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Arno Gatzemann, Year 5, Group 1

INTEGRATED STUDY MASTER THESIS

Precision of Recession Measurement with Digital Intraoral Scanners

Supervisor lect. Giedrius Krukonis

Head of Institute of Dentistry Prof. Dr. Vilma Brukiene

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arno.gatzemann@mf.stud.vu.lt

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Abstract

The integration of digital intraoral scanners into dentistry has revolutionized the procedure and efficiency of dental impression-taking techniques. This thesis provides a comprehensive literature review of the development and use of digital intraoral scanners, highlighting their growing importance in modern dental practices. Following a theoretical review, the thesis presents a comparison and evaluation of two specific digital intraoral scanning devices, the Medit-I700 and the TRIOS 3Shape, to assess their accuracy in capturing the periodontium and the gingival margin with a focus on recession.

An experimental approach was used to objectively measure and compare the accuracy of the two selected devices. The experiment involved the use of standardized procedures to simulate clinical dental impression taking, ensuring that the results are relevant and applicable to real-world settings.

Ten probands with clinical present recession were examined. The results showed a significant difference in accuracy between the two scanners: The TRIOS 3Shape achieved an accuracy of 79.59%, while the Medit-I 700 had a slightly lower accuracy of 75.51% compared to manual measurements with a periodontal probe. The accuracy of both scanners is labeled as ‚sufficient'. SPSS statistical analysis was employed to calculate statistical significant correlation between the data from the Intraoral devices and the manual reference measurement. Deviation occurred mostly in the measurement of recession less than 0,5mm.

The results highlight the differences in performance between different intraoral scanners and suggest that the selection of such devices should be based on empirical evidence of their accuracy. This study contributes to the body of knowledge by providing empirical data on the accuracy of intraoral scanners to assist dental professionals in making informed decisions about which technology to incorporate into their practices. Further research is recommended to examine the long-term reliability of these devices and their impact on patient outcomes in different dental settings, while monitoring and evaluation of upcoming new technologies and improvements of current technologies are emphasized.

Keywords: Digital intra-oral scanning devices, accuracy, measurement, recession, technology, digitalization, manual, experimental, study, implementation, workflow, guidelines, comparison, peridontal-probe, research, analysis

1 Introduction

The implementation of technical inventions is constantly changing the field of dentistry. Dentists worldwide can improve their work, invent new procedures and techniques, and enhance the patient experience thanks to new technical possibilities.

Alongside many useful tools such as the apex-locator, chairside x-ray, and ultrasonic instruments, there have been breakthroughs in the field, like artificial intelligence for radiographic caries-evaluation. It is important to note, that these breakthroughs are not always superior to the expertise of human dentists. Therefore, it is crucial to assess the quality and accuracy of any new or existing device to understand its operational capabilities, as well as its limitations and boundaries. The use of these inventions can improve the quality of treatment and implement state-of-the-art treatment guidelines [1].

Intra oral scanners were first introduced in 1989 and have since undergone constant improvement, making them widely used by dentists worldwide. The fabrication of a digital impression of the patient's mouth is considered a significant advancement in dental medicine. The benefits of digital impressions in dentistry include increased patient comfort and detailed information for both the dentist and the fabricating laboratory. The use of a detailed colored 3D-view, which is digitally stored, eliminates the risk of shrinkage, breakage, or loss, has significantly enhanced dental work [2].

Accurately depicting the presence and state of gingival attachment is crucial in aiding the laboratory during the fabrication of dental prostheses, as well as in the choice of treatment and projected outlook. However, questions have been raised about the accuracy of digital impressions in the dental field, particularly as the margin for error is relatively low and within millimeters. It is important to consider what can and cannot be accurately measured with this technology. Do the 3D-scans provide an accurate representation of both the teeth and surrounding gum tissue, even if the gingiva is loose or recessed? [2,3,4]

The following master thesis is evaluating those questions. Can Intra Oral scanners be used for not only diagnosing, but also accurately measuring gingival recession in patients? Answering those questions can help countless numbers of dentists worldwide in making better treatment choices. [5,3]

1.1 Goal

The research goal is to determine whether digital measurements of gingival reduction can be considered accurate and subsequently used for further dental treatment without the need for conventional manual measurement using a WHO-probe.
This aims to determine the integration and usability of digital scanning devices in a dentist's workflow.

1.2 Aim

Four aims contribute to the thesis' goal.
Aim one: Evaluation and review of the available literature in order to determine the ability of digital intraoral scanner to measure soft tissue attachment. The emphasis lies on the gingival margin and gingival recession from the cemento-enamel-junction (CEJ)
Aim two: Exploration of the current technical standard of digital intraoral scanners. Overview of the different functional principles.
Aim three: Implementation of a comparative experiment with the subsequent guidelines to answer the studies goal. The experiment had to be clear, reliable, and suitable to determine the accuracy and precision of the scanner regarding the raised questions.
Aim four: Statistical calculation to formulate a final answer on the goal and conclusions.

The study implemented inclusion and exclusion criteria for referred studies on PubMed and conducted a study analysis.
The aim of this thesis is to analyze the precision of intraoral recession measurement using digital intraoral scanners. This will be achieved by recording the extent of gingival reduction on ten patients with known present recession, manually, with a standardized periodontal probe on six sites (disto-buccal, buccal, mesio-buccal, mesio-oral, oral and disto-oral). The recording will be repeated using two digital scanners to produce a digital scan of the dentition and adjacent gingival tissues. The recession will be measured using available software methods on the same six sites (disto-buccal, buccal, mesio-buccal, mesio-oral, oral and disto-oral) of every tooth. The results will be statistically captured in table-form to determine accuracy through precision analysis.

A comparison of the results is conducted, and statistical precision is defined as a percentage. The accuracy of the scanners is evaluated as 'not sufficient', 'sufficient', or 'highly sufficient' based on a statistical analysis of the results. The manual measurement results of the periodontal probe are considered as 'correct' and serve as the benchmark for the analysis.

2 Literature Review

Digital intraoral scanners are becoming more common in dentistry due to their versatility in impression-taking, treatment planning, and fabrication of dental restorations. The accuracy of these scanners is crucial for their effectiveness and reliability in clinical practice.

Typically, accuracy is evaluated in terms of trueness and precision. Trueness refers to the accuracy of the scanner in capturing and reproducing intraoral structures, while precision evaluates the consistency and repeatability of the scanner in capturing the same structures across multiple scans.

The accuracy of digital intraoral scanners is influenced by several factors. Scanner technology plays a crucial role in generating accurate digital models. Different scanners use various technologies, such as confocal microscopy, structured light, or active triangulation, each with its own advantages and limitations. The accuracy of the generated models is also influenced by the software algorithms used to process captured images. Advanced algorithms can reduce noise and errors within the scan data. The accuracy of digital intraoral scanners is highly dependent on the operator's proficiency in utilizing the scanner correctly and maintaining proper scanning technique. (6,7) Adequate training and experience are essential prerequisites for achieving optimal accuracy [8].

Empirical studies have investigated the accuracy of digital intraoral scanners, often comparing them to conventional impression techniques such as conventional impressions or plaster models. Overall, these studies have demonstrated that digital intraoral scanners can provide comparable or superior accuracy to traditional methods, particularly when employed appropriately. (7, 8, 9, 10)

It is important to recognize that the accuracy of digital intraoral scanners may vary depending on factors such as the specific scanner model, scanning protocol, and clinical conditions. (7, 11) Dentists should carefully consider these factors when selecting and utilizing digital intraoral scanners in their practice to ensure optimal outcomes. Furthermore, advancements in scanner technology are ongoing and continue to improve the accuracy and reliability of digital intraoral scanning systems. This enhances their usefulness in modern dental practice. (12)

