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Effect of Whitening dentifrice on discoloration of tooth surface: an updated systematic review and meta-analysis

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Abstract

Tooth discoloration is a common cosmetic concern, often addressed using whitening dentifrices (WDFs). This updated systematic review and meta-analysis aimed to assess the effectiveness of WDFs in decreasing tooth surface discoloration compared to regular dentifrices (RDFs). A comprehensive search of multiple electronic databases identified 14 randomized controlled trials (RCTs) meeting the inclusion criteria. The meta-analysis showed that WDFs significantly reduced both the area and intensity of stains, with 94.45% and 77.78% efficacy, respectively. Studies incorporating adjunctive chemical agents in WDFs showed enhanced stain reduction. Despite significant heterogeneity ($I^2 = 91\%$) among the studies, the results consistently favored WDFs over RDFs. Low publication bias was detected, and sensitivity analyses confirmed the robustness of the findings. These results endorse the utilization of WDFs for managing extrinsic tooth stains, though further research is needed to standardize methodologies and assess long-term effects.

Keywords Whitening dentifrices, Tooth discoloration, Systematic review, Meta-analysis, Extrinsic stains

Introduction

Tooth discoloration or tooth staining is a prevalent concern among individuals seeking cosmetic dental interventions[1, 2]. Traditionally, the discoloration of teeth has been categorized based on the location of the stain, which can be either internal (intrinsic) or external (extrinsic) in nature. Additionally, it may be worth considering a separate category for stains or discoloration that have become integrated within the tooth structure (internalized) [3].

Various products with teeth remove stains, and pigment removal in dentistry targets extrinsic stains caused by food, smoking, and germs by air polishing with abrasive powders such as sodium bicarbonate or glycine, as shown by Pardo et al.[4]. Chemical compounds such as hydrogen peroxide assist in the decomposition of stains[5]. Intrinsic discolorations, resulting from systemic causes or pharmacological drugs, necessitate more intensive interventions like as oxidizing agents, micro-abrasives, or restorative procedures like veneers[6].

Based on the etiology of tooth staining, dentists should develop a customized treatment plan for each patient. In proposing this individualized treatment, dentists should consider the patient's preferences and expectations, current dental condition, and overall oral health [2]. The available treatment options can range from simple professional cleaning to applying bleaching gels that patients can use at home or under the dentist's supervision in the dental office [1]. Some over-the-counter whitening

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products include gels, rinses, whitening strips, and dentifrices. Whitening toothpastes have been gaining more attention from consumers due to their convenience and affordability. These types of products may be the most accessible option for many patients and consumers who are interested in whitening their teeth [7]. Whitening toothpastes typically contain the following common abrasive agents: charcoal, calcium carbonate, sodium bicarbonate (baking soda), dicalcium phosphate dehydrate, nanohydroxyapatite, hydrated silica, alumina, perlite, calcium pyrophosphate, and diamond powder [2].

The abrasive agents in whitening toothpaste can remove surface blemishes from the tooth surfaces, creating the impression that the teeth have undergone a whitening or coloration change. However, there needs to be more knowledge about the effectiveness of these whitening toothpastes compared to other products [1]. Additionally, the effects and alterations caused by these whitening dentifrices on stained teeth, regardless of the underlying cause of the staining, still need to be better understood. Therefore, this meta-analysis aimed to determine the impact of these dentifrices on the lobe stain index.

Materials and methods

Search strategy

Electronic databases, including PubMed, MEDLINE, and Scopus reviewed by two independent reviewers (A and B) based on PRISMA guidelines to identify relevant clinical trials to July 2024 [8]. The research protocol was registered on PROSPERO (registration ID: 654,181). The researchers employed a multifaceted search strategy, combining Medical Subject Headings (MeSH) terms and text-based keywords to identify relevant studies. They also conducted a comprehensive review of reference lists from selected articles, relevant review papers, and meta-analyses. The keywords included:"tooth-whitening"OR"tooth-bleaching"OR"carbamide peroxide"OR"hydrogen peroxide OR"bleaching"OR"home-bleaching"OR"vital bleaching (Table 1)."

Inclusion criteria and study selection

The inclusion criteria were randomized clinical trials (RCTs), articles published in English, articles that evaluated the outcome of teeth bleaching, articles that included at least one of the two groups, whitening dentifrices, and other products. After removing the duplicate articles, two independent reviewers (A and B) screened the titles and abstracts of the remaining articles. After that, the full-text articles were reviewed, and eligibility was decided upon through a consensus process. Any disagreements were resolved through consensus among the reviewers.

Data extraction

Two reviewers (A and B) independently extracted data from the articles using a pre-designed data extraction form. The extracted information from each article included author, year, country of origin, name of journal, number of groups, number of patients in each group, name of intervention group, name of control group, mean age of each group, type of the bleaching method, frequency of use of each bleaching method, evaluation time, evaluation method, reported adverse effect, the outcomes (reduction of stained area (LSI, Lobene stain index), reduction of stain intensity area (LSI, Lobene stain index), Vita Classic shade guide).

Table 1 Search strategies for PubMed and Scopus data bases

Search engine	Search strategy	Additional filters	Result
PubMed/MEDLINE	("Dentifrices"[Title/Abstract] OR"Toothpastes"[Title/Abstract] OR"whitening dentifrice"[Title/Abstract] OR"whitening toothpaste"[Title/Abstract] OR"bleaching toothpaste"[Title/Abstract]) AND ("tooth bleaching"[Title/Abstract] OR"tooth whitening"[Title/Abstract] OR"bleaching teeth"[Title/Abstract] OR"tooth stain removal"[Title/Abstract] OR"extrinsic stain removal"[Title/Abstract] OR"pigment removal"[Title/Abstract])	English 25 July 2024	152
Scopus	(TITLE-ABS-KEY (dentifrices) OR TITLE-ABS-KEY (toothpastes) OR TITLE-ABS-KEY (whitening AND dentifrice) OR TITLE-ABS-KEY (whitening AND toothpaste) OR TITLE-ABS-KEY (bleaching AND toothpaste)) AND (TITLE-ABS-KEY (tooth AND bleaching) OR TITLE-ABS-KEY (tooth AND whitening) OR TITLE-ABS-KEY (bleaching, AND teeth) OR TITLE-ABS-KEY (tooth AND stain AND removal) OR TITLE-ABS-KEY (extrinsic AND stain AND removal) OR TITLE-ABS-KEY (pigment AND removal)) AND PUBYEAR > 1969 AND PUBYEAR < 2025	English 25 July 2024	775

Risk of bias assessment

The risk of bias in the included studies was evaluated using the Cochrane Collaboration's guidelines for assessing clinical trials [9]. Each study was categorized as having a low, unclear, or high risk of bias based on predefined criteria. Two reviewers independently assessed the quality of the articles. Any disagreements between their evaluations were discussed until an agreement was reached. In cases where they could not resolve a discrepancy, a third researcher (C) was consulted to intervene and help determine the final quality rating for the disputed study.

Quality assessment and bias evaluation

We independently employed the JBI Critical Appraisal Checklist to assess the quality of RCTs (https://jbi.global/critical-appraisal-tools), including only those RCTs deemed to have fair to good quality.

Statistical analysis

A meta-analysis was performed using R version 4.4.0 to evaluate the effectiveness and side effects of whitening dentifrices compared to other products. For continuous outcomes, the analysis used the Mean Difference (MD) with 95% confidence intervals (CIs), while for dichotomous outcomes, it applied the risk difference (RD) with 95% CIs.

Heterogeneity among studies was assessed using the Chi-square and I-square tests. To identify potential sources of heterogeneity, a subgroup analysis was conducted. The I2 statistic was used to assess heterogeneity among the studies, and all statistical tests were two-tailed, with significance defined by a p-value of less than 0.05.

Publication bias assessment

Egger's regression test was applied to assess the possibility of publication bias. When Egger's regression detected significant publication bias ($p < 0.05$), the reviewers employed the Trim and Fill analysis to estimate any potentially missing effect sizes and to recalculate the overall pooled effect, adjusting for the impact of the suspected publication bias [10, 11].

Sensitivity analysis

As part of the meta-analysis, the researchers also performed a sensitivity analysis to evaluate whether the results heavily depend on any study included in the review. This involved the one-study-removed method, where each study was sequentially removed, and the impact on the overall findings and conclusions of the meta-analysis was assessed [12].

Results

Study and subject characteristics

The aggregate number of participants in all included studies is 1,597. The investigations were performed in many countries, including the USA, Canada, the UK, China, Brazil, and Italy, with sample sizes varying from 40 to 200 individuals. The majority of studies had more than 80 participants, with the biggest being 200 persons. The trials primarily examined the efficacy of WDF over normal dentifrices (RDF) in stain elimination, decrease of extrinsic pigmentation, and enhancements in plaque and gingival bleeding indicators. The research populations were varied, including numerous geographic regions, so guaranteeing extensive coverage of distinct demographic groupings.

