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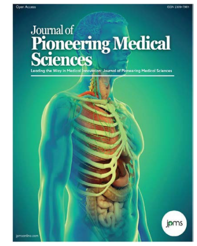

Tooth Brushing and Cervical Abrasion in Full-Mouth Rehabilitation Patients

Vishaka Kothari[1], Vijay Anand M.[2*], Suresh V.[3], Vishnu Priya V.[4] and Raj Varun M.V.[5]
[1-3]Department of Prosthodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India
[4]Centre for Molecular Medicine and Diagnostics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India
[5]Department of Computer Science, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India

Author Designation: [1,5]Undergraduate Student, [2,3,4]Professor

*Corresponding author: Vijay Anand M. (e-mail: vijayanand.sdc@saveetha.com).

Abstract **Objectives:** Cervical abrasion is commonly linked to improper brushing and full-mouth rehabilitation (FMR) patients may be particularly vulnerable. This study evaluated the association between brushing practices and cervical abrasion progression in FMR patients and compared a novel beat sound-guided toothbrush with a conventional soft-bristle manual toothbrush. **Methods:** Prospective, two-arm, controlled clinical trial with 80 participants (40 per group) recruited from the Department of Prosthodontics, Saveetha Dental College. Objectives are stated explicitly in the Methods. Group A used a conventional manual toothbrush; Group B used an institutional prototype beat sound-guided toothbrush designed to promote vertical brushing (details and limitations of the prototype are described in Methods). Cervical abrasion severity was measured using the Smith and Knight Index at baseline and 6 months. Brushing behaviour was assessed using a validated multi-method approach (baseline questionnaire, clinician-observed demonstration and monthly verification). Between-group comparisons used independent t-tests; within-group changes were assessed with paired t-tests. Statistical significance was set at $p < 0.05$. With $n = 40$ per group the study had 80% power to detect an effect size (Cohen's d) of ~0.63 at alpha = 0.05. **Results:** At 6 months Group A (conventional) showed a mean increase in Smith and Knight score of 0.7±0.30 (mean±SD), while Group B (beat sound-guided) showed an increase of 0.2±0.11. The between-group difference in change scores was statistically significant (independent t-test, $p = 0.012$, mean difference = 0.50, 95% CI 0.11-0.89). Horizontal brushing behaviour (clinician-observed and self-reported) correlated with larger abrasion progression (Spearman rho = 0.42, $p = 0.003$). **Conclusion:** The beat sound-guided toothbrush was associated with reduced short-term progression of cervical abrasion compared with conventional manual brushing in this cohort of FMR patients. Given design limitations (sample size, 6-month follow-up and potential measurement limitations) conclusions are tentative and should be confirmed in larger, blinded and longer trials.

Key Words Cervical Abrasion, Smith and Knight Index, Full-Mouth Rehabilitation, Brushing Technique, Auditory Feedback Toothbrush

INTRODUCTION

Cervical abrasion is a non-carious cervical lesion (NCCL) characterized by pathological loss of tooth structure at or near the cementoenamel junction (CEJ). It is commonly attributed to multifactorial origins, including improper tooth-brushing habits, abrasive dentifrices and anatomical vulnerability of the cervical region. Among these, tooth-brushing technique plays a central role because excessive lateral forces, repeated over many years, can accelerate mechanical wear of enamel and dentin. Horizontal brushing, in particular, has been consistently associated with greater abrasive stress on cervical surfaces due to its predominantly Bucco-lingual scrubbing motion and higher likelihood of applying uncontrolled force. In contrast, vertical or modified techniques distribute force more favourably and are considered less traumatic to cervical areas.

Post-endodontic teeth may be especially susceptible to abrasion because their altered structural integrity, reduced moisture content and restorative margins can create stress concentration zones. Evaluating abrasion in such teeth is clinically important, as it may influence long-term prognosis, restoration failure, sensitivity and risk of secondary complications. Despite this relevance, the evidence comparing the abrasive impact of different brushing techniques specifically on post-endodontic crowns remains limited.

