25,27,29,31] and 3D noncontact profilometers.[26,28,30] The measurements varied from one to five line tracings/scans per sample. Soliman and others (2020) used an environmental SEM and software analysis, while Lopes and others (2018) used an AFM.[8,24]

Surface gloss—To assess SG in the studies, six different glossmeters were used. The preferred glossmeter was a small area device supplied by NovoCurve (6/13 studies), while the remaining all used different devices, with varying measurement areas. All SG measurements were done at a 60° angle, and three to five measurement repetitions were performed for each sample.

Correlation Between Outcomes

Generally, when SR decreased, an increase in SG was noted, which justifies a negative linear relationship. A correlation between SR and SG was determined in 8 of the 13 studies included (64%). The strength of the correlation varied from $r^2 = 0.34$ to $r^2 = 0.96$ and was found to be material dependent, with results varying between experimental groups when subanalyses were carried out, as reported in the study of Cazzaniga and others (2017).[25] Additionally, two studies determined a correlation but failed to report it.[19,24]

Model Results

The assessment of convergence and mixing of chains within the MCMC approach has been carried out by looking at plots of autocorrelation and trace of the chains. Several chains were generated starting from different initial values, and all provided a rough indication of convergence after a small period. A numeric diagnostic Gelman-Rubin (GR) has also been considered, revealing no concerns.

Table 4 gives posterior means and interval estimates in the form of 95% equal-tail credible sets for the common effect, β_1, as well as for the roughness effect, β_2. Study-level parameter estimates are summarized in Table 4. The column corresponding to σ_j shows a relative low variability; on the log scales, the within-study variabilities are reasonably homogeneous across studies, yet not equal. The set of all study-level slope effects, $b_{j,2}$, suggests a large between-study variability. A negative correlation between the individual intercepts and slopes was found, as explained by $\Sigma_{1,2} = \Sigma_{2,1} = -0.2$.

Concerning the inverse prediction, to answer the main question, simulated scenarios can be seen in Table 5. Simulations were carried out using SG values spanning from 0.5 to 4.5 on the log scale, since values in the dataset have a minimum of 0.8 and a maximum of 4.5 on the log scale.

A roughness threshold of 0.2 = µm was considered for analysis or on the log scale log(2) = −1.609. Thus, log(SG) values indicating a roughness lower than −1.609 were sought. From Table 4 and Figure 3, it is possible to infer that at a log(GU) < 3.5 there is about 60% probability of having a SR lower than the threshold. With a log(*Gloss*) 4, all probability intervals have their boundaries below 1.6, indicating a SR below threshold (p~1).

Quality Assessment—Risk of Bias

The risk of bias assessment and judgment of each parameter is summarized in Table 6. The majority of studies (46%) were classified as having high risk of bias, followed by 38% with moderate risk of bias. Two studies (15%) were low risk. None of the studies included performed *a priori* sample size calculation, and all presented a control group or baseline measurement. Weighted plot summary is shown in Figure 4.

DISCUSSION

The purpose of this study was to determine whether SG measurement is a valid method of evaluating the effectiveness of a polishing procedure of direct resin composites, and, also, whether a minimum threshold gloss value can be proposed to inform clinicians and researchers that the samples/restorations are properly polished. To this day, no systematic review or subsequent analysis was found that determined the correlation between both these variables, taking into account the pooled results, by studying their codependence. The model presented in this study answered the question posed by confirming that SG can correlate with SR values, and thus effectively evaluate a polishing procedure.

This review included only direct resin composites. A direct restorative procedure is more subject to variability and difficulty in finishing and polishing procedures, making it clinically relevant.[16,32] Laboratory manufactured resin and ceramic restorations are produced in a controlled environment, less susceptible to protocol variations, and may be subject to additional gloss-producing measures, such as glazing.[33] Filler type is believed to be of paramount importance for final smoothness and gloss of composites. The majority of resin composites studied were microhybrids, which is not surprising, as universal restorative composites are of microhybrid filler type.[34] In what concerns aesthetic restorations, there is a common misconception that a resin composite with filler particles in a smaller range should be used, as there would be less changes in surface characteristics from wear-induced loss of filler particles. This influenced the industry into producing nanohybrid and nanofilled resin composites.[34,35] Kaizer and others (2014), however, in a systematic review, found that there is no significant influence of filler type on SG and SR.[35]

