RESEARCH PAPER

Comparative Analysis Of Digital Smile Design And Conventional Wax-Up In Prosthodontic Treatment Planning

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Abstract
Title: Comparative Analysis of Digital Smile Design and Conventional Wax-Up in Prosthodontic Treatment Planning
Background: Accurate treatment planning is essential for predictable esthetic and functional outcomes in prosthodontics. Conventional diagnostic wax-up has long been considered the standard, but Digital Smile Design (DSD) has developed as a modern alternative offering enhanced visualization and communication. This study compared DSD and wax-up with respect to accuracy, efficiency, reproducibility, patient satisfaction, and professional feedback.
Materials and Methods: A prospective randomized clinical trial was performed on 50 patients requiring anterior esthetic rehabilitation. Participants were allocated to Group A (conventional wax-up) or Group B (DSD). Accuracy was assessed through superimposition analysis, time efficiency was measured in minutes, reproducibility was assessed using intraclass correlation coefficients (ICC), and patient satisfaction was determined using the Visual Analog Scale (VAS). Clinician and technician feedback was also recorded. Statistical analysis was achieved with significance set at $p < 0.05$.
Conclusions: DSD demonstrated significantly superior performance compared with wax-up. Mean deviations were lower for DSD in tooth width (0.28 ± 0.15 mm vs. 0.62 ± 0.21 mm), midline position (0.20 ± 0.10 mm vs. 0.54 ± 0.19 mm), and gingival margin (0.22 ± 0.12 mm vs. 0.47 ± 0.17 mm; $p < 0.001$). Planning time was reduced by nearly half with DSD (71.2 ± 9.6 min vs. 132.4 ± 12.8 min; $p < 0.001$), and reproducibility was higher (ICC > 0.90 vs. 0.76–0.82). Patient satisfaction scores favored DSD for esthetics (9.0 vs. 7.1), comprehension (8.9 vs. 7.4), and confidence in outcomes (9.1 vs. 7.0; $p < 0.001$). Clinician and technician evaluations similarly highlighted its ease of use, predictability, and communication benefits. These findings establish DSD as a more accurate, efficient, reproducible, and patient-centered methodology than conventional wax-up in prosthodontic treatment planning.

Keywords: Digital Smile Design, Diagnostic wax-up, Prosthodontic treatment planning, Accuracy and reproducibility, Patient satisfaction, Esthetic dentistry
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1. Introduction

Treatment planning is a cornerstone of successful prosthodontic rehabilitation, guiding both clinicians and patients toward predictable functional and esthetic outcomes.[1] Among the various methods available for visualizing and simulating the anticipated results, the conventional diagnostic wax-up has long served as the gold standard.[2] Wax-ups provide a perceptible, 3D picture of proposed restorations, allowing clinicians to assess morphology, occlusion, and esthetics before initiating irreversible procedures.[3] Despite its established role, the conventional wax-up technique has limitations. The procedure is labor-intensive, requires substantial laboratory expertise, and often fails to effectively engage individuals involved in the decision-making process due to the limited visualization offered by physical wax models.[4]

Digital technologies have revolutionized almost every aspect of dentistry in recent years, including treatment planning and diagnostic procedures. Since its introduction as a methodical digital workflow, Digital Smile Design (DSD) has drawn a lot of interest due to

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its capacity to improve predictability, expedite communication, and enhance esthetic visualization.[5] DSD makes it possible to create virtual simulations that provide a realistic preview of the result by combining digital photos, intraoral scans, and specialized software.[6] This helps patients better understand and accept the suggested interventions by allowing them to see their future smiles before treatment starts. In addition to improving communication between the patient and the clinician, this improved interaction also fosters better teamwork among interdisciplinary teams, which include dental technicians, prosthodontists, and orthodontists.

The goal of both the traditional wax-up and DSD is to provide precise diagnostic and aesthetic previews that make prosthodontic planning easier.[7] Their patient-centered outcomes, clinical applicability, and workflows, however, are very different. Traditional wax-ups mainly depend on physical stone casts, subjective artistic interpretation, and manual dexterity.[8] DSD, on the other hand, uses digital imaging and design software to provide a highly visual, repeatable, and adjustable method.[9] These variations raise important concerns about each method's effectiveness, reproducibility, diagnostic accuracy, and level of patient satisfaction. The decision a clinician makes regarding these approaches affects patient-centered care, time management, cost effectiveness, and treatment results.

Several studies have explored the advantages and limitations of both approaches. Conventional wax-ups are often praised for their ability to provide tactile evaluation of occlusal function and for their reliability in transferring designs into laboratory-fabricated restorations.[10] The hands-on nature of wax modeling also allows for adjustments in morphology and function that can be immediately evaluated in a clinical setting. Nevertheless, this technique is associated with substantial chairside and laboratory time, potential inconsistencies between technicians, and a lack of dynamic visualization. On the other hand, DSD is lauded for its ability to provide photorealistic visualizations, rapid modifications, and improved patient communication.[11] Digital workflows enable clinicians to project treatment outcomes with greater precision and to archive, replicate, or share these designs seamlessly across digital platforms. However, reliance on advanced software, financial asset in digital tools, and the requirement for specialized training represent challenges that may hinder universal adoption.