Through a comprehensive review of the scientific literature and empirical evidence, the aim is to provide a thorough understanding of the intricate workings of digital intraoral scanners and their importance in contemporary dental practice.
There are many different IOS-devices available on the market. While the general working principle is nearly identical, no device is similar to the other and each comes with different specifications and price tags.
Current study results are unambiguous regarding the question whether IOS-devices are to be considered supreme in regard of overall precision and accuracy than conceptional impression taking methods using silicones and polymer. (13)
Over 12000 studies have been published in the last years, providing a broad foundation for both the understanding of the functionality as well as the application areas.
There are many different devices in the market today.
Through the emitting of light, which is received by photometric instruments in the device, a high resolution image can be obtained.
Three different technological trajectories are momentarily dominant.
Confocal microscopy, also called confocal laser scanning microscopy (CLSM) uses a spatial filter to remove aberrations in the emitted light, in this case coherent laser light. Several two-dimensional images are captured through a process called ‚optical sectioning' and merged into a three-dimensional structure, allowing the display of a very high resoluting 3D-scan. In opposition to a traditional microscope, a confocal device focuses a smaller beam of light at one narrow depth level at a time.
The Planscan and Emerald series from Planmeca, the CS3600 and CS3700 from Carestream Dental and the Medit i500 use the Structured Light technology. Different narrow bands of light are projected at a three-dimensionally surface. The lines of illumination appear geometrically distorted from other perspectives than the projector due to the shape of the scanned objects. The displacement of those lines allows the device an exact reconstruction of the object by obtaining the 3D coordinates of it including surface details.
The minority in the market are Stereo Vision scanners, like models from Condor or Dental Wings (Virtuo Vivo). Due to the principle of capturing photos from different angles by different cameras in the device, Stereo Vision-intraoral scanners are usually small in size and low in cost but require sometimes an extra step of spraying powder over the scanned object before the capturing and resembling not the latest technological advancements in the market.
While the baseline technology of the devices differs, they all share a common goal: the creation of a detailed three-dimensional scan of the teeth, including adjacent structures like the gingival tissues. (12)

Regardless of their differences, some conditions have been proven to be essential for a clinical satisfactory result. Dry conditions significantly enhance the accuracy. (2) This can be achieved by blow-drying of the teeth before scanning, as saliva significantly influences the scan. Often, as a mouth retractor, such as Optra-Gate is used, to keep lips and chins out of the scanning field. The use of artificial landmarks also enhanced trueness and precision as well as the use of an S-shaped pattern scanning-motion. (6)

Several studies confirmed in comparison, that the type of light used did not have a significant alteration of the scan-result.

However, the overall scanning time can be influenced by the illumination. Best conditions are between 500 and 10000 lux, varying by device. This creates for the need for optimizing ambient lightning illuminance for each Intraoral-scanning device to maximize the accuracy as well as the speed. (14, 15, 16)

It is very important to understand patient related factors and conditions in the scanning practice. (6)

Revilla-Leon et al. pointed out, that the scanning accuracy can be heavily influenced by a variety of conditions. This includes the type of tooth scanned, the presence and width of interdental spaces, arch shape and width variations, palate characteristics, wetness, presence and shape of existing restorations, edentulous areas, inter-implant distance, implant characteristics as well as the overall characteristics of the surface being digitized. (17, 18)

The understanding of these conditions is considered a crucial element for the accuracy of intra-oral scanners throughout the existing literature. (7, 14, 15, 16)

For implant scans, metallic implant scan bodies are more favorable than polymer bodies to minimize wear due to sterilization distortion. Patient related factors are the arch scanned, the implant position, the inter-implant distance, their depth, and angulation, making implant-scanning another challenge for practitioners. (18) The studies acknowledged, that the influence of these factors varies by different devices and their technical modalities.

The trueness and accuracy of existing scanners was examined in a study in 2023.(17)

Michelinakis et al found significant differences among the tested devices. (19) As heavily pointed out, the Planmeca Merald device showed notably lower trueness than the Medit i500 ($P<.001$), (which successor, the Medit i700, is used in this thesis‘ experimental determination of recession measuring accuracy and trueness) and the 3shape A/S TRIOS scanner ($P<.001$). (5)

In comparison to the conventional impression technique (manually using plastic, haptic materials and an impression tray), Pellitteri et al‘ studies emphasized that the general precision and trueness was greater while highlighting variances between different systems. The mean distinctions of the tested devices (Carestream CS3600, CEREC Omnicam and Trios 3shape) in comparison to manual impression taking was determinated between 100 and 200 micrometer, while the Trios 3shape was found to be the most ‚precise‘ and the biggest alterations were found for the Carestream device for measuring the transversal distance.

Another area of possible incorrections was found in the incisal margins, as well as the molar areas [9]. The 2D and 3D analyses showed slightly greater distortion in molar regions for digital impressions, while the Trios 3Shape was proven to be the most timesaving, meaning fastest, device in that comparison. (9)

2.1 Periodontal Pathologies

The exact representation and subsequently measurement of adjunctive tissues provides a challenging task for Intra Oral scanners. Prior investigations of scanner-reliability of periodontal tissues (gingival margin, tissue thickness, cemento-enamel-junction, etc.) showed promising results.

In a mean of published studies, where gingival recession was measured as the distance from the CEJ to the gingival margin parallel to the long axis of the tooth starting from the most apical point of recession, the Trios 3Shape digital measurement from the available software was found to be only slightly inferior in comparison to manual measurements in the mouth with a calibrated Williams Periodontal Probe and a caliper.

A study from 2019 by Fageeh et al (20) recorded the highest mean gingival recession measurement of 2.24 ± 0.97 mm using the conventional probe model (CP), while the lowest measurement of 1.64 ± 0.74 mm was noted with digital measurements of digitized cast models (DC).

The CP method exhibited the highest mean value of 2.11 ± 1 mm across all methods and examiners, with the digital measurements on cast models (CC) method showing the lowest at 1.91 ± 0.7 mm.

The ICCs for all methods combined and for all examiners combined were almost perfect, with values of 0.933 and 0.912, respectively. This indicates a high level of agreement and reliability in digital measurements.

The study described the differences in measurements obtained by different methods and examiners. Bland and Altman plots were used to illustrate the degree of agreement and identify biases, which were not clinically significant as the maximum difference did not exceed half a millimeter. However, the study acknowledged the broad 95% confidence intervals, which extend up to 2 mm and could potentially challenge the reliability of the methods used.

The study does not specifically mention or discuss the cemento-enamel junction.
Further scientific data about the detection, measurement and evaluation of the cemento-enamel junction is not present at the moment.
The author of this thesis found a study from 2021, evaluating the detection of the CEJ from Intraoral Ultrasonographs. (21)
The study, published in MDPI, presents and computer-assisted method for accurate identification of the cementoenamel junction in intraoral ultrasound. Using image processing techniques, including preprocessing, segmentation, and edge detection, this method aims to improve the accuracy of CEJ localization. Validation against manual expert judgement showed a minimum mean difference of 0.25 mm and high reliability, with intra-class correlation coefficients (ICCs) exceeding 0.98. (21)
Despite showing satisfactory results, this method differs significantly from the technology of intraoral scanners, due to the computer-aided processment and enhancement of the obtained images before evaluation. These functions are not yet present in IOS-devices but are chosen to be mentioned for reasons of completeness and due to lack of other research-material present at the moment as well as to demonstrate, where future technological advancements can contribute to the development.

2.2 Accuracy

The available literature highlighted repeatedly, that the type of structure scanned is considered important and alternated the accuracy results. While the most relevant literature mostly considered digital scans of the teeth superior in accuracy than in comparison to conventional impression taking, results reversed when examining accuracy of IOS-devices in regard of full-arch restorations.
2017, Ebeid et al investigated the accuracy of IOS-devices, with a focus on reliability and accuracy on full arch impressions. (10)
According to the study, digital impressions are comparable in accuracy to conventional impressions for fabricating crowns, fixed dental prostheses (FDPs), implant-supported crowns, and short-span FDPs. However, conventional impressions tend to yield better accuracy for full-arch restorations. (6,10, 18)
It is worth noting that digital impressions exhibiting commendable accuracy similar to conventional impressions in the creation of crowns, fixed dental prostheses (FDPs), and short-span FDPs. The digital impressions consistently produce marginal gap values that fall within

the clinically acceptable range, demonstrating their potential to deliver reliable outcomes for these types of restorations.

The study noted that the clinically acceptable range for marginal gap measurements is less than 120 µm, based on criteria outlined by McLean and von Fraunhofer. Values between 50 and 200 µm are commonly reported in the literature. (10)

Ebeid et al. found that conventional impressions are more accurate than digital counterparts. This highlights the need for further research and improvement in digital intraoral scanning, especially for full-arch restorations.

2.3 Durability

At the time of preparation of this review and research, there has not been a comprehensive study specifically focused on the lifespan or durability of intraoral scanners. However, information regarding the longevity of these devices can be gleaned from user experiences, manufacturer specifications, and anecdotal evidence from dental professionals. (10)

The quality of construction is one of the primary factors that impact the lifespan of intraoral scanners. High-quality materials and robust engineering contribute to longer lifespans for devices, compared to cheaper alternatives. Additionally, the frequency of use plays a significant role. For example, scanners in busy dental practices experience faster wear and tear than those used less frequently.

Maintenance practices also significantly affect the longevity of intraoral scanners. Regular cleaning, calibration checks, and adherence to manufacturer-recommended maintenance protocols are crucial for preventing premature failure and ensuring optimal performance over time. Neglecting maintenance tasks can lead to decreased accuracy and functionality, ultimately shortening the lifespan of the device.

