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Volumetric changes at implant sites: a systematic appraisal of traditional methods and optical scanning-based digital technologies

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One sentence summary: This review summarizes the available evidence regarding traditional and digital technologies for the evaluation of volumetric changes at implant sites, focusing on the reported outcomes and on the digital workflow for generating and analyzing volumetric changes

Data availability: Data sharing is not applicable to this article as no new data were created or analyzed in this study.

ABSTRACT

Aim: To evaluate techniques for assessing soft tissue alterations at implant sites and compare the traditionally utilized methods to the newer three-dimensional technologies emerging in the literature.

Materials and Methods: A comprehensive search was performed to identify interventional studies reporting on volumetric changes at implant sites following different treatments.

Results: 75 articles were included: 30 used transgingival piercing alone, one utilized caliper, 6 with ultrasonography, 6 on cone-beam computed tomography, and 32 utilized optical scanning and digital technologies. Optical scanning-based digital technologies were the only approach that provided "volumetric changes", reported as volumetric variation in mm^3, or the mean distance between the

surfaces/mean thickness of the reconstructed volume. High variability in the digital analysis and definition of the region of interest was observed. All the other methods reported volume variation as linear dimensional changes at different apico-coronal levels. No studies compared volumetric changes with different approaches.

Conclusions: Despite the emergence of optical scanning-based digital technologies for evaluating volumetric changes, a high degree of variation exists in the executed workflow which renders the comparison of study results not feasible. Establishment of universal guidelines could allow for volumetric comparisons among different studies and treatments.

Key words: Autogenous grafts, Dental implant, Digital data, Evidence-based dentistry, Soft tissue grafting, Soft tissue augmentation, Three-dimensional analysis

Clinical relevance

Scientific rationale for the study: Digital technologies have had a revolutionary impact in implant dentistry. Nevertheless, the workflow for generating and analyzing STL files, as well as the outcome measures for reporting the volumetric changes have not been systematically assessed thus far. In addition, there are no recommendations or guidelines on how to define the region of interest for evaluating the volumetric changes with the 3D image analysis software, leading to vast differences in the work process and outcome assessment.

Principal findings: Digital technologies based on optical scanning are the only approach described for assessing volumetric changes, while alternative techniques report linear changes in soft tissue thickness. The 3D digital models can be generated intraorally, or from scanning conventional dental casts. Different software are used for STL file superimposition and the digital analysis. The main outcome measures for reporting volumetric variations are volume change in mm^3, mean distance between the surfaces, and linear dimensional changes assessed at different apico-coronal planes.

Practical implications: The use of optical scanning and digital technologies for analysis of volumetric changes is an emerging and non-invasive tool that can advance the assessment of outcome interventions. Nonetheless, universal guideline precautions can be implemented for standardized assessment methods. These include a-priori operator calibration, determination of the regions of interest, and reporting the outcomes primarily as mean distance between the surfaces/mean thickness of the reconstructed volume (ΔD).

Introduction

Volumetric changes at implant sites have progressively become an outcome of interest in different clinical scenarios. A variety of methods have been described for evaluating volumetric changes, including the use of calipers either on dental casts prior to final crown delivery, piercing the peri-implant mucosa with needles, probes or endodontic instruments and the use of cone-beam computed tomography (CBCT). Transgingival piercing approaches have been frequently utilized for evaluating gain in gingival thickness following root coverage procedures in natural dentition (Barootchi et al., 2020c, Tavelli et al., 2019), while CBCT is routinely performed in implant dentistry for planning implant placement, or bone augmentation (Mandelaris et al., 2017, Tavelli et al., 2020c). Nevertheless, there are several restrictions of using CBCT for assessing volumetric changes, such as its limitation in visualizing the soft tissue and exposing the patient to unnecessary radiations (Loubele et al., 2009, Harris et al., 2012, Mandelaris et al., 2017). Therefore, it is not surprising that other non-invasive imaging techniques have been explored in dentistry (Benic et al., 2015). Magnetic resonance imaging (MRI) is a well-established tool in the medical field and it allows the assessment of soft and hard tissues without using ionizing radiations (Mendes et al., 2020). Although some possible advantages of MRI in the oral cavity have been described, its use in dentistry is still very limited and further studies are needed to assess its applicability, accuracy and cost-benefits (Mendes et al., 2020). Non-ionizing, real-time ultrasonography has been widely used in medicine (Bhaskar et al., 2018). Recent technological advances have allowed for the fabrication of miniature-sized probes with high-quality image and this may explain the increase use of ultrasonography in dentistry for a chair-side non-invasive evaluation of anatomical structures, periodontal and peri-implant tissues (Barootchi et al., 2020a, Chan and Kripfgans, 2020, Tattan et al., 2019). Nevertheless, potential limitation of this technology includes the inability to penetrate the bone and the narrow field of view (Bhaskar et al., 2018).

