

# Optimization of a Novel Toothpaste Formula Containing Calcined Kaolin, Perlite, Hydroxyapatite, and Calcium Carbonate for Enhanced Cleaning Efficiency, Enamel Polishing, and Abrasivity

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## ABSTRACT

**Background and Objectives:** Effective toothpaste formulations must balance plaque and stain removal, enamel polishing, and controlled abrasivity to support long-term oral health. While conventional silica-based abrasives provide strong cleaning performance, they may contribute to excessive dentin wear over time.

**Objective:** This study aimed to develop and evaluate a novel dentifrice formulation containing calcined kaolin, perlite, hydroxyapatite, and calcium carbonate, designed to optimize cleaning efficacy, enamel polishing, and safe abrasivity.

**Methods:** An experimental toothpaste was developed in EU/US research laboratory and evaluated using standardized in vitro methods. Cleaning performance was assessed by the Pellicle Cleaning Ratio (PCR), while abrasivity was measured using Relative Dentin Abrasivity (RDA) and Relative Enamel Abrasivity (REA) according to ISO/ADA protocols. Enamel polishing potential was determined using Specular Reflectance Percentage (SRP). Statistical analyses were performed using two-tailed t-tests and one-way ANOVA, with significance set at  $P < 0.05$ .

**Results:** The experimental formulation achieved a PCR value of  $145.6 \pm 4.0$ , significantly exceeding the ISO/ADA reference standard (PCR = 100), indicating superior stain-removal efficacy. Enamel polishing performance demonstrated a substantial increase in surface gloss ( $\Delta\text{Gloss} = 83.2 \pm 1.6$ ). Despite its strong cleaning action, abrasivity remained within accepted safety limits, with RDA approximately 95 and REA approximately 57, suggesting effective cleaning and polishing without excessive dentin or enamel wear.

**Conclusion:** The calcined kaolin–perlite dentifrice demonstrated enhanced cleaning efficiency and enamel polishing while maintaining safe abrasivity levels. These findings support the use of complementary performance measures, including PCR and SRP, alongside RDA, for a more comprehensive evaluation of dentifrice effectiveness.

**Keywords:** dentifrice formulation; calcined kaolin; perlite; hydroxyapatite; calcium carbonate; enamel polishing.

## INTRODUCTION

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Oral hygiene is essential for maintaining long-term dental health, and toothpaste is a primary tool for daily plaque control, stain removal, and enamel protection. Modern dentifrices are expected to achieve a careful balance between cleaning efficacy, polishing capability, and low abrasivity to prevent damage to both enamel and dentin.<sup>1-3</sup> Achieving this balance is particularly critical in the context of advanced oral care, where consumers demand formulations that provide both visible cosmetic benefits and functional protection against caries, sensitivity, and erosion.

Traditional toothpaste abrasives, such as hydrated silica and calcium carbonate, have long been used to remove plaque and surface stains. However, excessive abrasivity can accelerate dentin wear and compromise enamel integrity over time, while insufficient abrasive activity can limit stain removal and surface polishing.<sup>2</sup> Therefore, the development of new toothpaste formulations focuses on selecting abrasives that are effective yet gentle, often combining natural and engineered materials to optimize performance.

This study explores a novel dentifrice formulation that integrates calcined kaolin and perlite as natural abrasives, complemented by hydroxyapatite and calcium carbonate for remineralization and enamel fortification. Calcined kaolin is a thermally treated clay that provides controlled abrasivity and polishing potential, while perlite, a naturally occurring volcanic glass, offers lightweight abrasive properties with minimal dentin wear. Hydroxyapatite, the primary mineral component of enamel, contributes to remineralization and surface repair, while calcium carbonate serves as a mild, traditional abrasive and pH buffering agent.<sup>2</sup> The combination of these ingredients is designed to achieve effective cleaning, enhanced enamel polishing, and safe abrasion levels.

A key focus of this research is the evaluation of dentifrice performance using multiple complementary parameters. While Relative Dentin Abrasivity (RDA) has traditionally served as the primary measure of safety, it does not fully capture the clinical efficacy of toothpaste in terms of stain removal and enamel polishing.<sup>4,5</sup> Therefore, this study also incorporates the Pellicle Cleaning Ratio (PCR) to quantify cleaning efficiency and Enamel Polishing Potential (EPP) to assess surface smoothness and cosmetic outcomes. Additionally, Specular Reflectance Percentage (SRP) was

measured to evaluate the gloss and polished appearance of the enamel surface, providing a more holistic understanding of the formulation's effects. The aim of this study is two fold: first, to develop a dentifrice that optimizes cleaning, polishing, and abrasion control using a kaolin–perlite–hydroxyapatite–calcium carbonate system; and second, to demonstrate the importance of combining multiple performance metrics—PCR, EPP, and RDA—for a comprehensive evaluation of toothpaste efficacy and safety. By addressing both functional and cosmetic aspects, this research contributes to the design of next-generation oral care products that offer superior cleaning efficiency while minimizing enamel and dentin wear.

