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ORIGINAL ARTICLE

Assessment of gingival thickness using digital file superimposition versus direct clinical measurements

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Abstract

Objectives This study was aimed at evaluating the correlation and reproducibility of gingival thickness quantification using digital and direct clinical assessment methods.

Materials and methods Patients in need of tooth extraction were allocated into two groups according to the gingival thickness measurement method, either using an endodontic spreader (pre-extraction) or a spring caliper (post-extraction), both on the mid-facial (FGT) and mid-lingual (LGT). Pre-extraction Digital Imaging and COmmunications in Medicine (DICOM) and STereoLithography (STL) files of the arch of interest were obtained and merged for corresponding digital measurements. Inter-rater reliability between digital and direct assessment methods was analyzed using inter-class correlation coefficients (ICC).

Results Excellent inter-rater reliability agreement was demonstrated for all parameters. Comparison between the endodontic spreader and the digital method revealed excellent agreement, with ICC of 0.79 (95% CI 0.55, 0.91) for FGT and 0.87 (95% CI 0.69, 0.94) for LGT, and mean differences of 0.08 (− 0.04 to 0.55) and 0.25 (− 0.30 to 0.81) mm for FGT and LGT, respectively. Meanwhile, the comparison between the caliper and the digital method demonstrated poor agreement, with ICC of 0.38 (95% CI − 0.06, 0.70) for FGT and 0.45 (95% CI − 0.02, 0.74) for LGT, and mean differences of 0.65 (0.14 to 1.16) and 0.64 (0.12 to 1.17) mm for FGT and LGT, respectively.

Conclusions Digital measurement of gingival thickness is comparable with direct clinical assessments performed with transgingival horizontal probing using an endodontic spreader.

Clinical relevance Digital assessment of gingival thickness is a non-tissue invasive, reliable, and reproducible method that could be utilized as an alternative to horizontal transgingival probing.

Keywords Phenotype · Gingiva · Radiology · 3-D imaging

Introduction

Periodontal and peri-implant phenotype have progressively evolved into critical components of diagnosis and treatment planning in contemporary clinical practice [1, 2].

The term periodontal phenotype, which has been historically referred to as "biotype," pertains to the combination of gingival phenotype (gingival thickness and keratinized tissue width) and bone morphotype (facial bone plate thickness) [3]. Gingival thickness appears to be correlated with underlying bone thickness and, therefore, has been recognized as a key prognostic factor in periodontal and tooth replacement therapy [4–6]. Furthermore, flap thickness has been pointed out as a significant predictor for the outcomes of root coverage procedures [7, 8].

Peri-implant phenotype has been defined as the morphologic and dimensional features characterizing the clinical

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presentation of the tissues that surround and support osseointegrated implants [9]. The peri-implant phenotype has a soft tissue (peri-implant keratinized mucosa width, mucosa thickness, and supracrestal tissue height) and an osseous component (peri-implant bone thickness) [9]. Thick peri-implant soft tissue phenotypes have been linked to favorable peri-implant bone remodeling patterns [10, 11] and superior esthetic outcomes following the delivery of the final prosthesis [12, 13]. On the contrary, thin peri-implant phenotypes have been linked to a higher degree of gingival recession following immediate implant placement [14].

Different invasive and non-invasive methods have been described to quantify soft tissue thickness around teeth and implants. These methods include subjective visual inspection of soft tissue characteristics [15], visual assessment of probe transparency through the gingival sulcus [16–18], the use of cone beam computed tomography (CBCT) [5, 19], non-ionizing ultrasonography [20, 21], horizontal transmucosal bone sounding (aka transgingival probing) [22], or the use of a caliper after tooth extraction [23]. While each of these assessment modalities bears some advantages over the rest, there is a lack of consensus regarding a reliable, reproducible, and non-invasive approach to precisely assess gingival and peri-implant mucosa thickness in clinical practice and research. Digital workflows offer the possibility of combining STereoLithography (STL) files, which are detailed representations of the characteristics of scanned surfaces, with Digital Imaging and COmmunications in Medicine (DICOM) files for precise assessments of the soft tissue thickness at different locations [24].

