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CLINICAL RESEARCH

Three-dimensionally printed, noninvasive restorations in the treatment of localized tooth wear using the Dahl approach: A preliminary clinical trial

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ABSTRACT

Statement of problem. Localized tooth wear compromises function and esthetics, while conventional restorative options often require invasive preparation. Evidence on the long-term stability of 3-dimensionally (3D) printed restorations applying the Dahl concept is limited.

Purpose. The purpose of this preliminary clinical trial was to evaluate the clinical feasibility and long-term stability of 3D printed, noninvasive restorations implementing the Dahl concept for managing localized tooth wear while preserving tooth structure and restoring vertical dimension of occlusion.

Material and methods. Five patients with localized tooth wear received 3D printed computer-aided design and computer-aided manufacturing (CAD-CAM) restorations fabricated using digital workflows. Intraoral scans were performed at baseline and follow-up visits at 6, 12, and 24 months after insertion. Quantitative movement was analyzed using 3D superimposition techniques to assess posterior tooth extrusion and anterior tooth intrusion. The Wilcoxon rank sum test and independent *t* test were used for statistical analysis (α=.05).

Results. Posterior tooth extrusion demonstrated a characteristic time-dependent pattern with progressive stabilization from 0.37 ±0.25 mm at 6 months to 0.31 ±0.23 mm at 24 months. Movement variability decreased substantially over time, indicating predictable treatment outcomes. Anterior tooth intrusion remained clinically absent throughout the observation period (median ≤0.07 mm), confirming the preservation of vertical positioning. The 3D superimposition analysis corroborated quantitative measurements, revealing controlled bilateral posterior movements while maintaining anterior stability.

Conclusions. The provision of 3D printed, noninvasive restorations successfully implemented the Dahl concept, achieving predictable vertical dimension restoration with progressive occlusal stabilization over 24 months while preserving dental hard tissues. (J Prosthet Dent 2026;135:938.e1-e8)

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Clinical Implications

This conservative treatment approach combining 3D printing technology with established biological principles offers clinicians a reliable, minimally invasive method for managing localized tooth wear while achieving optimal functional and esthetic outcomes.

The global prevalence of pathological tooth wear remains imprecisely defined.[1,2] Reported incidence rates have varied widely, ranging from 26.9% to as high as 90% in both pediatric and adult populations, depending on study design and diagnostic criteria.[3–5] Nevertheless, there is growing consensus that pathological tooth wear will continue to pose a significant challenge in oral healthcare in the coming years.[6]

Tooth wear has been reported to be a multifactorial condition typically resulting from a combination of erosion, attrition, and abrasion. Lifestyle factors, particularly in industrialized societies, have contributed to the increasing incidence of erosive tooth wear. Dietary habits play a central role, while elevated levels of stress and the accompanying rise in parafunctional activity, such as bruxism, further exacerbate the problem.[7] This progressive and often irreversible loss of enamel and dentin can lead to dentin hypersensitivity, compromised esthetics, and a reduction in the vertical dimension of occlusion (VDO).

The progressive and irreversible loss of dental hard tissue because of tooth wear can lead to significant clinical consequences, for example, hypersensitivities, esthetic compromises, loss of vertical dimension of occlusion, phonetic impairments and reduced oral health-related quality of life. Current prosthetic treatment strategies for such patients are often invasive and financially demanding, while conservative approaches tend to be time-consuming and require long-term patient compliance.[8,9]

The global prevalence of pathological tooth wear has become the focus of increasing scientific inquiry, with a growing number of epidemiological studies published each year.[10] In patients with advanced tooth wear with reduced VDO, conservative management has historically relied on a phased treatment approach: initially, patients wear occlusal devices to condition the masticatory system, followed by extensive restorative rehabilitation involving partial or complete coverage crowns at a newly established occlusal vertical dimension.[11–13]