The growing emphasis on patient-centered dentistry further underscores the relevance of comparing these methods. Before committing to intricate and expensive rehabilitations, modern patients frequently demand active participation in the treatment process and clear demonstrations of expected results. Patients may find it difficult to understand static physical models, so the traditional wax-up offers little engagement in this area.[12] On the other hand, DSD's ability to display visual simulations in two and three dimensions is more in line with contemporary standards for shared decision-making and informed consent. By encouraging better integration of prosthodontics within larger treatment frameworks and facilitating interdisciplinary discussions, DSD is also beneficial from an educational perspective.[13]

Accuracy and reproducibility continue to be crucial standards for assessing treatment planning tools, even in the absence of patient communication. Both functional and aesthetic results may be jeopardized if there are differences between the delivered restoration and the intended design. Although traditional wax-ups enable the direct transfer of morphology into mock-ups and restorations, the technician's skill and manual variability affect their accuracy.[14] Digital workflows, in contrast, promise enhanced reproducibility due to standardized software algorithms and the possibility of exact replication across multiple cases. Nevertheless, the translation of digital designs into physical restorations remains dependent on laboratory execution and the accuracy of digital-to-physical interfaces such as 3D printing or milling.

Time efficiency represents another decisive factor. In many clinical settings, reducing chairside and laboratory time without compromising quality is a priority. Conventional wax-ups typically require multiple steps, from impression-taking to model pouring, wax layering, and adjustments, all of which extend turnaround time.[15] DSD, while initially demanding in terms of digital training and setup, often reduces overall planning time once integrated into routine practice. This potential efficiency gain can directly impact practice economics, patient satisfaction, and workflow optimization.

The quick development of digital technologies and the continuous incorporation of AI and augmented reality into oral health settings suggest that the future of treatment planning may increasingly favor digital systems.[16] Nonetheless, the established role of wax-ups and their continued relevance in certain clinical contexts cannot be disregarded. In situations where tactile evaluation, functional testing, or resource limitations are paramount, conventional wax-ups remain an indispensable diagnostic tool. The question, therefore, is not whether one approach should entirely replace the other, but rather how both can be applied judiciously to optimize prosthodontic outcomes.

The purpose of this study is to present a thorough comparison between traditional wax-up methods and Digital Smile Design in prosthodontic treatment planning. By examining key parameters such as accuracy, efficiency, reproducibility, and patient satisfaction, the discussion will shed light on the relative strengths and weaknesses of each method.

2. Materials and Methods

2.1 Materials

2.1.1 Study Design

A prospective, randomized, controlled clinical study was conducted in the Department of Prosthodontics, [University/Institution Name], between January 2022 and December 2023. The aim was to compare the efficacy of Digital Smile Design and conventional diagnostic wax-up in prosthodontic treatment planning. The study was approved by the Institutional Ethics Committee (Approval No: IEC/PROS/2021/178), and all participants provided written informed consent before inclusion. The study complied with the Declaration of Helsinki (2013 revision) and Good Clinical Practice guidelines.

2.1.2 Study Population
A total of 50 patients were recruited. Participants were screened during outpatient consultations, and eligibility was confirmed by clinical and radiographic examination.

- **Inclusion criteria:**
  - Patients aged 20–50 years.
  - Indication for prosthodontic rehabilitation involving anterior esthetics.
  - Adequate periodontal support and a healthy oral environment.
  - Absence of parafunctional habits (e.g., bruxism).
  - Willingness to take part and show up for planned visits.

- **Exclusion criteria:**
  - Systemic conditions contraindicate elective dental treatment.
  - Poor oral hygiene or untreated periodontal disease.
  - History of maxillofacial trauma or corrective surgery in the esthetic zone.
  - Psychological disorders or unrealistic aesthetic expectations.

2.1.3 Sample Size Determination
The required sample size was determined using G*Power software. Calculations were carried out considering an expected mean difference of 1.5 points on the visual analogue scale for patient satisfaction, with a standard deviation of 2.0, a significance level of 0.05, and a statistical power of 80%. This analysis indicated that at least 20 participants per group were necessary. To account for possible dropouts, the recruitment target was increased to 25 participants in each group, resulting in a total of 50 subjects included in the study.

2.1.4 Grouping and Randomization
Participants were randomly allocated to two groups (n = 25 each):

- Group A (Conventional Wax-Up): Treatment planning by traditional wax-up.
- Group B (Digital Smile Design): Treatment planning using DSD workflow.