The aim of this study was to evaluate the reliability and reproducibility of gingival thickness assessment using the superimposition of an STL file (representing the surface contour) onto the corresponding CBCT-acquired DICOM file (representing the underlying soft tissue and hard tissue structures) compared with two direct, commonly utilized measuring methods, namely the use of transmucosal horizontal probing using an endodontic spreader or a spring caliper.

Material and methods

Study design, ethical approval, and setting

This clinical investigation was designed as a cross-sectional study. The study protocol was approved by the University of Iowa Institutional Review Board (IRB) in October 2019 (HawkIRB #201909749). This study was conducted and monitored according to the principles of Good Clinical Practice (GCP) [25]. The clinical component of the study was conducted at the Department of Periodontics of the University of Iowa College of Dentistry (Iowa City, IA, USA).

Recruitment

Adult patients (≥ 18 years of age) in need of single tooth extraction were eligible to participate in this study. Patients previously enrolled in two separate clinical trials involving tooth extraction and different gingival thickness measurement protocols were invited to participate in this study. Hence, the study sample was comprised of two subsets of patients, according to the clinical method of gingival thickness measurement, either transmucosal probing with an endodontic spreader (ES) or the use of a spring caliper (SC).

All potential participants were required to read, understand, and sign the informed consent form, which included a thorough explanation of the study design and purpose.

Patients were selected according to the following eligibility criteria.

Inclusion criteria:

- Physical status under ASA categories I or II [26].
- Maxillary incisors, maxillary and mandibular canines, and maxillary and mandibular premolars.

Exclusion criteria:

- Periodontal attachment loss >1 mm affecting the study tooth at any location.
- Mid-facial or mid-lingual keratinized tissue width < 2 mm.
- Pregnancy or nursing mother.

Sample size calculation

Mid-facial/mid-lingual gingival thickness (mm) was the primary variable of interest. Sample size was calculated with an assumed power of 90% to detect a minimal clinically significant difference of 0.5 mm (using $\alpha = 0.025$; adjusted for two-sidedness) and a standard deviation of 0.35 mm (as reported by Alves et al. in 2018) [19]. A sample size of 34 measurements per clinical assessment modality was obtained, which translated into a minimum of 17 patients per group, since both facial and lingual measurements were obtained as part of this study.

Digital data acquisition

A preoperative CBCT scan was acquired for all participants. The scan was limited to the arch containing the study tooth in order to minimize radiation exposure to the patient. A protective lead apron was used for all patients. The field of view was 6 cm and the parameters were fixed at 120 kVp and 18.66 mAs with voxel size of 0.3 mm for all scans (i-CAT Next Generation, Imaging Sciences International Inc., Hatfield, PA, USA). In the SC group, a vinyl polysiloxane (Imprint™ 4 VPS, 3M Company, St. Paul, MN, USA) impression of the arch containing the region of interest was obtained immediately prior to the surgical intervention, and dental stone (Microstone, Whip Mix Corp., Louisville, KY, USA) casts were fabricated. Casts were subsequently scanned to generate STL files using a digital laboratory scanner (D2000; 3Shape A/S, Copenhagen, Denmark). In the ES group, STL files were obtained using an intraoral digital scanner (True Definition; 3M, St. Paul, MN, USA) prior to tooth extraction.

Clinical procedures

Single tooth extractions and gingival thickness measurements were completed by two independent, calibrated operators. All surgical procedures were performed under local anesthesia, injected into the vestibulum and lingual mucosa corresponding to the tooth of interest, while avoiding the region intended for gingival thickness measurements. For both (ES and SC) groups, facial gingival thickness (FGT) and lingual gingival thickness (LGT) measurements were assessed at 1 mm apical to the zenith of the mid-facial and mid-lingual gingival margin at an angle perpendicular to the long axis of the tooth.