Efficacy of whitening dentifrices

- Most studies demonstrated that whitening dentifrices (WDF) were significantly more effective than regular dentifrices (RDF) in reducing tooth stain area and intensity.
- 94.45% of the studies (17/18) reported a positive effect of WDF on reducing stain area[13–22], 77.78% (14/18) on reducing stain intensity[13–20, 22], and 100% (4/4) on improving composite stain scores[21, 23, 24].

Efficacy with and without adjunctive chemical agents:

- WDFs containing adjunctive chemical agents (e.g., triclosan, PVM/MA copolymer, hexametaphosphate) were effective in 91.67% (11/12) of studies for stain area[13–22], 66.67% (8/12) for stain intensity[13–20, 22], and 100% (2/2) for composite scores[23, 24].
- WDFs without adjunctive chemical agents showed 100% efficacy in reducing stain area and intensity across the studies.

Study and subject characteristics and outcome results

The studies considered in the analysis showed significant heterogeneity. All 14 papers considered in the analysis were randomized controlled trials. ETD's clinical parameters and adjustments are reported for each intervention group, including baseline, end, and incremental changes. (Fig. 1).

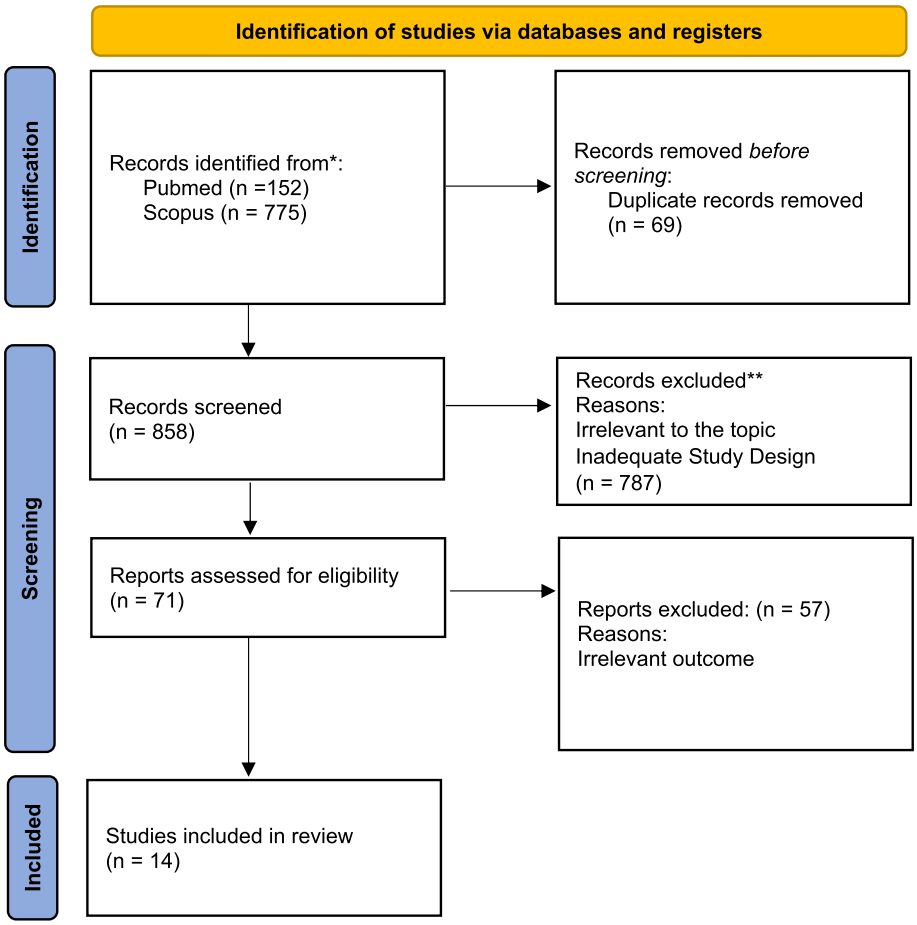

Fig. 1 Prisma flow diagram

Descriptive analysis

The original authors provided a thorough analysis of the key differences in tooth discoloration between WDF and RDF. In terms of staining area, intensity, and overall composite score, most comparisons showed a significant benefit for WDF (Figs. 2, 3, 4, 5, 6 and 7).

Meta-analysis

The meta-analysis evaluated baseline and final scores for stain area, intensity, and composite indices utilizing data from several clinical investigations. The findings consistently indicated that WDF formulations were much more successful in diminishing extrinsic stains compared to RDF. Research including several WDF formulations, such as those containing silica, hexametaphosphate, arginine, and supplementary agents, shown a significant reduction in LSI scores. The results were uniform across all demographics and testing methodologies, demonstrating considerable improvements in stain removal in WDF groups. The meta-analysis demonstrated that WDF formulations offer enhanced stain control relative to RDF, hence affirming its efficacy in addressing extrinsic pigmentation (Table 2).

Publication bias and sensitivity analysis

The funnel plot and Egger's regression test demonstrated low publication bias, which suggests that the findings of the meta-analysis are credible. The sensitivity analysis provided further evidence for the trustworthiness of the findings, showing similar patterns in the data even when individual studies were excluded. The findings consistently supported the superiority of WDFs over RDFs, hence validating the conclusion that WDFs are very efficient in decreasing tooth surface stains. The I2 statistic indicates a significant degree of variability with an index of 91%. The notable variability seen suggests that although WDFs generally succeed, their efficacy may vary based on the specific product mix, usage frequency, and individual patient attributes (Tables 3, 4 and 5).

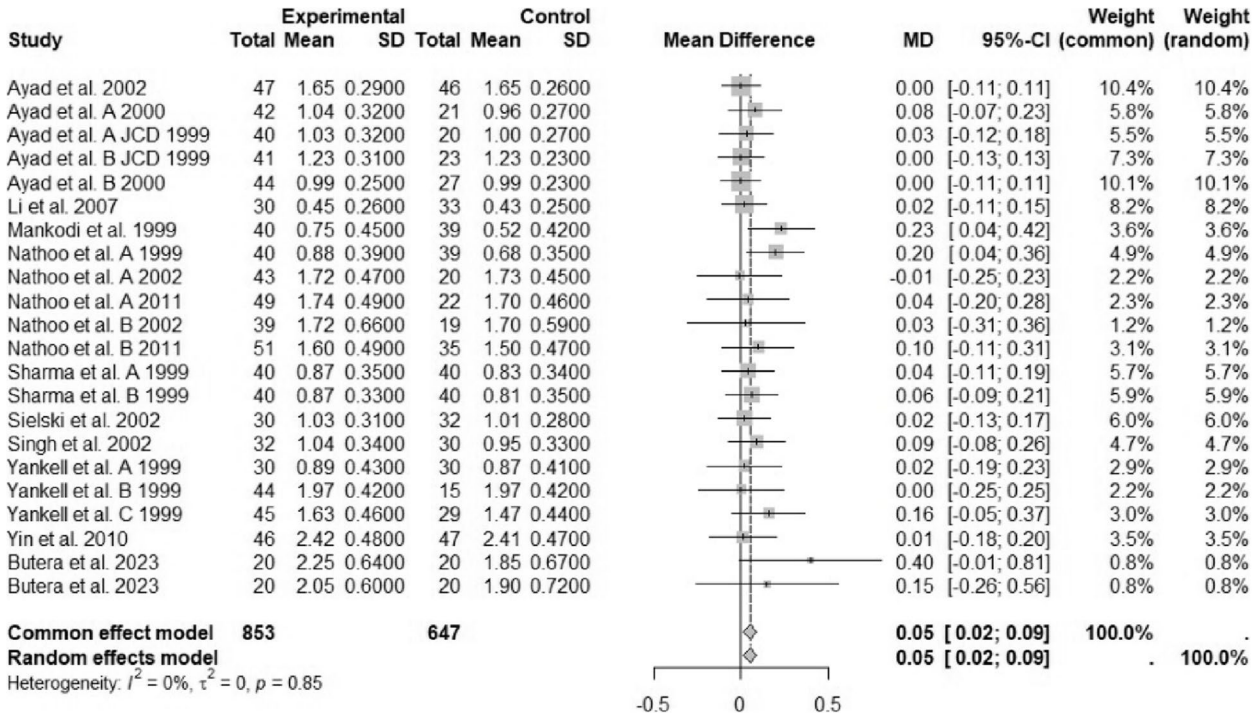

Fig. 2 Forest plot of the meta-analysis for Staining area score at baseline for the Lobene Stain Index