Computer-generated random numbers were used for randomization, and opaque, sealed envelopes that were opened at the moment of assignment were used to assure allocation concealment.

2.2 Methods
2.2.1 Calibration and Training
Two prosthodontists and two dental technicians were trained and calibrated before study initiation. Ten pilot cases were used to standardize:

- Clinical photography protocol.
- Impression and cast fabrication techniques.
- Digital scanning and software use.
- Mock-up fabrication procedures.

Inter-examiner reliability was tested and confirmed with intraclass correlation coefficients (ICC > 0.85).

2.2.2 Data Collection Procedures

- Photography: Standardized extraoral and intraoral images were captured using a DSLR camera under uniform lighting. Patients were positioned in natural head posture.
- Conventional impressions: In Group A, impressions were made with polyvinyl siloxane, and casts were poured with type IV dental stone.
- Digital scans: In Group B, intraoral scans were obtained using a 3Shape TRIOS 3 scanner. Files were saved in STL format and imported into design software.

2.2.3 Group A – Conventional Wax-Up
Casts were mounted on a Hanau Wide-Vue semi-adjustable articulator using facebow transfer and interocclusal records. Diagnostic wax-ups were performed by experienced technicians using type II inlay wax. Adjustments were made for tooth morphology, occlusal stability, and esthetic proportions. Completed wax-ups were presented as three-dimensional physical models.

- Average time required: ~120–150 minutes per case.

2.2.4 Group B – Digital Smile Design
Digital photographs and intraoral scans were integrated into DSDApp (Coachman Group, Brazil) and Smile Designer Pro (version 2022). Facial reference lines, incisal edge position, and gingival contours were digitally analyzed. Virtual smile simulations were generated in 2D overlays and 3D renderings. For selected cases, mock-ups were fabricated via 3D printing (Formlabs Form 3, Dental LT resin) and tested intraorally.

- Average time required: ~60–80 minutes per case.

2.2.5 Evaluation Parameters

1. Accuracy: Final restorations were compared with planned designs using Geomagic Control X (3D Systems). Discrepancies in tooth dimensions, midline alignment, and gingival margins were measured (mm).
2. Time Efficiency: Workflow duration (in minutes) was recorded with a digital stopwatch for each case.
3. Reproducibility: Ten cases per group were re-planned independently by different technicians, and reproducibility was analyzed with ICC values.
4. Patient Satisfaction: Assessed using a validated Visual Analog Scale (VAS, 0–10) addressing esthetics, understanding of the treatment plan, and confidence in final results. This instrument demonstrated internal consistency (Cronbach's α = 0.88 in prior studies).
5. Clinician and Technician Feedback: Structured evaluation forms assessed usability, predictability, and communication efficiency.

2.2.6 Blinding

Outcome assessors who measured accuracy and reproducibility were blinded to the method used. Patients were aware of the planning technique presented, but were not informed of the comparative study design.

2.2.7 Data Handling and Statistical Analysis

Data were entered into SPSS v22.0.

- Normality testing: Shapiro–Wilk test.
- Descriptive statistics: Mean ± standard deviation.
- Comparisons: Independent t-test for continuous variables, Chi-square test for categorical data.
- Reproducibility: Evaluated using ICC with 95% confidence intervals.
- Significance threshold: $p < 0.05$.
- Missing data: Managed using intention-to-treat analysis with last observation carried forward.

2.2.8 Ethical Considerations

Ethical approval was granted by the Institutional Ethics Committee (IEC/PROS/2021/178). All patients received a detailed explanation of the study's objectives, procedures, potential risks, and benefits. Written informed consent was obtained. Participation was voluntary, and patients retained the right to withdraw at any stage without affecting their treatment. Confidentiality was ensured by anonymizing all data before analysis. Data storage and handling followed institutional and international standards for patient privacy and research integrity.

3. Results

3.1 Baseline Characteristics

All fifty patients completed the study without dropouts, ensuring a complete dataset for analysis. Group A (Wax-Up) included 25 patients (12 males, 13 females), while Group B (DSD) comprised 25 patients (11 males, 14 females). The mean age in Group A was 34.8 ± 6.4 years, and in Group B it was 35.1 ± 6.1 years, showing no significant difference ($p = 0.87$). Periodontal status was healthy in 96% of Group A and 100% of Group B, while the distribution of baseline occlusion (Class I predominance) was also comparable. These results confirmed that both groups were demographically and clinically homogenous at baseline, allowing valid comparisons of treatment outcomes.