In the ES group, the operator inserted a standard no. 35 endodontic finger spreader (Kerr, Brea, CA, USA) perpendicular to the long axis of the axial root plane, as shown in Figure S1. The tip of the endodontic spreader was inserted through the circular rubber stopper at a peripheral point, aside from the premade orifice, in order to prevent undesired movement of the stopper and minimize assessment error. When tactile resistance was encountered, indicating full thickness penetration of the gingival tissue, the rubber stopper was passively positioned over the gingival surface. The resultant distance between the tip of the endodontic spreader and the internal border of the rubber stopper was measured using a standardized stainless-steel ruler and recorded to the nearest 0.5 mm. Tooth extraction was then performed with the use of elevators and extraction forceps, following a minimally traumatic approach.

In the SC group, minimally traumatic tooth extraction was performed first, minimizing trauma to the surrounding periodontal structures. Subsequently, a spring caliper (Iwanson Caliper, Hu-Friedy, Chicago, IL, USA) with blunt tips, to avoid tissue perforation, was used to measure the gingival thickness, as demonstrated in Figure S2. The spring caliper force was standardized by allowing the tips to passively rest on the soft tissues, with no additional manual pressure.

STL-DICOM superimposition

STL and DICOM files were superimposed to allow for discernible visualization of soft and hard tissue structures beneath the overlying surface. To achieve this, both STL and DICOM files were imported into an implant treatment planning software (Simplant Pro 18; Dentsply Sirona, York, PA, USA). Superimposition was automatically performed by matching 8 to 10 intraoral hard tissue landmarks, and a series of mathematical algorithms was automatically executed by the software to achieve optimal three-dimensional fit of the corresponding surfaces using their analogous points (Fig. 1). When the software generated a superimposition that was evidently short of a precise fit, the alignment was manually refined.

Digital measurements

Following DICOM and STL file superimposition, digital measurements corresponding to the clinical counterparts were performed comparably in both groups. In order to standardize these measurements, a sagittal section at the middle of each tooth was obtained and analyzed independently by two blinded examiners proficient in dental imaging software use (E.C.Q. and M.T.). To achieve inter-examiner calibration, measurements at a total of ten random sites were performed by both investigators to verify that an inter-class correlation coefficient (ICC) of at least 0.8 was achieved, after which data collection ensued. A single facial and lingual measurement per patient/site was performed. This was done by first placing a vertical line parallel to the long axis of the tooth 1 mm apical to the gingival margin. Next, a horizontal line meeting the apical-most point of the vertical line was drawn perpendicularly with the purpose of measuring the distance in millimeter between the STL outline and the tooth surface. This measurement was performed on both the facial and lingual aspect of each tooth (Fig. 2).

Data analysis

Mean and standard deviation values of clinical and digital measurements were obtained. For all statistical analyses, the measurement site was considered the statistical unit. Mid-facial and mid-lingual data was analyzed independently. Inter-rater reliability of digital measurements was assessed using ICC [27]. The agreement between digital and the two modalities of clinical measurements was also assessed by calculation of ICC. Additionally, Bland-Altman plots were constructed to identify the limits of agreement (LOA) between different measurement modalities, thereby evaluating the clinical significance of the resultant mean differences [28]. All data analyses were conducted using the SPSS version 25.0 (IBM Corporation, New York, NY, USA).

Results

Sample characteristics

A total of 40 patients (26 males and 14 females) with a mean age of 56.2 ± 13.2 participated in this study. Thirty-eight teeth were maxillary, while the remaining 2 were mandibular. Tooth type distribution was as follows: 7 central incisors, 5