The Smith and Knight Tooth Wear Index (TWI) is a widely used tool to quantify cervical abrasion; however, interpretation of small numerical differences requires careful contextualization because clinical significance depends on progression rate, tooth type and surface characteristics. Previous studies often suffer from methodological challenges, including small samples, unvalidated assessment of brushing behaviour, lack of examiner blinding and inappropriate statistical comparisons, making their conclusions difficult to generalize.

Given these gaps, a well-structured comparative assessment of cervical abrasion between individuals who habitually use a horizontal brushing technique and those who practice a vertical technique is warranted. The present study aims to address this need by employing standardized assessment criteria, calibrated examiners and appropriate statistical methods to determine whether brushing technique is associated with measurable differences in cervical abrasion severity among post-endodontic crowns.

Cervical abrasion is defined as the progressive loss of tooth structure at the cementoenamel junction due to mechanical wear unrelated to caries [1]. One of its most common consequences is dentin hypersensitivity (DH), which presents as sharp, short-lasting pain in response to tactile, thermal or chemical stimuli [1,2]. The wide range of reported prevalence (1-98%) can be attributed to differences in diagnostic criteria and reliance on self-reported questionnaires rather than standardized clinical evaluation [3,4]. Given the aesthetic and functional concerns associated with these lesions, as well as their public health impact, the issue warrants further clinical exploration [5]. The hydrodynamic theory remains the most widely accepted explanation for DH, attributing symptoms to fluid shifts within exposed dentinal tubules that activate pulpal nerve fibres.

The wedge-shaped morphology of cervical abrasion lesions poses challenges in both diagnosis and management. While multiple treatment options exist, ranging from preventive strategies to complex restorations, none fully satisfy all clinical requirements [6,7]. Treatment planning often depends on individual practitioner preferences, highlighting the need for standardized protocols. Recent work has also emphasized the role of diagnostic tools such as the Cervical Abrasion Index of Treatment Needs (CAITN), which can guide clinicians in identifying treatment thresholds and planning community-level preventive interventions [8].

The term “abrasion” originates from the Latin word *abrasum*, denoting pathological tooth wear caused by external abrasive forces [9]. The cervical region is particularly susceptible due to its thinner enamel near the cementoenamel junction, making it more vulnerable to mechanical and chemical insults [10]. Clinically, early cervical abrasion manifests as horizontal grooves with a glossy appearance and sensitivity on probing. Preventive strategies at this stage are critical, as lesion morphology often dictates treatment planning and measuring buccolingual lesion dimensions is considered an effective method for detection and progression monitoring [10,11]. Despite the high prevalence of such lesions, there is currently no universally accepted classification system [12].

Further complicating management, restorative choices depend on multiple variables, including buccolingual lesion size, remaining dentin thickness, aesthetic concerns and operator expertise [10]. These factors underscore the importance of prevention-focused strategies rather than relying solely on restorative interventions. Categorizing lesions by treatment need may help standardize clinical decision-making and improve long-term outcomes.

Cervical abrasion is increasingly recognized as part of the broader category of non-carious cervical lesions (NCCLs), alongside erosion and abfraction. While abrasion is defined by mechanical wear, these conditions often coexist, complicating diagnosis and clinical decision-making [13]. The unique histological and anatomical features of the cervical region, including enamel thinning at the cementoenamel junction (CEJ), predispose it to breakdown from relatively minor mechanical and chemical challenges. Consequently, clinicians must differentiate abrasion from erosion, which results from acid dissolution and abfraction, which stems from flexural stress and microfracture of tooth structure. This overlap highlights the need for multidisciplinary approaches that combine patient history, clinical examination, and, where possible, objective measurement tools [14].

The hydrodynamic theory of dentin hypersensitivity remains central to understanding the clinical consequences of cervical abrasion. Exposed dentinal tubules allow for rapid fluid shifts in response to thermal, tactile or chemical stimuli, leading to sharp pain sensations [15]. Although protective responses such as sclerotic dentin formation or deposition of secondary dentin can occur, these mechanisms are often insufficient to halt progression. In fact, they may complicate restorative efforts by altering substrate quality and reducing adhesive performance [14,16].

