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Integrated CBCT and Digital Intraoral Scanning for Precision Endodontic, Prosthetic, and Implant Treatment Planning

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ABSTRACT:

Background:

Digital integration of cone-beam computed tomography (CBCT) and intraoral scanning (IOS) has the potential to improve the precision and efficiency of multidisciplinary dental treatment planning. However, comparative evidence across endodontic, prosthetic, and implant applications remains limited.

Aim:

To compare treatment-planning efficiency and positional accuracy between a conventional workflow and an integrated CBCT–IOS digital workflow across endodontic, prosthetic, and implant treatment categories.

Materials and Methods:

This comparative study included 90 cases, equally divided between conventional and integrated CBCT–IOS workflows. Each workflow comprised 15 endodontic, 15 prosthetic, and 15 implant cases. Treatment-planning time was recorded for all cases. Endodontic accuracy was assessed using access trajectory and angular deviation, whereas prosthetic accuracy was evaluated using tooth-position, prosthetic margin, and occlusal discrepancies. Implant accuracy was determined from coronal, apical, depth, and angular deviations. Treatment-plan modifications following CBCT–IOS integration were also documented. Continuous variables were compared using independent-samples t-tests, with statistical significance established at probability (p) < 0.05.

Results:

The integrated workflow significantly reduced planning time in endodontic (11.2 ± 2.8

vs. 18.6 ± 4.2 minutes), prosthetic (17.1 ± 3.7 vs. 27.4 ± 5.6 minutes), and implant cases (20.3 ± 4.1 vs. 32.8 ± 6.4 minutes; all $p < 0.001$). Endodontic access trajectory deviation decreased from 0.82 ± 0.31 to 0.46 ± 0.18 mm and angular deviation from 7.24 ± 2.85° to 3.86 ± 1.62° (both $p < 0.001$). Prosthetic discrepancies were significantly lower with the integrated workflow for tooth position, margin position, and occlusion (all $p < 0.001$). Implant coronal, apical, depth, and angular deviations were also reduced, with statistically significant differences. Overall planning time decreased by 10.1 minutes (26.3 ± 7.8 vs. 16.2 ± 5.0 minutes; $p < 0.001$). Following CBCT–IOS integration, 11 of 90 cases (12.2%) required treatment-plan modification, with the highest proportion occurring in implant cases.

Conclusion:

Integration of CBCT and IOS substantially improved treatment-planning efficiency and spatial accuracy across endodontic, prosthetic, and implant applications. The findings support the use of an integrated digital workflow for more precise and streamlined multidisciplinary dental treatment planning.

INTRODUCTION

The increasing incorporation of digital technologies into dentistry has transformed the approach to diagnosis, treatment planning, and clinical execution. Conventional treatment planning frequently relies on separate sources of clinical, radiographic, and physical diagnostic information, which may require considerable time for interpretation and manual transfer. Although these approaches remain clinically useful, discrepancies between different records can complicate three-dimensional (3D) assessment and may limit the precision of treatment planning, particularly in anatomically complex cases [1].

Cone-beam computed tomography (CBCT) provides 3D visualization of dental and maxillofacial structures and allows assessment of root morphology, alveolar bone, anatomical limitations, and spatial relationships that cannot be adequately evaluated using conventional two-dimensional (2D) imaging [2]. However, CBCT primarily represents hard-tissue anatomy and may provide limited information regarding the detailed morphology of existing tooth surfaces, occlusal relationships, and soft-tissue contours. Intraoral scanners (IOS), in contrast, generate high-resolution digital surface models that can accurately reproduce dental morphology, arch form, and occlusal relationships. Integrating these complementary datasets may therefore provide a more comprehensive digital representation of the patient's clinical anatomy [3].

The combination of CBCT and IOS can be particularly valuable in endodontic, prosthetic, and implant treatment planning. In endodontics, 3D integration may facilitate identification of root canals and improve determination of access trajectories while minimizing unnecessary removal of tooth structure [4]. In prosthetic dentistry, superimposition of surface scans with 3D anatomical information may enhance tooth-position assessment, restoration design, margin localization, and occlusal planning [5]. In implant dentistry, combined datasets can facilitate evaluation of available bone, anatomical boundaries, prosthetic positioning, and the 3D relationship between the proposed implant and surrounding structures [6].

Despite the expanding application of digital dentistry, treatment-planning workflows are often evaluated within individual specialties rather than across multiple dental disciplines. Furthermore, improvements in planning efficiency and spatial accuracy associated with CBCT–IOS integration have not always been assessed using comparable quantitative parameters [7]. A comprehensive comparison across endodontic, prosthetic, and implant applications may therefore provide clinically relevant information regarding the practical advantages of integrated digital planning [8], [9].

The present study was designed to compare a conventional treatment-planning workflow with an integrated CBCT–IOS workflow across endodontic, prosthetic, and implant cases. The primary objectives were to evaluate differences in treatment-planning time and treatment-planning accuracy and to determine the frequency of treatment-plan modifications following integration of CBCT and IOS data. It was hypothesized that the integrated workflow would reduce planning time and improves spatial accuracy compared with the conventional approach.