Only one study included in this review evaluated SG and SR of bulk-fill resin composites. These materials represent a significant innovation.[10] Since they allow us to reduce chair time, they are becoming increasingly popular among professionals and widely used, especially in posterior restorations. Thus, surface quality of these composites should be further evaluated in order to validate them in these parameters for generalized clinical use, here having the main purpose of minimizing biofilm accumulation and the recurrence of secondary caries, as they are generally used in posterior, nonaesthetic areas.[36,37]

This systematic review included only studies with a control group or a baseline measurement of SR and SG. As a positive control, most of the studies used a Mylar strip, as it is widely accepted, this method produces the lowest SR and the highest SG, comparatively. Conversely, as a negative control, silicon carbide papers of smaller grit size or abrasive burs were used. A negative control will illustrate the effect of only performing finishing procedures on restorations without polishing of any sort, which was proven insufficient for attaining acceptable SG and SR on all the studies that used this type of control. Furthermore, finishing procedures should always be followed by final polishing.[12]

Table 3: *Summary of Studies Included in the Systematic Review*				
Author	**Intervention**	**Sample Size**	**Resin Composite**	**Finishing/Polishing System**
Lassila and others (2020)[10]	Effect of different finishing/polishing systems and curing modes on SR and SG of one resin composite	n=3	Filtek BulkFill (3M, St Paul, USA) - nanofilled	Mylar strip 1200grit SiC 2400 grit SiC 4000 grit SiC Sof-Lex spirals (3M, St Paul, USA) 2 step Jiffy Polishing points (Ultradent, St. Louis, USA) 1 step
Soliman and others (2020)[24]	Effect of different finishing/polishing systems on SR and SG of different resin composites	n=7	IPS Empress Direct (Ivoclar Vivadent, Schaan, Liechtenstein) nanohybrid Grandio (Voco) nanohybrid Filtek Z550 (3M, St Paul, USA) nanohybrid Filtek Z250 (3M, St Paul, USA) microhybrid	Optrapol (Ivoclar Vivadent, Schaan, Liechtenstein) 1 step Politip (Ivoclar Vivadent, Schaan, Liechtenstein) 2 step Sof-Lex discs (3M, St Paul, USA) 3 step
Lolita and others (2020)[19]	Effect of different finishing/polishing systems on the SR and SG of a nanoceramic resin composite	n=5	ceramX. SphereTec Universal (Dentsply Sirona, Charlotte, USA) nanohybrid	Mylar strip Enhance (Dentsply Sirona, Charlotte, USA) 1 step Diacomp Twist spirals (EVE, Keltern, Germany) 2 step Sof-Lex discs (3M, St Paul, USA) 4 step
Lopes and others (2018)[8]	Effect of different finishing/polishing systems on the SR and SG of two different resin composites	n=5	Brilliant Everglow (Coltene/ Whaledent, Altstätten, Switzerland) nanohybrid Filtek Supreme XT (3M, St Paul, USA) nanofilled	Sof-Lex discs (3M, St Paul, USA) 2 step Sof-Lex spirals (3M, St Paul, USA) 2 step SwissFlex Disc 2 step DiaTECH burs (EVE, Keltern, Germany) 2 step Enhance cups 2 step Diashine Polishing compound and suede disc (EVE, Keltern, Germany) 2 step Finishing abrasive bur

Table 3: *Summary of Studies Included in the Systematic Review*

SG Measurement	SR Measurement	Correlation Between Variables	Conclusion
Calibrated infra-red Zehntner-Glossmeter at 60º - 6x40 mm area	Surface profilometer using five profilometer tracings	Linear correlation determined (r^2=0.938)	The smoothest surfaces were obtained with laboratory polishing (4000 grit). Polishing protocols had an effect on the SG and SR
Glossometer (PICOGLOSS 560MC) at a 60º angle	Image analysis software together with environmental scanning electron microscope	Correlation analysis determined but not reported.	The multi-step system seems to be more effective on SR and SG results. Both variables were significantly influenced by filler type and finishing/polishing system
Small area gloss meter (NovoCurve) at 60º - 2x2 mm area	Surface profilometer using five profilometer tracings	Correlation analysis determined but not reported.	The four-step polishing system resulted in the highest SG and lowest SR
A glossmeter (Micro-Tri-Gloss 4520) was used at 60º over a 2x4 mm area	AFM was used to analyse the central region. 80 sections of 10x10 um were analysed per polishing protocol	Linear correlation determined (r^2=0.419)	Type of polishing system and resin composite influences the results. SG results in composites are related to surface roughness anisotropy and its conjoined effects.