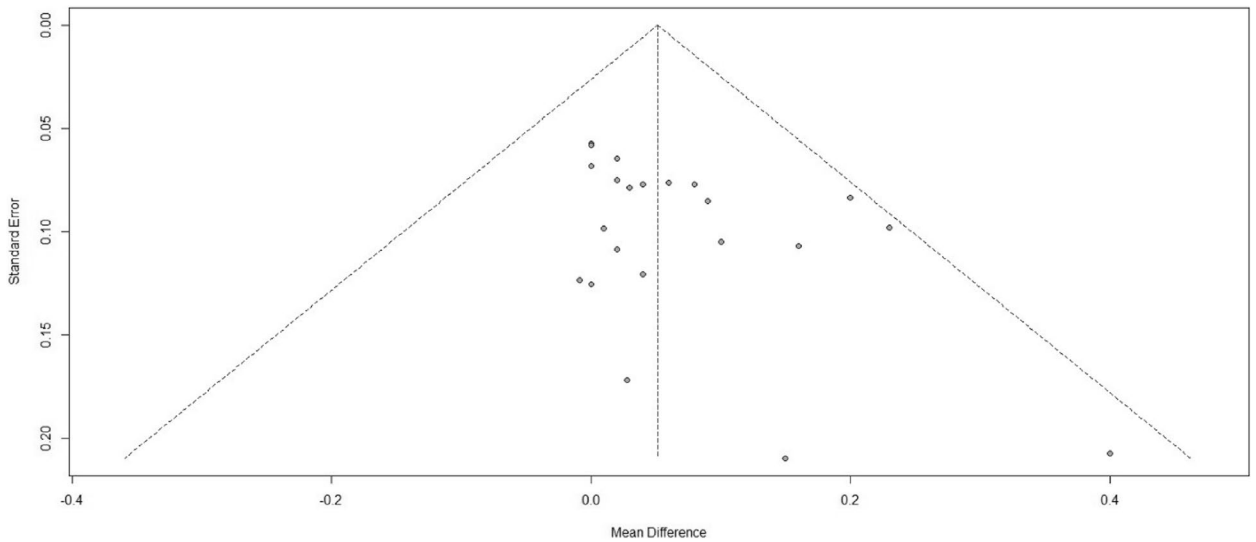

Fig. 3 Funnel plot of the meta-analysis for Staining area score at baseline for the Lobene Stain Index

Quality assessment

The included studies exhibited typically excellent quality, with JBI quality assessment ratings between 10/13 and 13/13 for RCTs, and we incorporated only RCTs of fair to good quality[28].

Meta-analysis results

- *Stain Area Reduction*: Significant improvement in stain area scores for WDF over RDF in 94.45% of studies.

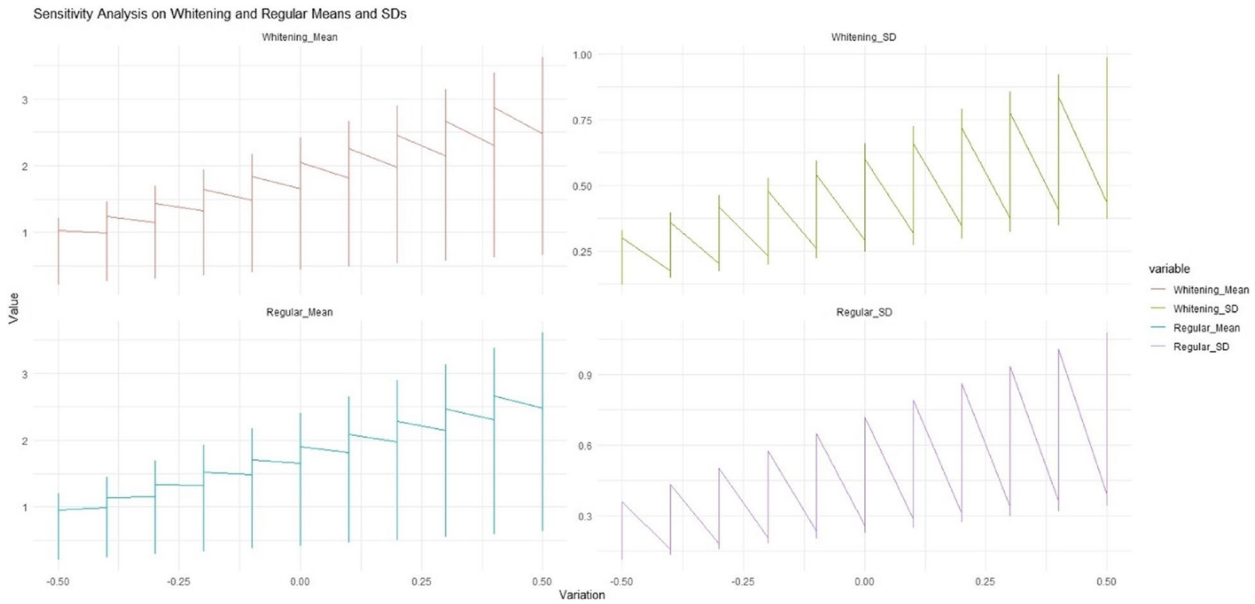

Fig. 4 Sensitivity analysis of the meta-analysis for Staining area score at baseline for the Lobene Stain Index

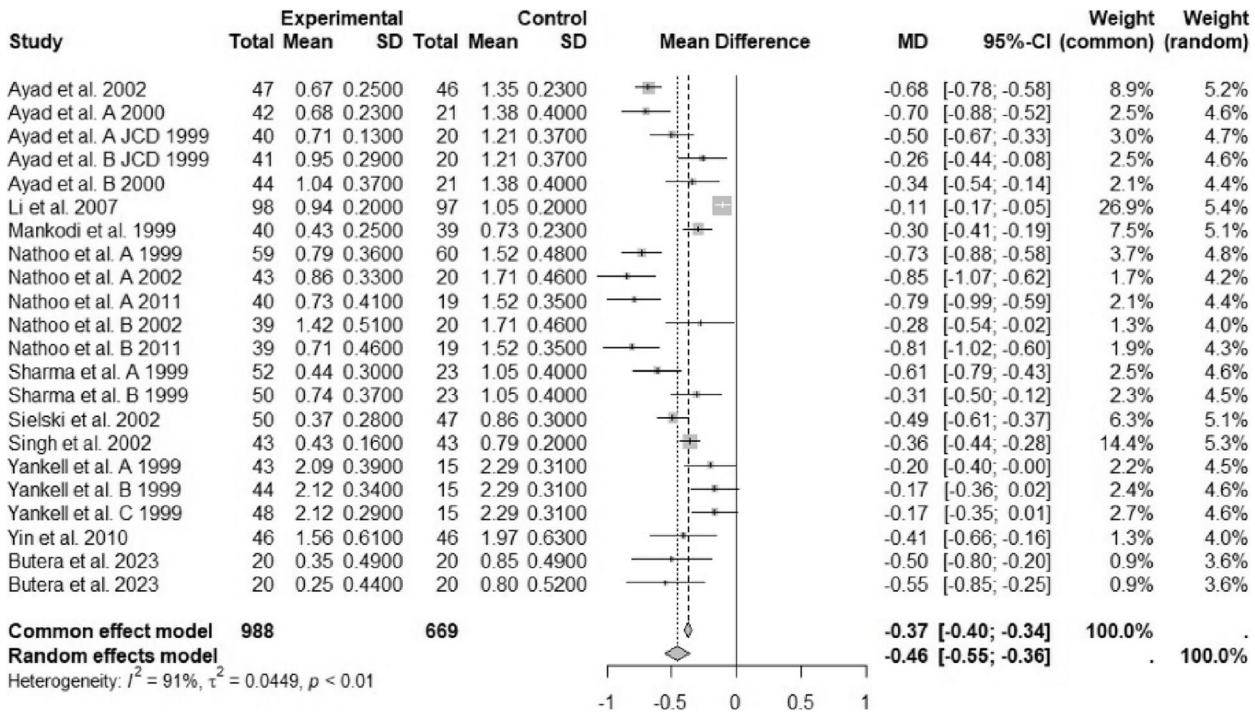

Fig. 5 Forest plot of the meta-analysis for Staining area endscore for the Lobene Stain Index

- *Stain Intensity Reduction*: There was a significant reduction in stain intensity for WDF in 77.78% of studies.
- *Composite Stain Score*: Significant improvements in composite stain scores for WDF across all relevant studies.