To address the preservation of remaining dental structures in patients with localized tooth wear, the Dahl concept offers a conservative alternative. First described by Dahl in 1975,[14] this approach involves placing localized restorations in supra-occlusion, triggering compensatory axial movements of the teeth: eruption of the posterior dentition and/or intrusion of the anterior segment. The goal is to re-establish a stable and functional occlusion through physiological adaptation over time.[15,16] In its original form, the Dahl appliance consisted of cobalt chromium overlays on the palatal surfaces of the maxillary anterior teeth.[15] While functionally effective, the appliance was esthetically unappealing and thus poorly accepted by patients.[15] In response, more esthetic and patient-friendly materials, such as direct composite resins or indirect restorations, have since been adopted to achieve similar outcomes.[8,15,17–19]

More recently, additive manufacturing (3-dimensional [3D] printing) has emerged as a suitable method of fabricating fixed dental restorations. This technology allows for the efficient and economical production of multiple restorations with complex geometries in a single print cycle,[20] with reduced fabrication time and material waste. Furthermore, the use of definitive computer-aided design and computer-aided manufacturing (CAD-CAM) materials allows for the production of noninvasive restorations with precisely tapered margins, enabling full preservation of the compromised tooth structure without additional preparation.[21] Clinical applications of 3D printed noninvasive restorations have been reported,[22–24] and 1 clinical report has described their use specifically for the Dahl concept.[25]

Combining 3D printing with the Dahl principle may present a novel, minimally invasive treatment option for patients with localized tooth wear. The ability to produce restorations that can be inserted without any hard tissue removal is particularly advantageous for patients in whom the preservation of remaining dental structure is critical. Furthermore, patients reported high satisfaction when fixed prosthetic concepts were realized.[26]

This preliminary clinical trial investigated the application of 3D printed, noninvasive restorations designed in accordance with the Dahl concept. The restorations were placed in the anterior regions of the maxilla and mandible, resulting in occlusal contacts confined to the anterior restored segment, extending from canine to canine in both arches. The buccal and lingual (or palatal) surfaces were completely covered, while the proximal contact areas were left uncovered. No contacts were present in the premolar and molar zones, creating space for posterior eruption and/or anterior intrusion as part of the occlusal re-establishment process. Posterior teeth were not restored to allow for observation of these adaptive changes.

The primary objective was to evaluate whether a 2-year clinical observation period would be sufficient to achieve stable occlusal conditions through the Dahl mechanism using 3D printed restorations. However, movements of the posterior teeth were consequently evaluated, as well as possible intrusion of the anterior teeth. The research hypothesis was that 3D printed, noninvasive restorations could be used to realize the Dahl approach and that occlusal contacts of the posterior teeth would be reestablished after 24 months of clinical function.

MATERIAL AND METHODS

The present clinical study received approval from the local Ethics Committee in 2020 (application number EA2/013/21) and was registered in the German Clinical Trials Register (application number: DRKS00024738). The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki.

Eligible participants included individuals aged 18 years or older without active temporomandibular joint disorders. Inclusion required the completion of all prior surgical, restorative, or periodontal treatments. Patients diagnosed with infectious diseases or who were pregnant at the time of recruitment were excluded. All enrolled participants were classified as of Physical Status I according to the American Society of Anesthesiologists (ASA) classification system.[27] According to the Tooth-Wear-Evaluation-System (TWES) 2.0, all 5 participants of the present study were classified as grade 3 (Fig. 1).[28]

Informed consent was obtained from all participants following an explanation of the study protocol. Upon consent, a comprehensive dental examination was carried out.

Following professional dental cleaning, all teeth were intraorally scanned (Primescan; Dentsply Sirona) without any tooth preparation. The scanning included all tooth surfaces (Fig. 2). The maxillomandibular relationship was recorded using buccal scans in maximum intercuspation. Mandibular movements were registered using a digital facebow (Zebris for Ceramill; Amann Girrbach AG) and a virtual articulator (Artex CR; Amann Girrbach AG), which allowed the calculation of the sagittal condylar angle, Bennett angle, and incisal guidance angle. These parameters were used to digitally design the functional occlusal surfaces.

Figure 1. Initial clinical situation of male patient (age 29) with severe localized tooth wear in anterior region and hypersensitivity because of exposed pulp.

