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Review Article

EVOLUTION OF INTRAORAL SCANNERS-A QUICK OVERVIEW

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ABSTRACT

Intraoral scanners play an increasingly essential role in modern orthodontic workflow by replacing the conventional impression material with this advanced imaging system that provides highly accurate details and is comfortable for the patients. Further evolution of these devices brings continuous innovation in the hardware and software domains, providing improved image precision, real-time processing, seamless integration with computer-aided design and manufacturing systems. With recent advancements in AI, it enables automatic data stitching, noise reduction, enhanced colour mapping, and also contribute to better diagnostic accuracy and clinical Efficiency. The combination of IOS datasets with cone beam computed tomography [CBCT]. And 3D facial imaging which enhance their clinical applications other than impression capture range to comprehensive digital orthodontic diagnosis, appliance design, and treatment monitoring. This review will present an in-depth look into the current state of affairs regarding developments in IOS technology and orthodontic appliances. It also discusses in detail the comparative performances with existing scanner systems and recognizes their advantages and limitations, and discusses various future developments such as AI-assisted scanning, augmented reality incorporation, tele orthodontic systems that promise to redefine digital orthodontic practice in the years to come.

Keywords: Intraoral Scanner, Orthodontics, CAD/CAM, Digital Impressions, Artificial Intelligence, 3D printing.

INTRODUCTION

The integration of IOS into orthodontic practice was one of the most significant technological milestones in modern dentistry. Traditional impression technique is often commonly associated with patient discomfort, material distortion, dimensional inaccuracies, time consuming laboratory steps (Radi *et al*.,2023). As clinical demands shift towards digital precision and efficiency, IOS become preferred alternatives by offering rapid, accurate, and reproducible optical impression (Eggmann *et al*.,2024). An IOS device usually function as digital imaging device which captures the geometry of dental and gingival surfaces using non-contact optical technology. The captured data then processed into 3D digital model that can be stored, analysed, and transferred within a minute (Mangano *et al*., 2016). Comparing with traditional methods, this process provides more stable foundation for diagnosis and treatment planning by eliminates errors that are associated with impression material shrinkage or plaster model expansion (Ender *et al*.,2013). over the last decade, refinement of IOS hardware, sensor reduction, data processing algorithm that led to constant improvement in accuracy, speed, colour reproduction (Flugge *et al*.,2018). Advanced scanning systems employ parallel confocal microscopy, active wavefront sampling, structured light projection to acquire high quality surface images. The technology upgrades enable seamless integration of IOS into computer-aided design and computer aided manufacturing (CAD/CAM) workflows which will enhance the fabrication of orthodontic appliance such as aligners, retainers, and indirect bonding tray. Beyond impression capture, IOSs have redefined digital diagnostics and Interdisciplinary collaboration. Also, IOS ability in integrating with CBCT and 3D facial scans enables clinicians to visualize the craniofacial complex linking skeletal, dental, and soft tissue structures in one digital data set, therefore improving diagnostic precision, and allows

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advanced treatment that includes orthognathic planning and smile designing (Figure 1).