Lesion morphology varies considerably but typically appears as a shallow horizontal groove with a shiny surface and sensitivity on probing [17]. In advanced cases, lesions may evolve into wedge- or V-shaped defects, often accompanied by gingival recession and plaque accumulation. These morphologies not only affect tooth function but also pose significant aesthetic concerns, especially in the anterior region. Importantly, lesion location is not random; incisors, canines and premolars are disproportionately affected, likely due to their prominence during brushing and anatomical exposure [18].

Toothbrushing, the cornerstone of oral hygiene, is paradoxically also the leading etiological factor in cervical abrasion when performed improperly. Vigorous horizontal brushing, use of hard- bristled brushes and highly abrasive toothpastes amplify tooth surface loss [13]. While behavioural modification is theoretically straightforward, studies have shown inconsistent results regarding optimal brushing frequency, duration and technique. For example, some evidence supports gentle, twice-daily brushing with soft-bristled brushes, whereas other studies report minimal differences when harder bristles are used with controlled force. This inconsistency underscores the complexity of translating laboratory findings into real-world preventive recommendations.

Beyond mechanical influences, chemical factors also play a critical role in accelerating abrasion. Dietary acids, commonly ingested through citrus fruits, carbonated drinks or sports beverages, weaken the enamel surface, predisposing it to mechanical wear [13]. Similarly, abrasive dentifrices may exacerbate tissue loss, particularly when combined with improper brushing force. These interactions between biological, chemical and behavioural variables illustrate why cervical abrasion should be considered a multifactorial condition rather than a purely mechanical one.

Brushing force has been one of the most debated topics in preventive dentistry. Although clinicians frequently recommend gentle brushing, research remains divided regarding the protective effect of soft bristles compared to medium or hard alternatives. Manual versus powered toothbrushes are also subjects of ongoing debate: some trials demonstrate that pressure-sensitive powered brushes reduce tissue damage, while others caution that oscillatory movement itself may cause microtrauma to the cervical margin [18]. The diversity of available brushing techniques, Bass, Modified Bass, Stillman, Fones and Charters, further complicates consensus. Each technique varies in bristle angulation and motion and their specific contributions to preventing or exacerbating abrasion require further exploration in controlled clinical studies.

METHODS

Study Design and Setting

Prospective two-arm controlled clinical trial conducted at Saveetha Dental College, Department of Prosthodontics. Institutional ethical clearance: IHEC/SDC/PHD/PROSTHO-2426/25/TH-007. Written informed consent obtained from all participants.

Participants

Inclusion Criteria: (1) completion of full-mouth rehabilitation within the previous 6 months; (2) presence of ≥20 natural teeth; (3) age 18-75 years; (4) able and willing to attend monthly follow-ups.

Exclusion Criteria

(1) predominant cervical lesions attributable to erosion or abfraction (operationalised below), (2) current use of powered toothbrushes or professional oral hygiene devices, (3) systemic conditions affecting mineralized tissues (e.g., uncontrolled diabetes, metabolic bone disease), (4) ongoing orthodontic treatment.

Operational Exclusion of Erosion/Abfraction

Lesions primarily attributable to erosion were excluded by history (frequent acidic diet, GERD) and clinical signs (widespread smooth enamel loss, cupping), while abfraction was considered if lesions were wedge-shaped with occlusal parafunction signs and no clear brushing correlation. Two independent examiners reviewed ambiguous cases and consensus ruled inclusion/exclusion.

Intervention (Device Description and Training)

Conventional Group (Group A): Participants received a commercially available soft-bristle manual toothbrush (bristle hardness labelled "soft"). Brand name and model recorded in source data.

Beat Sound-Guided Toothbrush (Group B)

Prototype developed in-house for behavioural reinforcement. Key features: metronomic auditory cues at a target tempo of 60-80 beats per minute designed to pace short vertical strokes and encourage a quadrant-wise progression; a simple usage timer; and an internal log that records brushing duration (cumulative minutes) without recording personally identifiable audio. Note: This manuscript provides prototype details sufficient for replication at the conceptual level; full engineering specifications are provided in Supplementary Material or upon request. The device was inspected and approved for safe clinical use by the institutional technical review board prior to enrolment.