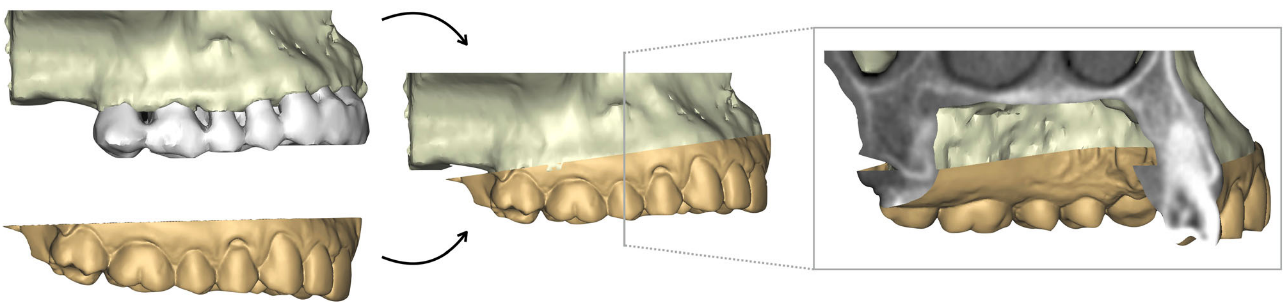

Fig. 1 Composite demonstrating the process of STL and DICOM file superimposition

lateral incisors, and 28 premolars. None of the study teeth presented a history of periodontitis. All sites exhibited minimal signs of inflammation prior to tooth extraction. All extractions were performed in a minimally traumatic fashion to preserve the integrity of the soft tissues. There was no instance of severe marginal tissue damage.

Inter-rater reliability

ICC between the measurements independently obtained by each investigator are displayed in Table 1. Within the ES group, an ICC of 0.90 (95% CI 0.75 to 0.96) was yielded for FGT measurements and 0.94 (95% CI 0.82 to 0.98) for LGT measurements. As for the SC group, an ICC of 0.87 (95% CI 0.68 to 0.95) was yielded for FGT measurements and 0.86 (95% CI 0.68 to 0.94) for LGT measurements. Therefore, excellent inter-rater reliability agreement was demonstrated for all study parameters assessed digitally.

Endodontic spreader versus STL-DICOM superimposition

Overall, the comparison between the endodontic spreader assessment and the digital superimposition method demonstrated excellent agreement. ICC pertaining to FGT and LGT values between these two modalities were 0.79 (95% CI 0.55 to 0.91) and 0.87 (95% CI 0.69 to 0.94), respectively (Table 2; Fig. 3a and b). Mean differences associated with these values were 0.08 mm (LOA −0.40 to 0.55) for FGT and 0.25 mm (LOA −0.30 to 0.81) for LGT (Table 2; Fig. 4a and b).

Spring caliper versus STL-DICOM superimposition

Quite notably, the comparison between the spring caliper assessment and the digital superimposition method demonstrated poor agreement. ICC pertaining to FGT and LGT values between these two modalities were 0.38 (95% CI −0.06 to 0.70) and 0.45 (95% CI −0.02 to 0.74), respectively (Table 2; Fig. 3c and d). Mean differences associated with these values were 0.65 mm (LOA 0.14 to 1.16) for FGT and 0.64 mm (LOA 0.12 to 1.17) for LGT (Table 2; Fig. 4c and d).

Discussion

Digital assessment of the dimensional features of periodontal and peri-implant soft tissues has been proven a highly reliable

Fig. 2 Sagittal section demonstrating the digital method of gingival thickness measurement following superimposition of an STL onto a DICOM file

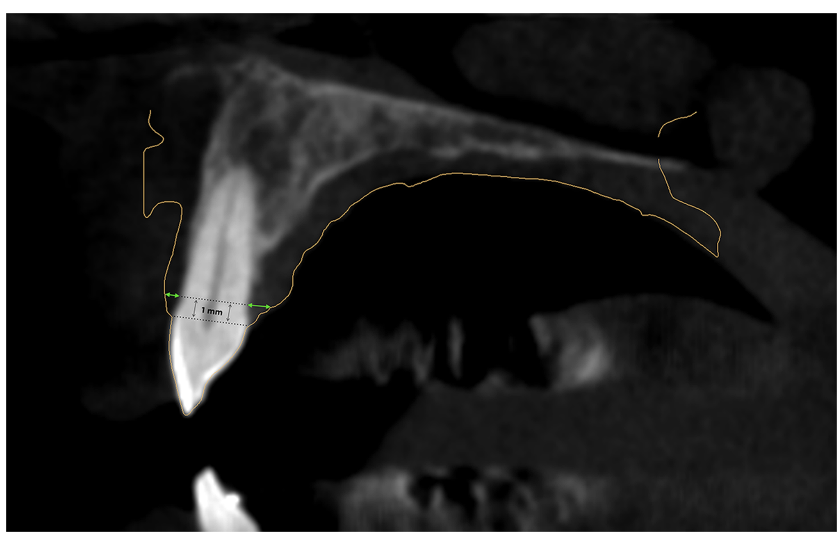

Table 1 Inter-rater reliability of the digital measurements obtained for each group (*ES*, endodontic spreader; *SC*, spring caliper)