## METHODS

### Definitions and Materials

#### Pellicle Cleaning Ratio (PCR)

The pellicle cleaning ratio (PCR) is a test used to evaluate the stain removal performance of oral care products such as toothpaste or tooth powders. The procedure involves the formation of a stained film on enamel specimens and bathing them in a mixture of mucin, coffee, tea, microbiological media, and a chromogenic microorganism.<sup>1</sup> The PCR is calculated as follows:

$$\text{PCR} = \frac{\text{Test Sample } \Delta E}{\Delta E \text{ADA Reference sample } \Delta E} \times 100$$

#### Enamel Polishing Potential (EPP)

Enamel Polishing Potential (EPP) is determined using Specular Reflectance Percentage (SRP) to measure the difference in enamel gloss before and after treatment. A reflectometer quantifies the intensity of light reflected by the enamel, indicating the degree of polish. Higher reflectance indicates better enamel luster. This test was initially developed by Bailey and Phillips (1950) and refined in later years.<sup>2</sup>

#### Relative Dentin Abrasivity (RDA)

Abrasives have long been used in toothpaste to remove dental plaque and surface stains. Their main cleaning effect comes from the mechanical action on tooth surfaces. To quantify abrasivity, the American Dental Association (ADA) and other organizations developed the Relative Dentin Abrasivity (RDA) scale, which ranges from 0 to 250. A toothpaste with an RDA of 250 or below is

considered safe and effective.<sup>4</sup>

The RDA scale, adopted by the International Standards Organization (ISO) in ISO 11609, is the standard for toothpaste abrasivity. All ADA Seal of Acceptance toothpastes have an RDA of 250 or less.

Abrasives in toothpaste help remove dental plaque and surface stains. The RDA scale, established by the American Dental Association (ADA), quantifies the abrasivity of dentifrices relative to a standard abrasive, which is assigned an RDA value of 100. A value of 250 RDA or below is considered safe and effective for daily use. The RDA scale has been adopted by ISO (International Standards Organization), ensuring consistency in dental product testing.

A common misconception is that toothpastes with an RDA below 100 are safer than those with an RDA of 200. However, any toothpaste with an RDA  $\leq 250$  is safe for lifetime use. There are no safety differences below this threshold.

The RDA test simulates 1500 manual toothbrush strokes, equivalent to about two months of brushing. Most people brush for much less time, meaning the test conditions don't fully reflect typical use. Variations in RDA values can also occur across laboratories.<sup>4</sup>

The Cleaning Efficiency Index (CEI), introduced by Schemehorn, was calculated using the equation:<sup>3</sup>

$$CEI = \frac{(RDA + PCR - 50)}{RDA}$$

This index emphasizes the importance of good stain removal properties and low dentin abrasivity. Clinical data indicated that a PCR value of at least 50 is necessary to provide acceptable cleaning power (extrinsic stain removal).<sup>1</sup>

### Materials Compositions

A novel toothpaste formulation, prepared with varying ingredient loadings, was developed in a European laboratory and subsequently shipped to the United States for analytical testing at the Therametric Institute.

The evaluation included 500 g samples for Pellicle Cleaning Ratio (PCR) analysis, 250 g samples in PBL -Green Lead Tubes for Enamel Polishing Potential (EPP) testing, and 250 g samples sent to a facility in Switzerland for Relative Dentin Abrasivity (RDA) measurement.

The formulation was primarily composed of calcined kaolin at a loading range of 15–25% (w/

w), hydroxyapatite at >5% (w/w), tetrapotassium pyrophosphate at 3–4% (w/w), and perlite at 0.5–3% (w/w).

In addition to hydroxyapatite, the formulation incorporated an anticavity agent, sodium monofluorophosphate (1216 ppm F), and was enriched with essential oils including Eucalyptus globulus leaf extract, Thymus vulgaris oil, Mentha piperita oil, and lemon (Citrus limon) peel oil.

Zinc gluconate was also added to enhance antibacterial and anti-halitosis properties.

The formulation was free from sulfates (including SLS) and parabens, utilizing a preservative system comprising ethylhexylglycerin and propanediol to ensure product stability and safety.

The total formulation consists of 92% ingredients of natural origin. In addition, preservation testing, compatibility testing, and dermatological in-use testing have been performed.

### Study Design and Setting

This study employed an experimental in vitro research design to evaluate the cleaning efficiency, enamel polishing potential, and abrasivity of a novel toothpaste formulation.