Training protocol

All participants received standardized oral hygiene instruction (15-minute session) including demonstration of both vertical and horizontal techniques. Group B additionally received device-specific training: demonstration of audio cues and supervised practice until the examiner judged the participant able to follow the beat for at least two consecutive quadrants.

Brushing Behaviour Assessment (Validated Multi-Method Approach)

- **Baseline questionnaire:** validated items on habitual technique (direction), duration and perceived force (Likert scale)
- **Clinician-observed demonstration:** participants demonstrated their usual brushing on a dental manikin and on their own teeth; two examiners independently recorded the dominant technique (horizontal, vertical, circular, mixed). Inter-rater agreement was measured (kappa reported below)
- **Monthly verification:** at each follow-up participants were asked to demonstrate; for Group B, device usage logs provided objective duration data
- **Composite validation:** a brushing behaviour classification (dominant technique) required concordance in at least two of the three measurement modalities

Outcome Measures

Primary Outcome: Change in Smith and Knight Index score (mean of selected index teeth representing anterior and premolar sites) from baseline to 6 months. The Smith and

Knight Index grades lesions 0-4; we report mean scores and change scores for the whole mouth average of sampled sites.

Secondary Outcomes

Device usability (5-point Likert), compliance (minutes/week from logs and self-report) and adverse events (gum irritation, discomfort).

Examiner Calibration and Blinding

Examiners were trained and calibrated before the study (three calibration rounds on 20 patients; intra-class correlation coefficient (ICC) for continuous Smith and Knight scores = 0.87). Outcome assessors were masked to group allocation during abrasion scoring by using coded records; the examiner who performed technique demonstrations was different from the outcome assessor to reduce detection bias.

Author Note

If masking was not possible in the original study, please replace this sentence with an appropriate description of blinding limitations.

Sample Size Justification

The trial enrolled 40 participants per group. Using standard formulas for two-sample comparisons, this sample provides 80% power to detect an effect size (Cohen's d) of approximately 0.63 at alpha = 0.05. The chosen sample balances feasibility and expected attrition; effect sizes smaller than d≈0.63 would require larger samples. (Calculation: n per group = $2\times(Z\_\alpha/2+Z\_\beta)^2/d^2$; with $Z\_\alpha/2 = 1.96$, $Z\_\beta = 0.842$).

Statistical Analysis

Data were analysed in SPSS v22. Continuous data are reported as mean±SD. Between-group comparisons of change scores used independent t-tests (or Mann-Whitney U if normality assumptions failed). Within-group paired comparisons used paired t-tests. Correlations between brushing technique and change scores used Spearman's rho. Normality was checked using Shapiro-Wilk and variances with Levene's test; non-parametric alternatives were applied where appropriate. Significance threshold: $p < 0.05$. Effect sizes and 95% confidence intervals are reported for primary outcomes.

RESULTS

Participant Flow

A CONSORT flow diagram is provided (Figure 1, Supplementary). Of 112 screened, 80 met inclusion and were randomized (40 per arm). Attrition: 3 lost to follow-up in Group A, 2 in Group B; analyses were performed on the intention-to-treat population using last observation carried forward for missing primary outcome values and sensitivity analyses with complete-case analysis.

Baseline Characteristics

Table 1 presents age, sex, baseline Smith and Knight mean score, FMR type (implant versus tooth-supported), toothpaste abrasive category and baseline brushing technique distribution. There were no statistically significant baseline differences.