WORKING PRINCIPLE OF INTRAORAL SCANNER

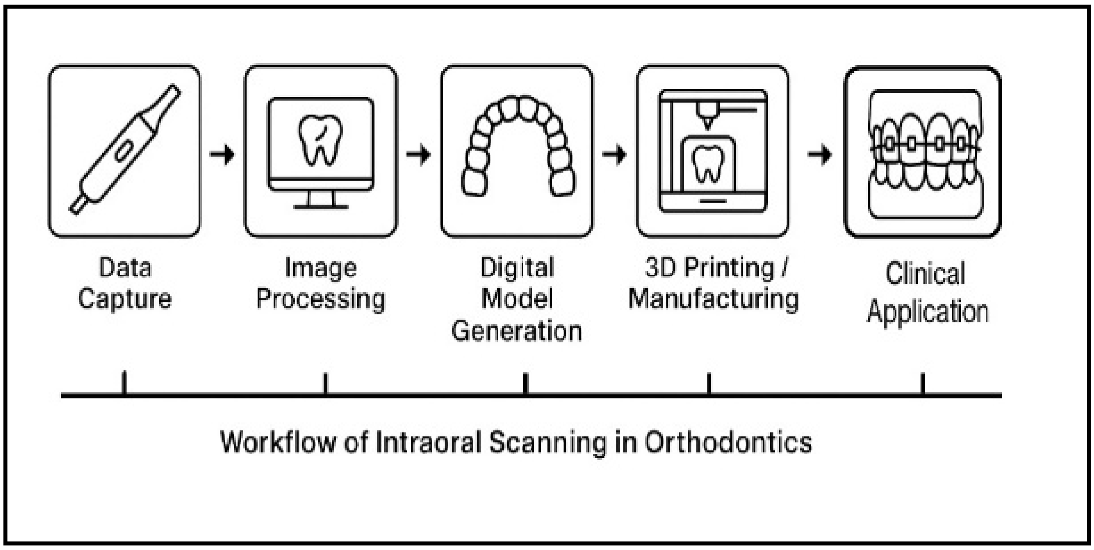


Figure 1. Workflow of intraoral scanning in orthodontics, from optical data acquisition and image processing to the generation of digital models, appliance design, 3D printing, and clinical application.

IOS functions by capturing optical impressions of the dental arches and surrounding soft tissue with help of advanced imaging technologies which translate light reflection into 3D virtual models. The fundamental principle of IOS operates by projecting a structured light or laser beam onto the tooth surface and recording its reflection through a high-resolution sensor. The captured data points referred to as point cloud then processed by integrated software algorithms to reconstruct the topography of the scanned area with micrometre-level precision (Flugge *et al*.,2018). different scanning system has distinct optical principles to achieve this objective. Confocal microscopy, which is used by the system such as TRIOS series, by capturing the images at multiple focal depths thereby producing highly detailed 3D surface data with minimal distortion (Mangano *et al*.,2016). In Planmeca Emerald S, structured light projection is used by projects a series of patterned light stripes onto the teeth, deformation of these patterns provides information on geometry of the scanned surfaces (Ender *et al*.,2013). In Medit i700 scanner, active wave front sampling imaging method is integrated, which allows rapid image capture with minimal motion-induced artifacts, this is particularly suitable for full arch scans (Jindanil *et al*.,2025). The quality of the digital scan is influenced by three parameters, such as trueness, precision, resolution. Trueness refers to how accurately the scan represents actual geometry of the object, while precision measures the reproducibility of the scans under identical condition (Eggmann *et al*.,2024). Resolution refers the level of surface detail the scanner can capture which directly affects the texture mapping and margin accuracy (van der Meer *et al*.,2012). These factors are determined not only by optical system but also by scanning strategy, operator skills and reflectivity of the scanned surface (Imburgia *et al*.,2017). Once the optical data are collected, specialized algorithms will align the multiple images using pattern recognition technique called image stitching. Early generation scanner requires a manual alignment that are prone to cumulative error, particularly in full arch scanning. Modern devices use AI assisted algorithms to automatically detect overlaps and eliminates redundant data thereby increasing accuracy as well as the scanning speed. The final scan output converted into standardized 3D file format, typically STL [Standard Tessellation Language], OBJ or PLY. STL is widely used because of its compatibility with all CAD/CAM systems. These files can be directly imported into orthodontics design software for appliance creation such as aligners, retainers, indirect bonding trays. Modern IOS when combined with CBCT and 3D facial surface scans, it creates a multi-layered digital patient model that merges skeletal, dental, soft tissue components into single coordinate system (Zehnder *et al*.,2016).This fusion enables clinicians to perform precise diagnostic evaluations, simulates orthodontic movements and visualize facial outcomes in real times (Jindanil *et al*.,2025). Emerging systems utilize cloud-based storage and real-time rendering, allowing instant transfer of digital impressions to laboratories or remote clinicians for review (Almoammar *et al*.,2024). This feature not only reduces turnaround time and also supports the growing field of tele-orthodontics (Figure 2).

