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Evaluating the Clinical Accuracy of Dental Monitoring's Smart STL Feature Following Maxillary Expansion with a Hyrax Appliance

by

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DEDICATION

This Thesis is dedicated to my family whose unwavering love and support have shaped every step of my journey.

To my girlfriend and her family, whose encouragement, kindness, and inspiration have continually pushed me to grow and achieve more than I thought possible.

Thank you for your patience and positive encouragement throughout my orthodontic residency.

This work is as much yours as it is mine.

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Abstract

Introduction:
Artificial intelligence (AI) and remote monitoring technologies have become increasingly integrated into orthodontic care, offering the potential to enhance treatment efficiency and reduce in-office visits. Dental Monitoring (DM) has introduced Smart STL, a novel tool that generates 3D digital models from patient-acquired smartphone scans. However, its clinical accuracy—particularly after significant skeletal or dental changes such as rapid palatal expansion—has not yet been validated. Establishing the reliability of Smart STL models is critical before they can be confidently adopted for post-expansion assessment and treatment monitoring.

Methods:
This retrospective study analyzes existing records of patients who underwent Hyrax-assisted maxillary expansion and were concurrently monitored using Dental Monitoring. Each patient had a post-expansion 3Shape digital model as well as a Smart STL model generated through DM's platform. Superimpositions will be conducted with MEDIT software using best fit analysis to compare clinical accuracy between the two digital models. The American Board of Orthodontics' (ABO) standard of <0.5 mm clinical discrepancy will be used as the threshold for acceptability.

Results:
Analysis of 11 patients demonstrated no statistically significant differences between Dental Monitoring Smart STL models and intraoral scanner models for both RMS and absolute mean deviation. All deviations remained below the ABO clinical threshold of 0.5 mm, indicating clinical equivalence between the two methods.

Conclusion:
Dental Monitoring's Smart STL feature provides clinically accurate and statistically equivalent models to intraoral scans following rapid maxillary expansion with a Hyrax appliance. These findings support the integration of Smart STL into orthodontic workflows as a reliable tool for remote monitoring and follow-up care.

Keywords: Dental Monitoring, Smart STL, Expansion, Artificial Intelligence, Intra-oral scanner, Superimposition, ABO standard

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LITERATURE REVIEW

1. Introduction to AI

Artificial Intelligence (AI) refers to the capability of machines and computer systems to replicate cognitive functions such as learning, reasoning, problem-solving, and decision-making (Stryker et al, 2024). Even though we are experiencing an exponential increase in capabilities with AI integration in many fields of study in 2025, it was not always as progressive as today.

Early Building Blocks

A simple way to explain the development of Artificial Intelligence involves the beginning of the 1940's. One of the first publications alluding to AI was work published by McCulloch and Pitts in 1943. Their publication describes a computer model used to learn based on a process comparable with neurons in the human brain. Boolean inputs (a binary input/output of true/false statements that requires a threshold to be considered "fired or activated"—like a neuron). The simplest models started as feedforward, simple input output functions. However, over the following decades, these became more sophisticated with the addition of more intricate functions, added layers, and bidirectional feedback, eventually becoming the building blocks of the modern day deep neural networks or DL. (Muthukrishnan, et al, 2020) (*Figure 1*)

A more sophisticated output came about (Non-Boolean) called a Perceptron in 1958 in which multiple variables with included weights on each variable, a bias factor "b", and a non-linear function "f" that processes the sum of all the values. (Muthukrishnan, et al,

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2020). This opened a wide flexibility to the model and became building blocks for modern neural networks with the future goal of efficiently performing machine learning tasks, even on the level of quantum data. (Sharma, et al, 2022). (*Figure 2*)

Early AI development faced setbacks due to limited computing resources and unrealistic expectations, leading to periods of stagnation known as 'AI Winters' in 1974 and 1980 (Ray, 2021).

2. Development of AI and Machine Learning

Simple AI was created where basic human intelligence was exhibited by machines. As time progressed, the 1980's led to the concept of Machine learning to where AI systems began learning from historical data (Stryker et al, 2024). The microcomputer revolution in 1997 was the first stage where AI demonstrated sufficient computational power when IBM developed the first chess playing supercomputer "Deep Blue," which gained much public attention and hype to resurface Artificial Intelligence. (*Figure 3)*

It was determined that two of the biggest limitations for advancing in machine learning capabilities rested on having large number of data sets, which required a large amount of data storage and Graphics Processing Unit (GPU) power (Muthukrishnan, et al, 2020).

What is Machine learning, and how is this concept unique in comparison to traditional computer programming? In classical programming, a computer is supplied with a dataset and algorithm. The algorithm informs the computer how to operate with the dataset to "*create*" outputs. With machine learning, a computer is given a dataset and all the outputs for different scenarios. This allows the computer to "*learn*" and generate its

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own algorithm, which can be used for predicting future dataset (Choi, Rene Y., et al, 2020). (*Figure 4*)

It was not until 2010 where the idea of Deep learning, a new type of automated learning that can mimic human brain function as if having a network of neurons formulate what we expect and hope for artificial human response. Now in 2025, we are at the early stages of specific deep learning models or foundation models called Generative AI that has the ability to create original content based off of voice recognition and text requests (Stryker et al, 2024). (*Figure 5)*

3. AI in Healthcare

With the rapid advancement of artificial intelligence (AI), its integration across multiple industries has garnered significant scholarly interest. The fields of medicine and dentistry are increasingly exploring the potential of AI to enhance clinical decision-making, improve diagnostic accuracy, and optimize treatment delivery. Within the healthcare sector, AI is envisioned as a transformative tool capable of reducing labor demands, increasing efficiency in managing large patient populations, and lowering overall costs. Recent developments have particularly focused on the implementation of AI-driven software solutions as a central component of this technological evolution.

<u>The Promise/Necessity</u>

The potential of AI to support clinical decision-making by revealing clinically relevant information within vast datasets is particularly compelling—especially in the context of current global clinician shortages (Stanfill et al., 2019). As workloads increase with more patients per professional, medical errors also increase. If AI can help resolve this

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longstanding challenge, it is likely to be embraced by physicians, hospital administrators, insurers, and patients alike (Gore et al., 2020). The overarching goal is to develop software capable of enhancing radiographic diagnosis, image analysis, forensic applications, and image quality—with a primary focus on streamlining clinical workflows and optimizing the delivery of care.

Limitations

In order to widely use artificial intelligence in the future for clinical practice, there are also other problems that need to be solved. If automated diagnosis *is* our future, the judgement criteria must be understood for the AI to support the huge amount of fine labeled open data sets, along with the variety of clinical presentations. If these solutions are correctly presented and developed with AI, then the future of AI will play an important role in development of automatic diagnosis systems, treatment plans, and possibly fabrication of treatment tools (Heo, Min-Suk, et al., 2020).

Concerns

While a prevailing fear is that artificial intelligence may eventually replace human clinicians, the American Medical Association offers a contrasting perspective. In 2024 AMA defined the role of AI in healthcare as “augmented intelligence,” stating that AI will be designed and used to enhance human intelligence rather than replace it (Chen 2020). (*Figure 6)*

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4. AI in Dentistry

Caries Detection

Different software programs have already been in development in the realm of dentistry involving diagnosis through panoramic radiographs and FMX (Full Mouth X-rays) to detect caries, periapical radiolucencies/opacities, and a plethora of other diagnosis. However, the AI models for accuracy of detection are still at an early stage. For example, in a recent study, deep learning for a dental caries detection model was about 51% accurate for advanced caries compared to 23% for primary caries. The more data accurately labeled for data sets will slowly increase the accuracy of primary and moderate caries to hopefully avoid misclassification in the future (Azhari, Amr Ahmed, et al., 2023)

EHR and AI Platforms

There are three main types AI platform services that have integrated in dentistry software including:

1. EHR (Electronic Health Record) for autofill, voice dictation, and language processing.
2. AI cloud platforms to support practices needing to build, manage, and deploy AI applications with massive data.
3. AI Firms – companies and start-ups that provide AI healthcare applications involving patient-facing, doctor facing, research, and telehealth.

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Teledentistry

Teledentistry is the remote facilitating of dental treatment, guidance, and education via the use of software communication platforms, instead of direct face-to-face contact with patients (Ghai et al, 2020). The earliest teledentistry started by the US military in 1994 to serve the US troops around the world. However, this idea became very prevalent during the COVID-19 Pandemic (Farronato 2021) in which face-to-face contact for dental treatment was not possible due to worldwide restrictions. Teleconsultation, diagnosis, triage, and monitoring are subunits of teledentistry that have important functions relevant to dental practice.

Dental Monitoring

As we live in a fast paced world, time is more so valuable than ever. As Artificial Intelligence software has found its way into dentistry, Dental Monitoring (DM) has begun to integrate into the orthodontic specialty. Dental Monitoring was developed to address the increasing demand for greater efficiency, convenience to patients, and increased precision in orthodontic care. Traditionally, orthodontic appointments would be around every 4-6 weeks, which is more frequent than patients would prefer. On many occasions, this can put more of a burden on both the patient and the practice, especially in aligner therapy or orthopedic expansion.