Parameter		Method	ICC	95% confidence interval		*P*
	n			Lower	Upper	
Facial gingival thickness	20	ES group	0.90	0.75	0.96	< 0.001
	20	SC group	0.87	0.68	0.95	< 0.001
Lingual gingival thickness	20	ES group	0.94	0.82	0.98	< 0.001
	20	SC group	0.86	0.68	0.94	< 0.001

and reproducible approach [29, 30]. To the best of our knowledge, this is the first study that aims at evaluating the reliability and reproducibility of gingival thickness measurements using digital superimposition of STL and DICOM files with conventional direct clinical assessment modalities, namely transmucosal probing using an endodontic spreader or a spring caliper. It was observed that digital measurements were comparable with direct clinical measurements obtained with an endodontic spreader pre-extraction. However, a poor correlation was observed between digital measurements and clinical measurements using a spring caliper post-extraction.

The use of a digital approach is substantiated by its non-tissue invasive, reproducible, and reliable nature. Other non-invasive methods to assess gingival thickness have been tested in previous studies. Eger and collaborators measured gingival thickness using an ultrasound device compared with an endodontic reamer in five porcine hemi-mandibles, reporting excellent validity and reliability [31]. However, despite promising study outcomes, this method remains limited in applicability because it is often associated with technical difficulty, posing a challenge when attempting to gain access for measurement, particularly in posterior segment, as well as being associated with minimal availability and high expense [16]. The sole use of CBCT scans to obtain soft tissue measurements has also been described. In 2018, Alves and coworkers conducted a study comparing the transgingival horizontal probing, visual assessment of periodontal probe transparency from the sulcus, visual assessment of intraoral photography, and a specific CBCT method (creating a vestibular space by separating the cheeks and lips from the alveolar process while the patient holds air intraorally) [19]. The authors reported that the best correlation was observed between transgingival probing and radiographic assessment using CBCT imaging. Our study did not include soft tissue thickness measurements on CBCT images due to the presence of a collapsed vestibule (i.e., overlapping of lip/cheek) in a handful of the scans, which made the discrimination between gingival tissue and the facial vestibule impossible.

Among the main outcomes of the present study was the excellent agreement in the comparison between the endodontic spreader assessment and the digital superimposition method between evaluators. In a previous study conducted by Sala et al., transmucosal probing with an anesthetic needle coupled with a rubber stopper and a spring tension-free caliper was compared with visual assessment of periodontal probe transmucosal transparency using a porcine model [32]. The authors pointed out that the use of an anesthetic needle was a reliable method regardless of the thickness measured. In a different study, Kloukos and coworkers evaluated gingival thickness using four different methods, namely transgingival probing with a periodontal probe and transgingival probing with an acupuncture needle, ultrasound device, and probe transmucosal transparency. The authors found that transgingival probing using a standard periodontal probe was more reliable than with an acupuncture needle. They indicated that an acupuncture needle seems to overestimate gingival thickness values, possibly due to excessive bending, given the reduced diameter of such instruments (0.18 mm) [33].

Another relevant finding in this study was the poor correlation between the measurements obtained with a spring caliper and those acquired with digital assessments. The use of a tension-free caliper was described by Kan et al. in an article published in 2010 where peri-implant mucosa thickness

Table 2 Agreement between digital assessments and the two modalities of clinical measurements

Group		Subgroup	Mean difference ± SD (limits of agreement) (in mm)	ICC	95% confidence interval		*P*
	n				Lower	Upper	
Facial gingival thickness	20	STL-CBCT versus EF	0.08 ± 0.24 (− 0.40 to 0.55)	0.79	0.55	0.91	< 0.001
	20	STL-CBCT versus SC	0.65 ± 0.26 (0.14 to 1.16)	0.38	− 0.06	0.7	0.027
Lingual gingival thickness	20	STL-CBCT versus EF	0.25 ± 0.28 (− 0.3 to 0.81)	0.87	0.69	0.94	< 0.001
	20	STL-CBCT versus SC	0.64 ± 0.27 (0.12 to 1.17)	0.45	− 0.02	0.74	0.016