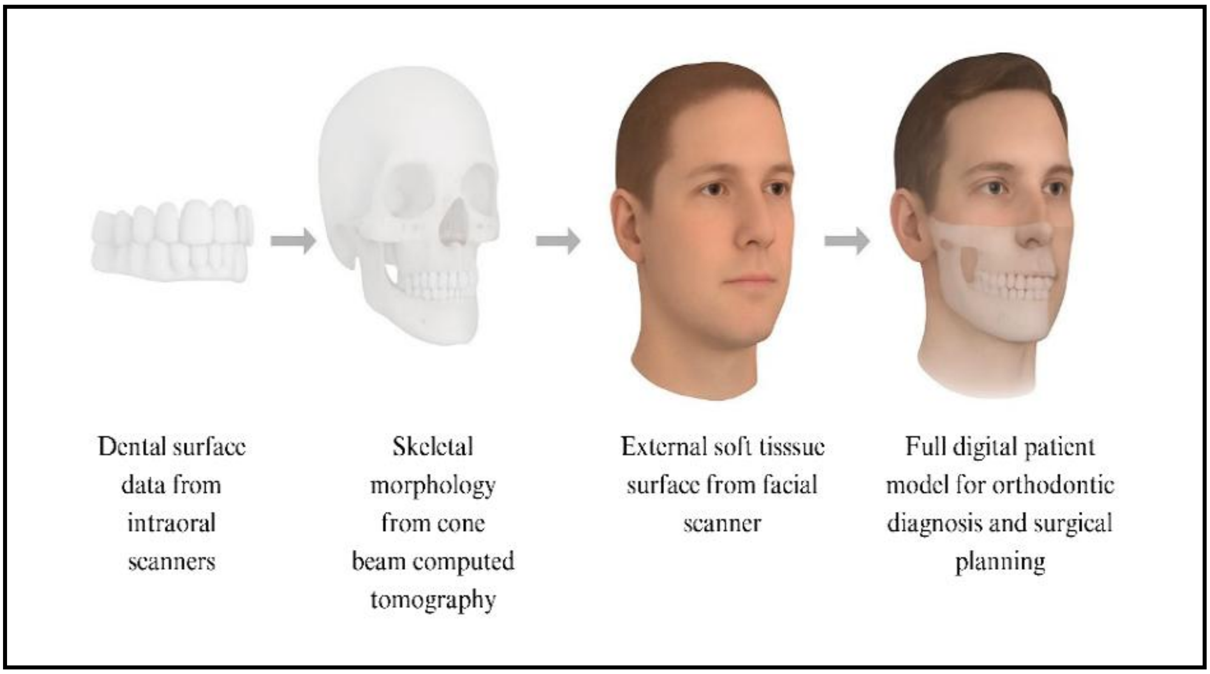


Figure 2. Integration of intraoral scanner data with CBCT and 3D facial scans for comprehensive orthodontic assessment.

CLINICAL APPLICATIONS OF IOS IN ORTHODONTICS

Figure 3 Shows IOS adoption in orthodontics has also expanded beyond the purpose of impression replacement. Now they serve as diagnostic, planning, and Monitoring tools. The ability to instantly generate accurate, colour-true digital models enhances workflow efficiency, interprofessional collaboration, patient engagement (Eggmann *et al*.,2024).

Digital Impressions and Diagnostic Records

Digital impressions are the most common applications of IOS in orthodontics. Clinicians can obtain precise virtual replica of the dental arches with greater comfort by eliminating conventional impression materials such as alginate or polyvinyl siloxane (Abdou *et al*.,2018). The accuracy of digital impressions ensures reliability of measurements such as arch length, tooth size, Bolton ratios, thereby improving diagnostic reproducibility (Ender *et al*.,2013). And also, digital impression can be immediately shared with laboratories through cloud-based systems (Revilla-Leon *et al*.,2019).