Purpose

This platform was created in combination with mobile technology and cloud based data storage/analysis to enable remote treatment monitoring. This was designed to modernize orthodontic workflows by incorporating digital and remote monitoring capabilities (Hansa et al., 2020). This software allows the orthodontist to track clinical

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changes of patients using intraoral scans taken via smartphone in the comfort of every patients' home.

Additional intended functions of DM include:

1. Reduce the frequency of in-office appointments without compromising quality of care (Moylan et al., 2019)
2. Improve patient compliance and motivation through real time visual feedback, including messaging board directly to the provider (Caruso et al., 2021)
3. Enable early detection of problems, such as aligners unseated properly, broken brackets, poor oral hygiene, etc (Giese-Kraft, 2022)

Distinction

What is truly unique to this software platform is the potential to bring BOTH In-office and Out-of-office efficiency to an orthodontic practice. The idea is to make sure to chair time in the office is optimized for visits requiring complex clinical interventions and eliminating "simple visits" (Guidice et al, 2022). It is the first commercially released platform to involve detection, diagnosis, treatment progress, and communication through real-time intra-oral photos. This simple process is taken on any smart phone with the assistance of a DM At-Home Kit. This revolutionized the idea of Teledentistry through patient-centered, digitally integrated care, particularly in post-pandemic climate where Tele-health has become increasingly vital (Shaver, 2022).

5. Maxillary Expansion and Conventional Measurement techniques

Of all the avenues of orthopedic treatment, Maxillary expansion is the most common, designed to correct transverse deficiencies of the upper jaw. Although several

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appliances have been developed to accomplish this correction, the simplest and most commonly used in early/adolescent patients is the hyrax expander. This is a tooth-borne maxillary expander with a jackscrew connected by bands on the maxillary molars (and sometimes premolars). Depending on the orthodontist's recommendation, the Hyrax expander is able to deliver rapid forces to separate the mid-palatal suture, enabling skeletal widening of the maxilla (da Silva Filho et al., 2008). (*Figure 7)*

This appliance is indicated for several reasons, including posterior crossbite, excess crowding, impacted teeth, and on some occasions, narrow nasal airways (not on its own, however). Typically for rapid palatal expansion, the protocol involved 0.25mm turns twice daily, totaling around 7-10mm of activation over a 2-3 week period.

The response biologically to expansion includes initial skeletal separation, which is then followed by bone apposition over time in the created space. The process usually involves a percentage of dental tipping, which is sometimes falsely perceived as true skeletal expansion.

Measuring Maxillary Expansion

First, we can look at measurements from a linear standpoint. Usually we measure lingual cusps intermolar and intercanine widths, but some will measure inter-premolar widths. Another method involves frontal cephalometric radiographs via molar angulation tracings with the CWRU transverse analysis to determine both initial transverse discrepancy and post expansion skeletal and dental expansion (Mostafa et al, 2017). (*Figure 8)*

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On a 3-Dimensional standpoint, orthodontists can use Cone Beam Computed Tomography (CBCT) to provide volumetric data on skeletal expansion, any alveolar changes during growth, and can provide measurements for nasal cavity width (Pirelli et al., 2021). Lastly, we can use Digital STL casts to superimpose pre and post digital scans to determine changes in the arch forms. Superimpositions on the palatal rugae and/or mid palatal sutures have been more consistently used as a reference (Holz et al, 2024).

6. AI in Orthodontics

As Remote Monitoring in orthodontics has gained prominence, so has AI Integration in Dental Monitoring. DM has the ability to Support personalized orthodontic care through automated progress tracking and alerts generated by machine learning models (Hansa et al., 2020). As Dental Monitoring is progressing its AI algorithm, the software is obtaining an abundance of data on an exponential level through the weekly scanned photos. With this collection, DM has been attempting to accurately track tooth movement during patients' orthodontic treatment through specific reference points marked on these intra-oral photos. One of the big picture end goals' is to provide a new feature to the platform called SMART .STLs (SMART Stereolithography models).

7. Dental Monitoring and Orthodontics

Dental Monitoring (DM) is at the forefront of AI-driven remote orthodontic treatment monitoring, with numerous studies exploring its accuracy, clinical applications, and potential to reduce in-office visits.

DM Compared to Typodonts: Morris et al (2019) conducted a simulation study that assessed the accuracy of 3D digital dental models generated by the Dental Monitoring

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(DM) smartphone application in both photograph and video modes. The researchers compared these models to those produced by the iTero Element intraoral scanner using ten typodonts set up with Class I malocclusion and anterior crowding. Over successive DM examinations, they found that the mean global deviations for both maxillary and mandibular arches were within clinically acceptable ranges, indicating that DM's photograph and video modes can reliably produce accurate 3D dental models suitable for clinical applications with up to three hundredths of a millimeter deviation. This gave hope for clinical usage, but still needed validation Intraorally.

DM Compared to Plaster Models: Moylan et al. (2019) conducted a pilot study evaluating DM's accuracy in assessing changes after rapid maxillary expansion (RME) using video scan data. By comparing intermolar and intercanine width measurements from DM-generated 3D models with traditional plaster models, they found minimal discrepancies (mean difference <0.2 mm), demonstrating statistical equivalence and clinical accuracy of DM in tracking linear measurements. Again, this continued increasing the potential for clinical usage, but needed intraoral validation.

DM Compared to CBCT: In a separate study, Arqub et al. (2023) characterized orthodontic tooth movement in real time using DM's tooth tracking technology. Their longitudinal comparison of DM tracking against CBCT and intraoral scan data validated the tool's ability to detect and quantify individual tooth movements accurately, underscoring its value in monitoring complex treatment phases remotely.

DM Diagnosis *During* Ortho Treatment: Hansa et al. (2021) provided a comprehensive case series on the clinical applicability of DM by documenting its role in detecting a wide

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range of issues, including aligner fit problems, attachment loss, gingival inflammation, caries, and poor oral hygiene. Their findings revealed that DM could reduce the number of in-office visits by approximately 25–33%, without compromising care quality. The study also emphasized DM's positive impact on patient compliance and engagement, as real-time feedback reinforced oral hygiene and timely appliance management.

DM's Initial Impact on Teledentistry: Maspero et al. (2020) conducted a systematic review of teledentistry tools during the COVID-19 pandemic, highlighting DM as one of the most reliable and clinically adopted platforms. The review confirmed that DM helped sustain orthodontic care continuity during lockdowns by enabling effective remote supervision.

DM Comparing Generated STLs to Intraoral Measurments: Kuriakose et al. (2023) explored the application of DM in monitoring skeletal expansion post-Hyrax appliance use. By comparing DM-generated models to Intraoral measurements at various time points, the study showed that DM could potentially be a reliable tracker for intercanine and intermolar width changes after expansion, suggesting its promise as a viable remote tool for post-expansion assessments.

Together, these studies demonstrate that DM has evolved from a proof-of-concept application to a clinically robust platform capable of supporting both aligner and fixed appliance therapy. While the accuracy of linear and volumetric measurements appears potentially reliable, especially in controlled scenarios, *continued validation*—particularly of features like Smart STL in more dynamic orthopedic contexts—is necessary to fully integrate DM into mainstream orthodontic diagnostics and follow-up care.

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Smart STL Feature

According to a published study from UIC Orthodontics program in 2023, the DM artificial intelligence tracking algorithm can successfully track tooth movement and reconstruct 3D digital models to a clinically acceptable degree (According to ABO Standards) for orthodontic application. (Homsi, Karen, et al, 2023). However, this study conducted involved both an intraoral iTero scan and DM scan at every appointment (10 in-office sessions for each patient) which is an extensive amount of data and not practical outside of the study. The STLs were successfully exported and compared to a gold standard scanned digital cast. This was the only study to successfully demonstrate the capability of tracking *minor* tooth movement through each adjustment appointment (Homsi, Karen, et al, 2023).

Research Gap

While existing literature predominantly evaluates minor orthodontic movements, the applicability of Smart STL models for large-scale movements—such as those seen with rapid palatal expansion—remains underexplored. Notably, there is a lack of validation studies comparing DM's Smart STL models to gold standard intraoral scans in these contexts. Maxillary palatal expansion—commonly treated using appliances like the Hyrax—is an example of rapid, large-scale tooth movement that has not been adequately studied in relation to Smart STL output. It remains unclear whether the AI algorithm can reliably identify reference points and generate clinically accurate STL models during such accelerated tooth movement. Furthermore, the minimal data input necessary to produce a clinically valid 3D model remains undefined.

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Research Purpose

This study aims to determine whether Smart STL models generated from DM after Hyrax expansion accurately reflect dental arch changes according to ABO measurement standards and gold standard intraoral scanners.

Research Question:

Is the STL model generated by Dental Monitoring's Smart STL feature after maxillary expansion using a Hyrax expander clinically accurate when compared to standard intraoral scanner STL models?

8. Clinical Implications

If the Smart STLs prove to be clinically accurate, the implications in the orthodontic practice setting would be profound:

1. This could validate the potential for a fully remote method of capturing 3D Digital cast models as a standard of scanning.
2. Improve the quality of monitoring during orthopedic treatments when comparing to treatment goals.
3. Generated Smart STLs could be integrated in ABO case documentation for remote preparation if needed.
4. Additional avenue for collecting data for further research projects.