MATERIALS AND METHODS

Study Design and Sample

A comparative observational study was conducted at a single tertiary care center over a period of 6 months, from July to December 2025, to evaluate the efficiency and accuracy of a conventional treatment-planning workflow compared with an integrated CBCT–IOS workflow. A total of 90 cases were included and equally distributed between the two treatment-planning approaches, with 45 cases (50.0%) assigned to the conventional workflow group and 45 cases (50.0%) to the integrated CBCT–IOS workflow group.

The study population was equally distributed among three treatment categories: endodontic, prosthetic, and implant cases, with 30 cases (33.3%) assigned to each category. Within each category, 15 cases were evaluated using the conventional workflow and 15 using the integrated CBCT–IOS workflow. This balanced allocation allowed comparison of planning efficiency and accuracy across different dental treatment applications.

Treatment-Planning Workflows

In the conventional workflow, treatment planning was performed using routinely available clinical records, conventional radiographic information, diagnostic models or impressions, and other standard diagnostic records appropriate to the treatment category. Planning was performed without integration of CBCT and IOS datasets.

For the integrated digital workflow, 3D CBCT datasets were combined with digital intraoral surface scans. The IOS datasets provided detailed information regarding tooth morphology, arch form, occlusal relationships, and surface anatomy, whereas CBCT provided 3D information regarding the underlying dental and maxillofacial structures. The datasets were superimposed within the digital planning environment to generate an integrated 3D representation for treatment planning.

The integrated dataset was subsequently used to assess treatment-specific anatomical relationships and to establish the proposed treatment position or trajectory. The same general planning objectives were applied to both workflows to permit direct comparison.

Endodontic Treatment Planning

30 endodontic cases were included, with 15 cases planned using the conventional workflow and 15 using the integrated CBCT–IOS workflow. Endodontic planning accuracy was assessed using access trajectory deviation and angular deviation.

Access trajectory deviation was measured in millimeters (mm) as the discrepancy between the planned and reference access trajectories. Angular deviation was expressed in degrees and represented the difference in angulation between the planned and reference trajectories. Treatment-planning time was recorded in minutes from initiation of the planning procedure until completion of the treatment plan.

Prosthetic Treatment Planning

30 prosthetic cases were evaluated, with equal allocation between the conventional and integrated workflows. Prosthetic planning accuracy was assessed using tooth-position discrepancy, prosthetic margin discrepancy, and occlusal discrepancy.

Tooth-position discrepancy was recorded as the linear difference between the planned and reference tooth positions. Prosthetic margin discrepancy represented the deviation between the planned and reference restorative margin locations. Occlusal discrepancy was assessed by measuring the difference between the planned and reference occlusal relationships. All linear measurements were recorded in mm.

Planning time was recorded in minutes for each prosthetic case and compared between the two workflows.

Implant Treatment Planning

30 implant cases were included, comprising 15 cases in each treatment-planning group. Implant planning accuracy was assessed using coronal deviation, apical deviation, depth deviation, and angular deviation.

Coronal and apical deviations were measured as the linear differences between the planned and reference implant positions at the corresponding implant levels. Depth deviation represented the difference in the planned and reference implant depth.

Angular deviation was measured in degrees and represented the discrepancy between the planned and reference implant axes. Treatment-planning time was recorded in minutes.

Assessment of Treatment-Plan Modification

For cases evaluated using the integrated CBCT–IOS workflow, the initial treatment plan was compared with the plan generated after integration of the CBCT and IOS datasets. Cases were classified into two categories: no modification required or treatment-plan modification required.

Modifications were documented separately for endodontic, prosthetic, and implant cases. The overall proportion of cases requiring modification was also calculated.

Outcome Measures

The primary outcomes were treatment-planning time and planning accuracy. Treatment-planning time was measured in minutes for each case. Accuracy was evaluated using treatment-specific quantitative parameters.

For endodontic cases, the primary accuracy variables were access trajectory and angular deviations. For prosthetic cases, tooth-position, prosthetic margin, and occlusal discrepancies were assessed. For implant cases, coronal, apical, depth, and angular deviations were recorded.

Secondary outcomes included the frequency and proportion of treatment plans modified following CBCT–IOS integration.

Statistical Analysis

Statistical analysis was conducted using the Statistical Package for the Social Sciences (SPSS), IBM SPSS Statistics version 26.0. Continuous variables were expressed as mean ± standard deviation (SD), whereas categorical variables were presented as frequencies and percentages. The normality of continuous variables was evaluated using the Shapiro–Wilk test. Variables demonstrating an approximately normal distribution were compared between the conventional and integrated CBCT–IOS workflow groups using the independent-samples t-test.

The principal outcome measures included treatment-planning time, access trajectory deviation, angular deviation, tooth-position discrepancy, prosthetic margin discrepancy, occlusal discrepancy, and implant positional deviations (coronal, apical, depth, and angular). Mean differences between the two workflows were calculated, with 95% confidence intervals (CIs) reported where applicable. Effect sizes were also considered to assess the magnitude of differences between the treatment-planning approaches. Statistical analyses were conducted separately for the endodontic, prosthetic, and implant categories, followed by an overall comparison of treatment-planning efficiency and accuracy. All statistical tests were two-tailed, and a p-value of <0.05 was considered indicative of statistical significance.