Additionally, rapid technological advancements may impact the lifespan of intraoral scanners. While some older models may remain functional for many years, newer innovations may render them obsolete sooner. Therefore, dental professionals should consider the expected lifespan of intraoral scanners when making purchasing decisions and plan for potential upgrades or replacements accordingly.

Dental practices should consider the expected lifespan of intraoral scanners when making purchasing decisions. Investing in high-quality, durable devices can provide long-term value and reduce the need for frequent replacements.

Several studies have examined the accuracy of IOS devices on single-tooth models. The author considered the study by Zarbakhsh et al., 'Accuracy of Digital Impression Taking Using Intraoral Scanner versus the Conventional Technique,' to be representative of this topic based on inclusion and exclusion criteria such as the number of examined devices, study reliability, and thoughtfulness of the process. The results of the different available researches were taken into account.

The study compared the accuracy of digital impression-taking using an intraoral scanner with the conventional technique. In the experiment, a typodont molar tooth was used as the standard model. Ten digital impressions were produced using a TRIOS intraoral scanner and sent to the manufacturers for analysis. In the conventional method, a stone die was created using addition silicone impression material, which was afterwards scanned with a computer-aided design/computer-aided manufacturing scanner. The study utilized an in-vitro experimental design to measure the gap between the framework and the model using the replica technique. Statistical analysis, employing chi-square test, was conducted to compare the results. (22)

Zarbakhsh et al.'s study found that the digital impression technique had a significantly lower mean thickness of replicas compared to the conventional technique at all tested points ($P < 0.0001$), indicating superior accuracy with the digital method.

Additionally, the intraoral digital scanner was notably more accurate than the conventional technique across all measured points. Therefore, the digital method is considered a reliable adjunct or alternative to the conventional technique, offering increased accuracy in impression-taking procedures. (22)

2.4 Diagnostics

The use of Digital Intraoral Scanners and their usefulness in terms of diagnostic ability, trueness, and reliability of implementation in treatment planning has been examined by various studies.

In a systematic review conducted in 2023, Angelone et al. Discussed the use of intraoral scanners (IOSs) in various diagnostic applications, with a primary focus on dental wear and caries detection. The study emphasized, that scanners equipped with integrated caries detection technology, such as iTero Element 5D, TRIOS 4, Emerald S, and a prototype developed by Michou et al., were predominantly used for identifying carious lesions. These scanners employed NIRI, fluorescence, and transillumination technologies. In terms of dental wear evaluation, commonly utilized scanners included True Definition, TRIOS 3, Cerec Omnicam, and Planscan. (23)

Geomagic Control X was found to be the preferred software for evaluating 3D dental models, especially in cases of dental wear when conducting model comparisons. Other specialized software tools, such as Geomagic Qualify, Mountains, VRMesh, Rstudio, WearCompare, TRIOS Patient Monitoring, OrthoCAD, and Maxilim software, were used for specific diagnostic tasks.

Discussions on dental wear assessment have emphasized the evaluation of Intraoral Scanners' (IOSs) capability to assess dental wear using metrology software such as Geomagic Qualify. Studies have compared IOSs with traditional methods and assessed their accuracy under diverse conditions. In the domain of caries detection, ongoing development of IOSs-devices with integrated caries detection technology has exhibited promise in identifying carious lesions, particularly occlusal and interproximal caries. (23) According to Angelone et al, the most accurate use of IOS-devices is in the detection of dental lesions.

Furthermore, Intraoral scanners (IOSs) have been found to be useful in assessing plaque levels and structural issues in the oral cavity, such as alterations in dental arch width, scarring, asymmetry, and soft tissue examination. Angelone et al. Underscored the potential of IOSs as diagnostic tools in clinical practice, providing quantitative parameters for clinical decision-making and benefiting both clinicians and patients. To strengthen the diagnostic utility of IOS-devices, further research and validation against traditional methods were recommended. This compliments the aim of this master thesis – to determine whether IOS-devices can provide reliable data on gingival recession of patients for diagnostic ability, treatment planning, and fabrication of dental prosthetic appliances.

2.5 Cone Beam Computed Tomography (CBCT)

Studies have shown that scanners can accurately image tooth structures and their positioning in the maxilla, mandible, and occlusion, allowing for precise treatment planning for dental restorations, prosthetic crowns, and orthodontic braces. An adjunctive technology frequently used is Cone Beam Computer Tomography (CBCT). Several studies have compared the reliability of Intraoral scanners and CBCT. (24)

CBCT is used in orthodontics to assess bone conditions and plan tooth movements with minimal complications. In implant prosthetics, it aids in assessing implantation feasibility and designing surgical procedures. Furthermore, 3D scanners enable accurate reproduction of dental arches, reducing the need for traditional impression materials and ensuring precise diagnosis and

treatment assessment. The importance of scanners and CBCT in modern dentistry is highlighted in the review, which also stresses the need for further research to improve their diagnostic and treatment planning capabilities.
Intraoral scanners have the advantage of eliminating the need for traditional impression materials, resulting in more consistent results without deformation. They also reduce the time required for procedures such as crown lengthening, surgical template creation, or occlusion redesign. Additionally, the direct transfer of data from intraoral scanners to CAD/CAM software streamlines the fabrication process of partial dentures and single crowns, reducing the need for multiple manufacturing steps.
Limitations of intraoral scanners include concerns about their accuracy compared to traditional impressions, which may require additional corrections and extended treatment time. (7, 24)
Cone beam computed tomography (CBCT) offers advantages over intraoral scanners due to its ability to provide more accurate imaging of oral cavity tissues and anatomical structures. This aids in various dental procedures, including implant prosthetics, crown lengthening, and orthodontic treatment planning. Furthermore, CBCT provides detailed 3D models that can be converted into STL files for use in stereolithographic procedures and 3D printing of surgical guides and dental restorations. (24)
Exposure to ionizing radiation is a concern, although the benefits often outweigh the risks when used for diagnostic purposes, according to Frackiewicz et al. (25)
In conclusion, it can be stated that digital intraoral scanners are a valuable addition to dental practices. Advanced technologies enable precise digital impressions and treatment planning.
However, there are notable differences among the various devices available on the market. (23)
Therefore, thoughtful decision-making is necessary to acquire the intraoral scanner that best fits the dentist's needs. Despite technological advancements, there are still precision inaccuracies when compared to conventional impression taking. (16) These inaccuracies must be carefully considered and further updated and investigated in the future.

3 Materials and Methods

The aim of this master thesis, whether digital intraoral scanning devices can provide adequate and reliable data on gingival recession of patients was answered through a comparative experiment. In order to provide ‚reproducible results‘, a detailed account of the experiment will be given.
The research was conducted by the author of the thesis.

To underline the relevance of the conducted research, a literature review on studies and articles regarding Digital Intraoral Scanners was carried out, with a focus on accuracy and trueness, as well as the implementation on examination, treatment planning, assessment modalities and further evaluation.

The review took in account literature from three databases (PubMed, Elsevier, Google scholar). A total of over 14.000 articles and studies with the topic ‚Digital Intraoral Scanner‘ have been published in these databases. The review implemented inclusion and exclusion criteria for referred studies on PubMed and conducted a study analysis.

The search was then limited to meet criteria such as written in English language, not older than 10 years, created from and published by reliable and trustworthy researchers and publication authorities (journals, universities). Emphasis was set on evaluation of accuracy and measurement of periodontal tissues, recognition of Cemento-Enamel junction and evaluation of tissue thickness. A lot of studies covered different topics than the main ones researched by the author of the thesis.

Specific studies about digital recession measurement are rare at the moment, underlining the necessity and relevance of the thesis‘ topic.

Overall, 25 studies, articles and reviews were included for the description in the review if they met all the criteria, i.e., they referred to Intraoral scanners used in dentistry.

The aim of this thesis is to analyze the precision of intraoral recession measurement using digital intraoral scanners. This was achieved by recording the extent of gingival reduction on ten patients with known present recession, manually, with a standardized periodontal probe. The recording was repeated using two digital scanners to produce a digital scan of the dentition and adjacent gingival tissues. The recession was measured using available software methods on the same six sites (disto-buccal, buccal, mesio-buccal, mesio-oral, oral and disto-oral) of every tooth.

For the experimental part, twelve patients with clinically present gingival recession were chosen.

Inclusion criteria consisted of patients with present recession and no contraindicative pathologies, like upcoming gingival surgery and intake of substances, inducing or enhancing further progress of recession, like bisphosphonates. This was achieved by medical examination, checking of medical history and a questionnaire. Exclusion criteria were unwillingness in participating in the experiment, upcoming gingival surgery, and intolerance of passive scanning with intraoral scanning devices (gag reflex, etc.)