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Statement of Thesis

This study aims to evaluate the clinical accuracy of Dental Monitoring's (DM) Smart STL feature for tooth tracking following orthopedic maxillary expansion using a Hyrax appliance. The goal is to determine whether Smart STL models derived from Dental Monitoring remote ScanBox Pro images are comparable to those generated by the 3Shape intraoral scanner, a gold standard in clinical practice.

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Evaluating the Clinical Accuracy of Dental Monitoring Smart .STL Feature Following Maxillary Expansion with a Hyrax Appliance

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Abstract

Introduction:
Artificial intelligence (AI) and remote monitoring technologies have become increasingly integrated into orthodontic care, offering the potential to enhance treatment efficiency and reduce in-office visits. Dental Monitoring (DM) has introduced Smart STL, a novel tool that generates 3D digital models from patient-acquired smartphone scans. However, its clinical accuracy—particularly after significant skeletal or dental changes such as rapid palatal expansion—has not yet been validated. Establishing the reliability of Smart STL models is critical before they can be confidently adopted for post-expansion assessment and treatment monitoring.

Methods:
This retrospective study analyzes existing records of patients who underwent Hyrax-assisted maxillary expansion and were concurrently monitored using Dental Monitoring. Each patient had a post-expansion 3Shape digital model as well as a Smart STL model generated through DM's platform. Superimpositions will be conducted with MEDIT software using best fit analysis to compare clinical accuracy between the two digital models. The American Board of Orthodontics' (ABO) standard of <0.5 mm clinical discrepancy will be used as the threshold for acceptability.

Results:
Analysis of 11 patients demonstrated no statistically significant differences between Dental Monitoring Smart STL models and intraoral scanner models for both RMS and absolute mean deviation. All deviations remained below the ABO clinical threshold of 0.5 mm, indicating clinical equivalence between the two methods.

Conclusion:
Dental Monitoring's Smart STL feature provides clinically accurate and statistically equivalent models to intraoral scans following rapid maxillary expansion with a Hyrax appliance. These findings support the integration of Smart STL into orthodontic workflows as a reliable tool for remote monitoring and follow-up care.

Keywords: Dental Monitoring, Smart STL, Expansion, Artificial Intelligence, Intra-oral scanner, Superimposition, ABO standard

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Introduction

Artificial Intelligence (AI) refers to the ability of machines and computer systems to replicate cognitive processes such as learning, reasoning, and problem-solving.[1] The foundation of AI dates back to the 1940s with McCulloch and Pitts' model of neuron-like computation. [2] Progress accelerated with the introduction of the Perceptron in 1958, which laid the groundwork for modern neural networks. [3] Early challenges, including limited computing power and unrealistic expectations, led to periods of stagnation known as 'AI Winters.' However, continued innovations in computational power, data storage, and algorithm design set the stage for deep learning and generative AI models.[4]

AI evolved significantly in the 1980s with the emergence of machine learning, which allowed computers to generate their own algorithms from datasets rather than relying on predefined rules. Notable milestones include IBM's Deep Blue chess computer in 1997 and the rise of deep learning in 2010, which used neural networks to mimic human brain function. [2] By 2025, generative AI represents a new frontier, capable of creating original content and responding to voice and text inputs. The growth of machine learning has been heavily dependent on access to large datasets, data storage capabilities, and GPU power.

AI began integrating into healthcare with the promise to enhance diagnostic accuracy, clinical decision-making, and efficiency. AI has the potential to reduce clinician workload, minimize errors, and lower costs by analyzing large datasets. Applications include, but not limited to, radiographic diagnosis, image analysis, and forensic applications. While promising, AI faces limitations related to dataset labeling, variability

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in clinical presentations, and the need for standardized decision-making criteria. Importantly, the AMA promotes AI as 'augmented intelligence,' emphasizing its role in supporting rather than replacing clinicians. [5]

Building on its successes in broader healthcare, AI has naturally extended into dentistry, where similar opportunities exist to enhance diagnostic accuracy, patient monitoring, and clinical efficiency. Some AI applications include caries detection, electronic health record integration, and tele-dentistry. Early models for caries detection showed limited accuracy, though performance improves with larger datasets. [6] Tele-dentistry gained prominence during the COVID-19 pandemic, offering remote consultation, diagnosis, and monitoring. [7] Dental Monitoring (DM) has emerged as a leading AI-based platform in orthodontics, enabling remote tracking of treatment progress via smartphone scans. DM's intention is to improve patient compliance and motivation through real time visual feedback [8], reduce the frequency of in-office appointments without compromising quality of care [9], and facilitate early detection of clinical issues. [10]

Dental Monitoring (DM) is a leading platform in AI-driven remote orthodontic treatment monitoring, with studies increasingly validating its accuracy, applications, and impact on clinical efficiency. Early research on typodonts[11] showed that DM-generated models from smartphone photographs and videos were within clinically acceptable accuracy compared to iTero scans, though intraoral validation was still needed. Moylan and colleagues further demonstrated equivalence between DM video-based models and plaster casts for rapid maxillary expansion, reinforcing its reliability in measuring transverse changes. [9] Arqub and colleagues expanded these findings by validating

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DM's real-time tooth-tracking technology against CBCT and intraoral scans, confirming its accuracy in detecting complex orthodontic movements. [12]

Beyond accuracy, DM has demonstrated significant clinical utility. Hansa's findings showed that DM can identify aligner fit problems, attachment loss, gingival inflammation, and hygiene issues, reducing in-office visits by 25–33% while improving patient compliance and engagement. [13] Maspero's work highlighted DM's role during the COVID-19 pandemic, identifying it as one of the most effective tele-dentistry platforms for maintaining continuity of care. [7] More recently, Kuriakose demonstrated DM's reliability in monitoring skeletal expansion with a Hyrax appliance, showing strong agreement between DM-generated SmartSTL models and intraoral measurements for intermolar and intercanine changes. [14]

Most recently, according to a 2023 UIC Orthodontics study, Dental Monitoring's AI algorithm can track tooth movement and reconstruct 3D models within clinically acceptable ABO standards. [15] The study, however, mentioned that both iTero and DM scans were required at every appointment (10 per patient), generating valuable research data but would be time consuming to continue do all the steps in a normal orthodontic practice setting. Despite this, it was the first study to demonstrate accurate tracking of minor tooth movement across sequential orthodontic adjustments.

Collectively, these studies demonstrate that DM has evolved from a proof-of-concept application to a clinically robust platform capable of supporting both aligner and fixed appliance therapy. While the accuracy of linear and volumetric measurements appears potentially reliable, especially in controlled scenarios, *continued validation*—particularly

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of features like Smart STL in more dynamic orthopedic contexts—is necessary to fully integrate DM into mainstream orthodontic diagnostics and follow-up care.

Maxillary expansion, often achieved with the Hyrax expander, is a common orthodontic procedure for correcting transverse deficiencies. Traditional measurement methods include linear intermolar and intercanine distances, frontal cephalometric radiographs, CBCT imaging in conjunction with Case Western Reserve University (CWRU) Transverse analysis, [16] and digital cast superimpositions. Digital STL models, superimposed on palatal rugae or the mid-palatal suture, provide accurate 3D assessment of expansion changes.

While DM's Smart STL has been validated for smaller orthodontic movements, a significant gap remains regarding its accuracy in large skeletal changes such as maxillary expansion, largely because Dental Monitoring does not currently provide clinical support for palatal expansion cases. As a result, no large-scale data or standardized workflows exist for evaluating Smart STL performance in this context. For the purpose of this study, Dental Monitoring made the Smart STL feature available specifically and exclusively for our research, allowing us to investigate an application that is not otherwise supported or widely implemented. This study therefore aims to determine whether Smart STL models generated after Hyrax expansion are clinically accurate when compared with intraoral scanner models, using ABO measurement standards.

If proven accurate, Smart STL models could transform orthodontic practice by enabling fully remote 3D digital cast generation, enhancing monitoring during orthopedic

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treatments, and supporting ABO case documentation. The ability to reduce in-office appointments while maintaining precision has important implications for efficiency, patient convenience, and research opportunities.

Methods

Study Design

This study was designed as a retrospective observational analysis utilizing existing clinical records of patients who previously underwent orthodontic treatment involving maxillary expansion with a Hyrax appliance in conjunction with remote monitoring via the Dental Monitoring platform. Eligible cases were identified from a digital database of patients who had completed the expansion phase and were monitored using the Dental Monitoring ScanBox Pro system. All records used in this study were de-identified prior to analysis. The study protocol was reviewed and approved by the Institutional Review Board (IRB) at Case Western Reserve University.

Sample Size and Power Analysis Justification

This study aims to evaluate the clinical accuracy of Dental Monitoring's Smart STL model generation by comparing it to 3-Shape-generated STL files following maxillary expansion. A primary outcome measure is the global deviation (in millimeters) between the Smart STL and 3-Shape STL models, assessed via 3D superimposition analysis.

To determine the minimum number of subjects required for adequate statistical power, a power analysis for a One Sample paired t-test was conducted. This design is appropriate because each patient will serve as their own control, with two intraoral scans (Smart STL vs. 3-Shape) compared at the final timepoint.