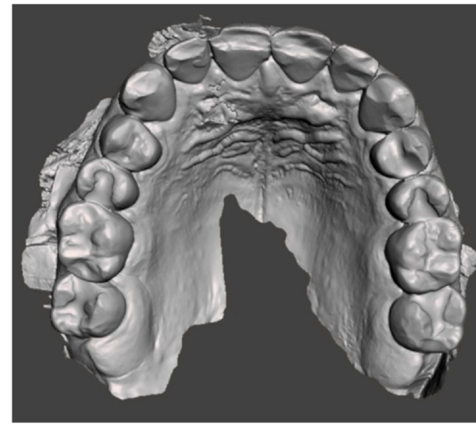

Figure 2. Intraoral scan of baseline situation showing localized anterior tooth wear extending from canine to canine.

The digital datasets were processed in a dental laboratory. Alterations to the vertical dimension of occlusion (VDO) were digitally planned, and restorations were designed using a software program (DentalCAD Galway 3.0; exocad GmbH) (Fig. 3). Additive manufacturing was carried out with an experimental CAD-CAM hybrid material for additive manufacturing. The material consisted of 30 to 50 wt% inorganic fillers with a particle size of 0.7 µm combined with silanized dental glass and methyl benzoylformate, diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide.

Key printing parameters included a minimum layer thickness of 0.3 mm, a cement gap of 0.06 mm, and a printing angle of 45 degrees. Postprocessing was performed in accordance with the manufacturer's guidelines.

Before insertion, the restorations were airborne-particle abraded with 50-µm aluminum oxide at 0.3 MPa for 10 seconds (Microetcher CD; KAVO/Danville Materials and Airsonic Alu-Oxyd; Hager & Werken). To prevent cross-bonding between adjacent restorations, thin sterilized medical polytetrafluoroethylene (PTFE) tape (Septotape; Septodont) was placed interproximally before cementation. A universal primer (Monobond Plus; Ivoclar AG) was then applied. If enamel was present, it was etched using 37% phosphoric acid. Both enamel and dentin were subsequently treated with a self-etch adhesive (Scotchbond SE; 3M ESPE). Final cementation was performed using a dual-polymerizing

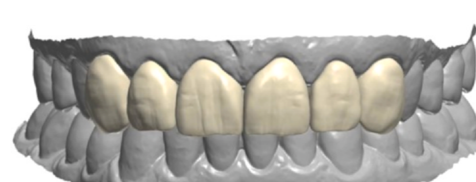

Figure 3. Digitally designed 3-dimensionally printed, noninvasive restorations implementing Dahl concept.

Figure 4. Clinical situation after insertion of 3-dimensionally printed, noninvasive restorations in maxilla from canine to canine.

resin cement (RelyX Ultimate; 3M ESPE) and light polymerized for 20 seconds per surface using a polymerization light (VALO Grand; Ultradent Products, Inc). After the removal of excess cement, the static and dynamic occlusion was verified, and the restorations were polished using a disk-based polishing system (Sof-Lex XT; 3M ESPE). Occlusal contacts were limited to the printed restorations (Fig. 4).

A baseline intraoral scan was obtained immediately after insertion. Follow-up assessments were scheduled after 6, 12, and 24 months to monitor occlusal changes. At each recall, new intraoral scans were acquired and compared with the baseline scan using a software program (Geomagic Control X; 3D Systems). The alignment process included an initial "transform fit" alignment using 4 manually selected anatomic landmarks on adjacent teeth, followed by a precise "best fit" alignment using the segmented teeth as reference surfaces. This analysis enabled the detection of posterior tooth eruption, intrusion of the restored units, or material degradation of the 3D printed restorations.

Statistical evaluation was conducted using a software program (R; R Foundation for Statistical Computing). Normality and equal variance of the data were assessed with the Shapiro–Wilk and Levene tests, respectively. The Wilcoxon rank sum test and independent *t* test were performed to compare the amount of movement of the posterior teeth in various follow-up periods (α=.05).

RESULTS

Posterior tooth movements exhibited a time-dependent pattern over the 24-month observation period. Mean ±standard deviation extrusion decreased from 0.37 ±0.25 mm at 6 months to 0.31 ±0.23 mm at 24 months (Table 1). Cumulative movement during the first year (0.34 ±0.20 mm) was significantly greater than during the second year (0.10 ±0.05 mm) (*P*=.01), indicating progressive stabilization.