The group of patients participating was furthermore selected from present patients of the author at Zalgirio University clinic, Vilnius, Lithuania, during general examination and priorly treated patients with known present recession and consisted of both male and female patients from Lithuania and Germany.

For privacy reasons, the names of the patients were anonymized and only referred to as numbers (Patient 1, 2, 3, etc.) in order to maintain confidentiality of data.

All patients had the right to withdraw from the experiment at any time. The participants were not affected by interpretation and reporting of the data and had the right to access their evaluations and digital intra-oral scans.

All patients gave informed consent to participate in the experiment and showed willingness to participate in the evaluations necessary to achieve the study aim.

The experiment lasted from November 2023 to April 2024 with several appointments for every patient (typically four).

Chosen methods for the research were mixed, both qualitative and quantitative.

The patients were evaluated with detailed medical history, physical examination, including manual recession measuring and two digital intra-oral scans by two different devices. The study type was retrospective, as results were calculated after examinations and measurement on patients were performed.

After identification of suitable patients with present gingival recession, recession measurement of six sites on any tooth (disto-buccal, buccal, mesio-buccal, mesio-oral, oral and disto-oral) was conducted with a standardized probe with markings in steps of 2mm. This measurement served as a baseline for the evaluation of accuracy and is therefore referred to as ‚correct‘ and ‚manual measurement.‘

In a following appointment, a digital intraoral scan was performed on the patients, with intra-oral scanning device Medit-I 700 (see 4.0 Intraoral scanning devices and 4.1 Medit-I 700).

A digital recession detection and analysis was conducted with the scanned data on the same sites (disto-buccal, buccal, mesio-buccal, mesio-oral, oral and disto-oral) of every tooth.)

The scan was done in sitting and supine position in the dental chair, exactly as the manual measurement. No anesthesia or further medication was administered to the study participants. Sufficient working conditions of dry teeth without interference of saliva and tongue was achieved by blow drying the teeth dry before the scan.

In another appointment, a second scan of all patients was prepared with a second, different intra-oral scanning device, the TRIOS 3Shape, and evaluation of the same tooth surfaces (disto-buccal, buccal, mesio-buccal, mesio-oral, oral and disto-oral) was conducted with the available software.

Figure 1: Intraoral Recession Measurement with a Periodontal Probe with 2mm markings on tooth number 34.

Figure 2: Intraoral Recession Measurement with a Periodontal Probe with 2mm markings on tooth number 46.

Figure 3: Procedure of scanning of a patient with Medit-I 700

The focus was thereby on the ability intraoral scanning devices to recognize recession of teeth, indicated by ‚right recognition – right positive', ‚false positive' (indicating recession where no recession is clinically present, and ‚false negative‘ (indicating no recession where recession is clinically present).

Overall, twelve probands were manually measured and scanned with the Medit-I 700 Intraoral scanner. Before the second scan, two probands decided not to further participate in the experiment, leaving the amount of data of probands with two scans and manual measurement to ten. For comparative reasons, the data from the two probands with only one scan has been excluded from the analysis.

The results were statistically captured in table-form to determine accuracy through statistical analysis. A comparison of the results was conducted, and statistical precision was defined as a percentage. The accuracy of the scanner was evaluated. The manual measurement results of the periodontal probe are considered as 'correct' and serve as the benchmark for the analysis.

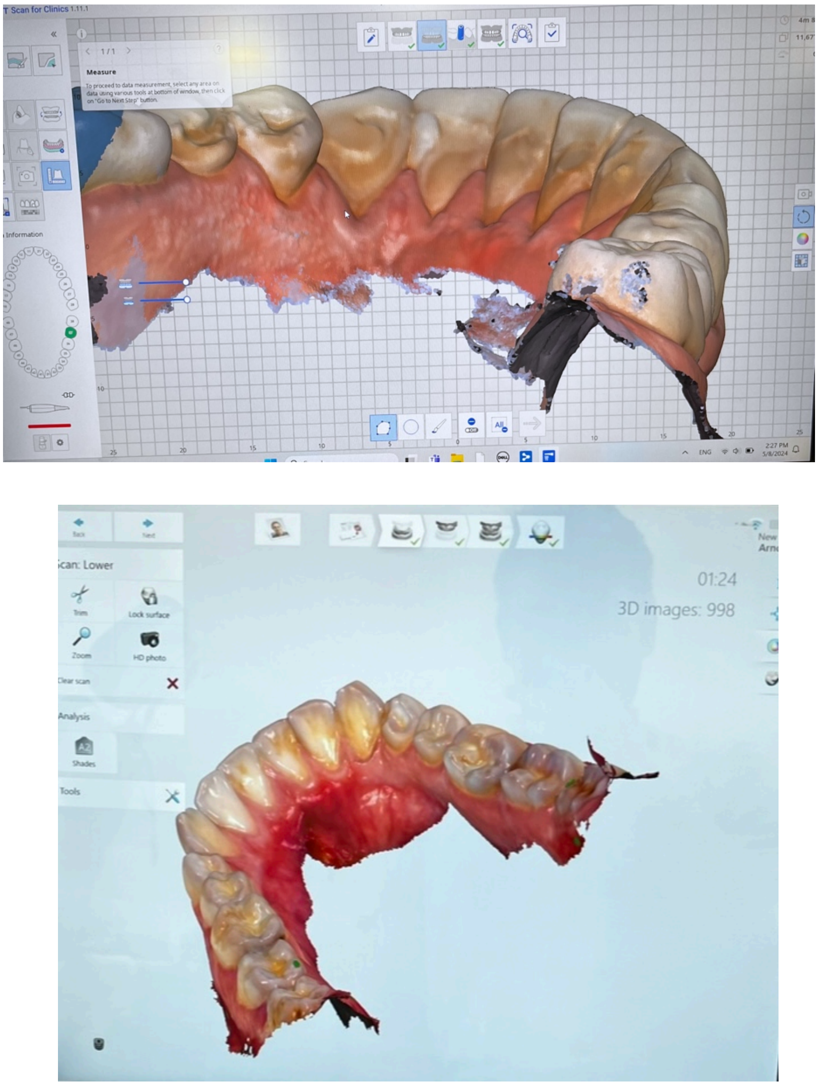

Figure 4: Software view: Medit-I 700 (upper) and TRIOS 3Shape (lower).

Figure 5: Device View: TRIOS 3Shape Scanner (left) and Medit-I 700 (right).

Both Scanners employed corresponding software to view the acquired digital images. The Trios 3Shape-IOS was a all-in-one solution with wireless scanner and corresponding touch-sensitive screen.
The Medit-I 700 had a wireless scanner and contrary to the 3Shape, the device had to be plugged in to a commercially available mobile computer. On the installed Medit Link app, it was possible to examine the scans.

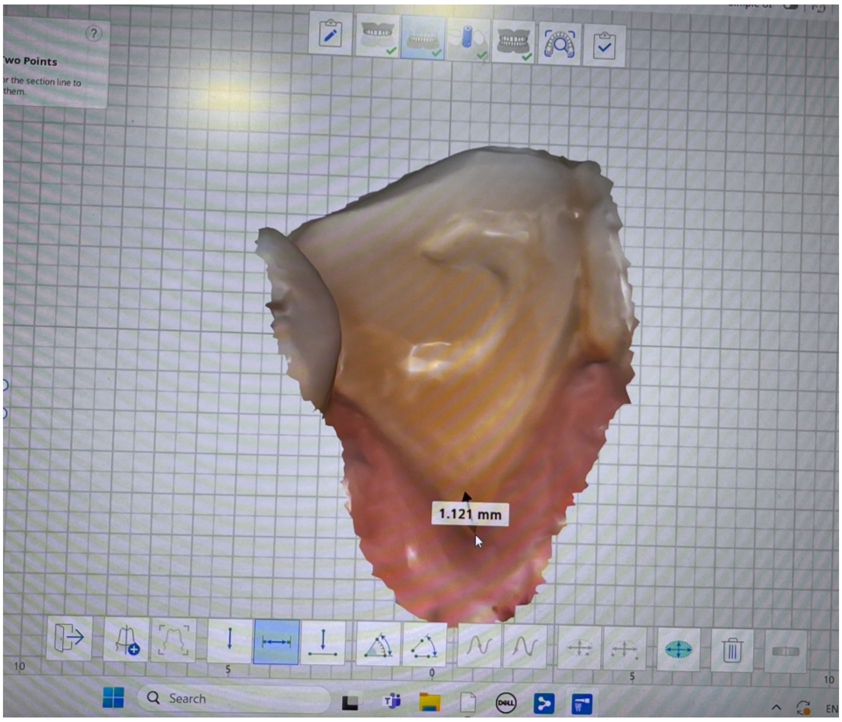

Figure 6: Digital Recession Measurement with Medit-Link Software (Medit-I 700)

The specifically for clinical analytic purposes- designed software of the Medit (Medit Scan for Clinics 1.11.1) was experienced as more user-friendly and advanced. Navigation through the menu was intuitive and allowed quick processing. Measurement of recession was achieved through a specific ‚point-to-point‘ measurement option, despite both devices had no specific feature for ‚recession or gingival margin height‘-measurement.