Table 3: *Summary of Studies Included in the Systematic Review (cont.)*

Author	Intervention	Sample Size	Resin Composite	Finishing/Polishing System
Cazzaniga and others (2017)[25]	Effect of surface treatments on the microbial adhesion of different resin composites	n=5	Enamel Plus HFO (Micerium, Avegno, Italy) microhybrid Estelite Asteria (Tokuyama, Yamaguchi, Japan) nanohybrid Filtek Supreme XTE (3M, St Paul, USA) nanofilled Sonicfill 2 (KaVo/Kerr, Brea, USA) nanohybrid	Mylar strip Sof-Lex discs (3M, St Paul, USA) 3 step Opti1Step (KaVo/Kerr, Brea, USA) 1 step Diamond bur Multi-blade carbide bur
Kamonkhatinkul and others (2014)[20]	Effect of finishing/polishing and toothbrushing cycles on the SR and SG of different resin composites	n=6	DuraFill (Heareus Kulzer, Hanau, Germany) microfilled Filtek Z250 (3M, St Paul, USA) microhybrid Filtek Z350 XT (3M, St Paul, USA) nanofilled Kalore (GC Corporation, Tokyo, Japan) nanohybrid Venus Diamond (Heraeus Kulzer, Hanau, Germany) nanohybrid Venus Pearl (Heraeus Kulzer, Hanau, Germany) nanohybrid	2400 and 4000 grit SiC Sof-Lex discs (3M, St Paul, USA) 1 step Venus Supra discs (Heraeus Kulzer) 1 step
Ereifej, Oweis, and Eliades (2013)[26]	Effect of different finishing/polishing systems on SR and SG of different resin composites	n=5	Filtek Silorane (3M, St Paul, USA) microhybrid IPS Empress Direct (Ivoclar Vivadent, Schaan, Liechtenstein) nanohybrid Clerfil Majesty Posterior (Kuraray, Tokyo, Japan) nanohybrid Premise (KaVo/Kerr, Brea, USA) microhybrid Estelite Sigma (Tokuyama, Yamaguchi, Japan) submicron	Control (320 grit to 4000 grit SiC) Opti1Step (KaVo/Kerr, Brea, USA) 1 step OptiDisc discs (KaVo/Kerr, Brea, USA) 3 step Kenda discs 3 step PoGo micropolisher disc (Dentsply Sirona, Charlotte, USA) 1 step

Table 3: *Summary of Studies Included in the Systematic Review*

SG Measurement	SR Measurement	Correlation Between Variables	Conclusion
Small area gloss meter (MG6-SA; KSJ) at 60° - 2x2 mm area	Surface profilometer using three line tracings	Linear correlation determined r^2 [0.336-0.542]	The one-step system showed the highest SG values. The correlation between SR and SG was material dependent and highest for the microhybrid composite.
Calibrated glossmeter (IG-331, Horiba) at a 60° - 3x6 mm^2 oval shaped area	Surface profilometer using five parallel tracings in two perpendicular directions	Linear correlation determined r^2=0.63	Both systems produced a high SG on the resin composites tested. Toothbrushing up to 40k cycles caused a significant decrease in SG and increase in RA, except for VEP and Z350 in Ra.
Measured with a glossmeter (NovoCurve) at 60° - 2x2 mm area	Noncontact 3D optical interferometric profilometer one scan per sample surface	Linear correlation determined r^2=0.871	One-step polishing systems resulted in better surface finish for the resin composites tested. The best polishing system is material dependent. The two variables had an impact on the SR and SG