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The clinically meaningful difference was defined as 0.5 mm, in accordance with the American Board of Orthodontics' cast grading criteria and prior literature assessing 3D model accuracy. A standard deviation (SD) of 0.3650 mm was used based on data reported in the 2023 UIC study by Dr. *Homsi*, which evaluated the in-vivo accuracy of Dental Monitoring-generated STL files at 10 different time points. [15] Specifically, their analysis showed global deviation standard deviations ranging between 0.2364 mm and 0.3650 mm (as shown in the figure below) depending on arch and timepoint, validating the use of 0.3650 mm as a conservative estimate. (*Table 1)*

Using these parameters and a two-sided alpha of 0.05, the required sample size was calculated to achieve 99% statistical power using the Z-based Normal approximation:

Standard deviation range: 0.2364 – 0.3650

- Standard deviation (σ): 0.3650 mm (conservative approach)
- Power: 99% (⇒ β = 0.05)
- Significance level (α): 0.05 (two-tailed)
- = 0.5mm

Thus, this study will observe a minimum of 10 existing patients (*Figure 9)*, each of whom underwent both Smart STL and 3-Shape scans for direct comparison. To account scan unusability, an additional 10–15% buffer may be added, targeting a final sample size of 11–12 patients.

This sample size ensures that the study is sufficiently powered to detect clinically meaningful differences in STL model accuracy with high confidence, while maintaining efficiency and feasibility within the scope of this in-vivo orthodontic research.

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Subject Selection and Inclusion/Exclusion Criteria

This retrospective chart review will be performed and this will involve data collected during the course of routine orthodontic care. All patients included in the study have already completed palatal expansion and have existing post-expansion .STL files from both Dental Monitoring (DM) and 3Shape intraoral scanner platforms. These files are stored as part of their clinical records.

I accessed the patient charts within DM software under anonymous mode in Dr. Alvetro's orthodontic practice, where the data is securely stored. The charts are not affiliated with CWRU and are maintained by the private office. I will retrieve only the post-expansion .STL models and de-identified patient information regarding their age at the end of the palatal expansion, so as to satisfy our inclusion criteria. For research purposes, Dental Monitoring has a feature that an office can use to blur personal identifier indicators and lets you see only de-identified alphanumeric files. A full waiver of HIPAA Authorization and a letter of support from the private practice confirming access was submitted during IRB Approval.

Inclusion Criteria:

- Patients ages between 8-18 years old
- Patients that had palatal expansion as a part of their treatment plan
- Patients files containing 2 post expansion digital files needed
- Patients were in good physical oral health

Exclusion Criteria:

- Patients who had previously initiated comprehensive orthodontic treatment.
- Patients that had exfoliating teeth during expansion process

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Equipment/Criteria and Procedures

Equipment:

(Refer to Figures 10 & 11 in Appendix C)

DM Scan Criteria (2D)

- Use ScanBox Pro Hardware
- ScanAssist feature activated for each patient
- Appropriate DM adapters used with newer phones as needed.
- DM Scans will be taken every week at home by the patient and at every office visit

ScanAssist

- New feature to standardize Intraoral scans with ScanBox Pro Hardware. (*Figures 12 & 13*)

1. Initial Records (T0):

- Scans of the maxillary and mandibular arches were taken using the 3 Shape Intraoral scanner PRIOR to insertion of Hyrax Palatal Expander. These scans will be used as baseline references for the DM software.

2. Subsequent Records:

- Post Expansion (T1)**:** 3 Shape Scan and DM Scan
- Pt completed DM (At-Home) Scans once a week
- During the expansion phase, the activation turns of the expansion appliance were measured during in office visits.

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Resident Research Procedure

Expected Generated Data / Results

- Regenerated STL from DM and 3 Shape Intra-oral Scanner at Post –Expansion follow-up appointment

Data Analysis

- Software Used for superimposition: Medit Scanning and Superimposition Software
    - Best Fit results based on the comparison between 3Shape Scan model and DM Generated STL model. (Scale of 0.5mm)
- Superimposition Analysis: Comparison of DM-generated models with Gold Standard 3 Shape IntraOral Scanned models at T1.
    - Preparation:
        - Gingiva: In order to reduce chances of increased deviation upon superimposition, the gingiva from the 3 Shape STL was manually removed in order to superimpose only dentition. However, in an effort to prevent introducing an additional variable into potential errors, the casts were trimmed twice per patient and compared by using “Best Fit” analysis to verify there would not be any significant changes between the superimpositions. For each patient case, the difference between superimposing each of the trimmed casts was proved insignificant and would not add any unwanted variable in the results. (*Figures 14 & 15*)

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- Manual or Automatic Best Fit: Next was the decision to superimpose via manual, or automatic "best fit" superimposition. The manual method requires selecting 3 points on each cast. 3 points per cast were the maximum number of spots to match between. The idea was to use the upper mesio-incisal angle of the upper central incisors as one point and the mesio-lingual cusp tip of the upper first molars for the other two. Unfortunately, throughout this process, the best method to try to standardize the point selection still led to unwanted deviation in the hundredths of millimeters. Due to consistency of results, it was decided to continue with the automatic best fit superimposition.

- The use of color heat map with an acceptance (green) of up to +0.3mm or -0.3mm deviation of DM STL from the reference 3 Shape STL. (*Figures 16 & 17*)

Statistical Tests:

- One-Sample t-Test
  - Why**:** To test if the mean deviation from 0.5 mm is statistically significant
  - How**:** For each patient's two casts at timepoint T1

Expected Outcomes

The study aims to determine the clinical accuracy of Dental Monitoring generated 3D digital SmartSTL models using smartphone cameras through Dental Monitoring scan box pro, hypothesizing no significant clinical differences compared to the in-office Intraoral scanners.

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9. Results

A total of 11 patients were included in the analysis, with each patient contributing a superimposed pair of STL files: one obtained from the Dental Monitoring, the Smart STL and the other from the reference 3 Shape intraoral scan. Two primary outcome measures supplied by Medit Superimposition software were assessed: the absolute average of deviation (mm) and the root mean square (RMS) deviation (mm).

The mean absolute average of deviation across all patients was [0.15mm ± 0.23mm], with values ranging from -1.79 (Min) to 1.73(Max). The mean RMS deviation was [0.23mm ± 0.23mm], with a range of -1.79 (Min) to 1.73(Max). When tested using paired t-tests, both Absolute Average and RMS outcome measures demonstrated p-values less than 0.05 (0.00041 and 0.0026 respectfully), indicating that there was no statistically significant difference between the Smart STL and the reference 3 Shape intraoral scans.

All deviations fell below the American Board of Orthodontics (ABO) clinical threshold of 0.5 mm, suggesting that the discrepancies observed between the two scan types were clinically acceptable. Descriptive statistics for both outcome measures are summarized in *Table 2*, and representative color deviation maps illustrating the superimposition results are presented in *Figures 16 & 17* and the raw data results of superimpositions for all patients presented in *Tables 3 & 4*.

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10. Discussion

Comparison to Existing Research

The present study evaluated the clinical accuracy of Dental Monitoring's Smart STL feature following maxillary expansion with a Hyrax appliance. Our results revealed no statistically significant differences between Smart STL models and intraoral scanner models for both RMS and absolute mean deviation. Moreover, the observed discrepancies were minimal and well below the ABO clinical acceptability threshold of 0.5 mm. These findings suggest that Smart STL reconstructions provide accuracy equivalent to that of intraoral scans, supporting their validity for monitoring changes after rapid maxillary expansion.

These outcomes are consistent with earlier validation studies. Morris, using typodonts, reported deviations in the hundredths of a millimeter when comparing DM-generated models with iTero scans, well within clinically acceptable ranges. [11] While their study highlighted proof-of-concept accuracy in simulated conditions, ours extends this evidence to intraoral patient data, where clinical variables such as saliva and patient movement could introduce error. The lack of significant differences in our results strengthens the argument that Smart STL maintains accuracy in real-world orthodontic contexts.

Moylan similarly found equivalence between DM-generated video models and plaster models in assessing intermolar and intercanine changes post-expansion, with differences <0.2 mm. Our study parallels these findings, demonstrating that Smart STL reliably captures post-expansion changes with precision comparable to established reference standards. [9]

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Arqub validated DM's dynamic tracking of individual tooth movements against CBCT and intraoral scan data. Although their study focused on longitudinal movement detection, our results complement their work by showing that static Smart STL reconstructions remain highly accurate even in orthopedic scenarios such as rapid maxillary expansion. [12]

While the UIC study by Homsi demonstrated that DM's AI algorithm could accurately track minor tooth movements across sequential appointments, it relied on dense data collection with iTero and DM scans at every visit, which limited its practicality outside of research. In contrast, the present thesis builds on and further validates these findings by showing that DM can also track *larger* tooth movements (such as those produced by rapid maxillary expansion) over a much shorter time frame. Similarly to the UIC model, which tracks incremental movements at each adjustment, this study shows that DentalMonitoring can accurately capture both subtle and major dental transformations (such as during palatal expansion) by using all DM scans throughout the treatment. This highlights the versatility of DM's Smart STL feature in detecting not just small, stepwise tooth movements but also substantial, treatment-induced shifts in dental position.[15]

Our findings are also in close agreement with those of Kuriakose, who evaluated DM-generated models in the context of skeletal expansion with a Hyrax appliance. Their study compared intermolar and intercanine width measurements from DM to intraoral measurements at multiple time points and found minimal discrepancies, concluding that DM could serve as a reliable remote monitoring tool for expansion outcomes. Similarly, our study demonstrated no statistically significant differences between Smart STL

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models and intraoral scanner models for both RMS and absolute mean deviation. By incorporating whole-arch superimposition analyses rather than focusing solely on linear transverse changes, our work builds on Kuriakose's results and provides additional evidence that DM's Smart STL technology is clinically accurate for evaluating complex post-expansion morphology. Together, these findings reinforce the reliability of Smart STL for tracking both skeletal and dental changes after maxillary expansion.[14]

Limitations

While the results of this study demonstrated no statistically significant differences between Dental Monitoring's Smart STL models and intraoral scanner models, several limitations should be acknowledged.