Treatment Planning and Appliance Fabrication

IOS data are directly integrated into orthodontic CAD/CAM systems to support digital treatment planning. Virtual setups allow clinicians to simulate tooth movement, design arch wires, and fabrication of custom appliances such as aligners, retainers (Flugge *et al*.,2018). Many commercial aligner systems such as Invisalign and ClearCorrect, primarily rely on IOS datasets for initial case planning (Radi *et al*.,2023). In indirect bonding procedures can be digitally designed with brackets virtually positioned on 3D models and accurately fits to the patient's using 3D printed trays (Alkhamees *et al*.,2024). This digital workflow reduces the chairside time, minimizes human errors and enhances the reproducibility of bracket placement compared with conventional methods (Jindanil *et al*.,2025).

Treatment Monitoring and Progress Evaluation

Sequential IOS are important tools to monitor tooth movement during active treatment. Superimposition of serial datasets allows the clinician to visualize positional changes of teeth; assess stability of anchorage and monitor treatment progress without additional radiographic exposure (Li *et al*.,2022). Digital overlays help in the identification of unwanted rotations or torque loss of the teeth at an early stage, thereby timely interventions. The ability to display real-time 3D models raises patient understanding of the treatment and improves compliance (Siqueira *et al*.,2021). Some studies have reported that patients' perception of digital scanning is more comfortable, less invasive, and faster compared with traditional methods (Abduo *et al*.,2018).

Integration with CBCT And Facial Scans

The integration of IOS data with CBCT and facial surface imaging has it transformed orthodontic diagnosis into a holistic, data-driven process. By aligning dental, skeletal, soft tissue structures, clinicians can carry out precise smile designing and facial harmony analysis. Such multi-modal datasets enhance inter-disciplinary communications between orthodontics, oral surgeon and prosthodontists during complex treatment planning (Jindanil *et al*.,2025). And also supports advanced applications such as orthognathic surgery planning and virtual patient modelling (Yao *et al*.,2023). The availability of high-resolution colour scans allows for the analysis of gingival and mucosal conditions, making IOS useful not only for orthodontics but also for periodontal assessment (Mangano *et al*.,2016).