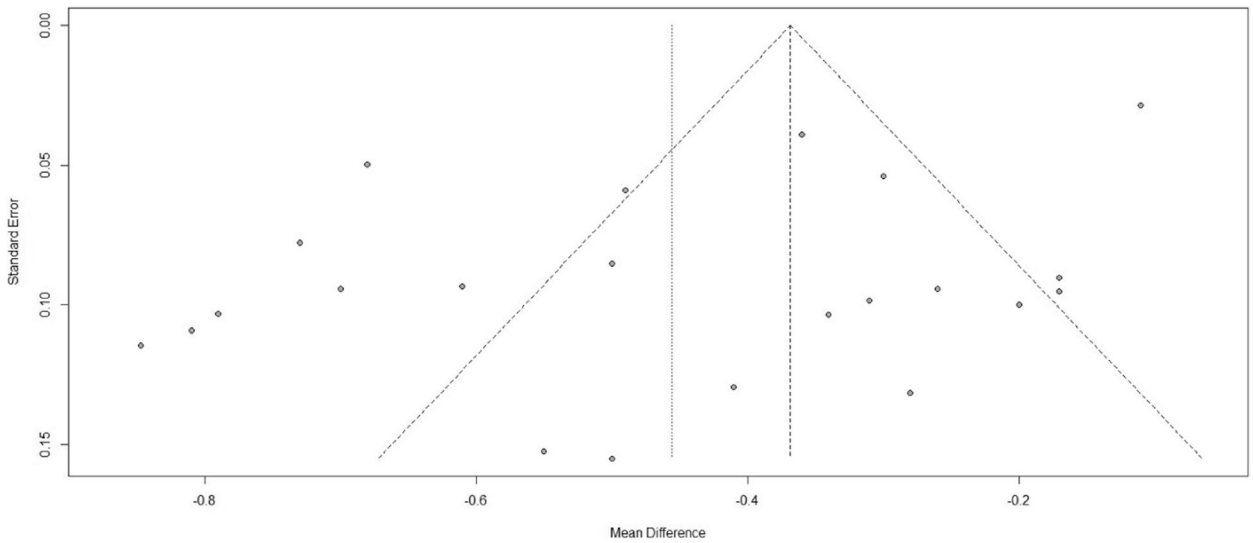

Fig. 6 Funnel plot of the meta-analysis for Staining area endscore for the Lobene Stain Index

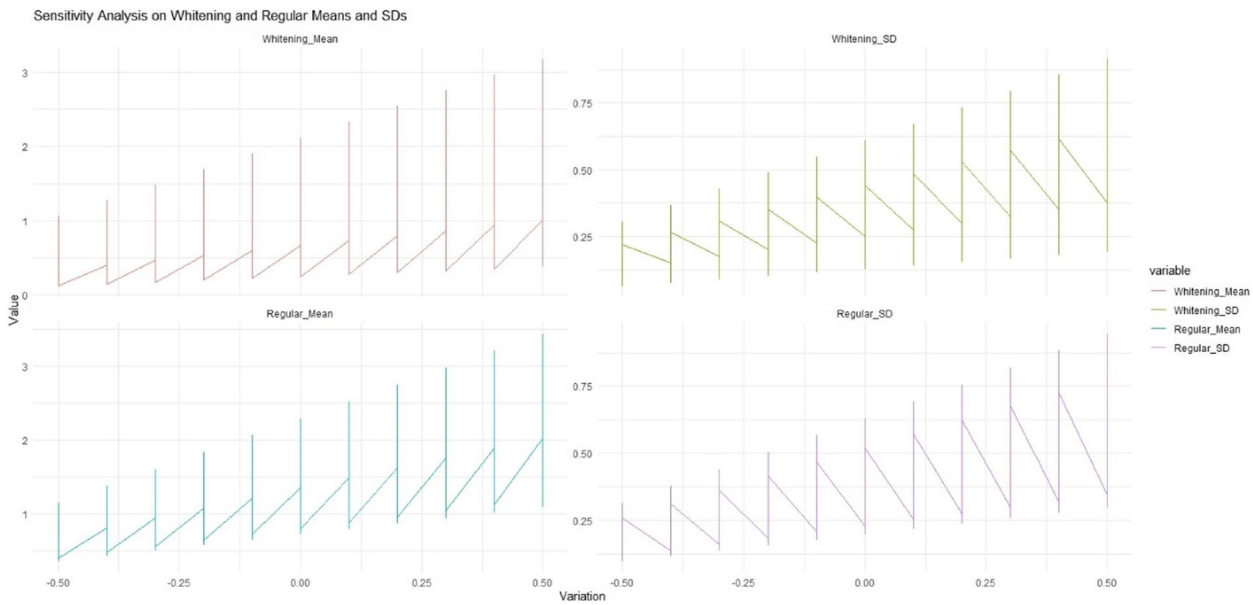

Fig. 7 Sensitivity analysis of the meta-analysis for Staining area endscore for the Lobene Stain Index

Analysis of the base score

The presence of symmetry in the funnel plot implies the existence of publishing bias, while an asymmetrical pattern reflects the presence of minor prejudice. Based on this study, the data points are uniformly spread around the mean difference, indicating a lack of significant publication bias. The sensitivity analysis plot displays the fluctuations in the means and standard deviations across several circumstances, namely whitening and regular. The presence of error bars and fluctuations indicates how changes influence the findings. Consistent patterns seen in the subplots suggest that the data obtained are dependable. Every horizontal line in the forest plot corresponds to specific research, while the diamond summarizes the total impact magnitude. The mean differences are centered about zero, and the total effect size (represented by a diamond) suggests a tiny positive impact, with a mean difference around 0.05. These findings indicate that teeth whitening toothpastes have a modest but favorable effect on diminishing tooth surface staining.

Table 2 Overview of the included studies relevant characteristics processed for data extraction

Authors (year)	Study design blinding duration	# Participants baseline (end) Population gender age (mean/range) smokers	Group *Brand* Ingredients *WDF subgroup characteristics*	Regimen: Toothbrush Frequency, duration Amount of toothpaste Other instructions	Conclusions of the original authors
Nathoo et al. (2011) [24]	RCT Parallel-groups Examiner blind Blinded to product 6 weeks	120 (117) Population from Piscataway, NY, USA ♀: 72 ♂: 45 Mean age: 41.86◊ Age range: 18–74 Smokers:?	**WDF1:** *?* 0,3% triclosan, 2.0% PVM/MA copolymer, 0,243% NaF and specially designed silica to occlude dentin tubules *Without adjunctive chemical agents* **WDF2:** *?* 0,3% triclosan, 2.0% PVM/MA copolymer, 0,243% NaF in a high cleaning silica base *Without adjunctive chemical agents* **RDF:** *?* 0.243% NaF in a silica base	Soft toothbrush Twice a day ? Refrain other oral hygiene products	Compared to the regular dentifrice (RDF), both the whitening dentifrice (WDF) and the positive control group showed statistically significant reductions in mean LSI. However, when comparing WDF1 to WDF2, no statistically significant reduction in mean LSI was observed
Yin et al. (2010) [22]	RCT Parallel-groups Examiner blind Blinded to product 8 weeks	? (92) Population from China ♀: 30 ◊ ♂: 62 ◊ Mean age: 42.85 ◊ Age range: 27–65 Smokers:?	**WDF:** *?* 8.0% arginine, high cleaning calcium carbonate, 1450 ppm fluoride *Without adjunctive chemical agents* **RDF**: *?* 8.0% arginine, calcium carbonate, 1450 ppm fluoride	Soft toothbrush Twice a day ? Refrain other oral hygiene products No instructions to alter diet of other habits	Compared to the regular dentifrice (RDF), participants using the whitening dentifrice (WDF) showed a statistically significant decrease in mean LSI
Li et al. (2007) [21]	RCT Parallel-groups Examiner blind Blinded to product 6 weeks	200 (193) ? ♀: 85 ♂: 108 Mean age: 33.6 Age range: 18–60 Smokers: 77Y/116 N	**WDF:** *Crest Vivid White (Procter & Gamble Co, Cincinnati, OH, USA)* 11.0% hexametaphosphate and 0.243% sodium fluoride *With adjunctive chemical agents* **RDF:** *Colgate Cavity Protection (Colgate-Palmolive Co, New York, NY, USA)* Sodium monofluorophosphate 0.76% (0.15% w/fluoride ion), sodium saccharin, sodium lauryl sulfate, cellulose gum, Dicalcium phosphate dihydrate, water,, tetrapotassium pyrophosphate, glycerin, sorbitol, flavor ◊	Crest Triple Care toothbrush (Procter & Gamble Co, Cincinnati, OH, USA) Twice a day for 1 min ? ?	The whitening dentifrice (WDF) demonstrated a statistically significant decrease in LSI compared to the regular dentifrice (RDF)

Table 2 (continued)