Analysis of movements between individual follow-up intervals revealed a markedly different pattern. Since the data were not normally distributed, the Wilcoxon rank sum test was applied. Over the 2-year observation period, cumulative movement during the first year (0.34 ±0.20 mm, 0–12 months) was significantly greater than during the second year (0.10 ±0.05 mm, 12–24 months; *P*=.01) (Figs. 5 and 6), indicating progressive stabilization of the restorations.

Three-dimensional superimposition confirmed bilateral posterior extrusion, with the greatest displacement in the molar regions (0.4 to 1.2 mm). The anterior segment displayed predominantly green coloration, corresponding to minimal displacement (Fig. 7).

The quantitative evaluation of anterior teeth revealed no clinically relevant intrusion at any time point. Median values remained ≤0.07 mm, indicating that early deviations reflected individual outliers rather than systematic movement (Table 2). The Wilcoxon rank-sum testing showed no significant differences between intervals (0–6 versus 6–12 months; 0–12 versus 12–24 months; *P*>.05) (Figs. 8 and 9).

Three-dimensional analysis of the anterior region demonstrated uniform green coloration within ±0.1 mm, confirming the vertical stability and absence of measurable intrusion (Fig. 10). No blue areas were observed, indicating that occlusal forces generated during posterior adaptation were not transmitted to the anterior teeth. Posterior regions showed variable patterns consistent with controlled eruption according to the Dahl mechanism.

Overall, the findings indicated early posterior adaptation followed by stabilization during the second year while maintaining vertical stability of the anterior teeth. The noninvasive 3D printed restorations preserved anterior tooth position and allowed controlled posterior movement consistent with the intended Dahl treatment concept.

DISCUSSION

The present study investigated 3D printed, noninvasive restorations used to implement the Dahl concept.

Table 1. Evaluation of movements of posterior teeth after insertion of 3-dimensionally printed, noninvasive restorations. Comparisons conducted between baseline and 12 months and 12 and 24 months

	Average (mm)	Standard deviation (mm)	Median (mm)	Minimal movement (mm)	Maximal movement (mm)
Baseline to 6 months	0.37	0.25	0.25	0.15	0.75
Baseline to 12 months	0.34	0.20	0.27	0.19	0.69
Baseline to 24 months	0.31	0.23	0.22	0.16	0.64
6 to 12 months	0.14	0.06	0.10	0.09	0.22
12 to 24 months	0.10	0.05	0.11	0.02	0.15

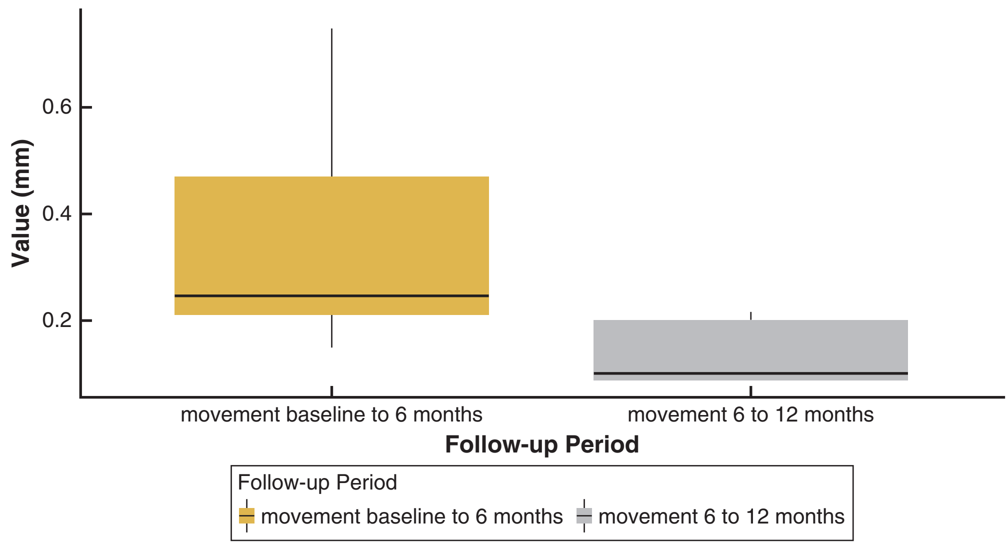

Figure 5. Comparison of posterior teeth movement between 0 and 6 months and 6 and 12 months (*P*=.06).