Optical scanners have been introduced in dentistry for obtaining digital impressions and generating three-dimensional (3D) digital images formatted as Standard Tessellation Language (STL) files (Benic et al., 2015). STL files can be generated using intraoral chair-side scanners (direct technique) or by scanning dental casts with desktop/laboratory scanners (indirect technique) (Benic et al., 2015, Bosniac et al., 2019, Mennito et al., 2019). The direct technique allows to reduce the number of steps necessary to obtain digital files minimizing patient discomfort while, on the other hand, the use of laboratory scanner may result in a higher precision of the digital impressions, but it requires additional steps that may introduce some inaccuracy (Benic et al., 2015, Bosniac et al., 2019, Mennito et al., 2019). Optical scanners were initially developed for digital impressions of teeth, implants and the surrounding soft tissue (Benic et al., 2015). However, advancement of these scanners and metrology software occurred during the last years,

allowing its emergence as a method to evaluate volume change in different clinical scenarios (Fickl et al., 2009, Strebel et al., 2009, Thoma et al., 2010, Lee et al., 2020). In particular, volumetric changes can be evaluated by superimposing 3D images generated at different time points in a non-invasive and highly reproducible way (Lee et al., 2020, Windisch et al., 2007, Schneider et al., 2014, Benic et al., 2015, Lehmann et al., 2012) (Figure 1). Therefore, with the increased interest towards soft tissue thickness at teeth and implant sites (Zucchelli et al., 2019, Stefanini et al., 2020a), it is not surprising that optical scanning-based digital technologies have been used for evaluating volumetric changes following implant placement, soft tissue augmentation at implant sites, ridge augmentation, ridge preservation and root coverage procedures (Fickl et al., 2009, Hosseini et al., 2020, Thoma et al., 2019, Barootchi et al., 2019, Gargallo-Albiol et al., 2019, Zucchelli et al., 2020, Tavelli et al., 2020b). Nevertheless, the workflow for generating and analyzing STL files, as well as the outcome measures for reporting the volumetric changes have not been systematically assessed in the literature. In addition, there are no recommendation or guidelines on how to define the region of interest (ROI) for evaluating the volumetric changes with the 3D image analysis software.

Therefore, the aim of the present article was to review the available literature on the methods used for assessing volumetric changes at implant sites, comparing traditional approaches relative to optical scanning-based digital technologies.

2. Material and methods

2.1 Protocol Registration and Reporting Format

The protocol of the present review was registered and allocated the identification number CRD42020176696 in the PROSPERO database, hosted by the National Institute for Health Research, University of York, Center for Reviews and Dissemination (www.crd.york.ac.uk/PROSPERO). This manuscript was prepared following the Cochrane Collaboration guidelines (Higgins et al., 2011).

2.2 Objectives

The goal of this review was to address the following focused questions:

1. What are the methods for assessing volumetric changes/mucosa thickness changes that occur following different treatments at implant sites?
2. How are the current digital workflows for assessing volumetric dimensional changes when optical scanners are used? And what are the volumetric changes measured and reported?
3. Were traditional and 3D optical scanning approaches compared when evaluating volumetric changes at implant sites?

2.3 PICOT question

The following Population, Intervention, Comparison, Outcomes, and Time (PICOT) framework (Stillwell et al., 2010) was used to guide the inclusion and exclusion of studies for the above-mentioned focused questions:

Population (P): Patients with dental implants or in need of dental implant therapy

Intervention (I): Implant placement, bone augmentation procedures around implants, peri-implant soft tissue augmentation using autogenous grafts or substitutes (i.e. connective tissue graft or collagen matrix), peri-implant soft tissue conditioning with prosthetic components and other direct implant-related treatments (i.e. surgical treatment of peri-implantitis) in which volumetric outcomes were assessed.