Authors (year)	Study design blinding duration	# Participants baseline (end) Population gender age (mean/range) smokers	Group *Brand* Ingredients *WDF subgroup characteristics*	Regimen: Toothbrush Frequency, duration Amount of toothpaste Other instructions	Conclusions of the original authors
Ayad et al. (2002) [18]	RCT Parallel-groups Blinded to product 6 weeks	? (93) Population from Mississauga, Ontaria, Canada ♀: 48 ♂: 45 Mean age: 36.58 ◊ Age range: 19–65 Smokers:?	**WDF:** *Colgate Total Plus Whitening Toothpaste (Colgate-Palmolive Co., New York, NY, USA)* 0.3% triclosan, and 2.0% PVM/MA copolymer in a 0.243% sodium fluoride silica base, of wich 10% of the silica is a high cleaning silica *Without adjunctive chemical agents* **RDF:** *Colgate Total Toothpaste (Colgate-Palmolive Co., New York, NY, USA)* 0.3% triclosan, and 2.0% PVM/MA copolymer in a 0.243% sodium fluoride silica base	Soft toothbrush Twice a day for 1 min ? Refrain other oral hygiene products	Participants using the whitening dentifrice (WDF) showed statistically significant reductions in both extrinsic stain area and intensity compared to those using the regular dentifrice (RDF)
Nathoo et al. (2002) [19]	RCT Parallel-groups Blinded to product 6 weeks	? (123) Population from Piscataway, New Jersey, USA ♀: 85 ◊ ♂: 38 ◊ Mean age: 32.69 ◊ Age range: 18–67 Smokers:?	**WDF1:** *Colgate Total Plus Whitening Toothpaste (Colgate-Palmolive Co., New York, NY, USA)* 0.3% triclosan, and 2.0% PVM/MA copolymer in a 0.243% sodium fluoride silica base, of wich 10% of the silica is a high cleaning silica *Without adjunctive chemical agents* **WDF2:** *Crest Multi Care Advanced Cleaning Toothpaste (Procter & Gamble Co, Cincinnati, OH, USA)* 7.0% sodium hexametaphosphate and 0.243% sodium fluoride in a silica base *With adjunctive chemical agents* **RDF:** *Colgate Winterfresh Gel Fluoride Toothpaste (Colgate-Palmolive Co., New York, NY, USA)* Toothpaste containing 0.243% sodiumfluoride in a silica base	Soft toothbrush Twice a day ? Refrain other oral hygiene products	The findings of this study suggest that the whitening dentifrice (WDF) was significantly more effective in reducing extrinsic tooth stain area and intensity compared to the regular dentifrice (RDF)

Table 2 (continued)

Authors (year)	Study design blinding duration	# Participants baseline (end) Population gender age (mean/range) smokers	Group *Brand* Ingredients *WDF subgroup characteristics*	Regimen: Toothbrush Frequency, duration Amount of toothpaste Other instructions	Conclusions of the original authors
Sielski et al. (2002) [20]	RCT Parallel-groups Blinded to product 6 weeks	97 (97) Population from Buffalo, New York, USA ♀: 50 ◊ ♂: 47 ◊ Mean age: 41.74 ◊ Age range: 23–65 Smokers:?	**WDF:** *Colgate Total Plus Whitening Toothpaste (Colgate-Palmolive Co., New York, NY, USA)* 0.3% triclosan, and 2.0% PVM/MA copolymer in a 0.243% sodium fluoride silica base, of wich 10% of the silica is a high cleaning silica *Without adjunctive chemical agents* **RDF:** *Colgate Total Toothpaste (Colgate-Palmolive Co., New York, NY, USA)* 0.3% triclosan, and 2.0% PVM/MA copolymer in a 0.243% sodium fluoride silica base	Soft toothbrush Twice a day for 1 min ? Refrain other oral hygiene products	The whitening dentifrice (WDF) is effective in removing extrinsic tooth stains
Singh et al. (2002) [25]	RCT Parallel-groups Blinded to product 6 months	87 (86) Population from New Jersey and Florida, USA ♀: 48 ◊ ♂: 38 ◊ Mean age: 43.45 ◊ Age range: 19–70 Smokers:?	**WDF:** *Colgate Total Plus Whitening Toothpaste (Colgate-Palmolive Co, New York, NY, USA)* 0.3% triclosan, and 2.0% PVM/MA copolymer in a 0.243% sodium fluoride silica base, of which 10% of the silica is a high cleaning silica *Without adjunctive chemical agents* **RDF:** *Colgate Total Toothpaste (Colgate-Palmolive Co., New York, NY, USA)* 0.3% triclosan, and 2.0% PVM/MA copolymer in a 0.243% sodium fluoride silica base	Soft toothbrush Twice a day for one minute ? Refrain other oral hygiene products	The whitening dentifrice (WDF) is more effective than the regular dentifrice (RDF) in removing extrinsic tooth stains
Ayad et al. (2000) [17]	RCT Parallel-groups, multicenter Blinded to product 6 weeks	? (128) Population from Manchester, UK and Mississauga, Ontario, Canada ♀: 47 ◊ ♂: 81 ◊ Mean age: 39.45 ◊ Age range: 18–63 Smokers:?	**WDF1:** *?* pyrophosphate, tripolyphosphate and a copolymer of methoxyethylene and maleic acid (PVM/MA in a 0.243% sodium fluoride/silica base *With adjunctive chemical agents* **WDF2:** *Aquafresh Whitening with fluoride (SmithKline Beecham Consumer Brands, Pittsburgh, PA, USA)* 0.243% sodium fluoride and sodium tripolyphosphate in a hydrated silica base *With adjunctive chemical agents* **RDF:** *Crest Regular (Procter & Gamble Co, Cincinnati, OH, USA)* 0.243% sodium fluoride in a hydrated silica base	Soft toothbrush Twice a day for one minute ? Refrain other oral hygiene products	The WDF removes extrinsic tooth stain effectively

Table 2 (continued)

Authors (year)	Study design blinding duration	# Participants baseline (end) Population gender age (mean/range) smokers	Group *Brand* Ingredients *WDF subgroup characteristics*	Regimen: Toothbrush Frequency, duration Amount of toothpaste Other instructions	Conclusions of the original authors
Ayad et al. (1999, AJD) [23]	RCT Parallel-groups Blinded to product 6 weeks	90 (88) Population from São Paulo, Brasil ♀: 49 ◊ ♂: 39 ◊ Mean age:? Age range:? Smoker: 43Y/45 N ◊	**WDF1:** *?* 10% aluminium oxide, 1500 ppm sodium monofluorophosphate in PCC base *Without adjunctive chemical agents* **WDF2:** *?* 0.5% calcium peroxide, 1500 ppm monofluorophosphate in a PCC base *With adjunctive chemical agents* **RDF:** *?* Fluoride	Soft toothbrush Twice a day for 1 min ? Refrain other oral hygiene products	Participants in the WDF groups showed statistically significant improvements compared to those in the RDF group
Ayad et al. (1999, JCD) [13]	RCT Parallel-groups Blinded to product 6 weeks	? (122) Population from Mississauga, Ontario, Canada ♀: 62 ◊ ♂: 60 ◊ Mean age: 37.60 ◊ Age range: 18–66 Smoker:?	**WDF1:** *Colgate Tartar Control Plus Whitening Fluoride Toothpaste (Colgate-Palmolive Co., New York, NY, USA)* Tetrasodium pyrophosphate, sodium tripolyphosphate, PVM/MA copolymer, aluminium oxide and 0.76% sodium monofluorophosphate in a hydrated silica base *With adjunctive chemical agents* **WDF2:** *Aquafresh Whitening with fluoride (SmithKline Beecham Consumer Brands, Pittsburgh, PA, USA)* 0.243% sodium fluoride and sodium tripolyphosphate in a hydrated silica base *With adjunctive chemical agents* **RDF:** *Crest Regular Fluoride Toothpaste (Procter & Gamble Co, Cincinnati, OH, USA)* 0.243% sodium fluoride in a hydrated silica base	Soft toothbrush Twice a day for 1 min ? Refrain other oral hygiene products	Participants in the WDF groups exhibited statistically significant improvements when compared to the RDF group

Table 2 (continued)

Authors (year)	Study design blinding duration	# Participants baseline (end) Population gender age (mean/range) smokers	Group *Brand* Ingredients *WDF subgroup characteristics*	Regimen: Toothbrush Frequency, duration Amount of toothpaste Other instructions	Conclusions of the original authors
Mankodi et al. (1999) [14]	RCT Parallel-groups Blinded to product 6 weeks	? (79) Population from the Manchester area, UK ♀: 35 ♂: 44 Mean age: 40.06 ◊ Age range: 23–67 Smoker:?	**WDF:** *Colgate Tartar Control Plus Whitening (Colgate-Palmolive Co., New York, NY, USA)* Tetrasodium pyrophosphate, sodium tripolyphosphate and a PVM/MA copolymer in a 0.243% sodium fluoride/silica base *With adjunctive chemical agents* **RDF:** *Colgate Winterfresh Fluoride Gel (Colgate-Palmolive Co., New York, NY, USA)* 0.243% sodium fluoride/silica base	Soft toothbrush Twice a day for 1 min ? Refrain other oral hygiene products	The WDF offered significantly better control over extrinsic tooth stain area and intensity compared to the RDF
Sharma et al. (1999) [15]	RCT Parallel-groups Blinded to product 6 weeks	? (149) Population from Toronto, Ontaria, Canada ♀: 92 ◊ ♂: 57 ◊ Mean age: 39.74 ◊ Age range: 19–69 Smoker:?	**WDF1:** *Colgate Platinum Whitening Toothpaste with fluoride (also marketed as Colgate Sensation Whitening Toothpaste with fluoride) (Colgate-Palmolive Co., New York, NY, USA)* 0.76% sodium monofluorophosphate tetrasodium pyrophosphate, PVM/MA copolymer and aluminiumoxide in a hydrated silica base *With adjunctive chemical agents* **WDF2:** *Aquafresh Advanced Whitening Toothpaste with fluoride (SmithKline Beecham Consumer Brands, Pittsburgh, PA, USA)* 0.243% sodium fluoride and sodium tripolyphosphate in a hydrated silica base *With adjunctive chemical agents* **RDF:** *Crest Regular (Procter & Gamble Co, Cincinnati, OH, USA)* Sodium fluoride 0.243% (0.15% w/v fluoride ion), sorbitol, water, hydrated silica, sodium lauryl sulfate, trisodium phosphate, flavor, sodium phosphate, cellulose gum, sodium saccharin, carbomer, titanium dioxide ◊	Soft toothbrush Twice a day for 1 min ? Refrain other oral hygiene products	The WDF is significantly more effective in removing extrinsic tooth stains than the RDF