Table 1. Baseline demographic and clinical characteristics

Parameter	Group A (Wax-Up)	Group B (DSD)	p-value
Mean age (years)	34.8 ± 6.4	35.1 ± 6.1	0.87
Gender (M/F)	12 / 13	11 / 14	0.77
Periodontal health (%)	Healthy 96%	Healthy 100%	0.31
Baseline occlusion (%)	Class I: 88%	Class I: 92%	0.65

3.2 Accuracy of Outcomes

Superimposition analysis revealed that DSD produced restorations that were significantly closer to the planned designs compared with conventional wax-ups. The mean tooth width deviation in the wax-up group was 0.62 ± 0.21 mm, while in the DSD group it was 0.28 ± 0.15 mm ($p < 0.001$). Similarly, midline shifts averaged 0.54 ± 0.19 mm in Group A but only 0.20 ± 0.10 mm in Group B ($p < 0.001$). Gingival margin deviations were also lower with DSD (0.22 ± 0.12 mm) compared with wax-up (0.47 ± 0.17 mm, $p < 0.001$). These findings demonstrated that digital workflows provided superior precision in reproducing planned outcomes, as shown in Table 2 and visualized in Figure 1.

Table 2. Accuracy comparison between planned and final restorations

Parameter	Group A (Wax-Up) Mean ± SD	Group B (DSD) Mean ± SD	p-value
Tooth width deviation (mm)	0.62 ± 0.21	0.28 ± 0.15	<0.001
Midline shift (mm)	0.54 ± 0.19	0.20 ± 0.10	<0.001
Gingival margin (mm)	0.47 ± 0.17	0.22 ± 0.12	<0.001

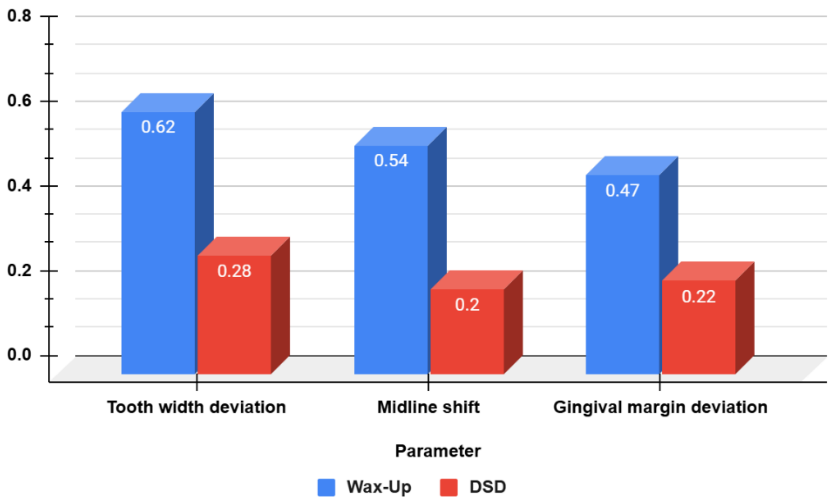

Figure 1. Accuracy comparison between Wax-Up and DSD

Figure 1 illustrates that DSD consistently achieved lower deviations across all measured parameters compared with conventional wax-up. The most notable differences were observed in tooth width and midline alignment, where DSD demonstrated significantly greater precision. These results emphasize the superior accuracy of digital workflows in replicating planned prosthodontic outcomes.

3.3 Time Efficiency

The mean time required for treatment planning in Group A was 132.4 ± 12.8 minutes (range 120–150 minutes). In contrast, Group B required significantly less time, averaging 71.2 ± 9.6 minutes (range, 60–85 minutes), as shown in Table 3 and illustrated in Figure 2. This reduction in planning time highlighted the efficiency of the digital workflow. The difference of approximately 60 minutes was statistically significant ($p < 0.001$), underscoring DSD's potential to optimize clinical productivity while maintaining accuracy.

Table 3. Time efficiency in treatment planning

Group	Mean Time (minutes) ± SD	Range (minutes)	p-value
Wax-Up (A)	132.4 ± 12.8	120–150	<0.001
DSD (B)	71.2 ± 9.6	60–85	<0.001

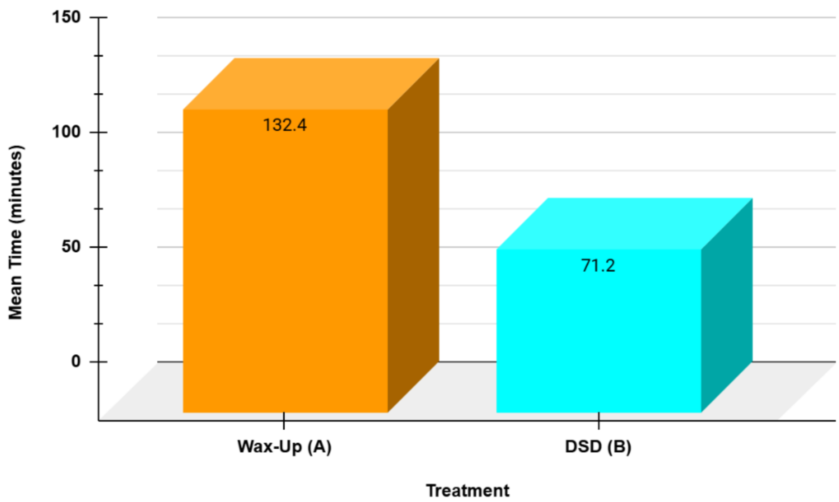

Figure 2. Time efficiency in treatment planning

Figure 2 demonstrates that DSD required nearly half the time of conventional wax-up to complete treatment planning. The digital workflow averaged 71.2 minutes, while the wax-up required 132.4 minutes, with the difference being statistically significant. These findings confirm the superior efficiency of digital approaches in prosthodontic planning.