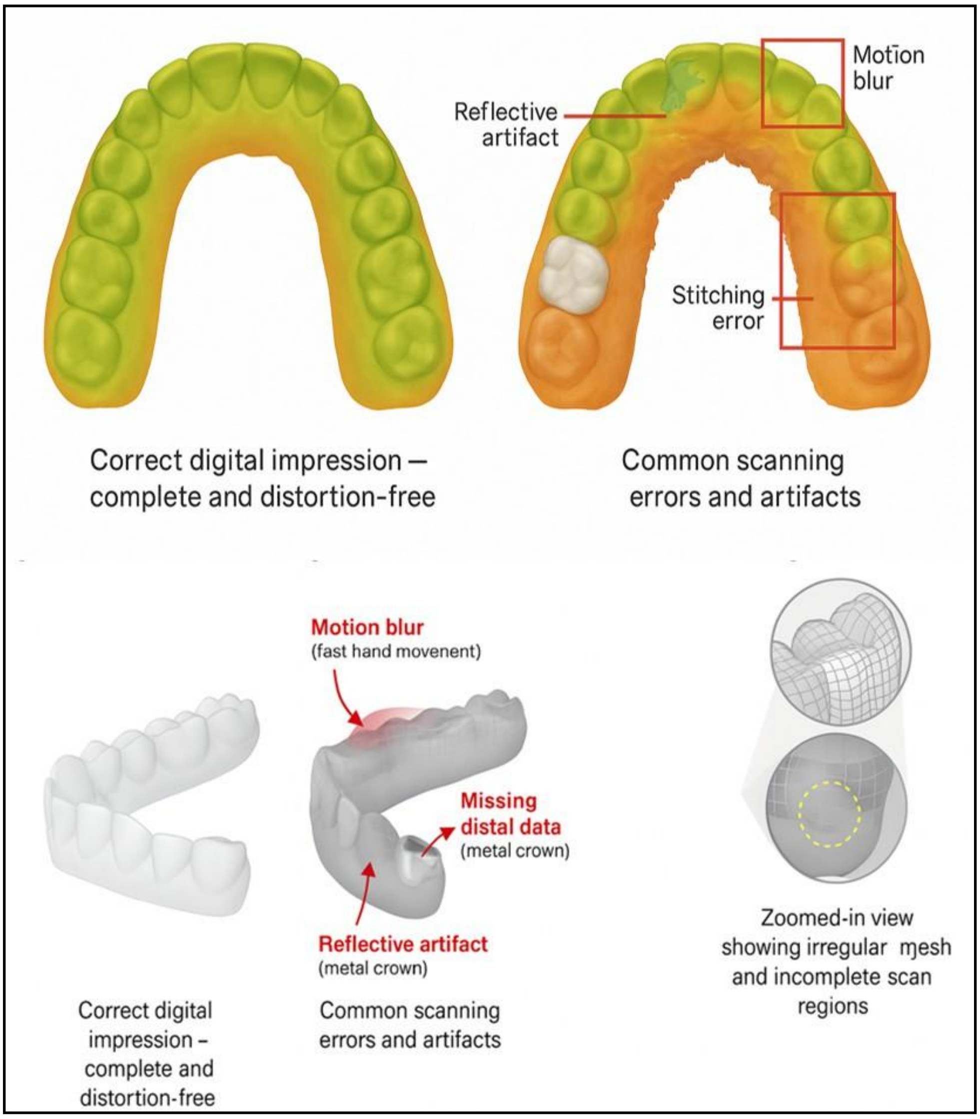


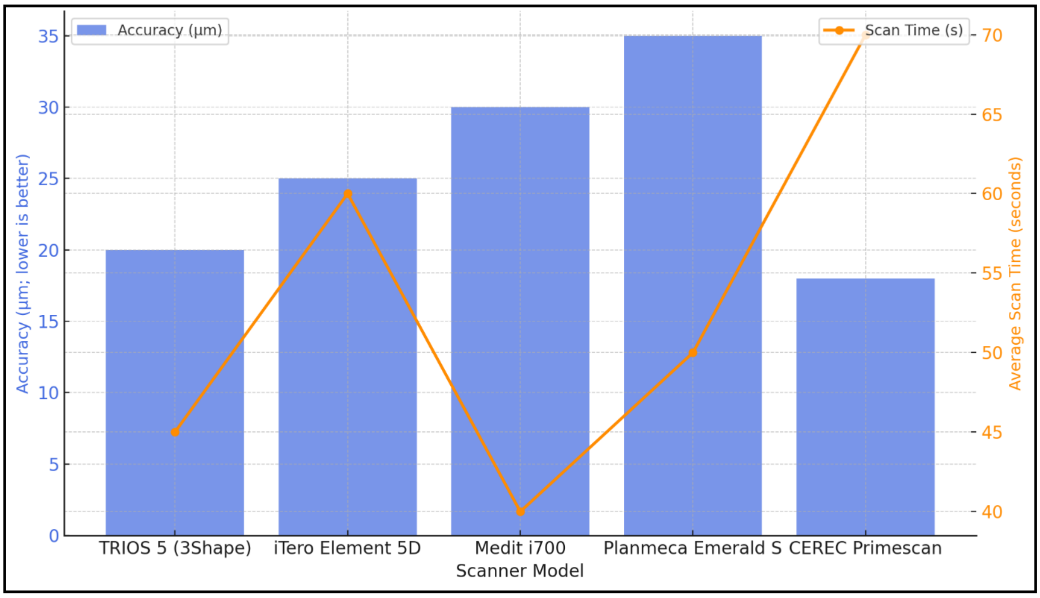
Figure 3. Some common scanning errors and artifacts showing motion blur, incomplete data, and reflective glare illustrate the importance of calibration, scanning strategy, and operator training.