RESULTS

Table 1 & Figure 1 illustrate the distribution of the 90 study cases according to treatment category and treatment-planning workflow. The cases were evenly divided between the conventional and integrated CBCT–IOS groups, with 45 cases (50.0%) assigned to each workflow. Each treatment category comprised 30 cases (33.3%). The endodontic category included 15 cases (16.7%) managed using the conventional workflow and 15 cases (16.7%) planned using the integrated CBCT–IOS workflow. An identical distribution was observed for the 30 prosthetic cases, with 15 cases (16.7%) in each workflow. Likewise, the 30 implant cases were equally divided, with 15 cases (16.7%) assigned to the conventional workflow and 15 cases (16.7%) to the integrated CBCT–IOS workflow. Overall, the study population was uniformly distributed across all three treatment categories and between the two treatment-planning approaches, ensuring balanced representation for comparative analysis.

Table 1: Distribution of Cases According to Treatment Category

Treatment category	Conventional workflow n (%)	Integrated CBCT–IOS workflow n (%)	Total n (%)
Endodontic	15 (16.7)	15 (16.7)	30 (33.3)
Prosthetic	15 (16.7)	15 (16.7)	30 (33.3)
Implant	15 (16.7)	15 (16.7)	30 (33.3)
Total	45 (50.0)	45 (50.0)	90 (100.0)

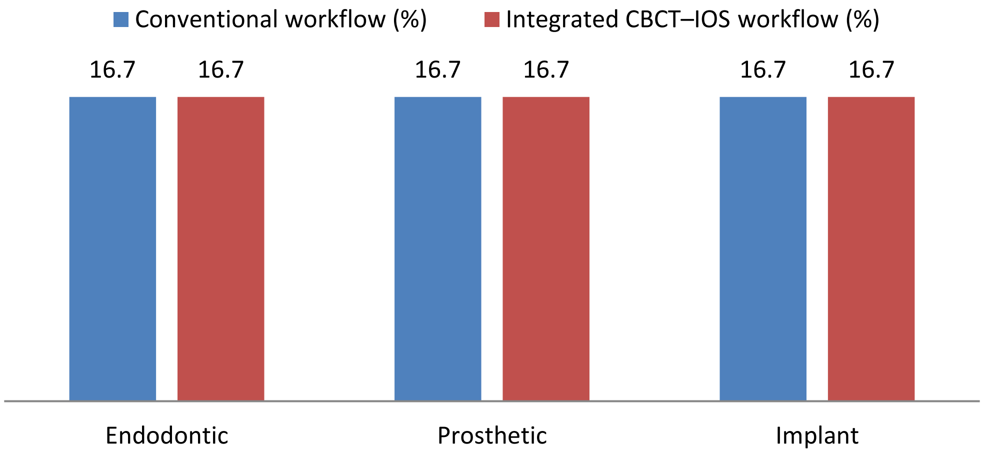

Figure 1: Distribution of Study Cases According to Treatment Category and Treatment-Planning Workflow

Table 2 & Figure 2 demonstrate a significant reduction in treatment-planning time with the integrated CBCT–IOS workflow across all three treatment categories. In endodontic cases, the mean planning time decreased from 18.6 ± 4.2 minutes with the conventional workflow to 11.2 ± 2.8 minutes with the integrated workflow, resulting in a reduction of 7.4 minutes ($p < 0.001$). For prosthetic cases, planning time was reduced from 27.4 ± 5.6 minutes to 17.1 ± 3.7 minutes, corresponding to a mean reduction of 10.3 minutes ($p < 0.001$).

The most pronounced improvement was observed in the implant group, where mean planning time decreased from 32.8 ± 6.4 minutes with the conventional approach to 20.3 ± 4.1 minutes with CBCT–IOS integration, representing a reduction of 12.5 minutes ($p < 0.001$). When all treatment categories were considered collectively, the mean planning time declined from 26.3 ± 7.8 minutes to 16.2 ± 5.0 minutes, yielding an overall reduction of 10.1 minutes ($p < 0.001$). These findings demonstrate that integrating CBCT with IOS significantly enhanced treatment-planning efficiency, with the greatest time-saving observed for implant planning.

Table 2: Comparison of Treatment-Planning Time Between Conventional and Integrated Digital Workflows

Treatment category	Conventional workflow Mean ± SD (min)	Integrated CBCT–IOS Mean ± SD (min)	Mean Difference (min)	p-value
Endodontic	18.6 ± 4.2	11.2 ± 2.8	7.4	<0.001
Prosthetic	27.4 ± 5.6	17.1 ± 3.7	10.3	<0.001
Implant	32.8 ± 6.4	20.3 ± 4.1	12.5	<0.001
Overall	26.3 ± 7.8	16.2 ± 5.0	10.1	<0.001

Independent-samples t-test; $p < 0.05$ considered statistically significant.

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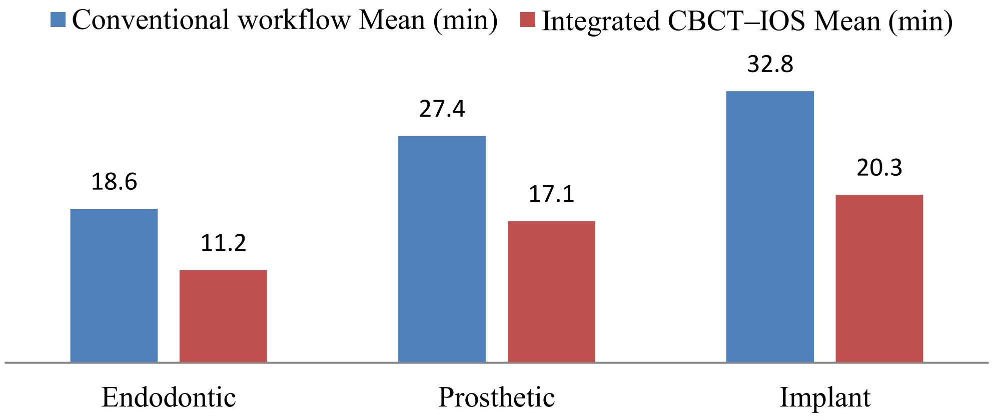