First, a limitation of the present study was the presence of residual bonding cement on the buccal, lingual, and occlusal surfaces of the maxillary first molars (upper 6's) when the final 3Shape intraoral scans were obtained. Upon review, it was noted that excess cement had likely been incompletely removed at the time of Hyrax appliance bonding, possibly due to the use of a cotton roll to wipe away material before curing, which resulted in hardened remnants within the central grooves. This artifact was consistently observed across the majority of superimpositions and likely contributed to localized increases in deviation values on the color heat maps. (*Table 5*) While this limitation introduced a minor source of error, the deviations remained well below the ABO clinical threshold of 0.5 mm, indicating that the residual cement did not meaningfully affect the overall validity of the results. Nonetheless, this highlights the importance of meticulous cement removal during appliance bonding and final scan acquisition to minimize confounding surface irregularities in future investigations.

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Second, patient-related factors introduced potential variability and bias. One source was the degree of patient proficiency in using the ScanBox Pro device to capture accurate upper and lower arch images. Minor inconsistencies in angulation, lighting, focus/blurriness or positioning could have contributed to subtle differences in Smart STL reconstruction.

Compliance was another consideration; although patients were instructed to submit scans on a weekly basis, adherence varied, and missed or delayed scans may have reduced consistency in longitudinal comparisons. The type of smartphone camera used also represented a variable, as differences in resolution and processing between devices could potentially affect image quality and, consequently, model accuracy.

Finally, the 3 Shape intraoral scan itself must be considered as a potential limiting factor, as it served as the reference standard for all comparisons. Although intraoral scanners are widely regarded as the accurate “Gold Standard”, they are not error-free, and any inaccuracies at the baseline scan would propagate through subsequent superimpositions. Taken together, these factors underscore the multifactorial nature of error in digital orthodontic workflows. While none of these limitations appeared to meaningfully impact the clinical reliability of our findings, they should be carefully considered in the design of future research to minimize variability and strengthen validation.

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11. Conclusion

The following conclusions were drawn from this study evaluating the clinical accuracy of Dental Monitoring's Smart STL feature in patients undergoing rapid maxillary expansion with a Hyrax appliance:

- Smart STL demonstrated **no statistically significant differences** compared to intraoral scanner models when measured using RMS and absolute mean deviation.
- All deviations remained **within the ABO's 0.5 mm clinical threshold**, confirming clinically acceptable accuracy after orthopedic expansion.
- Smart STL reliably generated updated intraoral STL files following expansion, supporting its use as a dependable tool for remote orthodontic assessment.
- Findings extend prior research by showing that Smart STL maintains **clinical equivalence** to intraoral scans in real-world patient cases, complementing earlier validations in typodonts, plaster models, and linear measurements.
- Smart STL offers potential workflow advantages, including improved remote monitoring capabilities, fewer in-office visits, and greater treatment efficiency.
- Study limitations—including residual cement artifacts, variation in ScanBox Pro usage, scan frequency compliance, smartphone camera variability, and dependence on the initial intraoral scan—produced only minor deviations that did not compromise clinical reliability.

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- These limitations highlight the importance of improved patient training, standardized scanning protocols, and future validation across broader patient populations and appliance types.
- Overall, Smart STL provides **clinically acceptable and statistically equivalent accuracy** for assessing post-expansion dental changes and represents a valuable adjunct to traditional orthodontic monitoring.

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Appendices

Appendix A: IRB Approval

IRB Administration Offices
UH IRB Phone: 216.844.1529
CWRU IRB Phone: 216.368.6925

INITIAL APPROVAL

Principal Investigator:	Tarek ElShebiny
Title:	In-vivo evaluation of Artificial Intelligence Driven Remote Monitoring technology for tracking Posterior tooth movement during Palatal Expansion and reconstruction of 3-dimensional digital models during orthodontic treatment.
Submission Number:	STUDY20241553
IRB Office:	CWRU IRB
Approval Date:	5/9/2025
Effective Date:	5/9/2025
Approval End Date	
Type of Submission:	Initial Study
Type of Review:	Expedited
Documents Reviewed:	• HIPAA Waiver.pdf, Category: Other; • Stephan Javaheri Dental Monitoring SMART .STL Protocol, Category: IRB Protocol; • Letter Of Acknowledgement - Dr. Lisa Alvetro, Category: Letter of Cooperation;

The IRB has reviewed this submission.

- Per Federal regulation, changes MAY NOT be made to any element of the current research without prior IRB approval, except to eliminate an immediate and apparent hazard to subjects enrolled in the study.
- Per Federal regulation, the research may not continue beyond the Approval End date. You must submit a continuing review form 6-8 weeks before this Approval End date in order to maintain IRB approval. Failure to maintain IRB approval is human subjects non-compliance. Please note that even if your study falls into a category that does not require an Approval End date, the institution may require a yearly "check-in" to confirm the status of the study.

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Appendix B: Abbreviation Key

DM – Dental Monitoring

CWRU – Case Western Reserve University

STL – Stereolithography (3D File Format)

ABO – American Board of Orthodontics

AI – Artificial Intelligence

DL – Deep Learning

GPU - Graphics Processing Unit

AMA – American Medical Association

FMX – Full Mouth X-Rays

EHR – Electronic Health Record

US – United States

HIPAA – Health Insurance Portability and Accountability Act

IRB – Institutional Review Board

SD – Standard Deviation

T0 – Timepoint 0 (initial)

T1 – Timepoint 1 (final)

RMS – Root Mean Square

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Appendix C: Descriptive Figures