Table 3: *Summary of Studies Included in the Systematic Review (cont.)*

Author	Intervention	Sample Size	Resin Composite	Finishing/Polishing System
Antonson and others (2011)[27]	Effect of different finishing/polishing systems on SR and SG	n=5	Esthet X (Dentsply Sirona) microhybrid Filtek Supreme XTE (3M, St Paul, USA) nanofilled	Astropol (Ivoclar Vivadent, Schaan, Liechtenstein) 3 step Enhance PoGo (Dentsply Sirona, Charlotte, USA) 1 step Sof-Lex discs (3M, St Paul, USA) 3 step EXL 695 discs (3M) 2 step
Yazici and others (2010)[28]	Effect of immediate and delayed polishing on SR and SG of different resin composites	n=10	Tetric Flow (Ivoclar Vivadent, Schaan, Liechtenstein) nanohybrid Venus (Heraeus Kulzer, Hanau, Germany) microhybrid Grandio (VOCO, Cuxhaven, Germany) microhybrid	Mylar strip Finishing was performed with 30 μm diamond finishing burs followed by Sof-Lex discs 3 step
Kameyama and others (2008)[29]	Effect of different polishing systems on SR and SG of different resin composites	n=5	Clearfil AP-X (Kuraray, Tokyo, Japan) microhybrid Estelite Sigma (Tokuyama, Yamaguchi, Japan) submicron	Diamond Point FG (Shofu, Kyoto, Japan) White Point CA Shofu, Kyoto, Japan Stainbuster (Danville Materials) Compomaster CA Shofu, Kyoto, Japan 1 step
Heintze, Forjanic, and Rousson (2006)[30]	The influence of the press-on and polishing time on the SR and SG of differentdental materials and the relationship between them	n=8	Heliomolar RO (Ivoclar Vivadent, Schaan, Liechtenstein) microfilled Tetric Ceram (Ivoclar Vivadent, Schaan, Liechtenstein) microhybrid Tetric Evoceram (Ivoclar Vivadent, Schaan, Liechtenstein) microhybrid	Astropol (Ivoclar Vivadent, Schaan, Liechtenstein) 3 step

Table 3: *Summary of Studies Included in the Systematic Review*

SG Measurement	SR Measurement	Correlation Between Variables	Conclusion
Small area glossmeter (NovoCurve) at 60º - 2x2 mm area	Surface profilometer using three line tracings at different locations	Not determined	Sof-Lex discs produced the lowest SR, while EXL-695 produced the highest gloss.
Small area glossmeter (NovoCurve) at 60º - 2x2 mm area	3D non-contact interferometric profilometer using three line tracings in different locations.	Not determined	The smoothest surfaces were produced with a Mylar strip. The effect of delayed finishing/polishing on the SG and SR is material dependent
Precision glossmeter GM 260 (Murakami color research Laboratory)	Surface profilometer using five profilometer tracings	Linear correlation determined r^2 [0.80-0.88]	The polishing procedures produced an effect on SG and SR. There is no significant difference between SR of both materials, even though ES had higher gloss. There is a clear relationship between average SR and SG
Small area glossmeter (NovoCurve) at 60º - 2x2 mm area	3D non-contact optical profilometer using a 1x1mm^2 area	Linear correlation determined r^2 [0.91-0.96]	The higher press on force increased SR in resin composites. SG and SR were time-dependant and negatively correlated. SG assessment may be a sufficiently accurate method to determine the polishability of materials.

Table 3: *Summary of Studies Included in the Systematic Review (cont.)*

Author	Intervention	Sample Size	Resin Composite	Finishing/Polishing System
Paravina and others (2004)[31]	Effect of different finishing/polishing systems on SR and SG of different resin composites	n=4	FZ-Dentin experimental microhybrid FZ-Enamel experimental microhybrid Heliomolar RO (Ivoclar Vivadent, Schaan, Liechtenstein) microhybrid Esthet-X (Dentsply Sirona, Charlotte, USA) microfilled Renamel Microfill microfilled	Mylar strip Carbide finishing bur Astropol (Ivoclar Vivadent, Schaan, Liechtenstein) 3 step Sof-Lex discs (3M, St Paul, USA) 3 step PoGo micropolisher disc (Dentsply Sirona, Charlotte, USA) 1 step Enhance and PRISMA Gloss (Dentsply Sirona, Charlotte, USA) 2 step
Hondrum and Fernandez (1997)[23]	Effect of different finishing/polishing systems on SR/SG a resin composite, glass ionomer and resin-modified glass ionomer	n=7	PRISMA APH (Dentsply Sirona, Charlotte, USA) microhybrid	Mylar strip Sof-Lex Discs (3M, St Paul, USA) 3 step Two striper MFS/MPS system 2 step Composite Finishing System Enhance Finishing/Polishing System (Dentsply Sirona, Charlotte, USA) 2 step Two striper MPS Contouring Burs (7901 and 9714)

Abbreviations: 3D: three-dimensional; ES: Estelite Sigma SiC: Silicon carbide; SG: specular gloss; SR: surface roughness