Figure 2: Comparison of Mean Treatment-Planning Time Between Conventional and Integrated CBCT–IOS Workflows Across Treatment Categories

Table 3 & Figure 3 demonstrate a significant improvement in endodontic treatment-planning accuracy with the integrated CBCT–IOS workflow. The access trajectory deviation was reduced from 0.82 ± 0.31 mm in the conventional group to 0.46 ± 0.18 mm with the integrated approach, representing a statistically significant improvement ($p < 0.001$). Similarly, angular deviation decreased substantially from 7.24 ± 2.85° to 3.86 ± 1.62° ($p < 0.001$).

In addition to improved spatial accuracy, the integrated workflow significantly enhanced planning efficiency. Mean treatment-planning time decreased from 18.6 ± 4.2 minutes with the conventional workflow to 11.2 ± 2.8 minutes with CBCT–IOS integration ($p < 0.001$). Overall, the findings indicate that integration of 3D radiographic and intraoral surface data provided greater precision in endodontic treatment planning while simultaneously reducing the time required for planning.

Table 3: Comparison of Endodontic Treatment-Planning Accuracy

Parameter	Conventional workflow Mean ± SD	Integrated CBCT–IOS Mean ± SD	Mean difference	p-value
Access trajectory deviation (mm)	0.82 ± 0.31	0.46 ± 0.18	0.36	<0.001
Angular deviation (°)	7.24 ± 2.85	3.86 ± 1.62	3.38	<0.001
Mean planning time (min)	18.6 ± 4.2	11.2 ± 2.8	7.4	<0.001

Independent-samples t-test; $p < 0.05$ considered statistically significant

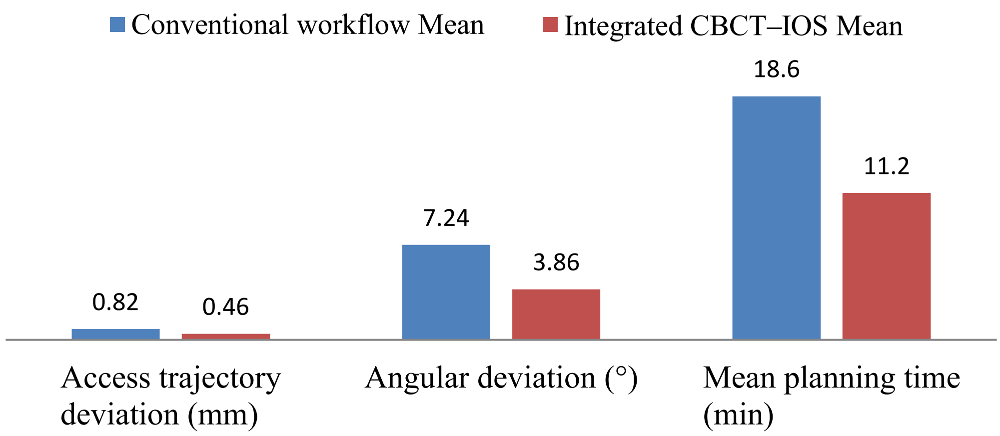

Figure 3: Comparison of Endodontic Treatment-Planning Accuracy and Planning Time Between Conventional and Integrated CBCT–IOS Workflows

Table 4 & Figure 4 demonstrate a significant improvement in prosthetic treatment-planning precision with the integrated CBCT–IOS workflow. The tooth-position discrepancy was reduced from 0.61 ± 0.24 mm with the conventional workflow to 0.34 ± 0.13 mm with the integrated approach. Similarly, the prosthetic margin discrepancy decreased from 0.48 ± 0.19 mm to 0.28 ± 0.11 mm, while occlusal discrepancy declined from 0.72 ± 0.28 mm to 0.39 ± 0.16 mm. All three accuracy parameters demonstrated statistically significant differences between the workflows ($p < 0.001$).

A substantial improvement was also observed in planning efficiency. The mean treatment-planning time decreased from 27.4 ± 5.6 minutes using the conventional workflow to 17.1 ± 3.7 minutes with CBCT–IOS integration, representing a reduction of 10.3 minutes ($p < 0.001$). Overall, the integrated digital approach provided significantly greater prosthetic planning accuracy while requiring less planning time.