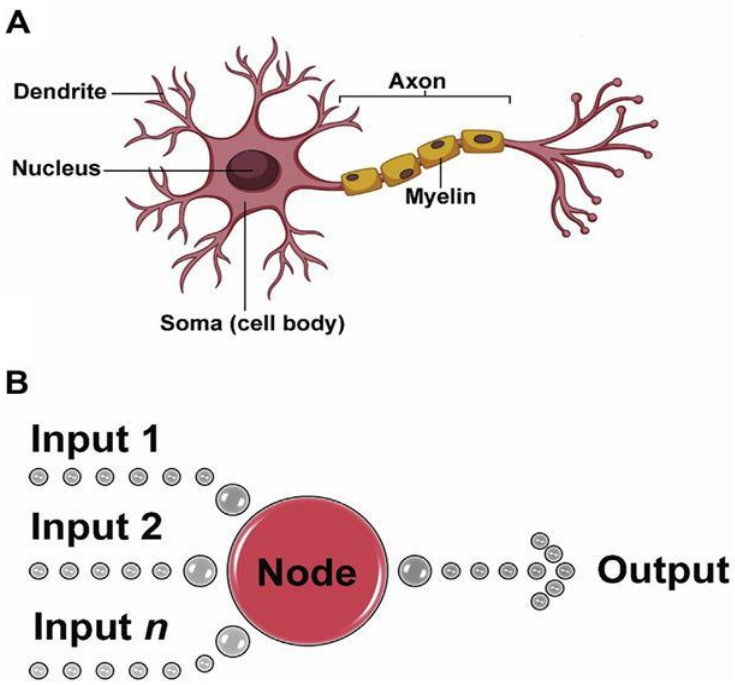


Figure 1. Neural Network Design

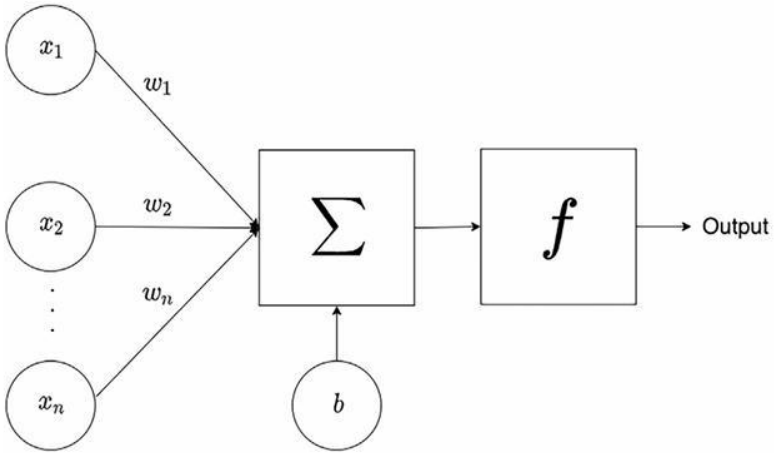


Figure 2: Visualization of the Perceptron

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Figure 3: Deep Blue

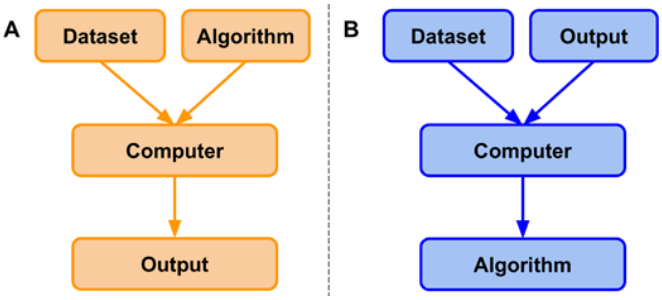


Figure 4: Traditional Computer Programming

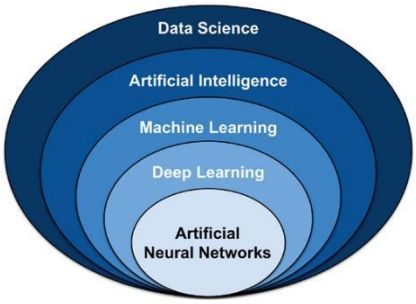


Figure 5: Levels of Artificial Learning

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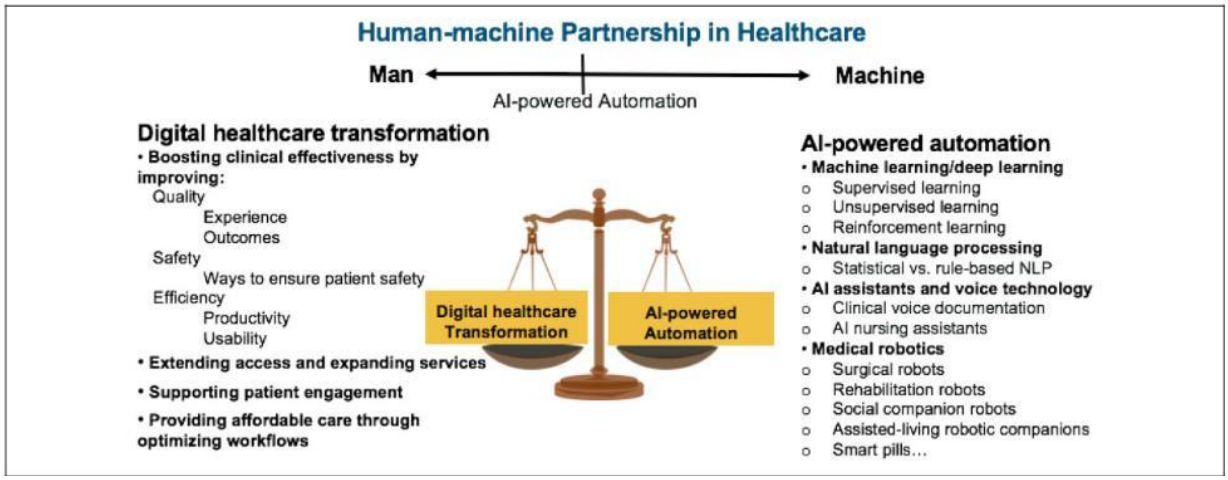


Figure 6: Human Machine Partnership in Healthcare

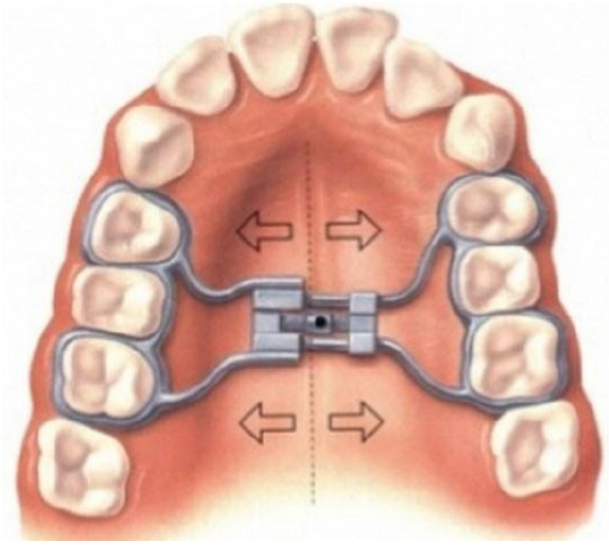


Figure 7: Example of Hyrax Palatal Expander (from TANATAREC Orthodontics)

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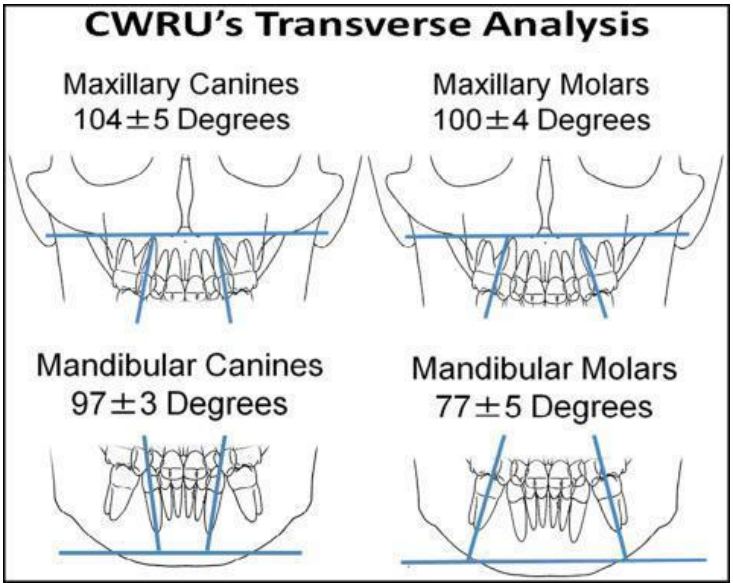


Figure 8: CWRU Transverse Analysis

$$n = \left(\frac{(Z_{\alpha/2} + Z_{\beta}) \cdot \sigma}{\Delta} \right)^2$$

$Z_{\alpha/2} = 1.96$

$Z_{\beta} = 2.33$ (for 99% power)

$$n = \left(\frac{(1.96 + 2.33) \cdot 0.3650}{0.5} \right)^2$$

$$n = \left(\frac{4.29 \cdot 0.3650}{0.5} \right)^2 = \left(\frac{1.56585}{0.5} \right)^2 = (3.1317)^2 \approx 9.81$$

$n = 10$ patients

Figure 9: Sample Size Calculation

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Figure 10: DM Scan Box Pro and Smart Phone



Figure 11: 3 Shape TRIOS 3D Scanner

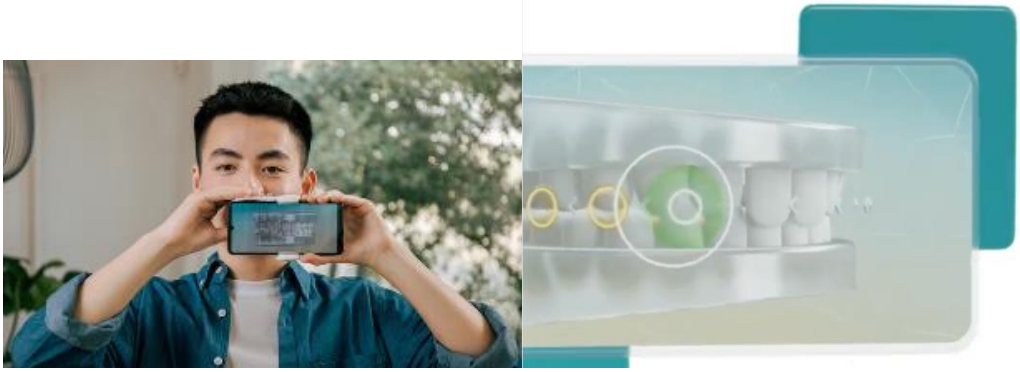


Figure 12: Photo of Scan Assist in Use

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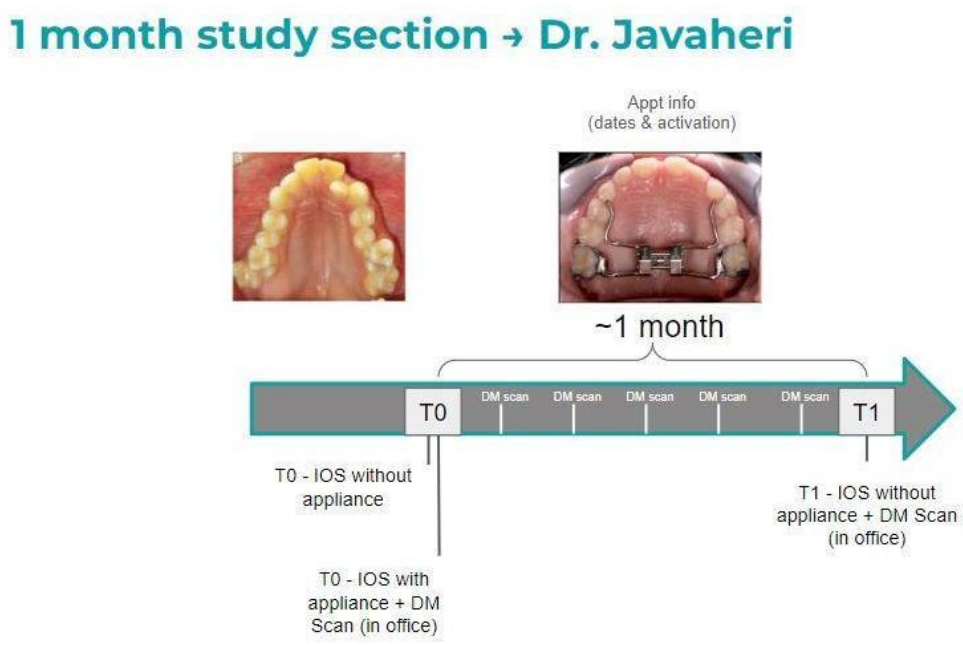