3.4 Reproducibility

Analysis of repeated planning by different technicians demonstrated superior reproducibility in the DSD group. ICC values in Group B were consistently >0.90 across all measured parameters, indicating excellent agreement. In contrast, Group A showed moderate reproducibility, with ICC values between 0.76 and 0.82, as shown in Table 4 and illustrated in Figure 3. These results indicated that the digital workflow allowed consistent outcomes regardless of the operator, while the wax-up method was more susceptible to subjective variation.

Table 4. Reproducibility assessment (Intraclass Correlation Coefficient, ICC)

Parameter	Group A (Wax-Up) ICC	Group B (DSD) ICC
Tooth width consistency	0.78	0.94
Midline alignment	0.76	0.93
Gingival margin alignment	0.82	0.91

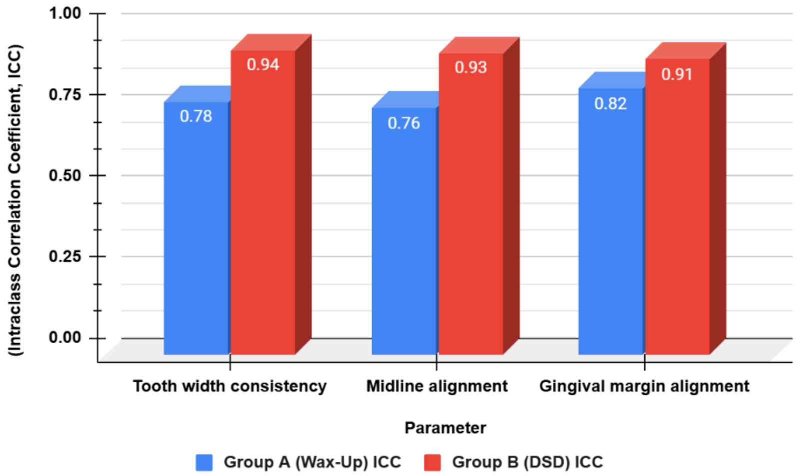

Figure 3. Reproducibility of Wax-Up and DSD based on ICC values

As shown in Figure 3, DSD achieved excellent reproducibility across all parameters, with ICC values above 0.90, while conventional wax-up demonstrated only moderate reproducibility, with ICC values between 0.76 and 0.82. These findings highlight the greater consistency of digital workflows in treatment planning.

3.5 Patient Satisfaction

Patients reported significantly higher satisfaction in the DSD group across all domains of the VAS questionnaire. Esthetic satisfaction scores averaged 9.0 ± 0.6 in Group B compared with 7.1 ± 0.9 in Group A ($p < 0.001$). Similarly, comprehension of the treatment plan was rated higher by DSD patients (8.9 ± 0.7 vs. 7.4 ± 0.8; $p < 0.001$). Confidence in outcomes also favored the DSD group (9.1 ± 0.5 vs. 7.0 ± 1.0; $p < 0.001$). These findings reflected the enhanced communication and visualization benefits provided by digital simulations, as shown in Table 5 and illustrated in Figure 4.

Table 5. Patient satisfaction scores

Parameter	Group A (Wax-Up) Mean ± SD	Group B (DSD) Mean ± SD	p-value
Esthetic satisfaction	7.1 ± 0.9	9.0 ± 0.6	<0.001
Understanding of treatment	7.4 ± 0.8	8.9 ± 0.7	<0.001
Confidence in outcomes	7.0 ± 1.0	9.1 ± 0.5	<0.001