Table 4: Comparison of Prosthetic Planning Accuracy

Parameter	Conventional workflow	Integrated CBCT–IOS	Mean difference	p-value
Tooth-position discrepancy (mm)	0.61 ± 0.24	0.34 ± 0.13	0.27	<0.001
Prosthetic margin discrepancy (mm)	0.48 ± 0.19	0.28 ± 0.11	0.20	<0.001
Occlusal discrepancy (mm)	0.72 ± 0.28	0.39 ± 0.16	0.33	<0.001
Mean planning time (min)	27.4 ± 5.6	17.1 ± 3.7	10.3	<0.001

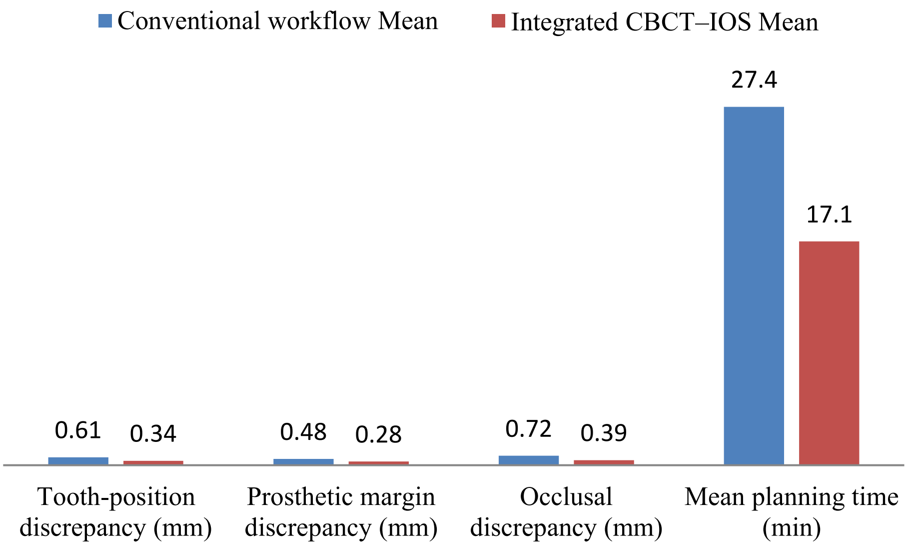

Figure 4: Comparison of Prosthetic Treatment-Planning Accuracy and Efficiency Between Conventional and Integrated CBCT–IOS Workflows

Table 5 & Figure 5 demonstrate that integration of CBCT and IOS significantly improved the precision and efficiency of implant treatment planning. Coronal deviation decreased from 1.06 ± 0.43 mm with the conventional workflow to 0.62 ± 0.25 mm with the integrated approach, while apical deviation was reduced from 1.54 ± 0.61 mm to 1.12 ± 0.48 mm. Similarly, depth deviation decreased from 0.71 ± 0.32 mm to 0.45 ± 0.21 mm. These differences were statistically significant ($p < 0.05$).

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A significant reduction was also observed in angular deviation, which declined from 6.18 ± 2.64° in the conventional group to 4.12 ± 1.86° with the integrated CBCT–IOS workflow ($p = 0.004$). Furthermore, mean treatment-planning time decreased substantially from 32.8 ± 6.4 minutes to 20.3 ± 4.1 minutes, representing a reduction of 12.5 minutes ($p < 0.001$). Overall, the findings indicate that CBCT–IOS integration enhanced both the 3D accuracy and time efficiency of implant treatment planning.

Table 5: Accuracy of Implant Positioning Using the Integrated Digital Workflow

Parameter	Conventional workflow	Integrated CBCT–IOS	Mean difference	p-value
Coronal deviation (mm)	1.06 ± 0.43	0.62 ± 0.25	0.44	<0.001
Apical deviation (mm)	1.54 ± 0.61	1.12 ± 0.48	0.42	0.012
Depth deviation (mm)	0.71 ± 0.32	0.45 ± 0.21	0.26	0.003
Angular deviation (°)	6.18 ± 2.64	4.12 ± 1.86	2.06	0.004
Planning time (min)	32.8 ± 6.4	20.3 ± 4.1	12.5	<0.001

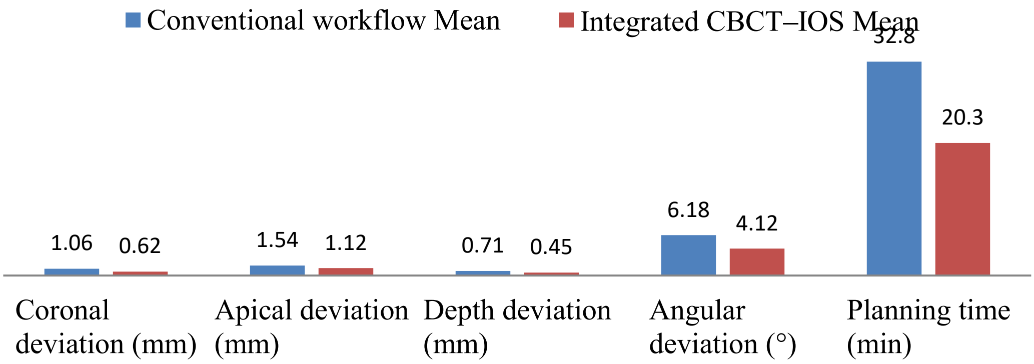

Figure 5: Comparison of Implant Positional Accuracy and Treatment-Planning Time Between Conventional and Integrated CBCT–IOS Workflows

Table 6 and Figure 6 summarize the changes observed in treatment plans after integration of CBCT and IOS data. Of the 90 cases, the initial treatment plan remained unchanged in 79 cases (87.8%), whereas 11 cases (12.2%) required modification after digital data integration. The frequency of modifications was 10.0% among endodontic cases and 10.0% among prosthetic cases. In comparison, 16.7% of implant cases required alterations to the original plan. Thus, implant cases demonstrated the highest rate of treatment-plan modification, suggesting that integration of 3D radiographic and intraoral surface information may have a greater influence on implant planning decisions.