Table 2 (continued)

Authors (year)	Study design blinding duration	# Participants baseline (end) Population gender age (mean/range) smokers	Group *Brand* Ingredients *WDF subgroup characteristics*	Regimen: Toothbrush Frequency, duration Amount of toothpaste Other instructions	Conclusions of the original authors
Yankell et al. (1999) [16]	RCT Parallel-groups Blinded to product 6 weeks	? (180) Population from Philadelphia, Pennsylvania, USA ♀: 105 ◊ ♂: 75 ◊ Mean age: 42.25 Age range: 19–77 Smokers:?	**WDF1:** *Colgate Tartar Control with Baking Soda & Peroxide Fluoride Toothpaste (Colgate-Palmolive Co., New York, NY, USA)* 0.76% sodium monofluoro phosphate, sodium bicarbonate, calcium peroxide, aluminium oxide, tetrasodium pyrophosphate and pentasodium triphosphate in a hydrated silica base *With adjunctive chemical agents* **WDF2:** *Aquafresh Advanced Whitening Toothpaste with fluoride (SmithKline Beecham Consumer Brands, Pittsburgh, PA, USA)* 0.243% sodium fluoride and sodium tripolyphosphate in a hydrated silica base *With adjunctive chemical agents* **WDF3:** *Rembrandt Tartar Control Low Abrasive Fluoride Whitening Toothpaste (Den-Mat Co., Santa Maria, CA, USA)* 0.76% sodium monofluoriphosphate, alumina and papain in a dicalcium phosphate dehydrated base *With adjunctive chemical agents* **RDF:** *Crest Regular Fluoride Toothpaste (Procter & Gamble Co, Cincinnati, OH, USA)* 0.243% sodium fluoride in a hydrated silica base	Soft toothbrush Twice a day for 1 min ? Refrain other oral hygiene products	All WDFs offer significantly better control over extrinsic tooth stains compared to the RDF
Butera et al. (2023) [26]	RCT, Parallel-groups, Examiner blind, Blinded to product, 3 months	40 (40) Population from Pavia, Italy ♀: 23 ♂: 17 Mean age: 34.7 Age range: 18–65 Smokers:?	**WDF:** Blanx Black (Coswell S.p.A., Funo di Argelato, BO, Italy) Activated charcoal **RDF:** Colgate Sensation White (Colgate-Palmolive, New York, NY, USA) Micro-cleaning crystals	Soft toothbrush Twice a day ? Refrain other oral hygiene products	Both tested toothpastes showed significant reductions in extrinsic pigmentation. The Trial group with activated charcoal showed total elimination of stains, but without significant difference between groups

WDF = Whitening Dentifrice
RDF = Regular Dentifrice

? = unknown/not provided

◊ = calculated by the authors of this review based on the data presented in the selected paper

RCT = Randomized Controlled Trial

Table 3 The methodological quality and potential risk of bias assessments for the individual studies included in this review

Study		Nathoo et al. (2011) [13]	Yin et al. (2010) [14]	Li et al. (2007)[15]	Ayad et al. (2002) [16]	Nathoo et al. (2002) [17]	Sielski et al. (2002) [18]	Singh et al. (2002) [19]	Ayad et al. (2000) [20]	Ayad et al. (1999 AJD) [21]	Ayad et al. (1999 JCD) [22]	Mankodi et al. (1999) [23]	Sharma et al. (1999) [24]	Yankell et al. (1999) [25]
Quality criteria														
	Study design	Parallel												
Internal validity	Random allocation	+	+	+	+	+	+	+	+	+	+	+	+	+
	Allocation concealment	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Blinded to product *	+	+	+	+	+	+	+	+	+	+	+	+	+
	Blinded to examiner	+	+	+	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Blinding during statistical analysis	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Balanced experimental groups	+	+	+	+	+	+	+	+	+	+	+	+	+
	Reported loss to follow up	+	NR	+	NR	NR	NR	+	NR	+	NR	NR	NR	NR
	# (%) of drop-outs	3 3%◊	NR	7 4%◊	NR	NR	NR	1 1%◊	NR	2 2%◊	NR	NR	NR	NR
	Treatment identical, except for intervention	+	+	+	+	+	+	+	+	+	+	+	+	+
External validity	Representative population group	+	+	+	+	+	+	+	+	+	+	+	+	+
	Eligibility criteria defined	+	+	+	+	+	+	+	+	+	+	+	+	+
	Sample size calculation and power	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Point estimates presented for the primary outcome	+	+	+	+	+	+	+	+	+	+	+	+	+
	Measures of variability presented for the primary outcome	+	+	+	+	+	+	+	+	+	+	+	+	+
	Unit of analysis	Subject												
	Include an per protocol analysis	+	+	+	+	+	+	+	+	+	+	+	+	+
	Include an intention- to-treat analysis	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 3 (continued)

Study		Nathoo et al. (2011) [13]	Yin et al. (2010) [14]	Li et al. (2007)[15]	Ayad et al. (2002) [16]	Nathoo et al. (2002) [17]	Sielski et al. (2002) [18]	Singh et al. (2002) [19]	Ayad et al. (2000) [20]	Ayad et al. (1999 AJD) [21]	Ayad et al. (1999 JCD) [22]	Mankodi et al. (1999) [23]	Sharma et al. (1999) [24]	Yankell et al. (1999) [25]
Quality criteria														
Clinical aspects	Validated measurement	+	+	+	+	+	+	+	+	+	+	+	+	+
	Calibration examiner	NR	NR	+	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Reproducibility data shown	+	+	+	+	+	+	+	+	+	+	+	+	+
Authors estimated methodological quality (% of items that met the quality standard)		**72**	**67**	**78**	**61**	**61**	**61**	**67**	**61**	**67**	**61**	**61**	**61**	**61**
Authors estimated risk of bias		**moderate**	**moderate**	**moderate**	**moderate**	**moderate**	**moderate**	**moderate**	**moderate**	**moderate**	**moderate**	**moderate**	**moderate**	**moderate**

Each item on the score list was rated as '+' if it included an informative description and a study design that met the quality standards, or '-' if it had an informative description but did not meet the quality standard for the study design. The percentage of items rated '+' was calculated and interpreted as follows: 0–40% indicating a high risk of bias, 40–60% suggesting a substantial risk of bias, 60–80% representing a moderate risk of bias, and 80–100% indicating a low risk of bias (24)

* = reporting criteria for estimation of the potential risk of bias

NA = not applicable

NR = not reported

◊ = calculated by the authors of this review based on the presented data in the selected paper

Table 4 Baseline, end and difference outcomes presented by and relative to stain area, stain intensity and a composite stain score