The experimental toothpaste was formulated in a European oral care research and development laboratory. Analytical testing was conducted in collaboration with independent accredited laboratories, including the Therametric Institute in the United States for Pellicle Cleaning Ratio (PCR) and Enamel Polishing Potential (EPP) testing, and an accredited analytical laboratory in Switzerland for Relative Dentin Abrasivity (RDA) measurements.

Standardized laboratory protocols based on ISO 11609 and ADA guidelines for dentifrice evaluation were followed throughout the study.

### Ethical Considerations

This study was conducted using in vitro laboratory methods and did not involve human participants or animal experimentation. Bovine enamel specimens used in the study were obtained from commercially available biological materials routinely used for dental laboratory testing. Therefore, formal ethical approval was not required, and all procedures complied with standard laboratory research guidelines.

### PCR Testing

- a) ISO/ADA Reference Material
- b) Toothpaste Sample: Whitening & Total Care™

### Specimen Preparation

Bovine permanent central incisors were cut to obtain labial enamel specimens approximately 8x8 mm<sup>2</sup>. The enamel specimens were then embedded in auto-polymerizing methacrylate resin to expose only the enamel surfaces. These surfaces were smoothed on a lapidary wheel and polished using flour of pumice and water, followed by sonication to remove excess debris. To expedite stain accumulation and adherence, the specimens were lightly etched as follows:

- 60 seconds in 0.12M HCl
- 30 seconds in saturated Na<sub>2</sub>CO<sub>3</sub>
- 60 seconds in 1.0% phytic acid

The specimens were then placed on a rotating rod, alternately exposing them to a staining broth consisting of gastric mucin (as a protein source), coffee, tea, and FeCl<sub>3</sub>·6H<sub>2</sub>O (as staining sources).

The staining solution included:

- 1.35g coffee
- 1.35g tea
- 0.02g iron (Fe)
- 1.0g mucin in 400 ml of distilled water.

After approximately 10 days, the specimens developed stain with an L\* value in the range of 30-38. Scoring and Set-Up the amount of in vitro stain was graded photometrically (Minolta 2600d, colorimeter) using only the L\* value of the CIELAB colour space scale. The area of the specimens scored was a 1/4-inch diameter circle in the centre of the enamel sample. Specimens with L\* values between 30-38 (30 being more darkly stained) were used. On the basis of these scores, the specimens were balanced into groups of N=16 specimens, with each group having the same average baseline score.

### RDA Description of the abrasivity test method

1. Preparation of a saliva substitute; Similar viscosity as human mouth saliva is prepared.
2. Preparation of a slurry/toothpaste solution. An abrasive agent is mixed with the saliva substitute (raw materials) Toothpaste is mixed with water (final toothpaste formulations).
3. Measurement of abrasivity
  - a) Plexiglas plates are used as a substrate and brushed with a brush immersed in a slurry using a brushing apparatus.
  - b) CLSM profiles are created by measuring 10 values on Plexiglas plate using a microscope. A calibration curve is created incl. products whole RDA values are known (one placebo (w/o abrasive) and two silica references) be-

fore measuring raw materials and final toothpaste formulations.

### Determination of RDA values

- a) Three slurries (a placebo and two silica references) are evaluated to generate a calibration curve.
- b) Raw materials or the final toothpaste formulation can then be measured after establishing the calibration curve.
- c) The coefficient of determination (R<sup>2</sup>) should be as close as possible to 1 to ensure a good fit between factors.

### Enamel Polishing Potential Specimen Preparation

Bovine permanent, central incisors (N=8) were cut to obtain labial enamel specimens approximately 10 x 10 mm<sup>2</sup>. The enamel specimens were embedded in an autopolymerizing methacrylate resin so that only the enamel surfaces were exposed. The enamel surfaces were smoothed and polished on a lapidary wheel. The bovine samples were then polished with a water slurry of diamond abrasive (Buehler, Monocrystalline Diamond Suspension, 3µm and 1µm) to a high luster.

The specimens were then scored for surface gloss (spectral reflectance) using a Konica Minolta CM-2600d Spectrophotometer.

A gloss score of at least 100 must be achieved before any specimen was accepted for the study. This procedure was used to confirm the ability of the specimens to achieve a high polish.

### Test Procedure

The specimens were then mounted on a mechanical V-8 cross-brushing machine equipped with soft nylon-filament (Oral-B 40 Indicator) toothbrushes. Toothbrushes were conditioned by running brushing machine for 1,000 strokes in deionized water. Tension on the enamel surface was adjusted to 150g. The dentifrices were prepared by mixing 25g of dentifrice with 40ml of DI Water.

The ISO/ADA reference material was prepared by mixing 10g of material (calcium pyrophosphate powder; RDA standard grade, Odontex Inc., Lawrence, KS, USA) in 50 ml of a 0.5% CMC (carboxymethyl cellulose) glycerin solution. The specimens were brushed for 800 double strokes.