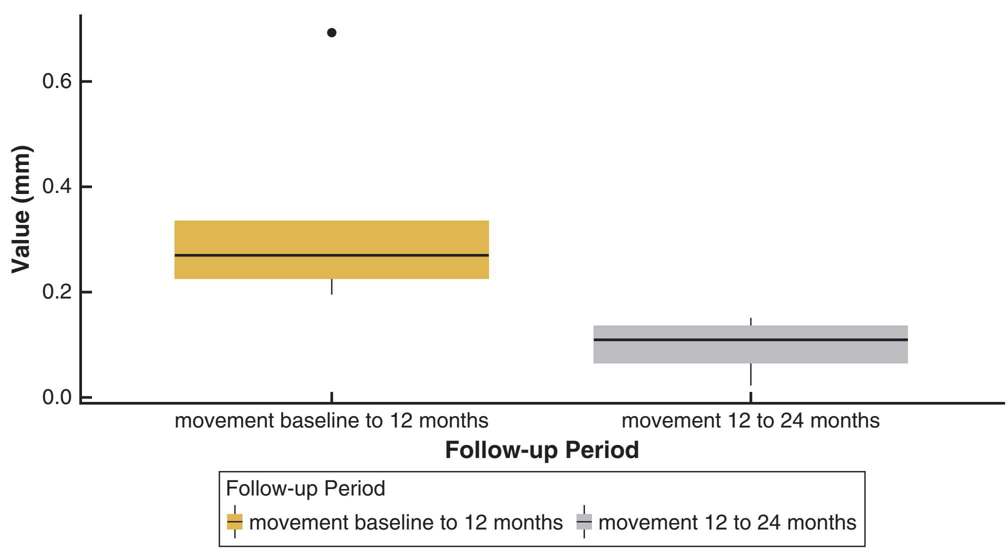

Figure 6. Comparison of posterior teeth movement between 0 and12 months and 12 and 24 months (*P*=.01).

Clinical data on this approach are limited, and the authors are unaware of previous studies on applying it to additively manufactured restorations. The research hypothesis that posterior occlusal contacts would reestablish within 24 months was accepted. The restorations initiated the intended Dahl effect, with complete posterior reestablishment observed after 24 months and no measurable intrusion of anterior teeth. Slight increases in intrusion values between 12 and 24 months may reflect material wear.

The movement pattern followed a characteristic time-dependent course consistent with previous descriptions of the Dahl concept.[25] Most vertical changes occurred within the first 6 months, representing the initial settling phase, while the progressive reduction in

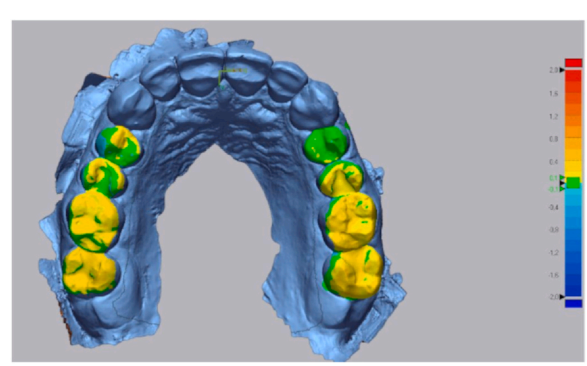

Figure 7. Three-dimensional displacement analysis (baseline to 6 months) showing bilateral posterior movements (*yellow*, 0.4–1.2 mm) and anterior stability (*green*). *Blue areas* indicate negative displacement. Scale in millimeters. 0–6 months and 6–12 months (*P*=.53).