Considering the finishing/polishing systems evaluated, Sof-Lex Discs (3M, St Paul, MN, USA) are a multistep system commonly used clinically and were one of the most used polishing systems in the studies included. These were able to achieve the high SG values and low SR, reaching the roughness threshold of 0.2 μm defined by Bollen, Lambrechts, and Quirynen in 1997[38] in some of the studies included in this review,[20,25,27,28,31] which was also supported by other researchers.[3] As previously found, SR is highly material dependent. In four of the five aforementioned studies, only the microhybrid resin composites attained values under the threshold for SR. The study by Khamonkhantikul and others, on the contrary, found SR values well under 0.2 μm in all the resin composites studied, including nanofilled and nanohybrid ones.[20] In line with previous findings, Lolita and others in 2020 studied a single nanoceramic resin composite, and polishing with Sof-Lex discs was not enough to obtain satisfactory SR values.[19] These results are contested by Kaizer and others in a systematic review that found that no evidence to support that filler type has an influence on such surface properties, by testing nanofill, submicron, and traditional microhybrid resin composites.[35] Over time, abrasion of the surface organic matrix with loss of filler leads to an increase in SR. Finishing/polishing such surfaces is able to return lower SR values, which also increases SG.[39] Achieving optimal SR of dental restorations is also important in mimicking natural enamel characteristics. While unpolished enamel may

Table 3: *Summary of Studies Included in the Systematic Review*

SG Measurement	SR Measurement	Correlation Between Variables	Conclusion
Small area glossmeter (NovoCurve) at 60° - 2x2 mm area	Surface profilometer which was used to measure four tracings at different locations	Linear correlation determined r^2= 0.77	The smoothest and shiniest surfaces were produced with the mylar strip, followed by the PoGo system. SG showed differences between the resin composites and SR was also material dependent.
Glossmeter (Model GM-060, Minolta Corp, Ramsey)	Surface profilometer which was used to measure lines perpendicular to the striations.	Correlation analysis determined but not reported.	The smoothest and shiniest surfaces were produced with the mylar strip. SG decreased while using rotary instruments.

range from 3 to 1 μm, polished enamel can reach values less than 0.5 μm, even 0.15 μm.[40,41] A mismatch of SR values between enamel and restorative materials will cause disparities in light reflectivity.[42]

Since there is a permanent search for simplified protocols in dentistry, single-step finishing/polishing systems such as Enhance PoGo (Dentsply Sirona, Charlotte, USA) were also evaluated but showed an unsatisfactory performance regarding the SR threshold range in all studies, except in those of Antonson and others, and Paravina and others.[27,31] These results lead us to believe that applying more complex multistep systems produces better results, as corroborated by the previous authors.[10,19,43] Contradicting these results, however, Paravina and others, Ereijef and others, and Cazzaniga and others, showed that the one-step polishing systems they tested performed better than the multistep.[25,26,31] This disparity of findings may be related to different protocols being followed in these investigations, even those using the same polishing systems. Some of the authors opted for skipping steps in complex systems. There was a lack of a systematized polishing time and pressure, RPMs at which the several steps were performed and overall use of water cooling, which may impact the results. Only one of the studies evaluated included polishing time as a variable.[30] It is important to lay out that this is a factor that will impact resulting SR and SG. The need for standardized protocols is, therefore, of the utmost relevance for any further studies and future clinical trials.

Table 4: *Posterior Features for the Study-specific Model Parameters*

Parameters	Mean	Confidence Interval	Parameters	Mean	Confidence Interval	Parameters	Mean	Confidence Interval
b1,1	-0.84	(-159, -0.02)	b1,2	-0.42	(-0.73, -0.10)	σ1	0.17	(0.09, 0.39)
b2,1	-0.38	(-1.12, 0.43)	b2,2	-0.28	(-0.65, 0.07)	σ2	0.4	(0.24, 0.75)
b3,1	0.95	(0.25, 1.75)	b3,2	-0.003	(-0.28, 0.30)	σ3	0.02	(0.01, 0.04)
b4,1	-0.96	(-1.83, 0.05)	b4,2	0.15	(-0.12, 0.46)	σ4	0.18	(0.07, 0.92)
b5,1	-0.85	(-1.60, -0.03)	b5,2	-0.17	(-0.59, 0.24)	σ5	0.24	(0.11, 0.86)
b6,1	-0.38	(-1.41, 0.68)	b6,2	-0.10	(-0.61, 0.38)	σ6	1.14	(0.61, 2.57)
b7,1	1.39	(0.52, 2.29)	b7,2	0.38	(0.03, 0.77)	σ7	0.2	(0.08, 0.93)
b8,1	0.13	(-0.61, 0.96)	b8,2	0.09	(-0.16, 0.37)	σ8	0.1	(0.06, 0.17)
b9,1	1.45	(0.78, 2,23)	b9,2	0.34	(0.10, 0.62)	σ9	0.02	(0.01, 0.05)
b10,1	-0.51	(-1.32, 0.37)	b10,2	0.01	(-0.26, 0.32)	σ10	0.07	(0.03, 0.3)
						Σ1,1	0.43	(0.20, 1.34)
						Σ1,2 = Σ2,1	-0.20	(-3.70, -0.08)
						Σ2,2	0.04	(0.02, 0.14)