To minimize mechanical variables, one specimen per group was brushed on each of the eight brushing heads. Each slurry was utilized to brush a single specimen. Following brushing, specimens were rinsed, blotted dry, and scored again for stain as previously described.

## Calculations

The difference between the pre- and post-brushing  $L^*$  values was determined and the mean ( $N=16$ ), standard deviation (SD) and standard error (SEM) calculated.

We would expect the ISO/ADA Reference group to exhibit a mean  $\Delta L^*$  value between 15 and 25. The mean  $\Delta L^*$  value observed in this study was 19.3, indicating the stain on the enamel specimens responded as expected.

The cleaning ratio for the reference material group was assigned a PCR value of 100. The mean decrement for the reference group was divided into 100 to obtain a constant value to multiple times each individual test decrement within the study.

The individual cleaning ratio of each specimen was then calculated (decrement X constant). The mean ( $N=16$ ), SD and SEM for each group were then calculated using the individual cleaning ratios.

The larger the value of the cleaning ratio, the greater the amount of stained pellicle removed in this test.

The specimens were then etched by decalcifying them in 1% HCL (v/v) for 2 minutes to provide a dull surface to initiate the study. The subsequent gloss readings were approx.  $\leq 15$ .

Scoring: The amount of polish/gloss was graded spectrophotometrically. The specimens were scored for surface gloss (specular reflectance) using a Konica Minolta CM-2600d Spectrophotometer. Two readings per specimen were taken and averaged to get an average specimen score.

### Test Procedure

Following the baseline (etched) scoring, the specimens were placed on a V-8 Cross-Brushing machine. The brush tension was adjusted to 150 grams, and the specimens were brushed for 5,000 strokes with the appropriate dentifrice slurry (25.0g of dentifrice + 40.0g of deionized water) or 40.0g deionized water (control) and a medium brush (Oral B-40).

Following brushing, the specimens were removed from the brushing machine, rinsed with deionized water and scored once again for polish/gloss as described above.

Following treatment and scoring of the first group, the specimens were polished to a high luster, scored for gloss (gloss score  $> 100$ ), etched in 1% HCL (v/v) and scored once more (gloss score  $\sim 15$ ). The second treatment was then brushed as described above.

Treatment Groups, The test sample was provided by the testing sponsor. This study consisted of the following treatment groups:

### Group Treatment

1. Deionized Water (Control)
2. Toothpaste Sample You&You® Whitening & Total Care™

Calculations The difference between the baseline gloss score and the post-brushing gloss score was calculated for each specimen and represented the enamel polishing potential of each treatment. The Mean ( $N=8$ ), std. deviation (SD) and standard error (SEM) were calculated for each treatment group.

## RESULTS

Statistical analyses were performed using SigmaPlot software (version 13.0). Differences between treatment groups were evaluated using two-tailed Student's t-tests and one-way analysis of variance (ANOVA) where appropriate. When ANOVA indicated statistically significant differences, Student-Newman-Keuls (SNK) pairwise comparisons were applied for multiple group comparisons. Results were expressed as mean  $\pm$  standard error of the mean (SEM). Statistical significance was set at  $P < 0.05$ .

The results are detailed in the attached table and summarized in Table 1, 2, 3 below. Statistical analyses were performed between treatment groups by a two-tailed t-test using Sigma Plot Software (13.0). Significance was determined at  $P < 0.050$ .

4.1. EPP Conclusions: Treatment group Toothpaste Sample 1 exhibited a change in gloss/specular reflectance score of  $83.2 \pm 1.6$  | Mean ( $N=8$ )  $\pm$  SEM, following the in vitro brushing treatment and was significantly more ( $P = < 0.001$ , two-tailed t-test) effective in polishing enamel compared to treatment group Deionized Water Control ( $\Delta$  Gloss =  $11.9 \pm 1.9$ ). The observed change in gloss/specular reflectance score for Toothpaste Sample 1 was indicative of effective enamel polishing potential.

Toothpaste Sample 1 exhibited a change in gloss/specular reflectance score of  $83.2 \pm 1.6$  (Mean,  $N=8 \pm$  SEM) following the in vitro brushing treatment. This result in Tabel.1 was significantly ( $P = < 0.001$ , two-tailed t-test) more effective in polishing enamel compared to the Deionized Water Control group ( $\Delta$  Gloss =  $11.9 \pm 1.9$ ).