4 Digital intraoral Scanners

Digital intraoral scanners have emerged as indispensable tools in modern dentistry, offering precise, efficient, and patient-friendly solutions for dental impressioning. An exploration of the operational principles underlying digital intraoral scanners, encompassing optical imaging, sensor technology, computational algorithms, and their synergistic integration is made.

Through a literature-review, empirical studies, and technological advancements, this paragraph aims to offer a broad understanding of the intricate mechanisms driving the functionality of digital intraoral scanners and their profound implications in contemporary dental practice.
However, it is noteworthy that the initial investment cost for an intraoral scanning device may be relatively high, typically starting from approximately 15,000 Euros with the inclusion of a proper software license.
The evolution of computer-aided design and computer-aided manufacturing (CAD/CAM) technology in dentistry dates back to the 1970s with the introduction of the concept by Dr. Francis Duret. In subsequent years, pioneers such as Dr. Werner Mörmann and Marco Brandestini developed the first intraoral scanner integrated with a CAD/CAM device, commercially available as CEREC by Sirona Dental Systems LLC in 1987. Since then, digital scanners have witnessed widespread adoption and continuous refinement within dental practices globally.
The expenses related to obtaining and upkeeping these devices differ greatly, which requires dental practitioners to carefully consider their investment decisions. Potential dental practices must take in account the intricacies of intraoral scanner costs, factors such as the initial purchase price, ongoing maintenance expenses, and potential returns on investment.

The purchase price of intraoral scanners varies depending on factors such as brand, model specifications, and included features. Entry-level scanners typically offer basic functionalities at a lower cost range of 5,000 to 15,000 EUR, making them accessible options for practices with limited budgets. Examples of mid-range scanners priced between 15,000 to $30,000 EUR include the 3Shape TRIOS 3 Basic and Planmeca Emerald S. These scanners offer a balance between cost-effectiveness and enhanced capabilities and may include additional features such as color scanning or improved accuracy. Other examples of mid-range scanners are the iTero Element 5D and Carestream CS 3700.
High-end scanners, which can cost 30,000 to $50,000 EUR or more, offer advanced features and superior accuracy, making them more suitable for practices with high performance demands. Two examples on the market are the 3Shape TRIOS 4 and Dentsply Sirona CEREC Primescan.

In addition to the initial acquisition cost, dental practitioners must consider ongoing maintenance expenses to ensure the longevity and optimal performance of intraoral scanners. These expenses comprise of software licenses, warranties, training programs, and technical support services. They are essential for maximizing the lifespan and functionality of the device.

However, these additional costs contribute to the overall investment required for intraoral scanner utilization.
To assess the return on investment (ROI) associated with intraoral scanner adoption, it is necessary to consider factors such as increased efficiency, improved clinical outcomes and patient satisfaction, and potential revenue generation. Intraoral scanners streamline clinical workflows and reduce chairside time, resulting in advanced clinical outcomes and increased revenue generation.
Furthermore, CAD/CAM technology allows for in-house restorations, potentially increasing revenue. However, the actual ROI may differ based on practice-specific factors, such as patient demographics, case volume, and integration with existing systems.
The widespread adoption of the technology has contributed to the growth of the intraoral scanning market, which reached a volume of approximately 644.8 million Euros in 2022 and is projected to surpass 1.3 billion Euros soon. Europe is the second-largest market globally, following the United States of America, with an annual calculated growth rate (CAGR) of 11.0%. Key players in this industry include Medit, Planmeca, market leader Dentsply Sirona, and 3Shape.

The optical imaging component of digital intraoral scanners is fundamental to their functionality, as it enables the capture of detailed surface topography and texture of intraoral structures. Several optical technologies are employed in these scanners, each offering distinct advantages in terms of accuracy, speed, and versatility. Structured light technology involves projecting a known pattern of light onto the intraoral surface and analyzing the deformation of this pattern to infer surface contours. This deformation is caused by the shape and texture of the object being scanned.

Structured light scanners typically use a combination of a light projector and a camera to capture the reflected pattern. By analyzing the distortion of the projected pattern, the scanner can determine the shape of the object in three dimensions. Structured light scanners are known for their high accuracy and are particularly well-suited for capturing detailed surface textures.

Confocal Microscopy: Confocal microscopy utilizes a focused beam of light to achieve depth resolution, allowing for precise imaging of structures at different focal planes within the tissue. In intraoral scanners, confocal microscopy techniques enable the capture of images with high spatial resolution and depth discrimination. By scanning the tissue with a focused beam of light and detecting the reflected or scattered light, the scanner can construct a three-dimensional representation of the surface topography. Confocal microscopy is particularly advantageous for capturing fine surface details and is commonly used in high-end intraoral scanners.

Laser Technology: Laser scanners emit a laser beam to capture surface details with micron-level precision. Laser scanners are capable of rapid scanning and can capture highly accurate 3D images of intraoral structures. The laser beam is directed onto the surface, and the reflected light is detected by a sensor, allowing for the reconstruction of the surface geometry. Laser scanners are known for their speed and accuracy and are often used in situations where rapid scanning is required, such as during intraoral scanning procedures.

Combination Technologies: Many modern digital intraoral scanners utilize a combination of optical technologies to achieve optimal performance. For example, some scanners may combine structured light and confocal microscopy to capture both surface texture and depth information simultaneously. By integrating multiple optical technologies, these scanners can achieve higher accuracy and provide more comprehensive 3D reconstructions of intraoral structures.

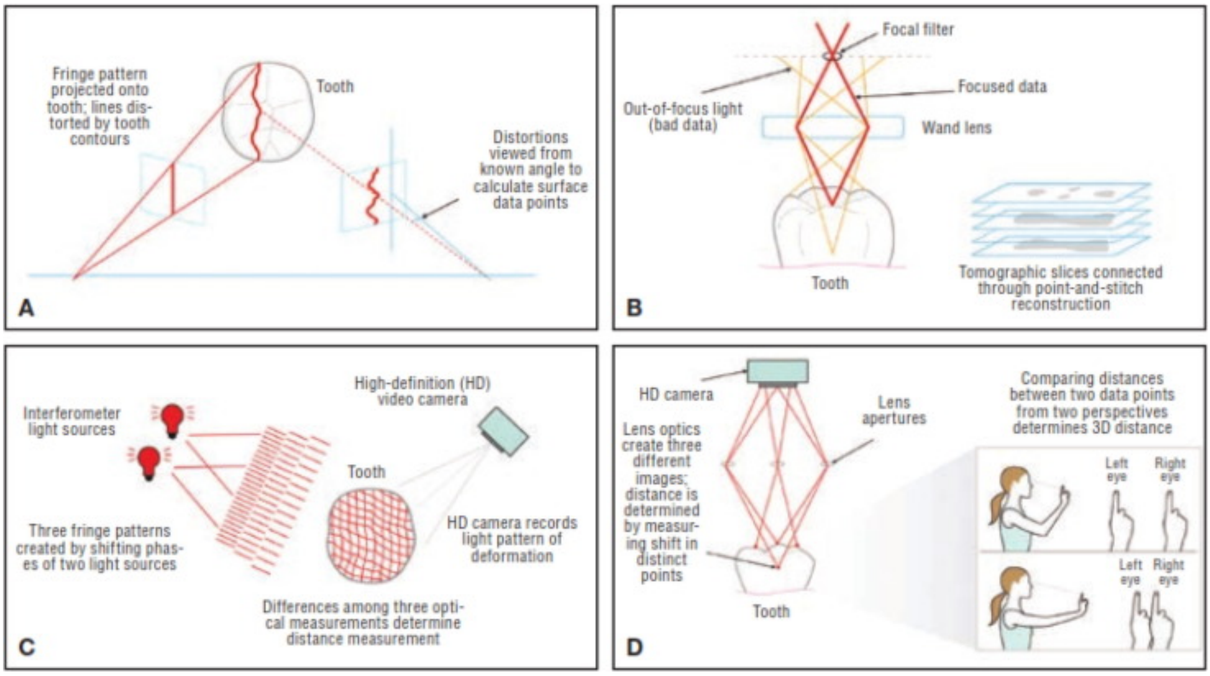

Figure 7: Optical technologies in Intra-Oral Scanners: (A) Structured Light; (B) Confocal Microscopy; (C) Inferometer; (D) Optical Multi Camera [S. Sehrawat, 2022]

The sensor technology is a critical component of digital intraoral scanners, responsible for converting optical signals into electrical signals that can be processed to generate digital images. The choice of sensor technology directly impacts the accuracy, resolution, and performance of intraoral scanners. This section provides an in-depth analysis of sensor technologies commonly used in digital intraoral scanners, highlighting their strengths and limitations.