Comparison (C): Any comparison among the included studies in terms of the methods for evaluating peri-implant mucosa variations and the digital workflow and assessment of volume changes prior to and after the intervention using 3D optical scanning.

Outcome (O): The current methods for assessing volumetric changes at implant sites, as well as the digital workflows utilized in combination with 3D optical scanning, including intraoral digital scanners vs conventional impressions and the use of laboratory optical scanners, the type of impression material, the type of scanner, the 3D software operated and the outcome measures for assessing volumetric changes were evaluated.

Time (T): Minimum follow-up of 3 months after the surgical intervention.

2.4 Inclusion Criteria

- Interventional human studies
- Optical scanners or alternative methods for assessing volumetric changes after therapy (soft/hard tissue augmentation), implant placement, immediate implant placement, bone augmentation at implant sites, peri-implant soft tissue conditioning with prosthetic components and other implant-related treatments (i.e. surgical treatment of peri-implantitis)
- Minimum follow-up period of 3 months

2.5 Exclusion Criteria

- Case reports, retrospective or animal studies
- Finite element analysis reports

- Studies exploring alveolar ridge preservation (via socket grafting) or augmentation procedures prior to the implant placement as intermediate treatments requiring further therapies
- Studies reporting peri-implant mucosal dimension at only a single time point

2.6 Information sources and search strategy (see Appendix)

2.7 Study selection (see Appendix)

2.8 Data extraction and analysis

Two examiners (LT and SB) independently retrieved all relevant information from the included articles using a data extraction sheet specifically designed for this review. At any stage, disagreements between the reviewers were resolved through open discussion and consensus. If a disagreement persisted, a third person (JM) settled the discussion. Aside from the outcomes of interest (approaches for assessing peri-implant mucosa variations, digital workflows and outcome measures for assessing volumetric changes), the following study characteristics were retrieved:

- Study design, geographic location, setting (university vs. private practice) and source of funding
- Population characteristics, age of participants, number of participants and treated sites (baseline/follow-up) and follow-up period
- Type of intervention, utilization of soft tissue grafting materials and techniques

For articles utilizing 3D optical scanning and digital technologies for assessment of peri-implant volumetric changes, the region of interest (ROI), the defect area, the utilization of other approaches for measuring volume variation, calibration and blinding of the 3D analysis operator, and study conclusions were also noted.

For articles utilizing alternative methods for evaluating peri-implant mucosal changes, the instruments used, the reference points, whether the operator that performed the measurements was calibrated and/or blinded and the comparisons with volumetric outcomes obtained with digital technologies were retrieved.

The gathered data from the included studies were planned for thorough descriptive presentation without preforming statistical quantification or comparisons, due to the wide range of variability in reporting.

2.9 Quality assessment and risk of bias (see Appendix)

3. Results

3.1 Search results and study selection

The literature search process is shown in Figure 2. Following removal of duplicates, 3,924 records were screened on the basis of titles and abstracts. Full-text assessment was performed for 176 articles. Based on our predetermined inclusion criteria, 75 articles were included in the qualitative analysis. The reason for exclusion of the other 101 articles is available in the Appendix (Supplementary Table 1). The inter-reviewer reliability in the screening and inclusion process, assessed with Cohen's κ, corresponded to 0.87 and 0.94 for assessment of titles and abstracts and full-text evaluation, respectively.