Table 6: Treatment-Plan Modification Following CBCT–IOS Integration

Treatment category	Cases with no modification n (%)	Cases with modification n (%)	Total
Endodontic	27 (90.0)	3 (10.0)	30
Prosthetic	27 (90.0)	3 (10.0)	30

Implant	25 (83.3)	5 (16.7)	30
Total	79 (87.8)	11 (12.2)	90

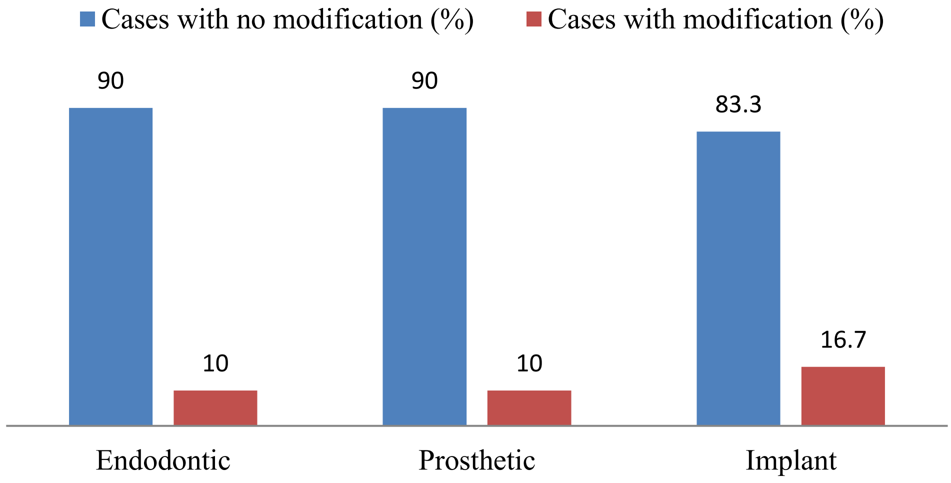

Figure 6: Distribution of Treatment-Plan Modifications Following Integration of CBCT and IOS Data Across Treatment Categories

DISCUSSION

The present study demonstrated that integration of CBCT with intraoral scanning significantly improved both the efficiency and accuracy of multidisciplinary dental treatment planning compared with the conventional workflow. Across endodontic, prosthetic, and implant cases, the integrated approach consistently reduced planning time and produced lower positional or geometric discrepancies. These findings support the concept that combining 3D radiographic information with high-resolution digital surface data can provide a more comprehensive basis for treatment planning.

In the endodontic group, integration of CBCT and IOS was associated with a marked reduction in access trajectory and angular deviations, together with a substantial decrease in planning time. Connert et al. (2022) [10] highlighted the expanding role of guided endodontics and emphasized that the integration of 3D imaging with digital surface information can facilitate more predictable access planning, particularly in anatomically challenging situations. Their discussion of guided endodontic workflows supports the present finding that digitally integrated planning can improve trajectory control while potentially reducing unnecessary removal of dental tissue. The lower deviations observed in the present study may therefore reflect the advantage of visualizing the intended access pathway within a combined 3D anatomical framework.

The reliability of the IOS component is also important when interpreting the present findings. Shah et al. (2023) [11] systematically evaluated the accuracy of digital impressions obtained using intraoral and extraoral scanning systems and demonstrated that digital scanning can provide clinically useful and accurate representations of dental structures, although accuracy may vary according to scanner characteristics, scanning protocols, and clinical conditions. Their findings provide a basis for using IOS data as a complementary surface dataset in integrated digital planning. In the present study, incorporation of IOS information alongside CBCT imaging allowed detailed dental surface morphology and occlusal relationships to be considered together with 3D anatomical structures.

The prosthetic findings further demonstrated significant reductions in tooth-position, prosthetic margin, and occlusal discrepancies following CBCT–IOS integration. These findings are consistent with the broader transition toward comprehensive digital workflows in fixed prosthodontics. Joda et al. (2017) [12] described the complete digital workflow as an increasingly integrated approach involving digital data acquisition, virtual planning, and computer-assisted clinical procedures. Their systematic review emphasized the potential of digital workflows to improve communication, standardization, and workflow efficiency. The improved prosthetic accuracy observed in the present investigation may similarly be attributed to the ability to evaluate multiple digital datasets within a unified planning environment rather than relying on independently interpreted records.

Occlusal planning represents another important application of IOS technology. Morsy and El Kateb (2024) [13] investigated the accuracy of intraoral scanners for static virtual articulation and reported that digital scanning can provide clinically relevant information for virtual articulation, although outcomes may be influenced by scanning and registration procedures. The significant reduction in occlusal discrepancy observed in the present study supports the clinical value of digital surface acquisition for evaluating occlusal relationships. Integration with CBCT may further strengthen this approach by providing simultaneous visualization of the underlying anatomical structures.

The present study also identified substantial improvements in implant planning. Coronal, apical, depth, and angular deviations were all lower with the integrated CBCT–IOS workflow, while implant planning time was reduced by 12.5 minutes. Tahmaseb et al. (2018) [14] reported that static computer-aided implant surgery provides improved positional accuracy compared with conventional freehand approaches, although deviations can occur at different levels of implant positioning. Their systematic review and meta-analysis emphasized the importance of accurate 3D planning and guided transfer of the planned implant position. The present findings extend this concept by demonstrating that integration of CBCT and IOS at the planning stage may enhance the spatial assessment of implant position while simultaneously improving planning efficiency.