Gloss consists a variety of surface phenomena that represent the ability of light reflectance of a surface, rather than one single parameter.[44] SG can be measured at standardized angles of 20°, 60°, and 85°.[1] Past literature and ISO 2813, ASTHD 523 and 2457, and DIN 67530, describe the 60° angle geometry as a general standard for moderate gloss values. At the extremes (<10 and >70 GU), it behaves nonlinearly, which stresses the need to use other geometries. The perception of gloss variations by different observers is also impaired in these extremes.[1] This explains why some values are indistinguishable at higher and lower SR values, following an exponential decay.[1,45]

In contrast to 20° and 85° angles, 60° angle measurement is the one that falls closest to the angle from which the average individual will observe the surface.[3]

Previous studies that evaluated different materials, such as photographic paper, chocolate, egg-shells, and metal finish, found strong correlations between surface texture and gloss reflectance.[46-49] Heintze and Zimmerli reported an exponential function to explain the correlation between SR and SG in dental resin composites.[50] Furthermore, these studies classified the relationship as an exponential increase in SG for a decrease in SR, especially concerning higher SG

Table 5: *Inverse Prediction—Posterior Quantiles for the Distribution of the Mean SR Value Considering SG in the First Column*

		log(RA): Quantiles					
Gloss	**Log(SG)**	**0.025**	**0.25**	**0.5**	**0.75**	**0.975**	**P[log(RA)≤1.609]**
1.65	0.5	1.17	2.17	2.71	3.28	4.91	0
2.72	1	0.61	1.50	1.97	2.47	3.93	0
4.48	1.5	0.04	0.84	1.23	1.66	2.90	0
7.39	2	–0.54	0.16	0.50	0.86	1.90	0
12.18	2.5	–1.12	–0.52	–0.24	0.08	0.92	0
20.09	3	–1.76	–1.22	–0.97	–0.70	–0.03	0.0466
33.12	3.5	–2.51	–1.95	–1.70	–1.45	–0.91	0.5946
54.60	4	–3.32	–2.69	–2.43	–2.18	–1.70	0.977
90.02	4.5	–4.21	–3.46	–3.16	–2.89	–2.41	0.977