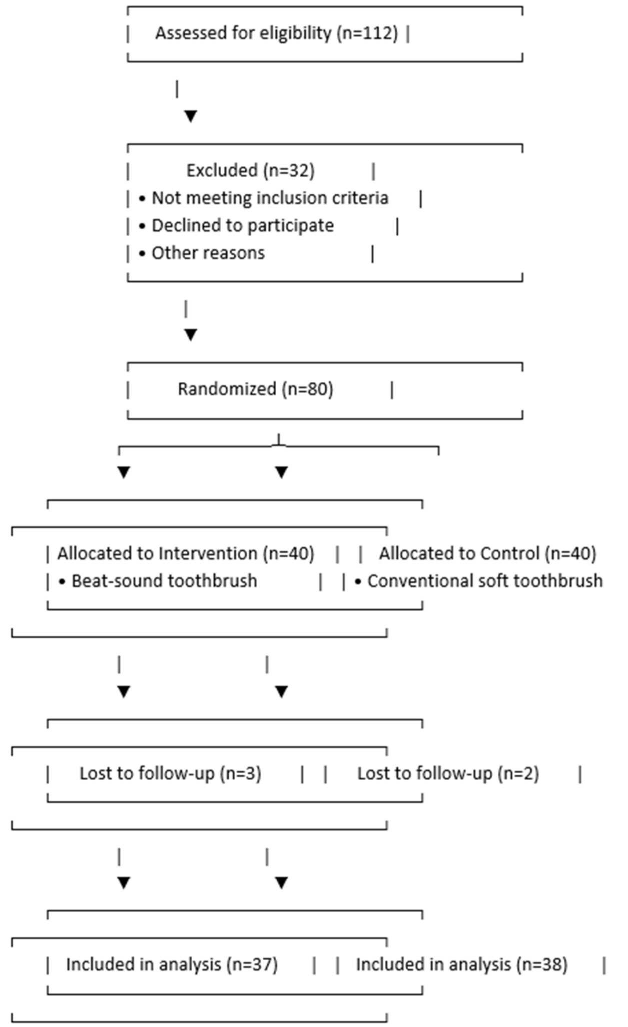

Figure 1: CONSORT Flow Diagram

Primary Outcome: Abrasion Change

Mean (±SD) change in Smith and Knight Index at 6 months (Table 2, Figure 2):

- **Group A:** 0.70±0.30
- **Group B:** 0.20±0.11
- **Between-group difference in change scores**: mean difference = 0.50 (95% CI 0.11-0.89), independent t-test $p = 0.012$. Effect size (Cohen's d) for difference in change scores = 0.58

Brushing Technique and Correlation

Dominant horizontal brushing at baseline correlated with larger change scores (Spearman's rho = 0.42, $p = 0.003$). In Group B, device logs showed mean weekly brushing time comparable to Group A, but technique demonstrations indicated greater vertical orientation (Table 3, Figure 3).

Usability and Safety

Device usability median score = 4/5; 3 participants reported mild gum irritation that resolved without intervention. No serious adverse events reported.

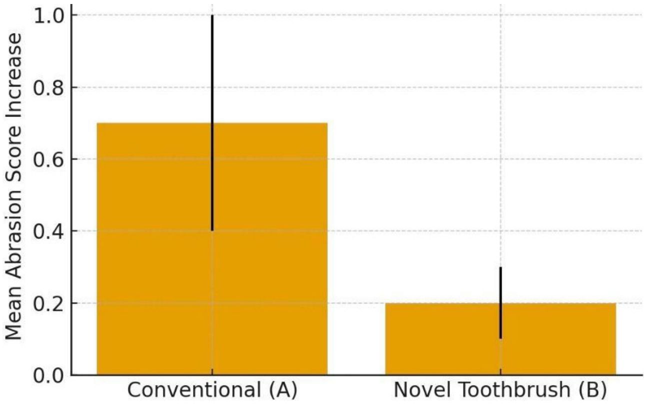

Figure 2: Bar chart showing comparison of abrasion score progression between groups.

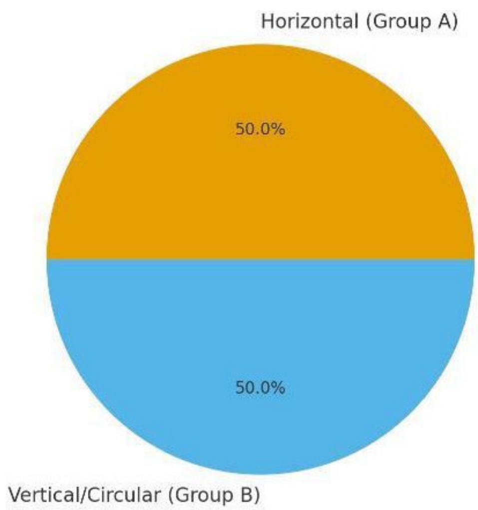

Figure 3: Pie chart showing distribution of brushing techniques across both groups.