ES, endodontic spreader method; *SC*, spring caliper method; *STL-DICOM*, digital superimposition method

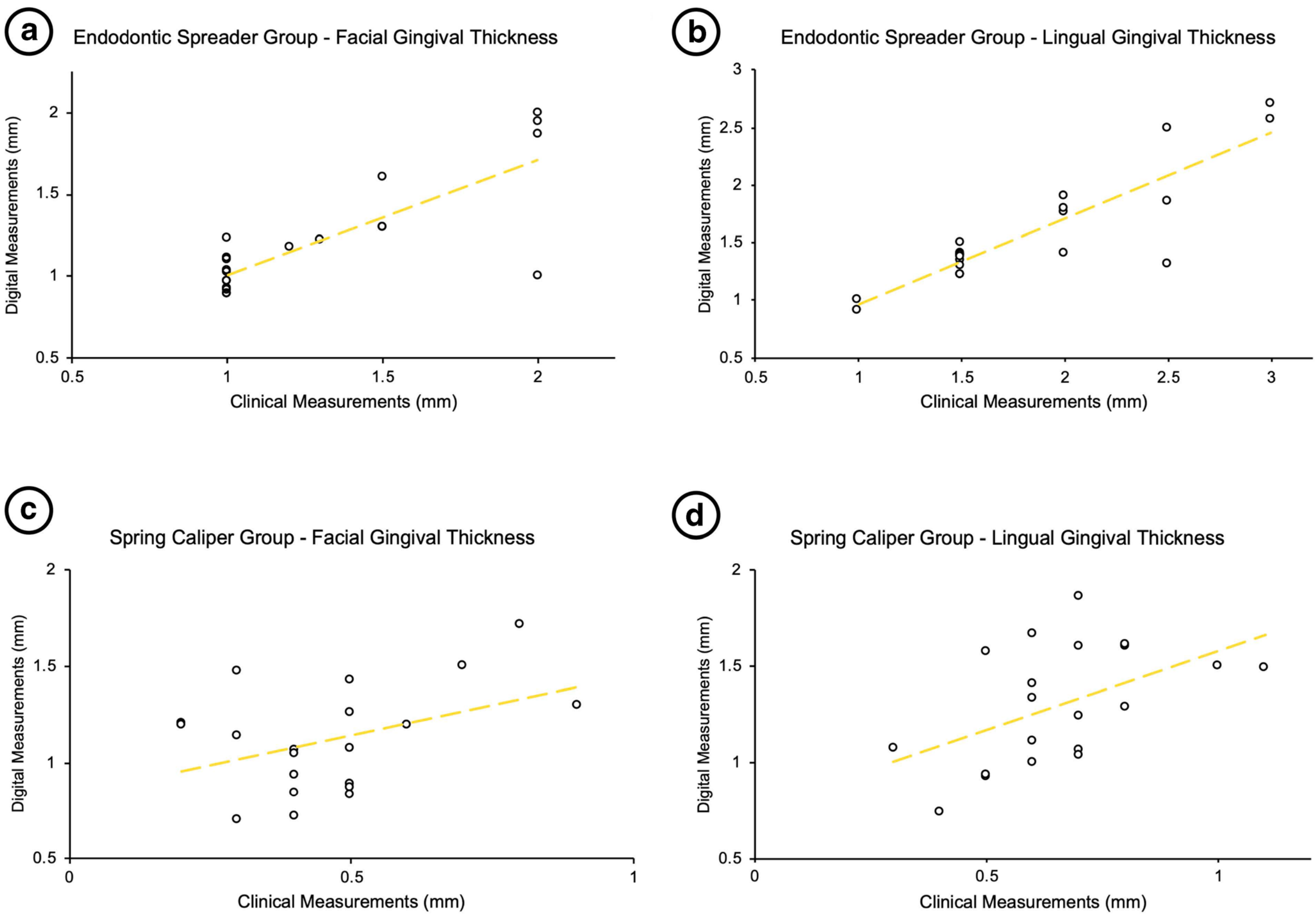

Fig. 3 Scatter plots depicting the correlation between different measurement modalities