Charge-Coupled Device (CCD) Sensors: CCD sensors have been widely used in digital intraoral scanners due to their excellent sensitivity, low noise levels, and proven track record in digital imaging applications. CCD sensors consist of an array of photosensitive elements (pixels) that convert incoming light into electrical charge. The accumulated charge is then read out sequentially, pixel by pixel, to generate a digital image. CCD sensors offer high image quality, with low noise and high dynamic range, making them well-suited for capturing detailed intraoral images, especially in low-light conditions. Studies have demonstrated the efficacy of CCD sensors in intraoral scanning, showing high levels of accuracy and reproducibility (Ahlholm et al., 2018).

Complementary Metal-Oxide-Semiconductor (CMOS) Sensors: CMOS sensors have gained popularity in recent years due to their advantages in terms of cost, power efficiency, and integration capabilities. CMOS sensors operate by converting incoming light into electrical charge within each pixel, with readout circuits integrated directly onto the sensor chip. This integration allows for faster readout speeds and lower power consumption compared to CCD sensors. CMOS sensors also offer flexibility in pixel design, enabling features such as on-chip amplification and noise reduction. While CMOS sensors may exhibit higher levels of noise compared to CCD sensors, recent advancements have significantly narrowed the performance gap between the two technologies. Studies have demonstrated the suitability of CMOS sensors for intraoral scanning applications, with comparable levels of accuracy and image quality to CCD sensors (Ahmed et al., 2017).

Hybrid Sensor Configurations: Some digital intraoral scanners employ hybrid sensor configurations, combining elements of both CCD and CMOS technologies to capitalize on their respective strengths. For example, a hybrid sensor may use a CMOS-based active pixel sensor array for image capture and processing, coupled with a CCD-based sensor for low-noise, high-dynamic-range readout. This hybrid approach can offer the benefits of both sensor technologies, including high sensitivity, low noise, and fast readout speeds, while mitigating their individual limitations. Research evaluating hybrid sensor configurations in intraoral scanners is limited, but theoretical analyses suggest potential advantages in terms of overall performance and versatility.

Computational algorithms form the backbone of digital intraoral scanners, playing a crucial role in processing raw image data and reconstructing accurate three-dimensional (3D) models of intraoral structures. The computational algorithms employed in digital intraoral scanners encompass image alignment, feature extraction, surface reconstruction, and error detection and correction.

Image alignment algorithms are essential for aligning and stitching together the multiple two-dimensional (2D) images captured during the scanning process to create a cohesive 3D model. These algorithms employ techniques such as feature matching, geometric transformation, and optimization methods to ensure accurate registration of individual images.

Feature Extraction: Feature extraction algorithms are utilized to identify and extract relevant anatomical features from the captured images, such as tooth contours, margins, and surface textures. These algorithms employ techniques such as edge detection, corner detection, and texture analysis to identify distinctive features within the images.

Surface reconstruction algorithms are responsible for reconstructing the three-dimensional (3D) surface geometry of intraoral structures from the extracted features and aligned images. These algorithms employ techniques such as triangulation, surface fitting, and mesh generation to generate a continuous and smooth representation of the surface.

Error detection and correction algorithms are essential for identifying and rectifying inaccuracies or artifacts in the reconstructed 3D model. These algorithms employ techniques such as outlier removal, surface smoothing, and geometric validation to identify and correct errors.

The seamless integration of optical imaging, sensor technology, and computational algorithms is paramount to the success of digital intraoral scanners. By harnessing these technologies in concert, the scanners offer clinicians unparalleled capabilities for capturing, analyzing, and visualizing intraoral anatomy. The synergy between these components enables clinicians to achieve precise digital impressions, facilitate accurate treatment planning, and enhance communication with patients and dental laboratory technicians. Furthermore, ongoing advancements in each of these domains continue to push the boundaries of digital intraoral scanning technology, driving improvements in accuracy, efficiency, and versatility.

Digital intraoral scanners operate based on a sophisticated interplay of optical imaging, sensor technology, computational algorithms, and their seamless integration. By harnessing these technologies, the scanners empower clinicians with capabilities for dental impressioning and treatment planning. A comprehensive understanding of the operational principles underlying digital intraoral scanners is essential for clinicians to leverage their full potential in clinical practice, ultimately leading to improved diagnostic accuracy, treatment outcomes, and patient satisfaction in dentistry.

4.1 Medit-I 700 Intraoral Scanner

Throughout the experiment, two intraoral scanners from different companies were utilized. One such scanner is the Medit-I 700, developed by the South Korean company Medit. Established in 2000, Medit has garnered a reputation for producing user-friendly devices with plug-and-scan technology. Notably, the Medit-I 700 received the RedDot Design Award in 2021 for its innovative design. The Medit-I 700 scanner leverages a combination of structured light technology and confocal microscopy techniques, facilitating high spatial resolution, depth discrimination, and precise surface reconstruction. This integration enhances its imaging capabilities, enabling accurate depiction of intraoral structures with fine surface details.

In contrast, some alternative intraoral scanners may rely solely on structured light or laser technology,like the aforementioned Carestream CS3600 potentially limiting depth resolution and the ability to capture intricate surface features effectively.

In terms of sensor technology, the Medit-I 700 is equipped with a high-resolution Charge-Coupled Device (CCD) sensor renowned for its sensitivity, low noise levels, and superior image quality. Moreover, it incorporates Complementary Metal-Oxide-Semiconductor (CMOS) technology for rapid signal readout and processing, thus improving workflow efficiency. Conversely, other scanners may employ different sensor technologies, such as exclusively CCD or CMOS sensors, which could impact image quality, scanning speed, and overall performance.

Regarding clinical applications, the Medit-I 700 scanner offers a diverse array of uses across restorative dentistry, prosthodontics, orthodontics, and implantology. It facilitates precise treatment planning, crown and bridge fabrication, orthodontic treatment simulations, and implant placement procedures. Furthermore, the seamless integration of the Medit-I 700 with CAD/CAM software, coupled with its open architecture for collaboration with dental laboratories, enhances its clinical versatility and utility.

Priced at approximately 24,900 Euros for a five-year period of use, including operating and tip fees, the scanner offers wireless and cable connectivity options, enhancing both operator and patient experiences. The scanning frame rate of up to 70 FPS, coupled with 3D-in-motion video technology and dual-camera optical triangulation, ensures exceptional sensitivity and image quality. Additionally, the scanner features LED lighting for optimal jaw illumination and a mirrored tip angled at 45 degrees to facilitate scanning of the distal molar area. The device's plug-and-scan functionality is facilitated by USB 3.1 Gen connectivity and Wireless-Hub technology.

4.2 TRIOS 3 Shape Intraoral Scanner

The 3Shape Intraoral Scanner was introduced to the dental market in 2009.
Weighing approximately 350 grams, this scanner is designed to be lightweight, ensuring maneuverability and ease of use for dental practitioners during intraoral scanning procedures.

The scanner utilizes optical technology to capture high-definition 3D images of the oral cavity. This technology uses structured light or confocal microscopy principles to project light patterns onto the dental surface. Sensors capture the patterns to create a digital impression. Algorithms process the data to generate precise 3D models of the teeth and soft tissues. Some models of the 3Shape scanner may incorporate artificial intelligence and machine learning to enhance scanning accuracy and efficiency.
Furthermore, the scanner can be integrated with CAD/CAM systems, which speeds up the transfer of digital impressions to dental laboratories, reducing turnaround times for the fabrication of dental restorations. Comparative studies have shown a significant reduction in chairside time and improved workflow efficiency with the adoption of the 3Shape scanner, thereby optimizing resource allocation and enhancing overall practice productivity.
The 3Shape Intraoral Scanner is designed to minimize patient discomfort during the scanning process, ensuring a positive chairside experience.
It offers comprehensive compatibility with CAD/CAM systems and other digital platforms commonly used in dental practice. Digital impressions captured by the 3Shape scanner can be easily integrated into the software for designing and fabricating custom dental restorations. Additionally, the scanner's real-time communication and data sharing capabilities among dental professionals enhance interdisciplinary collaboration and promote continuity of care across various treatment modalities.
As intraoral scanning continues to evolve as a cornerstone of modern dental practice, the 3Shape Intraoral Scanner drives advancements in clinical care, facilitating enhanced treatment outcomes and patient experiences.