COMPARATIVE EVALUATION OF IOS

These are the most important features of IOS evaluation that depend on its accuracy, precision, scanning speed, and clinical usability. These are directly influencing diagnostic reliability and overall treatment efficiency in orthodontics workflow.

Accuracy and Precision

The accuracy refers to trueness as well as precision. Trueness measures how closely the digital scan corresponds to the actual geometry of scanned object, precision refers to the reproducibility of the scans under identical condition (Ender *et al*.,2013). Modern IOS has high trueness values ranging from 15-40 µm, depending on scanning technology, arch length, and operator technique (Eggmann *et al*.,2024). Comparative studies show CEREC Primescan and TRIOS 5 (3Shape) has the highest trueness value of 18-20 µm showing the advanced confocal imaging and data reconstruction capacities (Flugge *et al*.,2018). Medit i700 and Planmeca Emerald S shows slightly lower trueness value of 30-35 µm but this performs more faster in full arch scanning (Mangano *et al*.,2016).



Graph 1. Relationship between scan accuracy and average scan time across popular intraoral scanners.

Blue bars represent accuracy (µm; lower values mean higher precision), while the orange line represents average scan time in seconds. Interpretation: Graph The chart shows that the relationship of scan speed versus precision is inverse. High-accuracy scanners, such as Primescan and TRIOS 5, need longer scanning times, whereas systems like Medit i700 and Planmeca Emerald S provide faster scanning at marginally reduced accuracy.

Scanning Speed and Workflow Efficiency

For clinical acceptance of IOS speed plays an important role. Systems such as Medit i700 and iTero Element 5D uses active wavefront sampling and AI assisted alignment to enhance scanning speed without any loss of details (Li *et al.*,2022). A full arch can be now completed within 40-70 seconds, depending on the operator's technique and the scanning path used (Al-Hassiny *et al.*,2023). In TRIOS 5 device lighter handpieces, touchscreen integration, and wireless connectivity has improved the operator comfort and reduced fatigue during extended use (Abdou *et al.*,2018). Synchronization with cloud increases workflow by allowing data transfer to dental laboratories with reduced manual error (Joda *et al.*,2017) (Table 1 & 2).

Table 1. Comparison of leading IOS and their advantages.

Scan Model	Manufacturer	Optical Technology	Colour Capture	Average Accuracy (µm)	Average Scan Time (S)	Advantages
TRIOS 5	3Shape [Denmark]	Confocal microscopy	True colour [HD]	20	45	Mostly used for full-arch scanning and restorative use
iTero Element 5D	Align technology [USA]	Parallel confocal imaging	True colour=Nearer Infrared Imaging	25	60	Caries detection by NIRI, mostly used in orthodontics aligners
Medit i700	Medit corp. [KOREA]	Active wavefront sampling	Full colour	30	40	Fastest scan speed, lightweight, open source for CAD/CAM compatibility
Planmeca Emerald S	Planmeca [FINLAND]	Structured light projection	RGB colour	35	50	Human engineered design, it can be used for everyday scanning

CEREC Primescan	Dentsply Sirona [GERMANY]	High- frequency structured light	True colour	18	70	More trueness and detail than expected. It can be used for prosthodontic and implant cases

Table 2. Advantages of intraoral scanners vs Traditional impressions.