Study	Index	Group	Mean (SD)			
			Baseline	End	Difference	Significant within groups
A. Mean (SD) for the stain index scores regarding stain area (sorted by index). Presented per included study by the group of interest for this review (WDF, RDF)						
Nathoo et al. (2011) [13]	Lobene Stain Index	WDF	1.63 (0.49)♦	0.73 (0.41)♦	− 0.90 (0.31)♦	?
		RDF	1.58 (0.53)♦	0.71 (0.46)♦	− 0.87 (0.27)♦	?
		RDF	1.61 (0.34)♦	1.52 (0.35)♦	− 0.09 (0.16)♦	?
Yin et al. (2010) [14]	Lobene Stain Index	WDF	2.42 (0.48)	1.56 (0.61)	− 0.86 (0.51)♦	YES
		RDF	2.41 (0.47)	1.97 (0.63)	− 0.44 (0.30)♦	YES
		RDF	1.61 (0.50)	1.52 (0.48)	− 0.09	YES
Li et al. (2007) [15]	Lobene Stain Index	WDF	1.15 (0.44)	0.94 (0.20◊)	− 0.20 (0.20◊)	?
		RDF	1.12 (0.42)	1.05 (0.20◊)	− 0.09 (0.20◊)	?
Ayad et al. (2002) [16]	Lobene Stain Index	WDF	1.65 (0.29)	0.67 (0.25)	− 0.98◊	YES
		RDF	1.65 (0.26)	1.35 (0.23)	− 0.30◊	?
Nathoo et al. (2002) [17]	Lobene Stain Index	WDF	1.717 (0.47)	0.858 (0.33)	− 0.859◊	?
		WDF	1.723 (0.60)	1.425 (0.51)	− 0.298◊	?
		RDF	1.726 (0.50)	1.705 (0.46)	− 0.021◊	?
Sielski et al. (2002) [18]	Lobene Stain Index	WDF	0.98 (0.30)	0.37 (0.28)	− 0.61◊	?
		RDF	1.08 (0.35)	0.66 (0.30)	− 0.42◊	?
Singh et al. (2002) [19]	Lobene Stain Index	WDF	1.04 (0.35)	0.43 (0.16)	− 0.61◊	?
		RDF	1.02 (0.28)	0.79 (0.20)	− 0.23◊	?
Ayad et al. (2000) [20]	Lobene Stain Index	WDF	1.04 (0.32)	0.68 (0.23)	− 0.36◊	?
		WDF	0.99 (0.25)	0.77 (0.25)	0.05◊	?
		RDF	0.96 (0.27)	0.99 (0.30)	0.42◊	?
Ayad et al. (1999, JCD) [21]	Lobene Stain Index	WDF	1.34 (0.36)	0.71 (0.13)	− 0.63◊	?
		WDF	1.23 (0.31)	0.95 (0.29)	− 0.28◊	?
		RDF	1.23 (0.33)	1.21 (0.37)	− 0.02◊	?
Mankodi et al. (1999) [23]	Lobene Stain Index	WDF	0.75 (0.25)	0.43 (0.25)	− 0.32◊	?
		RDF	0.73 (0.20)	0.73 (0.23)	0◊	?
Sharma et al. (1999) [24]	Lobene Stain Index	WDF	0.87 (0.36)	0.44 (0.30)	− 0.43◊	?
		WDF	0.86 (0.39)	0.74 (0.37)	− 0.12◊	?
		RDF	0.97 (0.52)	1.05 (0.40)	0.08◊	?

Table 4 (continued)

Study	Index	Group	Mean (SD)			
			Baseline	End	Difference	Significant within groups
Yankell et al. (1999) [25]	Lobene Stain Index	WDF	2.00 (0.49)	2.09 (0.39)	0.09◊	?
		WDF	1.97 (0.42)	2.12 (0.34)	0.15◊	?
		WDF	1.88 (0.37)	2.12 (0.29)	0.24◊	?
		RDF	2.02 (0.44)	2.29 (0.31)	0.27◊	?
		RDF	1.93 (0.28)	1.92 (0.33)	− 0.018 (0.181)♦	YES
		RDF	10.48 (6.05◊)	7.32 (4.26◊)	− 3.15	?
B. Mean (SD) for the stain index scores regarding stain intensity (sorted by index). Presented per included study by the group of interest for this review (WDF, RDF)						
Nathoo et al. (2011) [13]	Lobene Stain Index	WDF	1.12 (0.32)♦	0.59 (0.29)♦	− 0.53 (0.21)♦	?
		WDF	1.03 (0.26)♦	0.52 (0.23)♦	− 0.51 (0.19)♦	?
		RDF	1.07 (0.32)♦	1.04 (0.30)♦	− 0.03 (0.10)♦	?
Yin et al. (2010) [14]	Lobene Stain Index	WDF	2.05 (0.53)	1.24 (0.46)	− 0.81 (0.39)♦	YES
		RDF	2.06 (0.47)	1.51 (0.50)	− 0.55 (0.26)♦	YES
		RDF	1.26 (0.23)	1.22 (0.25)	− 0.04◊	YES
Li et al. (2007) [15]	Lobene Stain Index	WDF	1.28 (0.54)	1.29 (0.20◊)	0.00 (0.20◊)	?
		RDF	1.30 (0.55)	1.32 (0.19◊)	0.02 (0.19◊)	?
Ayad et al. (2002) [16]	Lobene Stain Index	WDF	1.81 (0.36)	0.74 (0.28)	− 1.07◊	YES
		RDF	1.79 (0.34)	1.45 (0.29)	− 0.34◊	?
Nathoo et al. (2002) [17]	Lobene Stain Index	WDF	1.365 (0.43)	0.692 (0.30)	− 0.673◊	?
		WDF	1.347 (0.33)	1.187 (0.43)	− 0.16◊	?
		RDF	1.376 (0.33)	1.275 (0.33)	− 0.101◊	?
Sielski et al. (2002) [18]	Lobene Stain Index	WDF	1.04 (0.35)	0.38 (0.31)	− 0.66◊	?
		RDF	1.09 (0.44)	0.75 (0.35)	− 0.34◊	?
Singh et al. (2002) [19]	Lobene Stain Index	WDF	0.99 (0.40)	0.44 (0.17)	− 0.55◊	?
		RDF	0.98 (0.33)	0.79 (0.23)	− 0.19◊	?
Ayad et al. (2000) [20]	Lobene Stain Index	WDF	1.43 (0.44)	0.95 (0.35)	− 0.48◊	?
		WDF	1.36 (0.33)	1.04 (0.37)	− 0.32◊	?
		RDF	1.39 (0.33)	1.38 (0.40)	− 0.01◊	?
Ayad et al. (1999, JCD) [21]	Lobene Stain Index	WDF	1.62 (0.34)	0.79 (0.17)	− 0.83◊	?
		WDF	1.64 (0.34)	1.21 (0.37)	− 0.43◊	?
		RDF	1.59 (0.34)	1.49 (0.42)	− 0.10◊	?

Table 4 (continued)

Study	Index	Group	Mean (SD)			
			Baseline	End	Difference	Significant within groups
Mankodi et al. (1999) [23]	Lobene Stain Index	WDF	0.90 (0.30)	0.46 (0.28)	− 0.44◊	?
		RDF	0.88 (0.26)	0.78 (0.36)	− 0.10◊	?
Sharma et al. (1999) [24]	Lobene Stain Index	WDF	0.82 (0.39)	0.39 (0.26)	− 0.43◊	?
		WDF	0.84 (0.38)	0.71 (0.38)	− 0.13◊	?
		RDF	0.88 (0.43)	1.00 (0.47)	0.12◊	?
Yankell et al. (1999) [25]	Lobene Stain Index	WDF	1.12 (0.43)	0.98 (0.23)	− 0.14◊	?
		WDF	1.17 (0.45)	1.05 (0.33)	− 0.12◊	?
		WDF	1.06 (0.38)	1.01 (0.26)	− 0.05◊	?
		RDF	1.15 (0.34)	1.10 (0.25)	− 0.05◊	?
		RDF	0.439 (0.167)♦	0.441 (0.187)♦	− 0.002 (0.147)♦	?
C. Mean (SD) for the stain index scores regarding stain composite score (sorted by index). Presented per included study by the group of interest for this review(WDF, RDF)						
Nathoo et al. (2011) [13]	Lobene Stain Index	WDF	2.41 (0.91)	0.82 (0.62)	− 1.59 (0.60)♦	YES
		WDF	2.19 (0.77)	0.76 (0.52)	− 1.43 (0.47)♦	YES
		RDF	2.28 (0.72)	1.99 (0.76)	− 0.29 (0.48)♦	YES
Li et al. (2007) [15]	Lobene Stain Index	WDF	2.51 (1.30)	2.17 (0.40◊)	− 0.32 (0.40◊)	?
		RDF	2.45 (1.28)	2.34 (0.40◊)	− 0.16 (0.40◊)	?
Ayad et al. (1999, AJD) [21]	Lobene Stain Index	WDF	2.32 (0.78)	0.79 (0.78)	− 1.53◊	?
		WDF	2.24 (0.34)	0.82 (0.30)	− 1.42◊	?
		RDF	2.29 (0.49)	1.12 (0.51)	− 1.17◊	?
		RDF	3.03 (0.79)	3.09 (0.92)	0.056 (0.648)♦	NO
		WDF	?	?	1.07	?
		RDF	?	?	2.05	?