5 Results

The selection of the patients consisted of present recession during dental examination and known recession-patients through medical records.
After all patients gave informed consent to participate in the experiment a manual recession analysis with a standardized probe was performed and the results have been noted.
The type and FDI numbering of the tooth were not incorporated as it was not found to play a crucial role in the experiment.
The evaluation procedure was repeated with the two digital scans of the patients and the results compared in table form for each patient. The results were grouped in table form for each proband, indicating right positive values (correct recognition of presence and extent of recession, with error less than 0,5mm), false positive (correct recognition but deviation from manual measured recession higher than 0,5mm) and false negative (incorrect recognition of presence of recession in comparison to manual measured standard).

Manual rec. measurement	3Shape right positive	3Shape false positive	3Shape false negative	Medit right positive	Medit false positive	Medit false negative
2		× (1,5mm)			× (1,5mm)	
1	×			×		
0,5	×			×		
1,5			× (0mm)	×		
0		× (0,5mm)			× (0,3mm)	
1	×					× (0mm)
1	×			×		

Table 1: Intraoral measurement Patient 1

Manual rec. Measurement (mm)	3Shape right positive	3Shape false positive	3Shape false negative	Medit right positive	Medit false positive	Medit false negative
0,5	×			×		
1	×			×		
1,5	×					× (0mm)
1	×			×		
1,5	×			×		

Table 2: Intraoral measurement Patient 2

Manual rec. Measurement (mm)	3Shape right positive	3Shape false positive	3Shape false negative	Medit right positive	Medit false positive	Medit false negative
2	X				X (1,5mm)	
0,5	X			X		
0,5	X			X		
0		X (0,5mm)		X		
0,5	X			X		
0,5	X			X		

Table 3: Intraoral measurement Patient 3

Manual rec. Measurement (mm)	3Shape right positive	3Shape false positive	3Shape false negative	Medit right positive	Medit false positive	Medit false negative
2,5	X			X		
2	X				X	
1,5	X			X		
1,5	X			X		
0,5			X			X
2		X		X		
2	X			X		

Table 4: Intraoral measurement Patient 4

Manual rec. Measurement (mm)	3Shape right positive	3Shape false positive	3Shape false negative	Medit right positive	Medit false positive	Medit false negative
1,5	X			X		
1	X			X		

Table 5: Intraoral measurement Patient 5

Manual rec. Measurement (mm)	3Shape right positive	3Shape false positive	3Shape false negative	Medit right positive	Medit false positive	Medit false negative
0,5			X	X		

Table 6: Intraoral measurement Patient 6

Manual rec. Measurement (mm)	3Shape right positive	3Shape false positive	3Shape false negative	Medit right positive	Medit false positive	Medit false negative
0,5	×			×		
1			×	×		
1	×			×		
0,5	×			×		

Table 7: Intraoral measurement Patient 7

Manual rec. Measurement (mm)	3Shape right positive	3Shape false positive	3Shape false negative	Medit right positive	Medit false positive	Medit false negative
1,5	×			×		
1	×					×
1	×				×	
0,5	×					×
0,5	×			×		

Table 8: Intraoral measurement Patient 8

Manual rec. Measurement (mm)	3Shape right positive	3Shape false positive	3Shape false negative	Medit right positive	Medit false positive	Medit false negative
0,5	×					×
0,5	×			×		
1	×					×
0,5	×			×		
0,5	×			×		
0,5			×	×		

Table 9: Intraoral measurement Patient 9

Manual rec. Measurement (mm)	3Shape right positive	3Shape false positive	3Shape false negative	Medit right positive	Medit false positive	Medit false negative
0,5	×			×		
0,5	×			×		
0,5	×			×		
1	×			×		
1	×			×		
1			×	×		

Table 10: Intraoral measurement Patient 10

6 Statistical analysis

Accuracy

Overall, 49 teeth have been included in the analysis. The right measurement has been captured by the 3Medit-I 700 scanner (less than 0,5mm deviation) for 37 teeth. This accounts for 75,51% of all teeth.

The 3Shape device captured 39 teeth correctly, which is an accuracy of 79,59%.

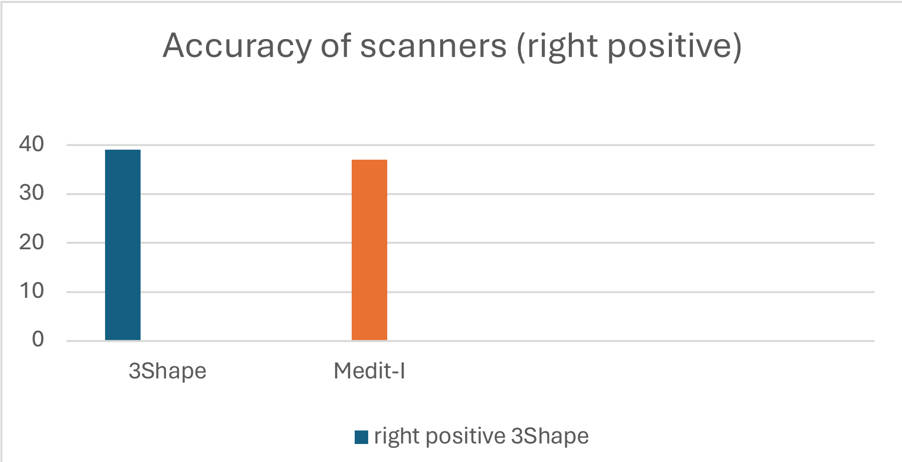

Figure 8: Accuracy of scanners (Right Positive)

False negative

False negative values (indicating no recession where clinical recession is present) accounted for 6 teeth (12,24%) with the 3Shape scanner from TRIOS and 7 teeth (14,29%) in the Medit-I 700.

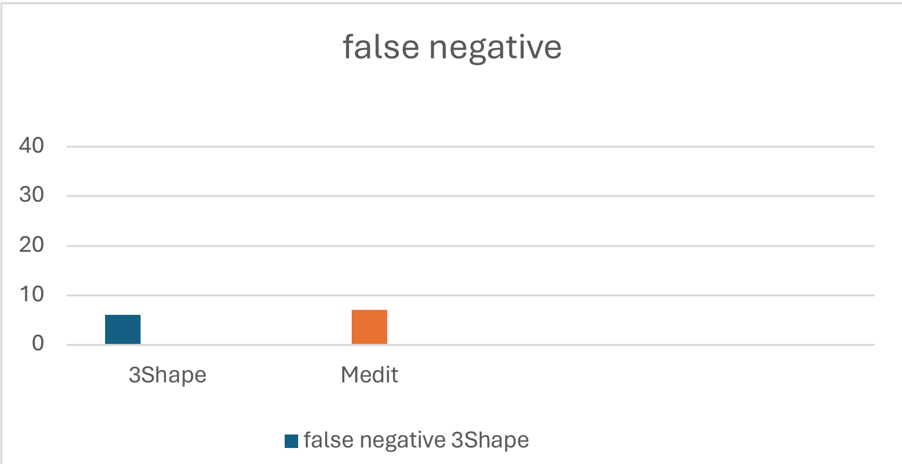

Figure 9: Accuracy of Scanners (False negative)

False positive

False positive measurements (indicating a too high or low amount of recession) have been noted for 4 teeth with the 3Shape device, which corresponds to 8,16% of the total tooth number and 5 teeth (10,20%) with the Medit-I 700 Intraoral Scanner.

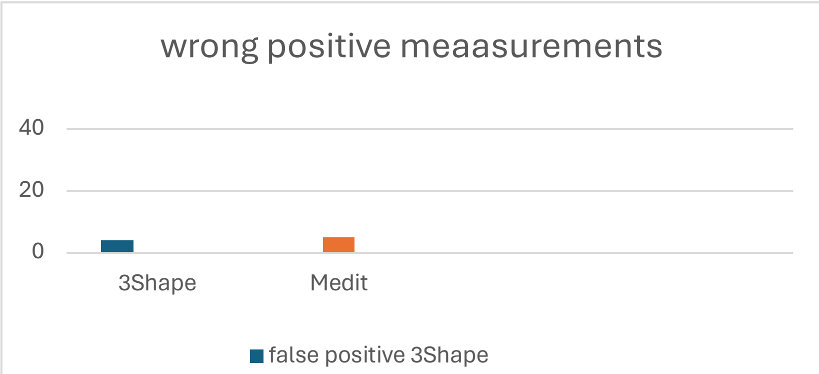

Figure 10: Accuracy of Scanners (Wrong positive measurements)

It is notably, that for both scanners, the most errors occurred in the correct recognition and measurement of extent of slight recession of 0,5mm. In those cases, some scans showed no presence of recession or had problems depicting the true extent precisely.