3.2 Characteristics of the included studies

Thirty articles (Anderson et al., 2014, Andreasi Bassi et al., 2016, Bashutski et al., 2013, Cairo et al., 2017, Clementini et al., 2019, D'Elia et al., 2017, Eisner et al., 2018, Farina and Zaffe, 2015, Froum et al., 2015, Fu et al., 2014, Guarnieri et al., 2019, Hanser and Khoury, 2016, Hutton et al., 2018, Linkevicius et al., 2015, Migliorati et al., 2015, Papapetros et al., 2019, Papi et al., 2019, Poli et al., 2019, Puisys et al., 2015, Schallhorn et al., 2015, Stefanini et al., 2016, Stefanini et al., 2020b, Thoma et al., 2016, Torkzaban et al., 2015, Ustaoğlu et al., 2020, Verardi et al., 2019, Wiesner et al., 2010, Zafiropoulos et al., 2016, Zucchelli et al., 2018, Zucchelli et al., 2013) only assessed mucosal variations using transgingival piercing approaches, one study used caliper (Rungcharassaeng et al., 2012), six studies CBCT (Chappuis et al., 2018, De Bruyckere et al., 2018, Frizzera et al., 2019, Kaminaka et al., 2015, Kato et al., 2018, Ko et al., 2020) and six articles ultrasonography (Cardaropoli et al., 2006, De Bruyckere et al., 2015, Eghbali et al., 2016, Eghbali et al., 2018, Puzio et al., 2018, Puzio et al., 2020).

Thirty-two of the included studies (Basler et al., 2018, Benic et al., 2017, Bertl et al., 2017, Bittner et al., 2020, Borges et al., 2020, Cabanes-Gumbau et al., 2019, Canullo et al., 2018, Clementini et al., 2020, De Bruyckere et al., 2020, Eeckhout et al., 2020, Fischer et al., 2019, Friberg and Jemt, 2012, Galarraga-Vinueza et al., 2020, Hinze et al., 2018, Hosseini et al., 2020, Huber et al., 2018, Jiang et al., 2020, Papi et al., 2020, Parvini et al., 2020, Rojo et al., 2018, Rojo et al., 2020, Sanz Martin et al., 2016, Sanz-Martin et al., 2019, Sapata et al., 2018, Schneider et al., 2011, Thoma et al., 2020, Tian et al., 2019, van Nimwegen et al., 2018, Wang et al., 2019, Wei et al., 2019, Wittneben et al., 2016, Zeltner et al., 2017) assessed volumetric changes with optical scanning-based digital technologies. Among them, four studies also assessed mucosal thickness (MT) changes with transgingival piercing methods (Hosseini et al., 2020, Huber et al., 2018, Papi et al., 2020, Thoma et al., 2020).

Detailed study characteristics are described in the Appendix and in the Supplementary Tables 2-7.

3.3 Digital workflow

Twenty-one studies (Basler et al., 2018, Benic et al., 2017, Bittner et al., 2020, Canullo et al., 2018, Clementini et al., 2020, De Bruyckere et al., 2020, Eeckhout et al., 2020, Fischer et al., 2019, Friberg and

Jemt, 2012, Hinze et al., 2018, Hosseini et al., 2020, Huber et al., 2018, Sanz Martin et al., 2016, Sanz-Martin et al., 2019, Sapata et al., 2018, Schneider et al., 2011, Thoma et al., 2020, van Nimwegen et al., 2018, Wang et al., 2019, Wittneben et al., 2016, Zeltner et al., 2017) reported generating 3D digital models from constructed dental casts obtained with different impression materials (including silicone, alginate, polyether, and polyvinyl siloxane) with the use of desktop 3D optical scanners (indirect technique). The other eleven studies (Bertl et al., 2017, Borges et al., 2020, Cabanes-Gumbau et al., 2019, Galarraga-Vinueza et al., 2020, Jiang et al., 2020, Papi et al., 2020, Parvini et al., 2020, Rojo et al., 2018, Rojo et al., 2020, Tian et al., 2019, Wei et al., 2019) had obtained the 3D digital models with the use of intraoral scanners (direct technique). Among them, six studies reported that a short-span area was scanned (Galarraga-Vinueza et al., 2020, Parvini et al., 2020, Rojo et al., 2018, Rojo et al., 2020, Tian et al., 2019, Wei et al., 2019), while other articles did not provide information regarding the size of the scanned area. The method of digital model superimposition was automated (using an algorithm of the software) in fourteen studies (De Bruyckere et al., 2020, Eeckhout et al., 2020, Fischer et al., 2019, Hinze et al., 2018, Huber et al., 2018, Sanz Martin et al., 2016, Sanz-Martin et al., 2019, Schneider et al., 2011, Thoma et al., 2020, Tian et al., 2019, van Nimwegen et al., 2018, Wang et al., 2019, Wei et al., 2019, Zeltner et al., 2017), and "hybrid"/semi-automated (by selecting reproducible points prior to the algorithm or by using a semiautomatic algorithm first followed by manual alignment) in eleven studies (Basler et al., 2018, Bertl et al., 2017, Borges et al., 2020, Clementini et al., 2020, Galarraga-Vinueza et al., 2020, Jiang et al., 2020, Papi et al., 2020, Parvini et al., 2020, Rojo et al., 2018, Rojo et al., 2020, Sapata et al., 2018), with the remaining articles that did not specify this aspect. Three studies reported the amount of range of errors/tolerance between the two STL files during the superimposition (Bertl et al., 2017, Tian et al., 2019, Wei et al., 2019).