The greater reduction in planning time observed for implant cases may be explained by the complexity of implant treatment planning, which requires simultaneous consideration of available bone, anatomical structures, prosthetic positioning, implant angulation, and depth. A digitally integrated CBCT–IOS dataset allows these parameters to be assessed within a common 3D framework, potentially reducing the need to alternate between separate diagnostic records. This interpretation is also supported by Siqueira et al. (2021) [15], who reported that intraoral scanning can reduce procedure-related time and improve patient comfort in fixed prosthodontic and implant-related workflows. Although their review evaluated broader clinical workflows rather than the specific planning-time endpoint used in the present study, their findings reinforce the efficiency advantages associated with digital scanning.

The present study also demonstrated that 12.2% of cases required modification of the initial treatment plan following CBCT–IOS integration. Implant cases showed the highest modification rate (16.7%), compared with 10.0% for both endodontic and prosthetic cases. This finding is clinically relevant because treatment-plan modification does not necessarily indicate failure of the initial planning process. Rather, it may reflect the additional diagnostic information revealed through 3D data integration. In implant dentistry, small changes in available bone, anatomical boundaries, prosthetic positioning, or implant angulation may influence the final treatment strategy. The higher modification rate in implant cases therefore suggests that integrated digital assessment may have greater decision-making value in procedures requiring precise 3D spatial planning.

The findings are also consistent with the concept of a complete digital workflow proposed by Joda et al. (2017) [12], in which digital acquisition, virtual planning, and clinical execution are increasingly interconnected. Similarly, Shah et al. (2023) [11] emphasized the importance of the accuracy of digital impressions in determining the reliability of downstream digital procedures. Thus, the effectiveness of CBCT–IOS integration depends not only on the availability of digital technologies but also on the quality of image acquisition, dataset registration, and interpretation.

From a clinical perspective, the results suggest that CBCT–IOS integration may be particularly beneficial when treatment planning requires simultaneous evaluation of hard-tissue anatomy, dental surface morphology, occlusion, and planned treatment position. The reduction in planning time across all three treatment categories indicates an efficiency advantage, whereas the reductions in positional and angular discrepancies suggest improved spatial precision. Nevertheless, these benefits should be interpreted within the context of appropriate case selection, operator expertise, imaging quality, and accurate digital registration.

Overall, the findings indicate that CBCT–IOS integration represents a potentially valuable component of contemporary digital dentistry. The combination of 3D radiographic imaging and digital intraoral surface data may facilitate more accurate, efficient, and coordinated planning across multiple specialties. Further prospective multicenter studies with larger samples and long-term clinical outcomes are warranted to determine whether the improvements in digital planning accuracy observed in the present study translate into measurable improvements in treatment outcomes, procedural predictability, and patient satisfaction.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the sample consisted of 90 cases, with 15 cases per workflow within each treatment category. Although this distribution allowed balanced comparison between groups, the relatively limited sample size may restrict the statistical power and generalizability of the findings. Larger studies involving multiple centers and a greater number of cases would provide stronger evidence.

Second, the study evaluated three broad treatment categories, but the clinical complexity within each category may have varied. Differences in tooth morphology, anatomical conditions, prosthetic requirements, and implant site characteristics could potentially influence both planning time and accuracy. Stratification according to case complexity would help determine whether the benefits of CBCT–IOS integration remain consistent across simple and complex cases.

Third, the comparison focused primarily on treatment-planning parameters rather than long-term clinical outcomes. Improved digital planning accuracy does not necessarily translate directly into superior treatment outcomes, reduced complications, or improved patient satisfaction. Future prospective studies should therefore assess postoperative accuracy, clinical complications, treatment duration, restoration performance, and patient-reported outcomes.

Fourth, the study relied on measurements of positional and geometric discrepancies as indicators of planning accuracy. Although these parameters provide objective quantitative information, they may not encompass all clinically relevant aspects of treatment quality. Assessment by independent clinicians or incorporation of validated clinical outcome measures could provide additional perspectives.

Finally, the analysis primarily used independent-samples t-tests for between-group comparisons. Future investigations with larger datasets could incorporate multivariable statistical models to account for potential confounding factors such as case complexity, operator experience, anatomical characteristics, and treatment modality. Prospective randomized or multicenter studies would further strengthen the evidence regarding the clinical effectiveness and reproducibility of integrated CBCT–IOS workflows.

CONCLUSION

Integration of CBCT and IOS significantly enhanced the efficiency and accuracy of digital treatment planning across endodontic, prosthetic, and implant applications. The integrated workflow consistently reduced treatment-planning time and produced lower deviations in endodontic access trajectories, prosthetic positioning and occlusal parameters, and implant positioning compared with the conventional workflow. The greatest reduction in planning time was observed in implant cases, while implant cases also demonstrated the highest frequency of treatment-plan modifications after digital data integration.

Overall, these findings suggest that combining 3D radiographic information with high-resolution intraoral surface data can provide a more comprehensive basis for multidisciplinary dental treatment planning. The integrated CBCT–IOS approach may therefore represent a valuable digital workflow for improving planning precision, efficiency, and clinical decision-making. Larger prospective and multicenter investigations incorporating long-term clinical outcomes are warranted to confirm these advantages and establish their broader applicability in routine dental practice.