The correct recognition of larger extent of recession (higher than 1,5mm) was nearly always present.

Paired samples t-test

To find out, whether there is statistical correlation of the data from the two scans, in comparison to the manual measured data, which was defined as ‚standard', a paired sample t-test was carried out.

Null-Hypothesis (H0): The mean accuracy of the sample is equal to the standard value.

Alternative Hypothesis (H1): The mean accuracy of the sample is not equal to the standard value.

The **p-value** is set at 0.005.

Paired Samples Test

		Paired Differences							Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
Pair 1	VAR00001 - VAR00003	-.95918	2.00218	.28603	-1.53428	-.38409	-3.353	48	<.001	.002
Pair 2	VAR00002 - VAR00003	-1.07143	2.00780	.28683	-1.64814	-.49472	-3.735	48	<.001	<.001

Figure 11: Paired Samples Test from SPSS

For both scanners (**VAR00001** – 3Shape & **VAR00002** – Medit), the **Mean Difference** value is negative. It measures the average of the differences to the sample (**VAR00003** – manual measurement). A negative mean indicates, that, on average, the measured values are lower than the standard.

The standard deviation is 2.00218 for the 3Shape device and 2.00780 for the Medit-scanner.

The **t-value**, which indicates the size of the difference relative to the variation in the standard (manual measurement) data, is -3.353 for the TRIOS 3Shape-scanner and -3.735 for the Medit scanner. Larger absolute t-values suggest a more significant difference between the groups. Negative mean values in the results of the differences between the two sets of measurements indicates that, on average, the values of the first set of measurements are lower than those of the second set. This can be due to the two different devices used and their different technical capabilities.

Significance (p-value): An **alpha-level** of 0.05 was used. The **p-value** in the test was smaller than 0.001 for both devices. 0.001 is smaller than 0.05 – therefore, the **Null-Hypothesis is rejected** and the **Alternative Hypothesis is adopted.** This indicates, that the mean accuracy of the scanners is **not** equal to the standard measurements.

Fisher's Exact Test

To calculate, whether a significant relationship between the measured values from the intraoral-scanners and the manually measured data is present, a Fisher's test was employed. This test is especially useful, when the present data pool is relatively small, in comparison to the chi-square test.

Null-Hypothesis (H0): There is no association between the variables.

Alternative Hypothesis (H1): There is no significant association between the two measurement sets regarding their ability to meet the standard.

The **p-value** is set at 0.05.

Two data sets were fabricated, for each device and compared to the standard measurement values, where ‚1' indicated ‚meets standard' and ‚2' represents ‚does not meet standard'.

VAR00001 * VAR00002 Crosstabulation

Count

		VAR00002		
		.00	1.00	Total
VAR00001	.00	11	7	18
	1.00	11	20	31
Total		22	27	49

Figure 12: Fishers test SPSS data comparison: 3Shape (VAR00001) and Medit (VAR00002) against standard measurement.

The crosstabulation of Fisher's test shows, that in 20 cases, both measurements, from Trios 3Shape device and Medit-I 700 both meet the standard. This accounts for 40,82%. In 11 cases (22,45%), both numbers did not meet the standard.

In 22,45% of cases (11 cases), the TRIOS 3Shape device met the standard, but the Medit-I 700 did not.

In 8,16% of cases (7 cases), the Medit-I 700 device met the standard, but the TRIOS 3Shape did not.

The total number of disagreements between the two sets (0 vs 1 and 1 vs 0) is 11+7 =18. This accounts for 36,73% of cases, where both devices had different measurements.

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	3.023[a]	1	.082	.136	.075	
Continuity Correction[b]	2.076	1	.150			
Likelihood Ratio	3.036	1	.081	.136	.075	
Fisher's Exact Test				.136	.075	
Linear-by-Linear Association	2.961[c]	1	.085	.136	.075	.054
N of Valid Cases	49					

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 8.08.

b. Computed only for a 2x2 table

c. The standardized statistic is 1.721.

Figure 13: Fishers test SPSS data comparison p-value

The **p-value** of the chi-square-test is 0.136 and therefore bigger than the set **p-value** of 0.05. The **Null-Hypothesis (H0)** is accepted.

This result suggests that any observed differences in the way the two sets meet the standard could likely be due to random variation rather than a systematic difference between the sets.

7 Clinical Recommendations

This experiment focused primarily on the metric of accuracy. It is critical for practitioners and decision-makers to consider a comprehensive set of factors when selecting an intraoral scanner. These include ease of use, software compatibility, speed of data acquisition, patient comfort, and overall cost effectiveness. Each of these factors can have a significant impact on the integration and usefulness of the technology in a dental practice.

False negative measurements occurred in 12,23% of the cases with the 3Shape device and 14,29% in the Medit device, indicating recession not being present in cases, where clinical recession is visible during manual clinician examination. This occurred mostly in cases of clinical recession of about 0,5 mm. This leads to the necessity and implication for clinicians to double check the scanning results manually.

The results of the Fisher analysis suggests that any observed differences in the way the two devices meet the standard could likely be due to random variation rather than a systematic difference between the sets. Although the p-value is not below the usual threshold for declaring statistical significance, it doesn't necessarily mean that there are no differences at all; it indicates that the evidence isn't strong enough to assert a statistically significant difference based on the data provided and the test performed.

The higher accuracy demonstrated by the 3Shape suggests that it may be more reliable in clinical settings where high precision is required such as complex prosthetic restorations and esthetic procedures (crowns in anterior region and veneers), where close adherence to the gingival margins is necessary. This difference in performance could play a critical role in clinical decision making, influencing both the choice of technology and the expected outcomes of patient treatments. Accurate digital impressions are critical to reduce the margin of error in the final restorative or orthodontic work, thereby improving overall treatment efficiency and patient satisfaction.

For clinicians, the ability to accurately document the morphology of periodontal tissues both before and after surgical procedures is particularly valuable. The digital scanning technology allows to perform precise comparative analyses of subtle changes in tissue architecture and depth, which are critical in assessing healing outcomes and the efficacy of surgical procedures. In addition, after evaluation of the scans, the utility of digital intraoral scanners extends into the long-term periodontal monitoring. By generating detailed three-dimensional records, practitioners are enabled to track the progression or regression of periodontal disease over time. The development and accuracy of Digital Intraoral scanners is expected to further advance in the future, with the improvement and implement of current and new optical, mechanical and digital technologies. It has yet to be determined, which role artificial intelligent algorhythms will play in the improvement of scanners. Therefore, close monitoring of new technologies and further evaluation of Digital Intraoral scanners is emphasized, as well as further comparisons of scanners with a larger sample sized could be indicated.

8 Conclusion

The capacity of Digital Intraoral Scanner to measure the soft tissue attachment is substantiated by the extant literature. The current technical standard and functional principles enable the devices to capture both teeth and the periodontium.

The implemented comparative experiment evaluated the accuracy of two commercially available digital intraoral scanners, the Medit-I700 and the TRIOS 3Shape, to ascertain which scanner exhibited superior accuracy in capturing dental impressions.

The 3Shape device exhibited slightly higher accuracy with 79,59% in comparison to the Medit-I 700 Intraoral scanner with 75,51%. Accordingly, in light of the thesis' goal, the accuracy of both scanners can be classified as 'sufficient.

The Fisher's exact analysis revealed no significant correlation between the between the two measurements in their ability to meet the standard. Both measurements were identical with the standard at the same time in 40,82% of cases.

The resulting question, whether this discrepancy from the standard has an impact on clinical implications in the dental office cannot be answered statistically, as the requirements for digital scan data considered ‚accurate', vary between different fields of use, cases, dental offices and practitioners.

Although the results were conclusive and the choice of methodology was effective in practice, difficulties during the experiment arose from scheduling problems with patients for the different intraoral scans and led to an increased number of visits for some patients, which did not affect the overall accuracy of the experiment. Two people withdraw their consent before the second scan and have therefore been excluded from the analysis for comparative reasons.

Possible limitations of the experiment could be the sample size and the choice of intra-oral scanners, though it was not depictable to compare all known intra-oral scanning devices for reasons of viability of the experiment in the setting of a master thesis.

Future research should extend beyond the confines of this study to examine a broader range of intraoral scanners and a wider range of clinical scenarios. This would help to develop a more robust understanding of how different devices perform in different types of dental cases. In addition, longitudinal studies are needed to assess the long-term reliability and durability of these scanners by evaluating how they perform over time in routine clinical use.

In summary, the findings of this thesis provide valuable insight into the comparative accuracy of intraoral scanners and serve as a foundation for further research and discussion within the field of digital dentistry. By continuing to explore and understand the capabilities and limitations of different intraoral scanning devices, the dental profession can better realize the potential of these technologies to improve clinical outcomes and the patient experience.

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