Table 2. Anterior tooth intrusion measurements demonstrating absence of clinically significant movement. Consistently low median values confirm stable vertical positioning over 24 months

	Average (mm)	Standard deviation (mm)	Median (mm)	Minimal movement (mm)	Maximal movement (mm)
Baseline to 6 months	0.45	0.57	0.07	0.04	1.28
Baseline to 12 months	0.08	0.04	0.05	0.04	0.13
6 to 12 months	0.07	0.05	0.05	0.03	0.14
12 to 24 months	0.11	0.15	0.06	0	0.36

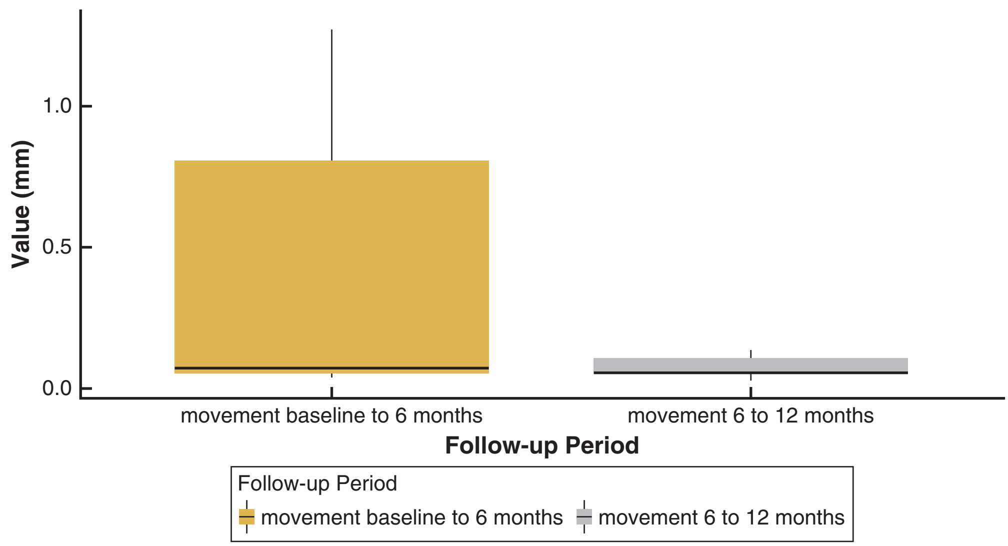

Figure 8. Comparison of anterior teeth movement between 0 and 6 months and 6 and 12 months (P=.06).

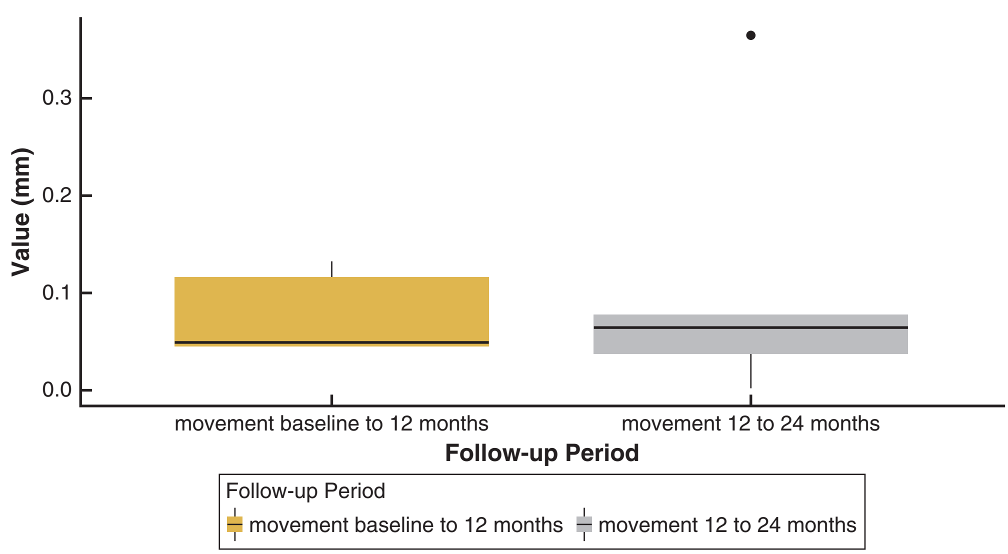

Figure 9. Comparison of anterior teeth movement between 0 and12 months and 12 and 24 months (*P*=.012).

displacement values and standard deviations indicated physiological integration of the restorations. The substantially lower movement values between 12 and 24 months suggest consolidation of periodontal adaptation and increasing resistance to further displacement.

Stabilization after the first year was demonstrated by markedly reduced interval movements, confirming successful restoration of posterior occlusal contacts. Three-dimensional superimposition supported these findings, revealing bilateral posterior displacement (0.4 to 1.2 mm) and reflecting heterogenous force distribution during early adaptation.