Table 1 includes the study design, intervention, types of impression materials, casts, digital scanners, and the utilized software for generating and analyzing the 3D digital models. Twelve studies reported that the examiner was calibrated in terms of reproducibility of the volumetric analysis 3D measurements (Borges et al., 2020, Clementini et al., 2020, Fischer et al., 2019, Galarraga-Vinueza et al., 2020, Hinze et al., 2018, Papi et al., 2020, Parvini et al., 2020, Sanz Martin et al., 2016, Sanz-Martin et al., 2019, Sapata et al., 2018, van Nimwegen et al., 2018, Wang et al., 2019). In particular, in one study the calibration included performing all the measurements twice with an interval of one week (Sapata et al., 2018), while in another study the examiner had to repeat the measurements three times every other week on five randomly chosen participants (Wang et al., 2019). The coefficient of reproducibility was reported in six studies, ranging from 0.8 to 0.93 (Borges et al., 2020, Papi et al., 2020, Parvini et al., 2020, Sapata et al., 2018, van Nimwegen et al., 2018, Wang et al., 2019) (Table 1). Additionally, in ten studies, the operator who had performed the volumetric analysis had been blinded to the interventions (Borges et al., 2020,

Clementini et al., 2020, Fischer et al., 2019, Rojo et al., 2018, Rojo et al., 2020, Sanz Martin et al., 2016, Sapata et al., 2018, Thoma et al., 2020, Wang et al., 2019, Zeltner et al., 2017). All the included studies reported the software used for the volumetric analysis, with SMOP software (Swissmeda AG, Zurich, Switzerland) being the most utilized (14 articles) (Basler et al., 2018, Benic et al., 2017, Clementini et al., 2020, De Bruyckere et al., 2020, Eeckhout et al., 2020, Fischer et al., 2019, Hinze et al., 2018, Huber et al., 2018, Sanz Martin et al., 2016, Sanz-Martin et al., 2019, Sapata et al., 2018, Thoma et al., 2020, van Nimwegen et al., 2018, Zeltner et al., 2017), followed by Geomagic (3D systems, Rock Hill, USA) in 8 studies (Borges et al., 2020, Jiang et al., 2020, Papi et al., 2020, Rojo et al., 2018, Rojo et al., 2020, Tian et al., 2019, Wang et al., 2019, Wei et al., 2019) (Table 1). Comparison of the volumetric outcomes using different software were not explored among the included studies. A high level of variability in the determination of the ROI was observed (Supplementary Table 2 in the Appendix).

3.4 Volumetric and linear outcome measures

Studies that employed optical scanning and digital technologies evaluated volumetric and/or linear changes (Table 1), and studies using ultrasonography, CBCT, transgingival piercing or calipers only reported information on linear soft tissue thickness (Appendix, Supplementary Tables 4-8).