Figure 13: How Data was Gathered In-Office

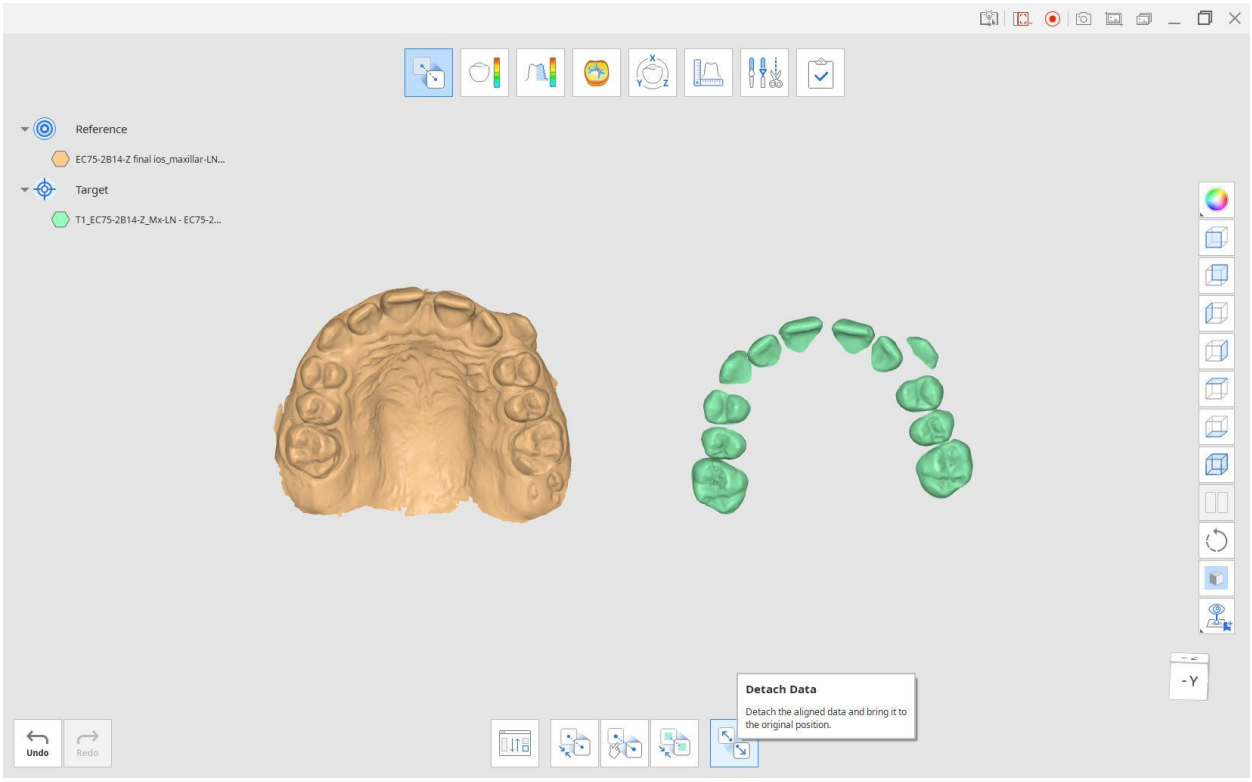


Figure 14: Before Gingival Removal

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Figure 15: After Gingival Removal

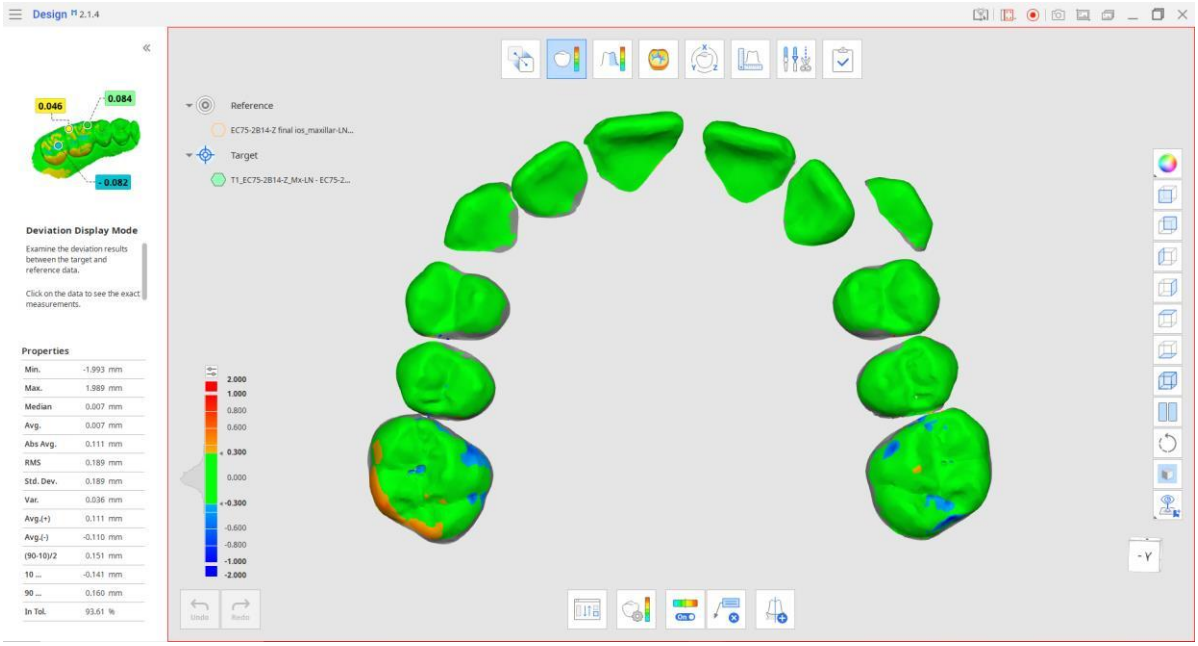


Figure 16: Color Heat Map After Superimposition of DM and 3 Shape Casts

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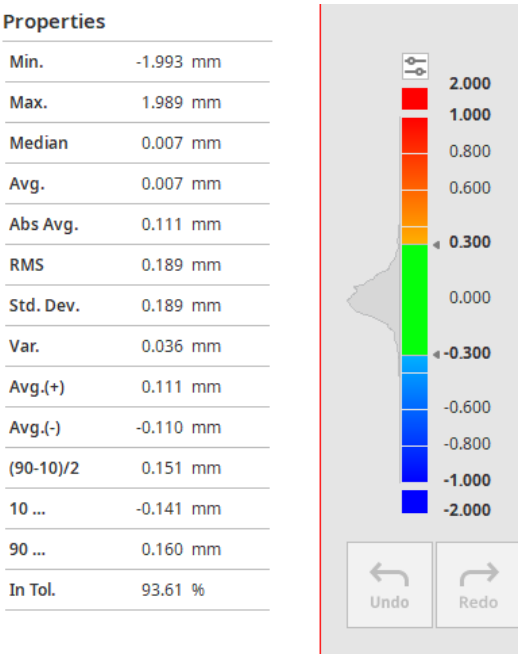


Figure 17: Properties of Superimposition and Color Legend

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Appendix D: Tables

Table II. Descriptive Data of DM and iTero comparison analysis from T_2-T_{10}

Timepoints	*Arch*	*n*	*Estimated mean discrepancy ± standard deviation*	*Avg + discrepancy*	*Avg − discrepancy*
T_2	Maxilla	24	−0.0111 ± 0.2509	0.1683	−0.1959
	Mandible	22	−0.0307 ± 0.2364	0.1572	−0.1835
T_4	Maxilla	24	−0.0073 ± 0.3161	0.2263	−0.2527
	Mandible	22	−0.0241 ± 0.3007	0.2050	−0.2413
T_6	Maxilla	24	−0.0003 ± 0.3416	0.2506	−0.2774
	Mandible	23	−0.0147 ± 0.3225	0.2255	−0.2646
T_8	Maxilla	24	0.0096 ± 0.3650	0.2738	−0.2949
	Mandible	23	−0.0154 ± 0.3471	0.2481	−0.2857
T_{10}	Maxilla	24	0.0106 ± 0.3615	0.2704	−0.2890
	Mandible	23	−0.0005 ± 0.3470	0.2556	−0.2812

Note. Values are measured in millimeters. Statistically significant (P <0.050).
Avg +, Average positive; *Avg* −, Average negative.