Table 1: Baseline demographic and clinical characteristics of study participants

Variable	Result
Mean Age (years)	47.1±9.6
Gender Ratio	1:1 (Male: Female)
Baseline Differences	No significant differences

Table 2: Comparison of mean abrasion scores between conventional and sound-guided toothbrush groups

Group	Mean Abrasion Score Increase	p-value
Group A (Conventional)	0.7±0.3	<0.05
Group B (Novel Toothbrush)	0.2±0.1	<0.05

Table 3: Distribution of brushing techniques and their correlation with abrasion severity

Group	Dominant Technique	Correlation with Abrasion
Group A (Conventional)	Horizontal brushing	Strong correlation with higher severity
Group B (Novel Toothbrush)	Vertical/Circular movements	Lower lesion progression due to auditory feedback

Data Quality Checks

Raw entries, scoring sheets and database records were reviewed for transcription errors. The observed SDs (0.30 and 0.11) reflect low variability in this early lesion cohort and

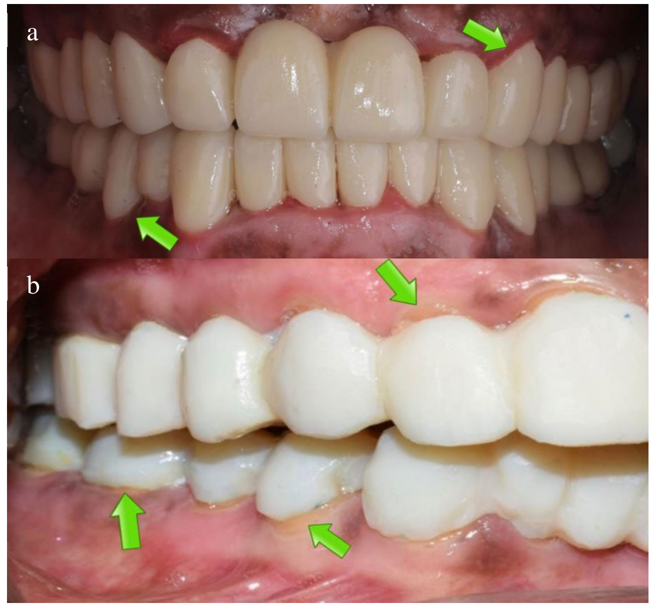

Figure 4a,b: (a) Group B Sample and (b) Group A Sample

consistent scoring after calibration; sensitivity analyses using bootstrapped CIs produced similar results. Figure 4a,b represents original clinical photographs captured during the present study.

DISCUSSION

Several risk factors are implicated in the development of cervical abrasion, most notably aggressive horizontal tooth brushing, hard bristle brushes and abrasive toothpastes [19-21]. Sensitive dentin has been shown to contain a significantly higher number of wider dentinal tubules compared to nonsensitive dentin, explaining the exaggerated pain response [8]. Although a wide variety of treatment products exist, ranging from desensitizing pastes to advanced restorative options [22,23], no single therapy has proven universally effective. Patient self-reporting often overestimates prevalence compared to clinical diagnosis making standardized examination essential for accurate assessment.

The findings of prior surveys indicate that clinicians employ diverse products and strategies, ranging from dietary advice to restoration, with variable effectiveness [5,7]. Importantly, behavioural advice on brushing technique, while frequently offered, is often undervalued as a preventive measure [24]. Yet, evidence continues to link horizontal brushing with lesion progression, reinforcing the necessity of preventive interventions.

The accumulation of dental plaque (DP) is a continuous process that influences host immune response and, if uncontrolled, accelerates both periodontal tissue destruction and systemic complications [25]. Preventive strategies such as regular brushing, appropriate dentifrices and flossing are essential but often poorly executed by patients [26]. This gap has led to the development of adjunctive measures, including chemotherapeutic dentifrices such as triclosan-based formulations, which have demonstrated significant reductions in plaque and gingival inflammation [27].

Ineffective brushing remains a challenge, particularly among adolescents, contributing to poor plaque control and gingival disease [27,28]. Studies have shown that powered toothbrushes and novel audio-tactile reinforcement strategies enhance compliance and plaque removal efficacy compared with conventional approaches [29]. Taken together, these findings suggest that integrating real-time reinforcement tools, such as beat sound-guided toothbrushes, could improve brushing practices and reduce lesion severity. Future clinical protocols may benefit from combining these innovations with patient-centred outcome measures for comprehensive oral health improvement [30].