With recent advances in intraoral scanning technology, precise quantification of dental morphology has

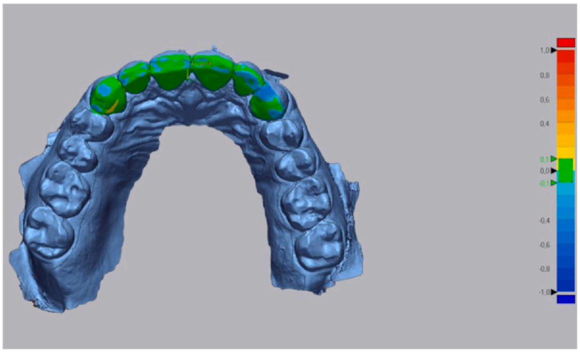

Figure 10. Absence of anterior tooth intrusion (*green areas*, ±0.1 mm) demonstrating stable vertical positioning of restored frontal segment. Scale in millimeters.

become feasible. However, the accuracy of serial scan superimposition remains sensitive to matching errors, especially in areas undergoing morphological change.[29] Progressive tooth eruption also reduces intersurface distances between scans.[30,31] To mitigate these effects, each occlusal surface was segmented individually at baseline and compared with follow-up scans, allowing a more reliable assessment of subtle vertical changes.

The pronounced stability of the anterior region aligned with the biomechanical principles of the Dahl concept. The consistently low median intrusion values (0.05 to 0.07 mm) indicated that the anterior teeth maintained their vertical position; this is clinically relevant as intrusive displacement could compromise both esthetics and function. Limited published data exist on anterior intrusion in this situation.[16,32] However, adaptive remodeling within the temporomandibular joint (TMJ) complex may also take place during occlusal adaptation and could partially account for the absence of measurable anterior intrusion in the present study. This potential mechanism was not evaluated but should be considered in future investigations.

The decreasing interindividual variability over the first year supported the predictability of the protocol. Initial outliers likely reflected measurement variation or physiological adaptation rather than clinically relevant intrusion. Overall, the results indicated that the critical phase of posterior adaptation occurred early, whereas stability and long-term predictability were achieved after approximately 12 months.

Direct composite resin techniques have traditionally been used to implement the Dahl concept because of their minimally invasive nature and predictable adhesion, as reported by Attin et al.[8,18,19] However, the manual buildup of individual occlusal surfaces is time consuming. Additive manufacturing offers standardized morphology, reproducibility, and efficient implementation. Clinical applications of 3D printed noninvasive restorations have recently been reported,[22–24] and 1 preliminary clinical study has described their use specifically for the Dahl concept.[25] High patient satisfaction has also been reported following the fixed prosthetic approaches used for Dahl-type treatments.[26] The noninvasive and reversible nature of this method is particularly advantageous in younger patients with localized severe tooth wear.

Limitations of this study included that submillimeter measurements were susceptible to instrumental imprecision and that the observed movements (0.02 to 0.04 mm) were minimal and may lie within the detection threshold. The small sample size and exploratory design limited generalizability. Larger trials and comparative studies using different additive and subtractive CAD-CAM materials are needed to establish definitive recommendations.

Future research should aim to refine digital planning workflows, evaluate material performance, and investigate long-term outcomes. Comparative studies between 3D printed and conventional restorative approaches would further support evidence-based guidelines for minimally invasive occlusal rehabilitation.

CONCLUSIONS

Based on the findings of this clinical explorative study with an observation time of 24 months, the following conclusions were drawn:

1. Three-dimensionally printed, noninvasive restorations implementing the Dahl concept achieved predictable posterior tooth extrusion (0.37 ±0.25 mm to 0.31 ±0.23 mm) while preventing anterior intrusion (median ≤0.07 mm).
2. Progressive stabilization with reduced movement variability validated this approach as a reliable, minimally invasive treatment modality for vertical dimension restoration in complex rehabilitative dentistry.
3. Overall, the results demonstrate a time-dependent reduction in movement values across the observation period. While the first year was characterized by relatively higher variability, the second year revealed consistent and markedly reduced movements.

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