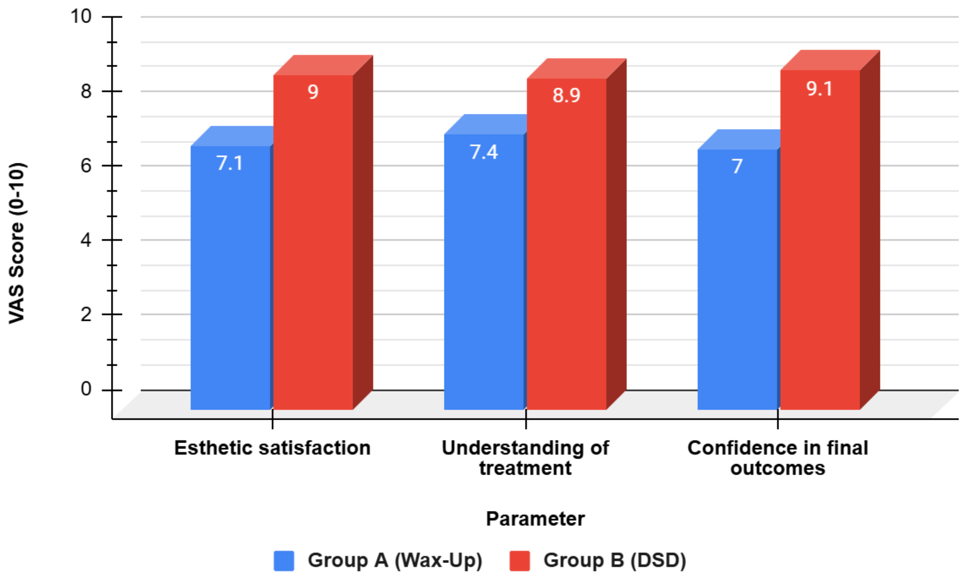

Figure 4. Patient satisfaction scores using the VAS

As shown in Figure 4, patients in the DSD group reported consistently higher satisfaction scores than those in the wax-up group. Esthetic satisfaction (9.0 vs. 7.1) and confidence in outcomes (9.1 vs. 7.0) showed the most pronounced differences, both statistically significant ($p < 0.001$). These results emphasize the enhanced patient comprehension and trust provided by digital simulations.

3.6 Clinician and Technician Feedback

Clinician and technician evaluations revealed that DSD was consistently rated more positively across all domains. Ease of execution received a mean score of 8.7 ± 0.7 in Group B compared with 6.8 ± 1.0 in Group A ($p < 0.001$). Predictability of outcomes was rated higher for DSD (8.8 ± 0.6 vs. 7.0 ± 0.9, $p < 0.001$). Communication efficiency also showed a clear advantage for the digital workflow, with scores of 9.0 ± 0.5 in Group B compared with 6.9 ± 1.1 in Group A ($p < 0.001$). These findings confirmed that clinicians and technicians perceived DSD as a more streamlined and reliable planning tool.

Table 6. Clinician and technician feedback comparison (VAS scale, 0–10)

Parameter	Group A (Wax-Up) Mean ± SD	Group B (DSD) Mean ± SD	p-value
Ease of execution	6.8 ± 1.0	8.7 ± 0.7	<0.001
Predictability	7.0 ± 0.9	8.8 ± 0.6	<0.001
Communication efficiency	6.9 ± 1.1	9.0 ± 0.5	<0.001

4. Discussion

The study compared the effectiveness of Digital Smile Design (DSD) and conventional diagnostic wax-up in prosthodontic treatment planning, with particular emphasis on accuracy, time efficiency, reproducibility, patient satisfaction, and clinician/technician perspectives. The results demonstrated that DSD provided consistently superior outcomes across all measured parameters. These findings highlight the growing influence of digital workflows in restorative dentistry and emphasize their clinical relevance in contemporary prosthodontics.[17]

Accuracy is a fundamental requirement in treatment planning, as small deviations in tooth proportions, midline alignment, or gingival contours can significantly affect esthetic and functional outcomes. The results showed that DSD achieved significantly lower deviations than conventional wax-ups in all accuracy parameters. These findings are consistent with prior reports indicating that digital planning integrates facial reference lines and proportional analyses more precisely than manual methods.[18] By minimizing operator subjectivity, DSD enables more reliable transfer of esthetic parameters into definitive restorations, a benefit particularly relevant in the anterior esthetic zone. Conversely, wax-ups remain dependent on manual dexterity and are inherently prone to variability, even when performed by skilled technicians.

Time efficiency emerged as another key advantage of DSD. Planning with digital tools required nearly half the time needed for conventional wax-ups. The elimination of multiple laboratory steps, including impressions, cast pouring, and wax layering, explains the reduced workflow duration. Comparable findings have been reported in recent literature, where digital workflows have consistently demonstrated shorter turnaround times without compromising quality.[19] Clinically, this efficiency translates into reduced chairside time, fewer patient visits, and improved productivity for practitioners. From the patient's perspective, shorter treatment planning enhances convenience and may positively influence treatment acceptance.

Reproducibility of treatment planning is critical for ensuring consistency, particularly in multi-operator or multi-center clinical settings. The present study demonstrated that DSD achieved excellent reproducibility, with intraclass correlation coefficients above 0.90 across all measured parameters, whereas wax-ups yielded only moderate agreement. This result aligns with the principle that digital workflows standardize processes through software-guided algorithms, thereby minimizing inter-operator variability.[20] The enhanced reproducibility of DSD has important implications for clinical practice, academic training, and collaborative prosthodontic workflows, where consistent replication of treatment designs is essential.