measurements in the esthetic zone were obtained using direct visual assessments, transmucosal probe transparency, or direct measurements with a tension-free caliper. They reported that a mere visual assessment was not a reliable method to distinguish between different peri-implant mucosa phenotypes. However, comparisons between transmucosal probe transparency with direct caliper measurements rendered no statistically significant differences [23]. Interestingly, in a previously discussed study based on an animal model, the authors showed that the use of a tension-free caliper failed 100% of the time when attempting to assess thick phenotypes, also reporting a 14% failure rate with thin phenotypes. Furthermore, they pointed out that the use of a tension-free caliper tends to underestimate mucosal thickness [32]. In a cadaver study conducted by Fu et al. (2010), alveolar bone and mucosa thickness were measured after tooth extraction using a spring caliper at 2 mm apical to the alveolar bone crest, both mid-facially and mid-lingually [5]. Interestingly, no statistically significant differences between radiographic and clinical measurements were found, except for palatal gingival thickness. In the present study, it was observed that the use of a caliper was not a reliable method to assess gingival thickness, both on facial and lingual locations. Fu and coworkers reported a mean palatal soft tissue thickness of 1.74 ± 0.86 mm using the radiographic assessment method and 1.0 ± 0.30 mm when using the caliper. Quite remarkably, in our study, mean palatal soft tissue thickness using digital STL-DICOM superimposition was 1.31 ± 0.33 mm, while caliper measures rendered a value of 0.66 ± 0.21 mm. Hence, despite the conflicting findings reported by Sala et al. [32], it may be inferred that the use of a spring caliper, as compared with a tension-free caliper, is not a reliable method to assess gingival and peri-implant soft tissue thickness.

Arguably, the main limitation of digital measurements is that it requires more time to obtain the datasets and make the actual assessments, compared with direct clinical measurements. A CBCT scan and an STL file had to be obtained to do the file superimposition and subsequent digital measurements. Additionally, the files have to be adequately merged, and a meticulous assessment method, which requires training and expertise, has to be followed to avoid measurement errors. Digital measurements may indeed have some degree of error, possibly leading to unreliable data. However, it must be acknowledged that these problems are generally associated with the use of low-quality digital data (e.g., inclusion of artifacts), inadequate file processing, and an invalid or non-standardized