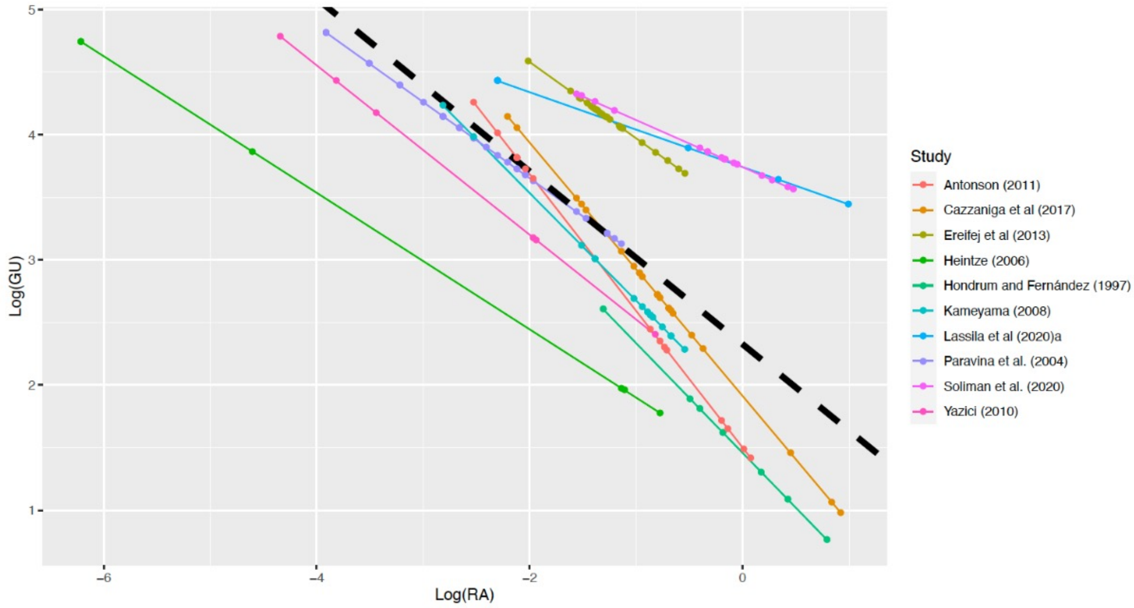

Figure 3. *The dashed black line represent the mean population effects—is the straight line with intercept and slope and . The other lines represent study specific-estimates indicating how the conditional mean responses from each study deviate from the population trend.*

values. Heintze and Zimmerly further pointed out that the exponential increase takes place between 0.3 and 0.1 μm, and that SG measurements can be done to distinguish correctly polished materials. Egilmez and others also found a clear relationship between SG and SR in the resin composites tested by them. These authors report an exponential growth below 0.1 μm.[51] SR and SG have, however, not only been linearly correlated by the primary studies included in this review but also by previous authors. It is important to point out that the strength of the correlation varies according to the surface properties and incident angle. This makes SG an anisotropic characteristic.[50]

Gloss is dependent upon the lightness of the samples, which highlights that the shade of the resin composite is relevant when gloss is to be measured. Filler particles are associated with bulk scattering. A resin composite with higher filler load allows more light to be reflected, and this results not only in better optical properties but also higher gloss values.[52] Nonetheless, most of the variations seen in SG, in polymers, is governed by their surface texture.[53] As mentioned before, no evidence of difference between microhybrids, nanofilled, or submicron resin composites has been found in SG and SR.[35]

Different shades of the same composite exhibit differences in their properties, one of them being related to their polymerization kinetics, affecting final rate and degree of conversion, which, in turn, affects physico-mechanical properties.[54,55] This may mean that they would respond differently to finishing and polishing procedures, as the softer surface produced by incomplete polymerization is more susceptible to scratches and abrasions; however, no studies included in this review explored this variable.[28,55] Surface properties are also influenced by chemical and physical wear of the composites, and laboratory simulations of clinical conditions should be considered. Only one study included in this paper standardized the press-on force with which the polishing systems were used and evaluated its influence on SG and SR.[30] These authors found that the force applied while polishing has significant influence on SG. In the study of Antonson and others, there is also reference to the pressure applied while polishing.[27] These authors conducted a preliminary study evaluating operators and their polishing perception on the pressure and its impact on calibration. Nevertheless, there was no investigation on the influence of the pressure applied.

The glossmeters used in the primary studies have different measuring areas, and this may introduce gloss measurement variations. The measurement area is especially important in uneven surfaces with anisotropic texture, as smaller measurement areas can lessen the variation arising from topographic changes.[56] There is no agreed threshold to acceptable or unacceptable gloss values, as previously pointed out. Cook and Thomas proposed a scale for the SG of polymers. These authors state that values above 60 GU, and in between 60 and 70 GU, are acceptable; between 70 and 80 GU

Table 6: *Risk of Bias Assessment of the Primary Studies Included in This Review, Using a Yes/No Scale*

Study	SSC	SR	CG	PC	AOA	BOA	CRO	O
Lassila and others[10]	N	N	Y	Y	Y	N	Y	Moderate
Soliman and others[24]	N	N	Y	Y	N	N	N	High
Lolita and others[19]	N	N	Y	N	Y	N	Y	High
Lopes and others[8]	N	N	Y	Y	Y	N	N	High
Cazzaniga and others[25]	N	Y	Y	N	Y	N	N	Moderate
Kamonkhatinkul and others[20]	N	Y	Y	N	Y	N	N	High
Ereifej and others[26]	N	N	Y	N	N	N	Y	High
Antonson and others[27]	N	Y	Y	N	Y	Y	Y	Low
Yazici and others[28]	N	Y	Y	N	Y	Y	Y	Low
Kameyama and others[29]	N	Y	Y	Y	Y	N	N	Moderate
Heintze and others[30]	N	N	Y	Y	Y	N	Y	Moderate
Paravina and others[31]	N	Y	Y	N	Y	N	Y	Moderate
Hondrum and Fernandez[23]	N	N	Y	N	Y	N	Y	High