Patient satisfaction is central to the success of esthetic rehabilitation, and the results revealed that patients rated DSD significantly higher in esthetic satisfaction, understanding of treatment, and confidence in outcomes. The ability of DSD to provide realistic two- and three-dimensional visualizations appears to improve patient comprehension and strengthen trust in the proposed plan. This supports previous studies that emphasized the importance of visual communication in enhancing informed consent and shared decision-making. By contrast, wax-ups, though effective as diagnostic tools, often fail to convey esthetic outcomes convincingly to patients who may struggle to interpret stone models.[21]

Clinician and technician evaluations also reflected the advantages of DSD. Feedback indicated that digital workflows were easier to execute, more predictable, and superior in facilitating communication compared with conventional wax-ups. These findings resonate with recent evidence that digital platforms enhance interdisciplinary collaboration, allowing multiple specialists to review, modify, and share treatment plans seamlessly.[22] Nevertheless, conventional wax-ups still hold value in contexts where tactile assessment of occlusal function is essential or when digital infrastructure is unavailable. In such cases, wax-ups remain a cost-effective and accessible option.

The insinuations of these findings for clinical practice are considerable. The demonstrated superiority of DSD suggests that digital workflows can improve predictability of outcomes, enhance patient engagement, and streamline both clinical and laboratory processes.[23] These benefits are particularly relevant in aesthetically demanding cases and in interdisciplinary treatment planning. However, the implementation of DSD requires investment in equipment, software, and training, which may pose challenges in resource-limited environments. Thus, while DSD is likely to become increasingly dominant, conventional wax-ups may continue to play a role in selected cases.

Several limitations must be acknowledged. The study was limited to fifty patients and conducted at a single institution, which may restrict generalizability. The focus on anterior esthetic cases further narrows applicability, as outcomes may differ in posterior or full-mouth rehabilitations. Patient satisfaction was assessed using a validated questionnaire, but qualitative methods such as interviews might have provided richer insights. In addition, the study did not evaluate long-term clinical outcomes such as durability and functional performance of restorations, which are essential for comprehensive assessment.

Future research should therefore expand to larger, multi-center randomized trials involving diverse populations. Longitudinal investigations are necessary to determine whether the advantages of DSD observed in planning and short-term satisfaction translate into sustained clinical and esthetic success over time. Emerging technologies, including artificial intelligence and augmented reality, may further enhance the capabilities of DSD, allowing for automated analysis and real-time patient simulations. Evaluating these innovations in controlled trials will be critical to shaping the future of digital prosthodontics.

In conclusion, this study demonstrated that Digital Smile Design provided superior accuracy, efficiency, reproducibility, and patient-centered outcomes compared with conventional wax-up. While wax-ups remain clinically relevant in certain contexts, digital workflows offer a more predictable and efficient approach that aligns with the demands of modern prosthodontic practice. The integration of DSD into routine treatment planning represents not only a technological advancement but also a paradigm shift toward patient-centered, collaborative dentistry.

5. Conclusion

The study showed that Digital Smile Design (DSD) has distinct advantages over traditional diagnostic wax-up for prosthodontic treatment planning. As far as precision is concerned, restorations designed with DSD showed mean deviations of 0.28 ± 0.15 mm for tooth width, 0.20 ± 0.10 mm for midline position, and 0.22 ± 0.12 mm for gingival margins, in contrast to 0.62 ± 0.21 mm, 0.54 ± 0.19 mm, and 0.47 ± 0.17 mm, respectively, in the wax-up group ($p < 0.001$). These findings emphasize the greater accuracy of digital workflows in converting planned results to clinical reality. Efficiency was also notably enhanced with DSD, taking 71.2 ± 9.6 minutes on average compared to 132.4 ± 12.8 minutes for wax-up ($p < 0.001$). Reproducibility also benefited DSD, with intraclass correlation coefficients always above 0.90, while those for wax-up ranged from 0.76 to 0.82. Patient satisfaction scores were supportive of these benefits. DSD yielded mean VAS ratings of 9.0 for esthetic satisfaction, 8.9 for understanding of treatment, and 9.1 for confidence in results, as opposed to 7.1, 7.4, and 7.0, respectively, for wax-up ($p < 0.001$). Feedback from the clinician and technician also preferred DSD with mention of easier ease of performance, better predictability, and better communication. DSD provides a more accurate, time-saving, reproducible, and patient-centered process than traditional wax-up. Although wax-ups continue to have limited applicability in certain situations, the inclusion of DSD in everyday practice is a major step forward for contemporary prosthodontics.