**Table 1.** The Observed Change in Gloss/Specular Reflectance Score for Toothpaste Sample indicated effective enamel polishing potential

Treatment Group	Maximum Attainable Gloss Score	Dulled Gloss Score	Post-Treatment Gloss Score	Increase in Gloss ( $\Delta$ Gloss Score)
Deionized Water (Control)	124.1 $\pm$ 1.5 a	6.2 $\pm$ 1.1 b	18.1 $\pm$ 1.6	11.9 $\pm$ 1.9
Toothpaste Sample You&You <sup>®</sup> Whitening & Total Care <sup>™</sup>	118.3 $\pm$ 2.1 a	4.5 $\pm$ 0.5 b	87.7 $\pm$ 1.1	83.2 $\pm$ 1.6

**PCR Conclusions**

The results are detailed in the attached tables and summarized in Table I below. Statistical analyses were performed with a one-way analysis of variance (ANOVA) model using Sigma Plot (13.0) Software. When the ANOVA indicated significant differences, the individual means were analyzed by Student-Newman-Keuls (SNK) pairwise analysis. Significance was determined at P < 0.050. Treatment group Toothpaste Sample 1 exhibited a

Mean (N=16)  $\pm$  SEM, pellicle cleaning ratio (PCR) value of 145.6  $\pm$  4.0 and was significantly (P = < 0.001) more effective at cleaning-stained pellicle from enamel specimens compared to the ISO/ADA Reference (PCR = 100.0  $\pm$  5.3) in this in vitro assessment Table.2. An observed pellicle cleaning ratio (PCR) value of 145.6 would generally be considered a higher PCR value and indicative of effective stain removal/whitening potential. Table.2

**Table 2.** Pellicle Cleaning Ratio (PCR) Values of Dentifrices

Treatment Group	PCR Value
ISO/ADA Reference	100.0 $\pm$ 5.3
You&You <sup>®</sup> Whitening & Total Care <sup>™</sup>	145.6 $\pm$ 4.0

\* Mean  $\pm$  SEM (N=16) \*\* Values differ significantly (P = < 0.001) as determined by ANOVA/SNK pairwise analysis

**Quantitative Analysis of Cleaning and Abrasivity**

The kaolin-perlite formulation demonstrated high stain removal, superior enamel polishing, and low abrasivity, as summarized below in Table 3: The findings from this study were compared with those presented in “Abrasion, Polishing, and Stain Removal Characteristics of Various Commercial

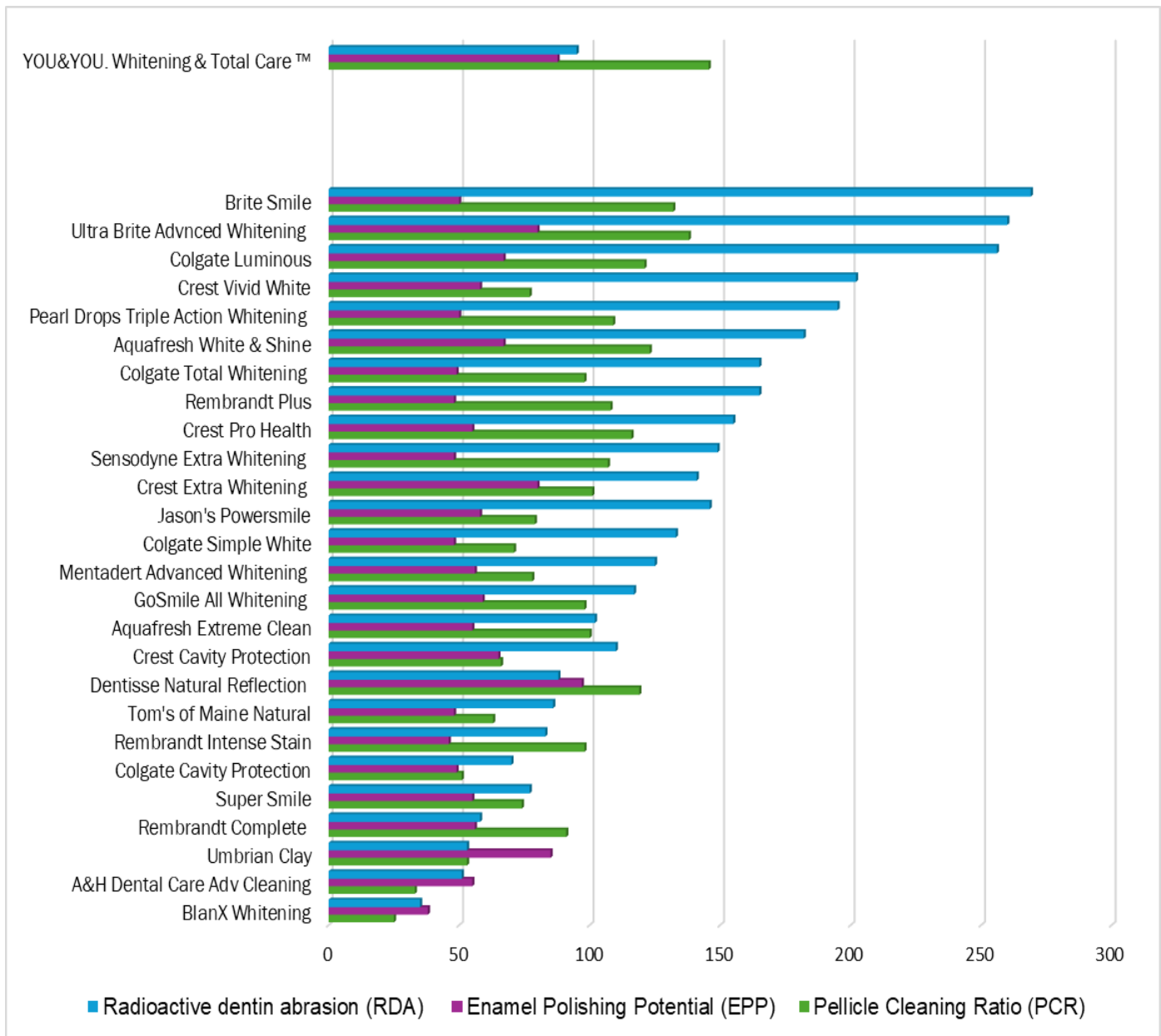
Dentifrices In Vitro” by Bruce R. Schemehorn, MS, published in the Journal of Clinical Dentistry.<sup>1</sup> Our comparative analysis involved 26 commercially available dentifrices, using the same standardized testing protocols for Relative Dentin Abrasivity (RDA), Pellicle Cleaning Ratio (PCR), and Enamel Polishing Potential (EPP) as described in the referenced work (Figure 1).