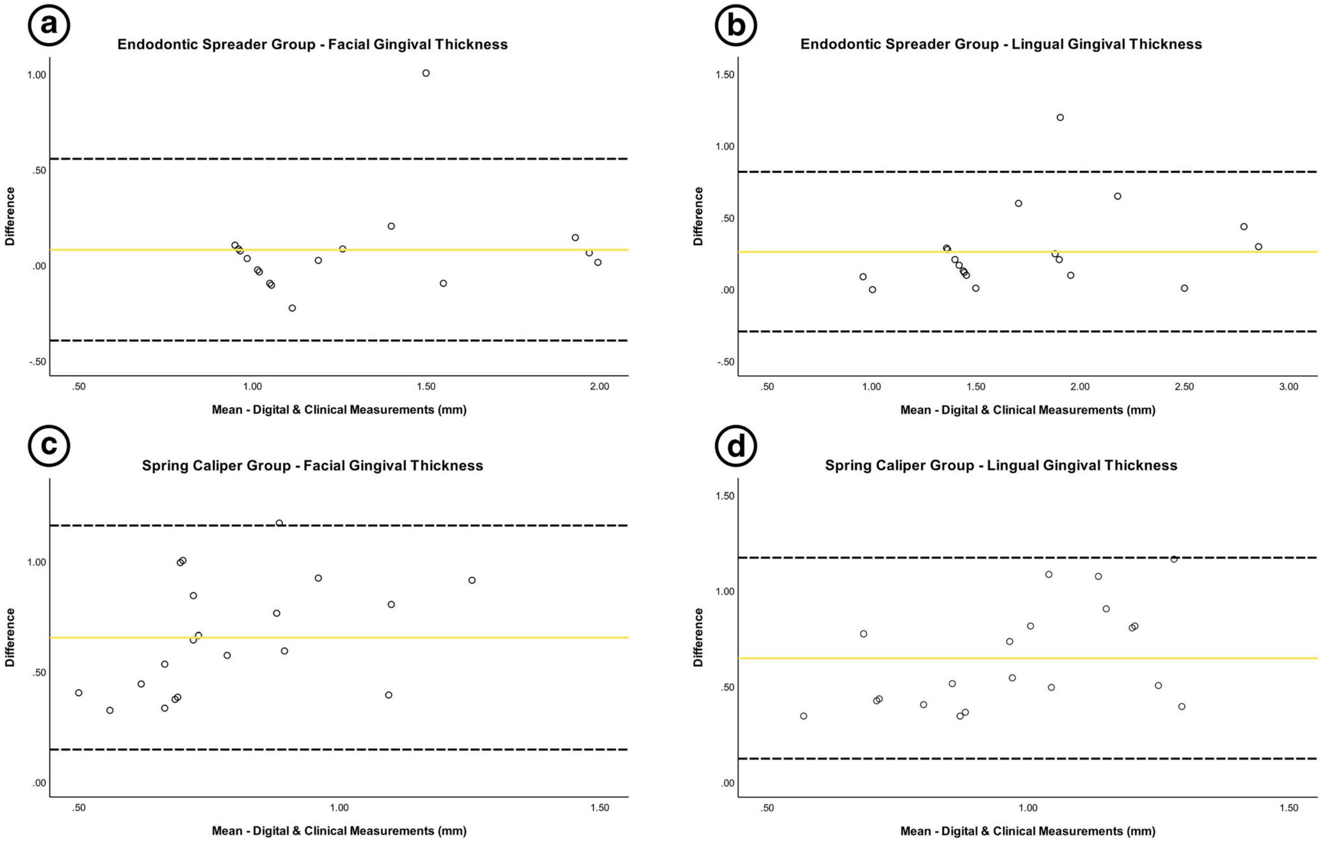

Fig. 4 Bland-Altman plots depicting the level of agreement between different measurement modalities

assessment method. An important factor to take into account is scan resolution. Scans with a smaller voxel size (e.g., 0.1 mm) render a higher level of detail, therefore increasing measurement precision. In this study, all CBCT scans were obtained with a standard voxel size 0.3 mm, which may have affected the precision of certain measurements. Another potential limitation of the study is that measurements were made only once per each calibrated examiner, so intra-observer reliability was not measured. However, both examiners were calibrated prior to conducting study-related assessments, so the calculation of intra-observer variability was considered unnecessary. All study sites had ≥ 2 mm of facial and lingual keratinized tissue prior to extraction. Whether the findings would be different if sites exhibiting a reduced amount of KT were included is to be determined in future studies with a different sample.

Findings from this study can be extrapolated across several applications. For example, STL-CBCT file superimposition-based assessments can be used in clinical practice as a non-invasive, reproducible, and reliable alternative to evaluate the need for periodontal and peri-implant phenotype modification during the treatment planning and maintenance phases, as well as to reliably analyze soft tissue changes over time in research settings. However, it is important to point out that while average numbers can be used as "benchmark" values, clinical decisions should be made on a case by case basis. Therefore, clinical judgment should prevail over strict application of average numeric values emanating from the literature.

Conclusion

Digital measurement of gingival thickness using STL-DICOM file superimposition represents a reproducible and reliable method that is comparable with direct transmucosal probing measurements performed with an endodontic spreader. On the contrary, the use of a spring caliper does not seem to be a reliable assessment method.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The study protocol was approved by the University of Iowa Institutional Review Board (IRB) in October 2019 (HawkIRB #201909749). This study was conducted and monitored according to the principles of Good Clinical Practice (GCP) [25]. All clinical procedures were performed in accordance with the ethical standards of the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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