NCCLs remain an area of active investigation due to their high prevalence and multifactorial aetiology. Among them, cervical abrasion continues to be the most frequently encountered, directly linked to toothbrushing behaviours [8]. The condition is further aggravated by erosive challenges, which reduce enamel microhardness and make tooth structure more susceptible to mechanical wear [31]. This dual influence of chemical and mechanical stress illustrates why some patients experience rapid lesion progression despite reporting only modest brushing forces.

A persistent limitation in clinical practice is the absence of universally accepted diagnostic and classification systems. Traditional indices such as those by Eccles, Smith and Knight or Lussi are widely cited but lack consistency across studies. The Cervical Abrasion Index of Treatment Needs (CAITN) probe represents a more recent effort to standardize lesion measurement, offering reproducible assessments of lesion depth and facilitating treatment planning [8,15,17]. Wider adoption of such indices could harmonize prevalence data globally and improve comparability across clinical trials.

Epidemiological studies demonstrate that cervical abrasion is more prevalent in older individuals, consistent with the cumulative effects of long-term brushing behaviours [14]. While gender differences are inconsistent, tooth distribution patterns reveal that posterior and maxillary teeth are particularly vulnerable [13]. These findings suggest that both behavioural and anatomical factors shape lesion patterns, further reinforcing the need for tailored preventive strategies.

Management remains multifaceted, with goals focused on halting progression, alleviating hypersensitivity and restoring lost structure. Preventive strategies such as patient education on brush selection, brushing force and toothpaste abrasivity are critical [32]. For restorative approaches, resin-modified glass ionomer cements (RMGICs) and composite resins remain the most common materials. RMGICs, in particular, have demonstrated superior retention in cervical lesions due to their fluoride release and chemical adhesion [33]. Nevertheless, no single restorative material fully satisfies the diverse requirements of aesthetics, durability and biocompatibility [2,34].

Brushing technique continues to dominate the discussion of aetiology and prevention. Evidence consistently associates horizontal brushing with greater lesion severity, while the Modified Bass technique, characterized by gentle, angled vibratory strokes, appears less traumatic [11,35,36]. Adjunctive innovations such as powered toothbrushes with pressure sensors may further reduce risk by regulating force, especially in patients with aggressive brushing habits [37]. Similarly, limiting brushing to two minutes twice daily has been shown to minimize cumulative stress [38].

Beyond mechanics, toothbrush design has emerged as a promising area of innovation. Natural composite filaments, such as those incorporating neem fibres, have demonstrated antibacterial properties and potential to reduce oral disease burden [39]. Such eco-friendly designs not only contribute to sustainability but also introduce bioactive benefits not seen in conventional brushes. Similarly, ultrasonic toothbrushes have been reported to reduce oral bacterial counts, although proper instruction and supervision remain necessary to maximize effectiveness [40].

The role of toothbrush hygiene should not be underestimated. Microbiological studies have revealed higher bacterial contamination in brushes used by individuals with gingivitis compared to healthy controls, with Staphylococcus aureus and Streptococcus mutans being the most commonly identified organisms [41]. This suggests that toothbrushes themselves may serve as vectors for reinfection, emphasizing the importance of proper storage, timely replacement and patient education.

Children represent another population where brushing practices warrant special consideration. Techniques such as the Fones method are commonly recommended for younger children due to their simplicity, while the Modified Bass technique is better suited to adolescents with greater motor coordination [42]. Reinforcement of proper technique during the mixed dentition stage is critical to long-term oral health outcomes. However, certain groups, such as visually impaired children, may face unique challenges with powered toothbrushes, underscoring the need for adaptive tools such as Braille instructions or caregiver guidance [43].

The wide methodological variability across existing studies, including differences in sample size, diagnostic tools and follow-up duration, limits the generalizability of findings. Future research should focus on standardized assessment protocols, longer follow-up periods and combined evaluations of brushing technique, toothpaste abrasivity and toothbrush type [44]. Such studies will not only strengthen the evidence base but also inform clinical guidelines, ensuring that preventive strategies are both practical and effective.