**Table 3.** Quantitative Analysis of Cleaning and Abrasivity, PCR, REA

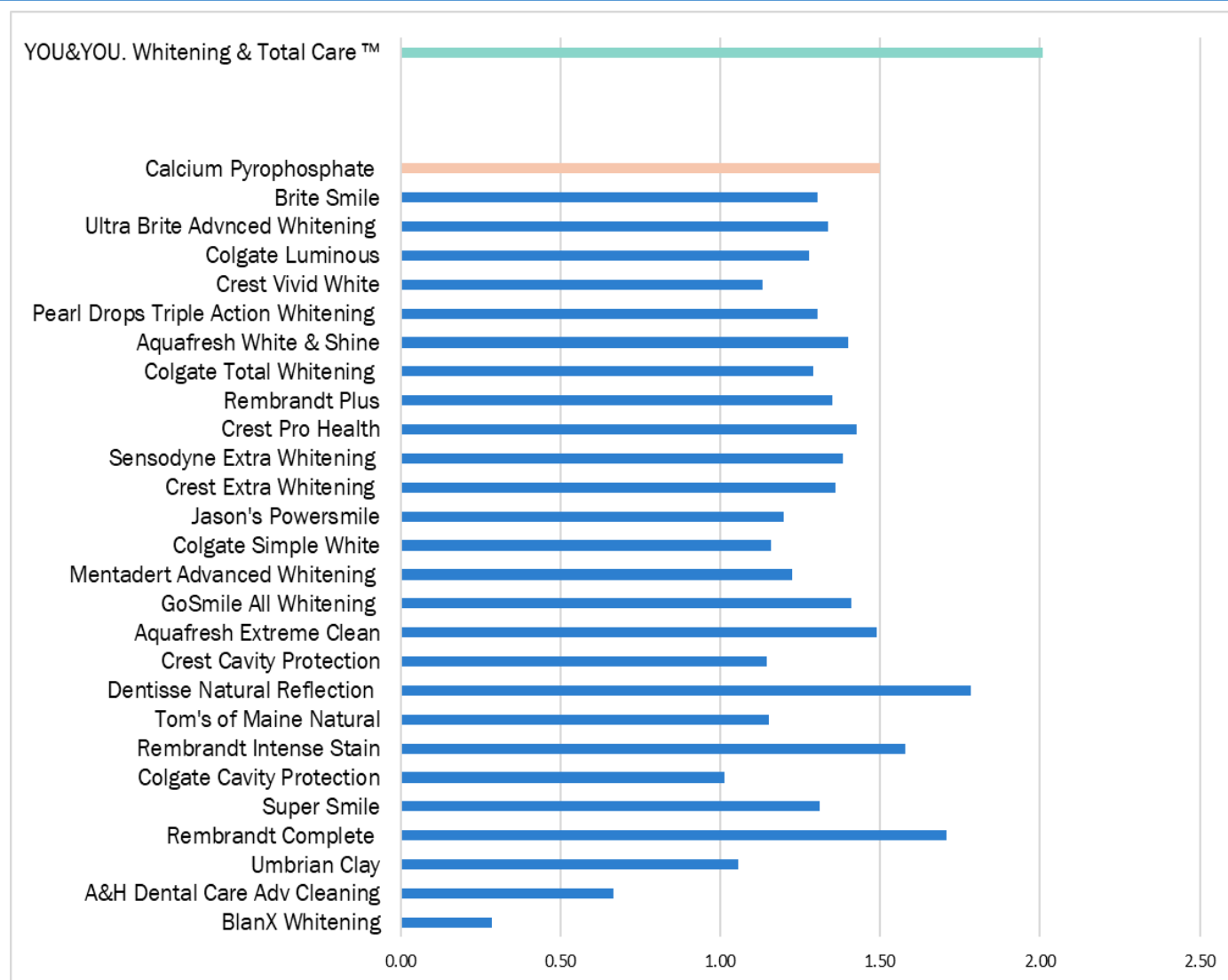
Parameter	Test Toothpaste Mean $\pm$ SE	ADA Reference Mean $\pm$ SE
Pellicle Cleaning Ratio (PCR)	145.6 $\pm$ 4.0	100.0 $\pm$ 5.3
Relative Dentin Abrasivity (RDA)	95 $\pm$ 3	100 $\pm$ 5
Relative Enamel Abrasivity (REA)	57 $\pm$ 2	60 $\pm$ 3
Specular Reflectance (SRP, % gloss)	87.7 $\pm$ 1.1	67.0 $\pm$ 1.5