TABLE 1: Mean Discrepancy and Standard Deviation from UIC STL Analysis

	Results summary table					
	Measure	Mean ∓ SD	Min	Max	P Value	Significance
1	ABS AVG DEV (mm)	0.15 ∓ 0.23	-1.79	1.73	0.00041	significant
2	RMS DEV (mm)	0.23 ∓ 0.23	-1.79	1.73	0.0026	significant

TABLE 2: Results Summary

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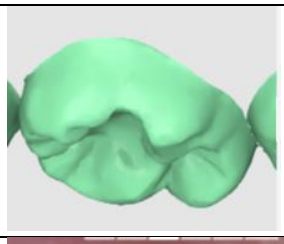
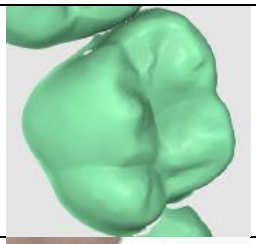
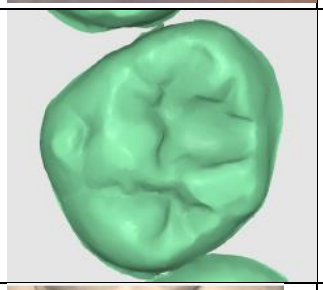
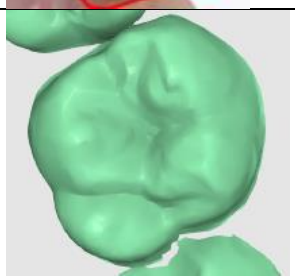
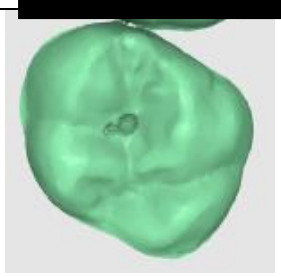
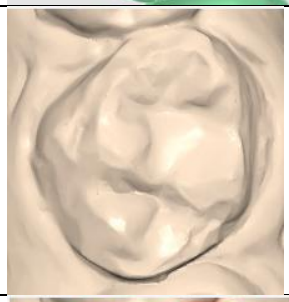
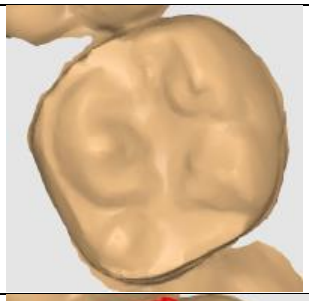
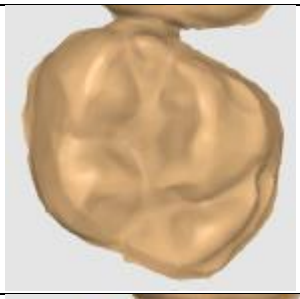
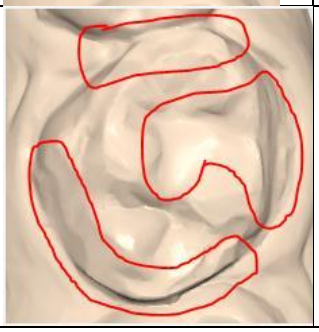
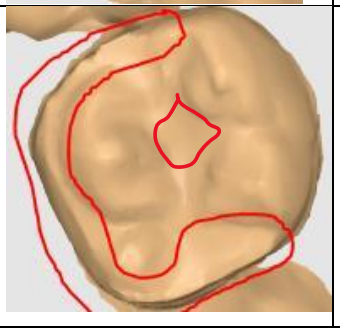
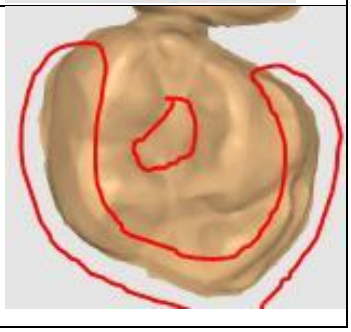
Patient	*Min*	*Max*	*Median*	*ABS Median*	*AVG*	*ABS AVG*	*RMS*	*STD DEV*
Patient 1	*-0.998*	*0.997*	*0.019*	*0.019*	*0.026*	*0.181*	*0.236*	*0.234*
Patient 2	*-1.969*	*1.95*	*-0.022*	*0.022*	*-0.031*	*0.177*	*0.266*	*0.264*
Patient 3	*-0.978*	*0.944*	*0.012*	*0.012*	*0.012*	*0.105*	*0.15*	*0.149*
Patient 4	*-1.999*	*1.974*	*0.025*	*0.025*	*0.12*	*0.184*	*0.266*	*0.266*
Patient 5	*-1.9*	*1.917*	*-0.019*	*0.019*	*-0.031*	*0.156*	*0.22*	*0.217*
Patient 6	*-1.998*	*1.656*	*-0.009*	*0.009*	*-0.037*	*0.125*	*0.239*	*0.237*
Patient 7	*-1.987*	*1.979*	*-0.01*	*0.01*	*-0.035*	*0.123*	*0.21*	*0.207*
Patient 8	*-1.963*	*1.998*	*-0.015*	*0.015*	*-0.022*	*0.136*	*0.215*	*0.213*
Patient 9	*-1.989*	*1.832*	*-0.016*	*0.016*	*-0.045*	*0.138*	*0.23*	*0.225*
Patient 10	*-1.982*	*1.843*	*-0.033*	*0.033*	*-0.061*	*0.158*	*0.238*	*0.231*
Patient 11	*-1.886*	*1.978*	*-0.024*	*0.024*	*-0.059*	*0.153*	*0.239*	*0.232*
Average	*-1.79*	*1.73*	*-0.01*	*0.02*	*-0.01*	*0.15*	*0.23*	*0.23*

Table 3: PART 1 RAW Data from Superimpositions

Patient	VAR	AVG (+)	AVG (-)	(90-10)/2	10	ABS 10	90	In Tol%
Patient 1	*0.055*	*0.193*	*-0.167*	*0.286*	*-0.249*	*0.249*	*0.322*	*81.99%*
Patient 2	*0.07*	*0.163*	*-0.189*	*0.266*	*-0.308*	*0.308*	*0.233*	*83.45%*
Patient 3	*0.022*	*0.108*	*-0.101*	*0.154*	*-0.135*	*0.135*	*0.172*	*94.17%*
Patient 4	*0.071*	*0.179*	*-0.189*	*0.274*	*-0.256*	*0.256*	*0.293*	*82.98%*
Patient 5	*0.047*	*0.138*	*-0.171*	*0.245*	*-0.286*	*0.286*	*0.204*	*86.26%*
Patient 6	*0.056*	*0.093*	*-0.153*	*0.161*	*-0.191*	*0.191*	*0.131*	*92.8%*
Patient 7	*0.043*	*0.094*	*-0.149*	*0.164*	*-0.191*	*0.191*	*0.137*	*93.48%*
Patient 8	*0.046*	*0.126*	*-0.143*	*0.199*	*-0.221*	*0.221*	*0.177*	*91.52%*
Patient 9	*0.051*	*0.104*	*-0.164*	*0.199*	*-0.245*	*0.245*	*0.154*	*90.64%*
Patient 10	*0.053*	*0.115*	*-0.189*	*0.231*	*-0.312*	*0.312*	*0.15*	*87.33%*
Patient 11	*0.054*	*0.109*	*-0.186*	*0.245*	*-0.342*	*0.342*	*0.147*	*85.3%*
Average	*0.05*	*0.13*	*-0.16*	*0.22*	*-0.25*	*0.25*	*0.19*	*0.88*

Table 4: Part 2 RAW Data from Superimpositions

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	PT #1	PT #2	PT #3
T0 Buccal/Lingual			[redacted]
T1 Buccal/Lingual			[redacted]
T1 Buccal/Lingual Excess Cement			[redacted]
T0 Occlusal			
T1 Occlusal			
T1 Occlusal Excess Cement			

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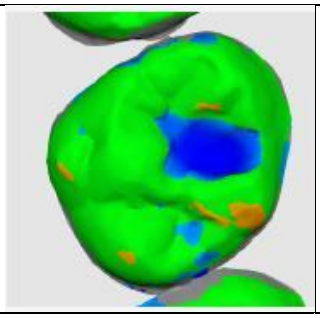
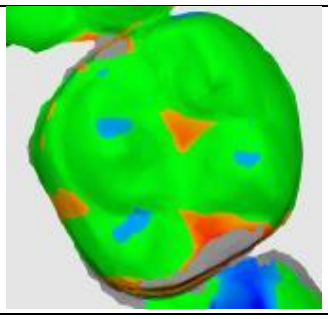
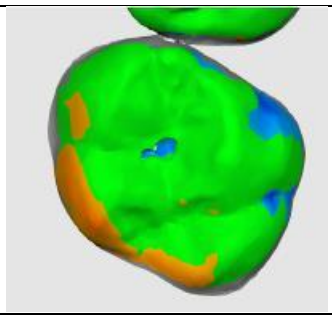
Superimposition			

Table 5: Errors – Remaining Cement on Dentition from Hyrax Bands