Parameter	Traditional Impressions	Intraoral Scanners	Clinical Significance
Accuracy and reproducibility	Results in material distortion, expansion, shrinkage	High trueness, precision, digital reproducibility	Ensure consistent data for diagnosis and appliance fabrication
Patient comfort	Causes gag reflex, discomfort, breathing difficulty	Highly comfortable because of no impression trays and no materials required	Patients experience improved because of reduced gagging
Time efficiency	Time consuming for mixing, setting, disinfection, model pouring and fabrication	Instant digital capture and cloud transfer	Reduces chairside and lab time
Data storage	Need for physical model storage which has high risk of damage	Digital files will be stored in cloud or system	Enables easy retrieval and reprinting
Communication with lab	Manual model transport chance for damage	Direct file sharing via CAD/CAM software	Faster and error free collaboration with lab
Environmental impact	Disposable of used trays, alginate, plaster	Material free workflow	Promotes eco-friendly dentistry
Post processing	It requires casting, trimming, and disinfection	Direct Standard Tessellation Language or Polygon File Format output ready for CAD	Simplifies clinical work
Cross compatibility	Only limited reuse of the models	Used in multiple CAD/CAM platforms	Increases treatment versality

Clinical Usability and Patient Perception

From the patient's point of view, IOS is more comfortable and with a reduced gag reflex compared to conventional methods of impression (Siqueira *et al*.,2021). Besides, digital scanning reduces contamination risk, and there is no need for disinfecting the impression tray (Almoammar *et al*.,2024). Digital models can be used to educate the patient wherein clinicians can visualize malocclusion, simulate corrections, and explain the treatment objectives in reality time by using 3D scans (Jindanil *et al*.,2025). This type of approach usually promotes patient satisfaction and compliance during treatment (Abduo *et al*.,2018).

Technological Advancements and Future Perspectives

Modern scanners represent the intelligent diagnostic hub that integrates with AI, cloud computing, additive manufacturing, and augmented reality visualization. These innovations are redefining orthodontic workflows, shifting clinical practice to data-driven precision and remote care models (Eggmann *et al*.,2024) (Figure 4).

Artificial Intelligence and Machine Learning Integration

Machine learning algorithms will identify tooth margins themselves and remove unnecessary soft tissue data and correct artifacts in real time (Li *et al*.,2022). Deep learning networks have learned to detect scan inconsistencies and improve stitching accuracy, scan duration. AI also optimizes occlusal fit alignment through the analysis of the bite registration pattern, which leads to better trueness and smoother model surfaces (Mormann *et al*.,2006). In the field of orthodontics, AI-driven technology has the potential to predict the movement of teeth by identifying deviations between planning and the actual performance of the aligner (Yao *et al*.,2023). This type of prediction allows early detection of treatment inefficiencies and helps in personalized appliance adjustments.

Digital Twin Simulation and Predictive Planning

A digital twin represents a fully virtual, continuously updated model of the patient's oral cavity that shows the biological changes during treatment (Yao *et al*.,2023). Using sequential IOS software, it can generate simulations of predicted outcomes prior to appliance fabrication (Eggmann *et al*.,2024). As computing power and AI accuracy continue to improve, digital twin technology will mostly evolve into predictive tool which is capable of suggesting independent optimal treatment plans, based on historical and biometric datasets (Ströbele *et al*.,2023).