Abbreviations: SSC, sample size calculation; SR, sample randomization; CG, control group; PC, polishing Compliant with Sequence, rpm, and Water Cooling; AOA, Appropriate Outcome Assessment; BOA, Blinding of the Outcome Assessment; CRO, Correct Reporting of the Outcomes; O, overall.

are good; and beyond that are excellent.[57] Considering the model approach undertaken in this study, it was possible to prove that values >55 GU have a probability close to 100% of correlating with SR values below the so-called SR threshold of 0.2 μm, which is currently known to be rather a range.[12] These findings support Cook and Thomas' scale.

Currently, the gold standard method of evaluating surface texture after finishing/polishing of restorative materials is by measuring SR, which can only be accomplished *in vitro*. By validating SG as a method for assessing whether restorations are properly polished, this method could potentially be used clinically. A standard reference value could thus be formulated, and clinicians would have a direct quantative and objective measure to assess surface finish of their restorations. The complexity of the tooth surface in regards to microstructure and curvature, together with drawbacks to standardization of measurement readings *in vivo,* should be considered.[1,58] Feasibility of clinical extrapolation warrants further research, as clinical studies measuring this outcome are nonexistent.[1]

Further studies should evaluate surfaces with rougher texture and evaluate gloss simultaneously, as few studies included samples with SRs above 1.2 μm. Such data will allow us to optimize the model proposed in this review.

As limitations to this review, it is important to consider variations in incident lighting. These should be taken into account when assessing SG and comparing study to study. Standardization of SG measurements in dentistry is required. Furthermore, R_a values are highly variable from technique to technique, in determining SR, and direct comparisons should be cautious.[59] Nonetheless, the majority of the included studies measured the samples using a profilometer, and only one study used atomic force microscopy (AFM) measurements.

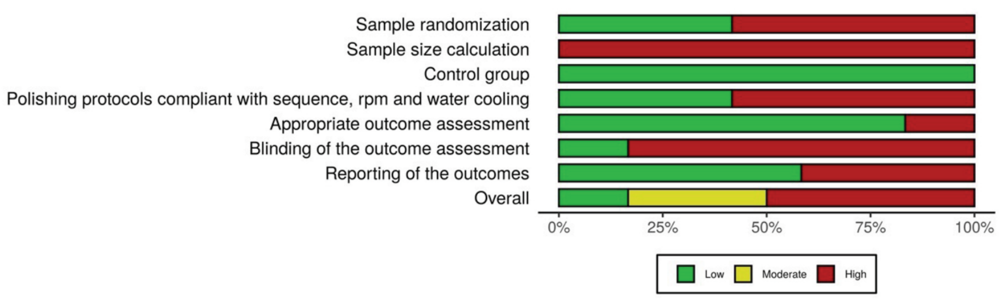

Figure 4. Weighted Plot Summary for Risk of Bias Assessment, Built Using the Robvis 2.0 Webtool.

Most studies included were of high or moderate risk of bias, which stresses the need for consistent methodological parameters in future laboratory studies. Compliance with sequence, rotations per minute (rpm), and water cooling of polishing/finishing systems is needed to standardize comparisons. Blinding of the outcome assessment by examiners and sample size calculations would also improve the internal validity of the studies. Selective reporting of outcomes was also an issue, with the correlations being determined in text but not shown in graphs and with no supporting model. It is important to understand that these differences may lead to overestimation or underestimation of results.[60,61]

CONCLUSIONS

Based on the results and limitations of the present review, the following can be concluded:

1. Evidence from laboratory studies that supports SG can be used to measure the effectiveness of finishing/polishing systems, as it is positively correlated with a decrease in SR.
2. A large between-study variability was seen, whereas within-study differences were more homogeneous. At low SR values, SG does not change at the same proportion as it did in higher SR. There is a decrease in the slope of the linear regression at higher SG values.
3. Based on the linear, mixed-effects model from the pooled results, the threshold for SR (0.2 μm) corresponds to >55 GU. This should be considered the acceptable reference threshold for well-polished samples. Thus, the gloss of polished surfaces is recommended to be above this threshold.

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Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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