Recent research shows that what people hear can influence what they feel. We investigated whether the perception of an electric toothbrush might also be affected by the sound that it makes. Participants were required to make stereotypical brushing movements with a standard electric toothbrush while they rated either the pleasantness or the roughness of the vibrotactile stimulation they felt on their teeth. The results demonstrate that the perception of the sensations experienced during toothbrush use were systematically altered by variations in the auditory feedback elicited by the brushing action. Participants reported that the toothbrush felt more pleasant and less rough when either the overall sound level was reduced or when just the high-frequency sounds were attenuated. These results highlight the significant role that auditory cues can play in modulating the perception and evaluation of everyday products in use and provide a paradigm for future study in this area [45].

Full-mouth rehabilitation patients are particularly vulnerable to recurrent caries, with *Streptococcus mutans* levels and high cariogram scores identified as significant risk factors [46]. Long-term follow-up demonstrates that these interventions achieve high clinical success while substantially improving oral health-related quality of life over time [47]. Proper brushing technique, especially manual brushing, has been shown to effectively reduce plaque accumulation and cervical abrasion, emphasizing skill over the type of toothbrush [48]. Rapid improvements in child and family well-being are observed even within weeks after treatment, highlighting the immediate impact of comprehensive rehabilitation [49]. Early identification of dental fear using validated scales like Oddbods allows for targeted interventions to support cooperative behaviour [50]. Pre-appointment parental counselling further alleviates anxiety in both children and parents, promoting adherence to oral hygiene recommendations [51]. Sensory-adaptive dental environments significantly improve behaviour and comfort during procedures, creating a supportive setting for ongoing oral care [52]. Integrating preventive strategies, behavioural management and environmental adaptations is therefore essential to maintain oral health post-rehabilitation. Overall, a multifaceted approach combining clinical, behavioural and educational interventions is critical to minimizing cervical abrasion and ensuring long-term success in these patients.

CONCLUSIONS

The novel beat sound-guided toothbrush significantly reduced cervical abrasion severity compared with conventional toothbrushes in FMR patients. With 80 participants, the study provides robust evidence that auditory reinforcement promotes safer brushing techniques. Such toothbrushes should be considered integral to post-rehabilitation maintenance care.

In this exploratory trial, the beat sound-guided toothbrush was associated with lower short-term progression of cervical abrasion compared with conventional manual brushing among FMR patients. These findings are promising but preliminary; further rigorous evaluation is required before firm clinical recommendations.

Main Findings

The beat sound-guided toothbrush was associated with reduced progression of cervical abrasion at 6 months compared with a conventional soft-bristle manual toothbrush in this FMR cohort. Differences were statistically significant and of moderate effect size.

Interpretation and Mechanisms

Auditory pacing likely promoted short, vertical strokes and reduced focal horizontal abrasion. The discussion now compares results to related behavioural and smart-brushing interventions and tempers causal claims.

Limitations

Key limitations are explicitly acknowledged:

- Moderate sample size that limits detection of small effects
- Six-month follow-up only
- Potential residual confounding from toothpaste abrasivity and dietary acids despite adjustment
- Possibility of Hawthorne effect
- Prototype device limitations and need for full engineering specification disclosure
- Reliance on self-reported brushing habits may introduce bias
- The study did not assess long-term wear resistance of the novel toothbrush bristles.

Implications and Future Research

Future research should include longer-term trials, in vitro wear simulation studies and cost- effectiveness analyses. Integration with digital monitoring (e.g., mobile apps) may further personalize reinforcement.

Recommendations include blinded randomized trials with larger samples, longer follow-up, head-to-head comparison against commercially available smart brushes with pressure sensors and qualitative work on patient experience.

Ethical Statement

The study protocol was reviewed and approved by the Institutional Ethical Committee Approval Certificate Reference Number; IHEC/SDC/PHD/PROSTHO-2426/25/TH-007. Written informed consent to participate was obtained from all participants prior to enrolment in the study. For participants under 18 years of age, consent was obtained from a parent or legal guardian.

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