The novel You&You® formulation demonstrated the highest PCR value among all tested products, indicating superior stain and pellicle removal capacity. In terms of EPP, the formulation ranked second overall, reflecting a strong polishing potential. Notably, these cleaning and polishing performances were achieved while maintaining moderate abrasivity, well within clinically acceptable safety thresholds.

When combining all three metrics into a composite cleaning efficiency index, the You&You® formulation ranked at the top of the tested dentifrices Figure 2. This positions the product as highly effective in balancing natural cleaning performance, enamel polishing, and minimal wear, making it a promising candidate for advanced oral care applications.



**Figure 1.** Comparison of YOU&YOU Whitening Total Care™ Dentifrice VS research’s results of 26 Commercial Dentifrices available at the market



**Figure 5.** Cleaning Efficiency Index (CEI)

## DISCUSSION

The novel kaolin-perlite-hydroxyapatite toothpaste exhibited exceptional cleaning and polishing performance in vitro. It achieved a Pellicle Cleaning Ratio (PCR) of 145.6 ( $\pm 4.0$ ) versus 100 for the ADA reference, placing it above the range reported for typical commercial dentifrices (PCR 25–138).<sup>1</sup>

Likewise, its enamel polishing ( $\Delta$ gloss  $\approx 83.2$ , SRP  $\approx 87.7\%$ ) far exceeded water control and most paste formulations. Crucially, these improvements came with a moderate Relative Dentin Abrasivity (RDA  $\approx 95$ ), which lies at the low end of the 36–269 range seen in Schemehorn's survey.<sup>1</sup>

In other words, our formulation removed substantially more stain and produced higher enamel reflectance than standard products, while remaining

safely below the 250-RDA safety threshold. Together, these findings demonstrate that the toothpaste meets the intended balance of maximal cleaning and polishing with minimized wear.

These results agree with reports that optimized natural abrasives can outperform conventional silica. For example, Wang et al. found that whitening pastes using finely ground platy perlite particles cleaned slightly better, polished much more, and caused less abrasion than a high-cleaning silica paste.<sup>6</sup> This mirrors our observation: the calcined kaolin-perlite blend gave superior stain removal and a very high gloss compared to typical synthetic formulations.

The enhancement is attributed to particle morphology and size distribution, as fine platy particles (and calcination) sharpen cleaning action while

reducing dentin cutting. Moreover, the inclusion of hydroxyapatite and calcium carbonate likely contributed to the whitening effect.<sup>5</sup> Systematic reviews conclude that hydroxyapatite toothpastes significantly whiten enamel,<sup>5</sup> which supports our high polishing results. In this way, the biomimetic remineralizers in the formulation may have reinforced the enamel surface, further boosting gloss without adding abrasion.<sup>7</sup>

Our findings also align with Schemehorn, who noted that most high-PCR whitening pastes contained abrasive silicas and tended to have high RDA. In contrast, the few non-silica outliers (notably a refined kaolin clay dentifrice) showed high PCR with low RDA.<sup>1,3</sup>

You&You@ toothpaste behaves like this exception: it achieves outstanding stain removal (PCR 145.6) without elevated dentin wear. This demonstrates that controlled natural clays can decouple cleaning efficacy from abrasivity. Polishing measurements further support this: Schemehorn found kaolin-based pastes yielding near-maximum reflectance scores ( $\approx 97$ ), consistent with high enamel luster.<sup>1</sup>

Notably, one recent study found that experimental toothpastes containing mineral clays did not significantly change enamel smoothness.<sup>8</sup> The discrepancy suggests that formulation details matter: our use of calcined kaolin and precise particle engineering (along with hydroxyapatite) produced a much larger polishing gain.