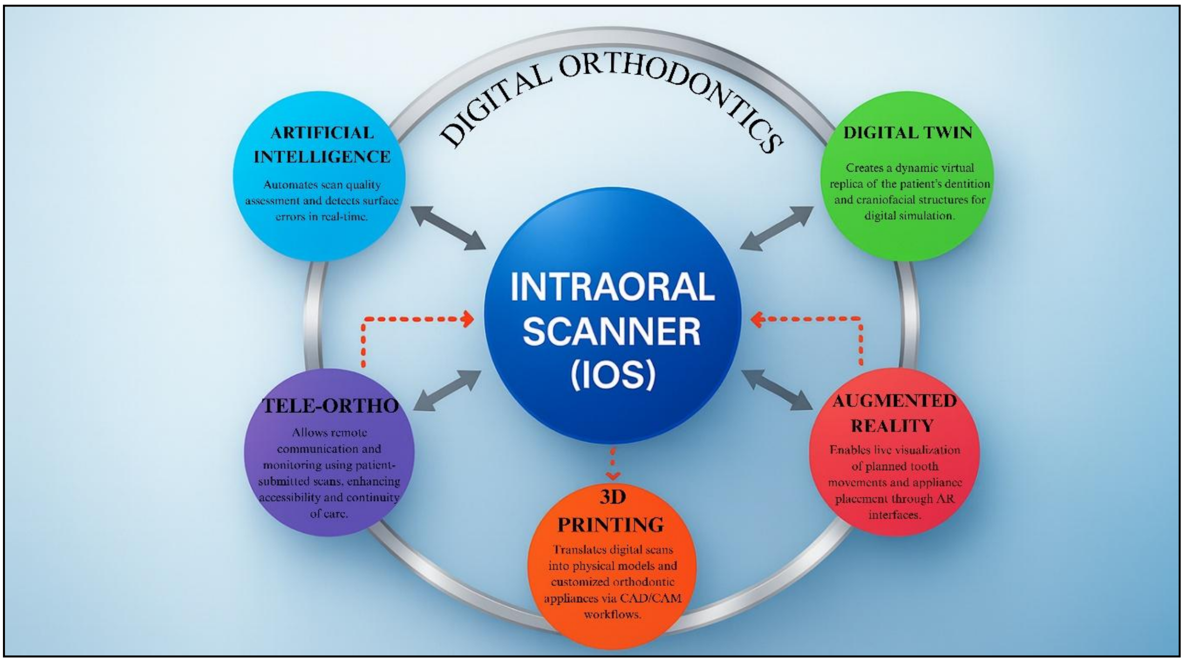


Figure 4. Future pathway of digital orthodontics

Augmented Reality and Visuallization Technologies

Augmented reality systems help clinicians verify bracket positioning and simulate tooth movement during bonding procedures (Ströbele *et al*.,2023). This technology not only increases accuracy and also educates the patient by visualizing expected post treatment results directly on facial scans (Jindanil *et al*.,2025). The combination of AR and IOS technology holds potential in tele-education, allowing live remote supervision of procedures using real time scan projections (Almoammar *et al*.,2024).

3D Printing and Additive Manufacturing

Digital scan data now can be directly exported to 3D printers for fabrication of aligners, retainers, study models, Indirect bonding trays (Celik *et al*.,2023). Recent improvements in print resolution, material strength, and biocompatibility made it possible to produce clinically durable devices with minimal post processing. For instance, light curable resins especially formulated for dental applications now allows faster print speeds without compromising dimensional stability (Revilla-Leon *et al*.,2019). This seamless connection between IOS and 3D printing gives the same day appliance fabrication and chairside repair work, in turn reducing turnaround time.

Tele-Orthodontics and Remote Patient Monitoring

High-resolution digital scan can be securely uploaded to cloud platforms, enabling clinicians to evaluate progress of the treatment remotely and provide asynchronous consultations (Almoammar *et al*.,2024). This gives access to patients particularly in remote and underserved regions. By combining tele-monitoring with AI analytics, clinicians can receive automatic alerts when there are any deviations in planned treatment (Li *et al*.,2022). Early detection of misalignments or non-compliance of the appliances can significantly improve outcomes while reducing unnecessary clinic visits. As 5G connectivity and cloud security advance, tele-orthodontics is expected to become a standard adjunct to routine orthodontic practice.

CONCLUSION

IOS have become an essential part in orthodontic practice, replacing the conventional impressions with faster and precise digital systems by improving patient comfort, reduces chairside time by providing reliable 3D data for diagnosis and appliance design. Recent advancements in AI, digital-twin simulation and augmented reality have extended use beyond impressions. when combine with CBCT, facial imaging, 3D printing enables comprehensive digital planning and customized treatment. However, challenges remain like equipment cost, software issue, training still limit the use universally. Moreover, IOS is expected to provide central hub of digital orthodontics which is capable of recording, analysing, and interpreting data in real time.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

Not applicable

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AI TOOL DECLARATION

The authors declares that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

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