References

1. Jukić A. Functional aspects of esthetic fixed prosthodontic therapy.

2. Tsang E. *Influence of Diagnostic Wax-Up Method on Digital Implant Planning Position* (Master's thesis, The University of Texas School of Dentistry at Houston).
3. Abduo JT. Evaluation of virtual planning as a tool for prosthodontic treatment.
4. Masson E, Kumar A, Grigoriadis A, Destruhaut F, Nabet C, GALIBOURG A. Conventional vs. digital wax-up: a crossover study on accuracy and undergraduate student satisfaction. Digital Dentistry Journal. 2025 Mar 18:100003.
5. Alharkan HM. Integrating digital smile design into restorative Dentistry: A narrative review of the applications and benefits. The Saudi Dental Journal. 2024 Apr 1;36(4):561-7.
6. Lobo S, Argolinha I, Machado V, Botelho J, Rua J, Li J, et al. Advances in Digital Technologies in Dental Medicine: Enhancing Precision in Virtual Articulators. Journal of Clinical Medicine. 2025 Feb 23;14(5):1495.
7. Alaoffey AS, Asiri MA, Alhazmi TA, Alshetaiwi AA, Almobarak AM, Alqasir YH, et al. Digital dentistry: transforming diagnosis and treatment planning through CAD/CAM and 3D printing. Egyptian Journal of Chemistry. 2024 Dec 1.
8. JAYAN DP. CAST METAL RESTORATIONS.
9. Rivera M, Blatz MB. Leveraging Digital Smile Design Technology in Esthetic Restorative Dentistry. Compendium of Continuing Education in Dentistry (15488578). 2024 Nov 1;45(10).
10. Chisnoiu AM, Staicu AC, Kui A, Chisnoiu RM, Iacob S, Fluerașu M, et al. Smile Design and Treatment Planning-Conventional versus Digital Pilot Study. J Pers Med. 2023 Jun 21;13(7):1028. Doi: 10.3390/jpm13071028. PMID: 37511641; PMCID: PMC10381669.
11. Jain A, Bhushan P, Mahato M, Solanki BB, Dutta D, Hota S, et al. The Recent Use, Patient Satisfaction, and Advancement in Digital Smile Designing: A Systematic Review. Cureus. 2024 Jun 16;16(6):e62459. doi: 10.7759/cureus. 62459. PMID: 39022468; PMCID: PMC11251929.
12. Tatarciuc M, DIACONU-POPA D, CUDALB AM, VITALARIU A. STUDY ON THE BENEFITS OF USING DIAGNOSTIC WAX-UP IN DENTAL TREATMENT. The Medical-Surgical Journal. 2020 Jun 30;124(2):326-31.
13. Ebadollahi Novin M. *A multidisciplinary approach in the planning of complex oral rehabilitation* (Doctoral dissertation, University of Zagreb, School of Dental Medicine).
14. Buduru S, Manziuc M, Varga P, Buduru R, Balhuc S, Kui A, et al. Clinical comparative study between the classical and the digital wax-up and indirect mock-up. Medicine in Evolution. 2020 Mar 31;26(1):70-81.
15. Šimunović L, Čimić S, Meštrović S. Three-Dimensionally Printed Splints in Dentistry: A Comprehensive Review. Dentistry journal. 2025 Jul 10;13(7):312.
16. Meto A, Halilaj G. The Integration of Cone Beam Computed Tomography, Artificial Intelligence, Augmented Reality, and Virtual Reality in Dental Diagnostics, Surgical Planning, and Education: A Narrative Review. Applied Sciences. 2025 Jun 4;15(11):6308.
17. Joda T, Zitzmann NU. Personalized workflows in reconstructive dentistry—Current possibilities and future opportunities. Clinical Oral Investigations. 2022 Jun;26(6):4283-90.
18. Cervino G, Fiorillo L, Arzukanyan AV, Spagnuolo G, Cicciù M. Dental restorative digital workflow: digital smile design from aesthetic to function. Dentistry journal. 2019 Mar 28;7(2):30.
19. Att W, Witkowski S, Strub JR, editors. Digital workflow in reconstructive dentistry. Quintessenz Verlag; 2021 Feb 1.
20. Mohammadi AT, Mohammad Taheri SA, Karamouz M, Sarhaddi R. Rising Innovations: Revolutionary Medical and Dental Breakthroughs Revolutionizing the Healthcare Field. Nobel Sciences; 2024 Aug 1.
21. Farrell EH, Whistance RN, Phillips K, Morgan B, Savage K, Lewis V, et al. Systematic review and meta-analysis of audio-visual information aids for informed consent for invasive healthcare procedures in clinical practice. Patient Education and Counseling. 2014 Jan 1;94(1):20-32.
22. Al-Enezi FM, Alruwaili YS, Alruwaili HS, Alshammari AL, Alanazi AS, Daheshi MM, et al. Technological Advancements in Healthcare: Examining the Role of Digital Tools in Strengthening Interprofessional Collaboration Among Nursing, Radiology, Physiotherapy, Prosthetics, and Dental Practitioners. Journal of International Crisis and Risk Communication Research. 2024;7(S11):3103.
23. Oye E, Owen A. Revolutionary Advancements in CAD/CAM Systems: Transforming the Future of Dental Restoration.