In summary, the evidence indicates that the formulation meets its design goals better than many existing products. Its exceptional Cleaning Efficiency Index ( $\approx 2.01$ ) reflects this balance of high PCR and low RDA. These comparisons highlight a key insight: optimizing abrasive particle properties (shape, size, composition) can dramatically improve cleaning and polishing without sacrificing safety. This also points to future directions – for instance, refining particle morphology or adjusting abrasive ratios could further enhance performance. In the broader context, these results reinforce the need to evaluate toothpastes with multiple parameters.

As Maragliano-Muniz emphasizes, any dentifrice with  $RDA \leq 250$  is considered safe for lifetime use.<sup>4</sup> So our moderate RDA inherently meets safety standards. Coupled with our data, this supports the view that one must consider stain-removal (PCR) and polishing (EPP) outcomes alongside RDA. In fact, Schemehorn et al. observed that

dentifrice stain-removal ability and abrasivity were [not necessarily directly] related, echoing our finding that high cleaning power need not entail high wear.<sup>1</sup>

Altogether, our results advance the understanding that a multifaceted testing framework (PCR, EPP, RDA) is essential for assessing toothpaste performance, paving the way for evidence-based improvements.

### Limitations

This study did not include Scanning Electron Microscopy (SEM) or surface microhardness testing, as its focus was on evaluating the cleaning functionality of a natural-ingredient toothpaste designed for daily professional use. The aim was to achieve effective plaque and stain removal without harming tooth structure, while addressing the misconception that Relative Dentin Abrasivity (RDA) alone defines toothpaste efficacy.

The formulation leverages Functionalized Calcium Carbonate technology featuring a biomimetic core-shell structure (calcium carbonate core with a hydroxyapatite shell). This structure provides a high surface area for enhanced reactivity, promoting enamel repair through ionic substitution that converts calcium carbonate into hydroxyapatite.<sup>7</sup>

Engineered calcium delivery vehicles — core-shell  $\text{CaCO}_3 \rightarrow \text{HAP}$  systems, hydrogel-stabilized Ca/P clusters, and biomimetic hydroxyapatite — have been repeatedly shown to accelerate mineral deposition and increase surface microhardness of demineralized enamel *in vitro* and *in situ*.<sup>6</sup>

The toothpaste is also fortified with sodium monofluorophosphate, compatible with hydroxyapatite, with soluble and insoluble fluoride fractions evaluated. But no enamel solubility or SEM analyses were performed as these were outside this study's scope.

Future research prefer to incorporate SEM evaluations to better understand the microstructural changes and correlate these findings with key performance metrics such as Relative Dentin Abrasivity (RDA), Pellicle Cleaning Ratio (PCR), and Enamel Polishing Potential (EPP). Such comprehensive analysis would provide deeper insights into the relationships between material structure and clinical efficacy.

### CONCLUSION

The novel calcined-kaolin/perlite formulation achieved the target objective of superior cleaning

and polishing while maintaining low abrasivity. It significantly outperformed the ADA reference in stain removal (PCR  $\approx$ 145.6) and enamel gloss (EPP  $\Delta$ gloss  $\approx$ 83.2) while keeping RDA ( $\sim$ 95) well below the safety threshold.<sup>1</sup>

These results confirm that the ingredient blend (kaolin, perlite, hydroxyapatite, calcium carbonate) delivers the intended benefits. In line with Aim 1, the toothpaste provides effective plaque/stain removal and a highly polished enamel surface, yet with gentle wear on tooth structure.

The findings also address Aim 2 by demonstrating that RDA alone is insufficient to judge toothpaste safety or efficacy. Consistent with expert guidance, any RDA  $\leq$ 250 is regarded as safe, and our formulation's RDA is comfortably below this level. Crucially, we attained high cleaning efficiency and polish at moderate RDA, underscoring that performance depends on more than abrasivity. This aligns with Schemehorn's conclusion that stain removal does not require proportionally higher abrasion.

Consequently, a comprehensive evaluation (incorporating PCR and EPP alongside RDA) provides a fuller picture of dentifrice performance. The study validates using these multiple metrics to guide formulation and regulatory decisions. In summary, the optimized toothpaste meets the original aims: it balances enhanced cleaning/polish with minimized abrasion and exemplifies the value of multidimensional testing beyond RDA alone.

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### Conflict of Interest

The author declare no conflicts of interest.

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