Conflicts of Interest: Nil

Financial Support: None

REFERENCES

[1] Abduo J, Elseyoufi M. Accuracy of Intraoral Scanners: A Systematic Review of Influencing Factors. Eur J Prosthodont Restor Dent. 2018 Aug 30;26(3):101-121. doi: 10.1922/EJPRD_01752Abduo21. PMID: 29989757.

[2] Special Committee to Revise the Joint AAE/AAOMR Position Statement on use of CBCT in Endodontics. AAE and AAOMR Joint Position Statement: Use of Cone Beam Computed Tomography in Endodontics 2015 Update. Oral Surg

Oral Med Oral Pathol Oral Radiol. 2015 Oct;120(4):508-12. doi: 10.1016/j.oooo.2015.07.033. Epub 2015 Aug 3. PMID: 26346911.

[3] Fokas G, Vaughn VM, Scarfe WC, Bornstein MM. Accuracy of linear measurements on CBCT images related to presurgical implant treatment planning: A systematic review. Clin Oral Implants Res. 2018 Oct;29 Suppl 16:393-415. doi: 10.1111/clr.13142. PMID: 30328204.

[4] Shah N, Thakur M, Gill S, Shetty O, Alqahtani NM, Al-Qarni MA, Alqahtani SM, Elagib MFA, Chaturvedi S. Validation of Digital Impressions' Accuracy Obtained Using Intraoral and Extraoral Scanners: A Systematic Review. J Clin Med. 2023 Sep 8;12(18):5833. doi: 10.3390/jcm12185833. PMID: 37762774; PMCID: PMC10532392.

[5] Joda T, Zarone F, Ferrari M. The complete digital workflow in fixed prosthodontics: a systematic review. BMC Oral Health. 2017 Sep 19;17(1):124. doi: 10.1186/s12903-017-0415-0. PMID: 28927393; PMCID: PMC5606018.

[6] Siqueira R, Galli M, Chen Z, Mendonça G, Meirelles L, Wang HL, Chan HL. Intraoral scanning reduces procedure time and improves patient comfort in fixed prosthodontics and implant dentistry: a systematic review. Clin Oral Investig. 2021 Dec;25(12):6517-6531. doi: 10.1007/s00784-021-04157-3. Epub 2021 Sep 27. PMID: 34568955; PMCID: PMC8475874.

[7] Tahmaseb A, Wu V, Wismeijer D, Coucke W, Evans C. The accuracy of static computer-aided implant surgery: A systematic review and meta-analysis. Clin Oral Implants Res. 2018 Oct;29 Suppl 16:416-435. doi: 10.1111/clr.13346. PMID: 30328191.

[8] Bernauer SA, Zitzmann NU, Joda T. The Complete Digital Workflow in Fixed Prosthodontics Updated: A Systematic Review. Healthcare (Basel). 2023 Feb 25;11(5):679. doi: 10.3390/healthcare11050679. PMID: 36900684; PMCID: PMC10001159.

[9] Wadhawan R, Kumari C, Bain P, Bansal D, Ngairangbam J, Kumari N. Leading-edge developments in guided endodontics: utilizing next-generation tools. Quest J Med Dent Sci Res. 2024;11(9):30-42. doi:10.35629/076X-11093042.

[10] Connert T, Weiger R, Krastl G. Present status and future directions - Guided endodontics. Int Endod J. 2022 Oct;55 Suppl 4(Suppl 4):995-1002. doi: 10.1111/iej.13687. Epub 2022 Feb 4. PMID: 35075661; PMCID: PMC9790195.

[11] Shah N, Thakur M, Gill S, Shetty O, Alqahtani NM, Al-Qarni MA, et al. Validation of digital impressions' accuracy obtained using intraoral and extraoral scanners: a systematic review. *J Clin Med.* 2023;12(18):5833. doi:10.3390/jcm12185833. PMID: 37762774.

[12] Joda T, Zarone F, Ferrari M. The complete digital workflow in fixed prosthodontics: a systematic review. BMC Oral Health. 2017 Sep 19;17(1):124. doi: 10.1186/s12903-017-0415-0. PMID: 28927393; PMCID: PMC5606018.

[13] Morsy N, El Kateb M. Accuracy of intraoral scanners for static virtual articulation: a systematic review and meta-analysis of multiple outcomes. *J Prosthet Dent.* 2024;132(3):546-552. doi:10.1016/j.prosdent.2022.09.005. PMID: 36333175.

[14] Tahmaseb A, Wu V, Wismeijer D, Coucke W, Evans C. The accuracy of static computer-aided implant surgery: A systematic review and meta-analysis. Clin Oral Implants Res. 2018 Oct;29 Suppl 16:416-435. doi: 10.1111/clr.13346. PMID: 30328191.

[15] Siqueira R, Galli M, Chen Z, Mendonça G, Meirelles L, Wang HL, Chan HL. Intraoral scanning reduces procedure time and improves patient comfort in fixed prosthodontics and implant dentistry: a systematic review. Clin Oral Investig. 2021 Dec;25(12):6517-6531. doi: 10.1007/s00784-021-04157-3. Epub 2021 Sep 27. PMID: 34568955; PMCID: PMC8475874.