WDF whitening dentifrice

RDF regular dentifrice

◊ calculated by the authors of this review based on the presented data in the selected paper

? unknown/not given

₪ insufficient data presentation

♦ additional data provided by the original authors

Table 5 A summary of the statistical significance levels comparing the effectiveness of a whitening dentifrice to a regular dentifrice in reducing tooth stains, as measured by the stain index scores for area, intensity, and composite score

Study	Intervention	Adjunctive chemical agents?	Area	Intensity	Composite	Comparison
Nathoo et al. (2011) [13]	WDF1	No	□	□	>	RDF
	WDF2	No	□	□	>	
Yin et al. (2010) [14]	WDF	No	>	>	□	RDF
Nathoo et al. (2008) [27]	WDF	No	>	>	□	RDF
Li et al. (2007) [15]	WDF	Yes	>	=	>	RDF
Ayad et al. (2002) [16]	WDF	No	>	>	□	RDF
Nathoo et al. (2002) [17]	WDF1	No	>	>	□	RDF
	WDF2	Yes	>	=	□	
Sielski et al. (2002) [18]	WDF	No	>	>	□	RDF
Singh et al. (2002) [19]	WDF	No	>	>	□	RDF
Ayad et al. (2000) [20]	WDF1	Yes	>	>	□	RDF
	WDF2	Yes	>	>	□	
Ayad et al. (1999, AJD) [21]	WDF1	No	□	□	>	RDF
	WDF2	Yes	□	□	>	
Ayad et al. (1999, JCD) [22]	WDF1	Yes	>	>	□	RDF
	WDF2	Yes	>	>	□	
Mankodi et al. (1999) [23]	WDF	Yes	>	>	□	RDF
Sharma et al. (1999) [24]	WDF1	Yes	>	>	□	RDF
	WDF2	Yes	>	>	□	
Yankell et al. (1999) [25]	WDF1	Yes	>	>	□	RDF
	WDF2	Yes	>	=	□	
	WDF3	Yes	=	=	□	
	WDF2	?	□	□	?	
Overall positive for WDF			17/18 (94.45%)	14/18 (77.78%)	4/4 (100%)	
Overall positive for WDF with adjunctive chemical agents			11/12 (91.67%)	8/12 (66.67%)	2/2 (100%)	
Overall positive for WDF without adjunctive chemical agents			6/6 (100%)	6/6 (100%)	2/2 (100%)	

WDF = Whitening dentifrice,

RDF = Regular dentifrice,

> = significant difference in favor of test group (WDF),

< = significant difference in favor of control group (RDF),

= = no significant difference,

□ = no data available,

? = inconclusive data that does not allow conclusions concerning statistical significance between groups

Analysis of the end score

The asymmetry in the funnel plot shows the possibility of publication bias or heterogeneity in the research findings. The points exhibit a certain level of asymmetry and are distributed unequally, suggesting the presence of bias. A horizontal line shows each research in the forest plot, while the diamond summarizes the overall impact magnitude. The mean differences constantly exhibit negative values, and the total effect size (shown by a diamond) indicates a mean difference of around − 0.37. These findings suggest that whitening toothpaste effectively lowers the staining on the surface of teeth. The heterogeneity index (I^2) of 91% indicates a significant level of diversity across the studies. The sensitivity analysis plot illustrates the fluctuations in means and standard deviations across multiple settings, namely whitening and regular conditions. The presence of comparable patterns and error bars in all subplots indicates the reliability of the results. Furthermore, the steady rises in values demonstrate the durability of the findings across numerous changes.

Whitening dentifrices consistently demonstrated superior efficacy in reducing tooth surface discoloration

compared to regular dentifrices. The presence of adjunctive chemical agents in some WDF formulations enhanced their effectiveness, although WDFs without these agents also performed significantly better than RDFs. The results highlight the importance of formulation in the efficacy of whitening products and provide robust evidence supporting the use of WDFs for managing extrinsic tooth stains.

Discussion

This review aimed to evaluate the impact of these dentifrices on the lobe stain index. Fourteen studies, including 22 comparative analyses, were selected for inclusion. A descriptive summary of statistical significance from the studies indicated that whitening dentifrices outperformed regular dentifrices in at least 77.78% of the comparisons. Meta-analysis revealed that the mean difference in final scores was significant for stain area, intensity, and composite scores. These results align with conclusions from earlier narrative reviews by Davies et al. [29], Van Loveren & Duckworth [30], and Joiner [31].

The meta-analysis showed substantial heterogeneity in the end scores (I2 = 91%), while heterogeneity for baseline scores was minimal (I2 = 0%). The low heterogeneity at baseline suggests that the groups were well-matched at the beginning of the studies. The high I2 value in the end scores likely reflects clinical or methodological differences—or both—among the studies, which is expected [32]. Since all studies used a parallel design, no clear methodological cause for this heterogeneity was identified.

The challenge lies in determining the best approach to analyze studies with high heterogeneity. The Cochrane Handbook offers several strategies for this [32]. One recommended approach is a random-effects meta-analysis, which assumes that study outcomes follow a normal distribution across different studies.

This method does not replace a comprehensive examination of heterogeneity; it is mainly intended for cases where heterogeneity remains unexplained. A large dataset is required for this approach, as was available in this review. However, when heterogeneity tests show significance, readers should interpret the difference with caution, as it may not accurately represent the effect within any specific population studied [33].

In this review, the meta-analyses for composite scores of stain area were divided based on whether the studies applied the original Lobene Stain Index [34]. Results for stain area between these two indices were not merged due to the use of different cut-off points.

Efficacy of whitening dentifrices

The findings of this comprehensive investigation and synthesis confirm the effectiveness of toothpaste specifically designed for whitening teeth in decreasing the discoloration of tooth surfaces. When comparing conventional dentifrices (RDFs) to WDFs, most studies found that WDFs considerably reduced both the size and strength of tooth stains. More precisely, 94.45% of the studies indicated that WDFs had a beneficial impact on lowering the area of stains, 77.78% on reducing the severity of stains, and 100% on improving composite stain ratings. These results are consistent with earlier research that suggests that WDFs may efficiently control extrinsic stains by using abrasive agents that physically eliminate surface stains.

Adjunctive chemical agents

Using additional chemical agents in some WDF formulations significantly improved their ability to remove stains. For example, research has shown that WDFs, including compounds such as triclosan, PVM/MA copolymer, and hexametaphosphate, demonstrated better outcomes in 91.67% of cases for stain area, 66.67% for stain intensity, and 100% for composite scores. This indicates that while the abrasive nature of WDFs is essential, using chemical agents may provide an additional advantage, most likely via chemical reactions that dissolve stains or hinder their attachment to tooth surfaces.

Meta-analysis and statistical considerations

The meta-analysis findings showed that WDFs outperformed RDFs regarding stain area and composite scores, with statistically significant gains. 94.45% of the investigations showed a noteworthy improvement in reducing the stained area, while 77.78% of the studies showed a substantial decrease in stain intensity. The composite stain ratings showed considerable improvement in all relevant investigations. The results were constant even after doing sensitivity analysis, which verified that the conclusions were not too reliant on any one research.

Implications for clinical practice

These results have significant ramifications for clinical practice. Dentists may suggest WDFs as the primary choice for patients who want to address external tooth discoloration, especially those searching for a convenient and affordable treatment. When choosing products for patients with difficult stains, it is essential to consider the improved effectiveness of WDFs when used with other chemical agents.

Limitations

Although the results are favorable, it is essential to recognize some constraints. There is significant variation within studies, indicating the necessity for more standardized research to separate and identify the effects of

specific WDF formulations. Furthermore, it is necessary to perform long-term studies to evaluate the continued effectiveness and safety of WDFs. Further research should also examine the influence of WDFs on inherent and internalized discolorations to comprehend their overall effectiveness fully.

All of the research included in this review assesses negative consequences, although none indicate that these consequences were really seen. Nevertheless, tooth brutal tissue erosion assessment was not included as a criterion. When there is too much abrasion, the teeth' enamel and dentin might be damaged. This balances how well something cleans and how much it wears down the teeth. Oral care product makers have precisely adjusted the amount of abrasives in their products to cater to the particular requirements of consumers in terms of teeth whitening effectiveness and speed while also controlling the potential damage to dental hard tissues caused by the abrasives. This element requires more assessment in an"in vivo"setting.

Suggestions for future research

Subsequent investigations on the impact of whitening toothpastes should prioritize examining their long-term effectiveness and safety, particularly regarding enamel degradation and dentine sensitivity. Implementing standardized research methodologies and assessment techniques will improve the comparability and reliability of findings across different investigations. Examining the influence of WDFs on inherent and ingrained discolorations and evaluating their effectiveness compared to other teeth whitening techniques will provide a thorough comprehension of their advantages. Detailed investigations into the abrasiveness of various formulations are required to find the right balance between effective cleaning and the risk of tooth damage. To enhance product formulations and suggestions, it is crucial to focus on patient-centered outcomes, conduct subgroup analysis, and research individual constituents. Ultimately, the safe and successful use of WDFs in cosmetic dentistry may be achieved by verifying laboratory results via clinical trials and diligently monitoring any adverse effects.

Conclusion

In conclusion, this systematic review and meta-analysis prove that whitening dentifrices effectively reduces tooth surface discoloration. WDFs outperform regular dentifrices in managing extrinsic stains with and without adjunctive chemical agents. These findings support using WDFs as a practical and effective solution for tooth whitening in everyday dental care.

Abbreviations

WDF	Whitening dentifrice
RDF	Regular dentifrices
RCT	Randomized controlled trial
MeSH	Medical Subject Headings
MD	Mean Difference
CI	Confidence intervals
RD	`Risk difference

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Authors' contributions

S.H.S: Conceptualization, Methodology, Writing—Original Draft, M.Kh: Data Curation, Formal Analysis, Writing—Review & Editing, M.Y: Investigation, Resources, Supervision, E.K: Project Administration, Funding Acquisition, Writing—Review & Editing.

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