3.4.1 Outcomes of volumetric changes

Volumetric changes evaluated with digital analysis were reported as volume in mm^3 (Vol), mean distance between the surface/mean thickness of the reconstructed volume (ΔD), and as linear dimensional (LD) changes. One article reported the volumetric outcomes only as differences in the area (in mm^2) (Bertl et al., 2017), while the peri-implant soft tissue contour/surface area and its contraction rates were considered as one of the main volumetric outcomes in two studies from the same group (Galarraga-Vinueza et al., 2020, Parvini et al., 2020) (Supplementary Table 2 in the Appendix, as well as previously quoted Figure 1). Vol changes in mm^3 were reported in 10 studies (Borges et al., 2020, Cabanes-Gumbau et al., 2019, Clementini et al., 2020, De Bruyckere et al., 2020, Friberg and Jemt, 2012, Papi et al., 2020, Sanz-Martin et al., 2019, van Nimwegen et al., 2018, Wang et al., 2019, Wittneben et al., 2016). LD changes were assessed in 15 studies (Basler et al., 2018, Benic et al., 2017, Bittner et al., 2020, Clementini et al., 2020, Galarraga-Vinueza et al., 2020, Hosseini et al., 2020, Jiang et al., 2020, Papi et al., 2020, Rojo et al., 2018, Rojo et al., 2020, Sanz Martin et al., 2016, Sanz-Martin et al., 2019, Sapata et al., 2018, Wang et al., 2019, Wei et al., 2019), while the ΔD was analyzed in 22 articles (Basler et al., 2018, Borges et al., 2020, Cabanes-Gumbau et al., 2019, Canullo et al., 2018, Clementini et al., 2020, De Bruyckere et al., 2020, Eeckhout et al., 2020, Fischer et al., 2019, Friberg and Jemt, 2012, Galarraga-Vinueza et al., 2020, Hinze et al., 2018, Huber et al., 2018, Parvini et al., 2020, Sanz Martin et al., 2016, Sanz-Martin et al.,

2019, Sapata et al., 2018, Schneider et al., 2011, Thoma et al., 2020, Tian et al., 2019, van Nimwegen et al., 2018, Wei et al., 2019, Zeltner et al., 2017).

Thirteen studies analyzed the ΔD as the main outcome (instead of Vol changes) for considering the difference among the sites that may vary in area (Basler et al., 2018, Eeckhout et al., 2020, Fischer et al., 2019, Hinze et al., 2018, Huber et al., 2018, Parvini et al., 2020, Sanz Martin et al., 2016, Sapata et al., 2018, Schneider et al., 2011, Thoma et al., 2020, Tian et al., 2019, Wei et al., 2019, Zeltner et al., 2017).

The ΔD was either automatically calculated by the software or obtained with the following formula: ΔD=ΔVolume/ΔArea. The volumetric outcomes of the included studies are depicted in the Supplementary Table 2 of the Appendix.

The included articles reported the 3D digital analysis and volumetric outcomes following implant placement with or without bone augmentation, immediate implant placement, soft tissue augmentation, prosthetic peri-implant soft tissue conditioning and surgical treatment of peri-implantitis (Supplementary Table 3 of the Appendix).

3.4.2 Mucosal thickness changes

Throughout studies, dimensions of the MT have been assessed with transgingival piercing methods, calipers, CBCT and ultrasonography (Supplementary Tables 4-7 in the Appendix). The difference in MT between two time points reflects the change in MT. As the software for volumetric analysis requires the superimposition of two STL files, the 3D digital approach can evaluate MT changes (reported as LD changes) but not the MT at a specific time point. LD/MT changes with 3D digital technologies were evaluated at the midfacial aspect of the implant site, with perpendicular lines most commonly drawn 1-, 3- and 5 mm apical to the soft tissue margin (Supplementary Table 3 of the Appendix).

Large heterogeneity was observed among the articles using transgingival probing techniques, CBCT, and ultrasonography in terms of reference points for measuring MT changes (Supplementary Table 8). Among the 75 included articles, only four assessed volumetric/MT changes using 3D digital technologies or another approaches (Hosseini et al., 2020, Huber et al., 2018, Papi et al., 2020, Thoma et al., 2020). In the studies of Huber et al. and Thoma et al., involving the same patient population, 3D digital technology was utilized only for assessing volumetric changes, reported as ΔD, while linear variations in mucosal thickness were evaluated using endodontic files that penetrated the mucosa 1 mm apical to the soft tissue margin (Huber et al., 2018, Thoma et al., 2020), and a comparison between the two different methods was not explored. Hosseini et al. performed transgingival piercing with an endodontic instrument for assessing MT changes at 1 and 3 mm reference points apical to the implant crown, while they used 3D digital approach for assessing the dimensional changes in the facial alveolar contours, for the soft tissue

component and also the alveolar process (Hosseini et al., 2020). While MT was not significantly different between the test and control groups at any time, the 3D analysis showed that implant sites that received connective tissue graft had significantly more facial dimensional gain than the control group after 5 years.

Given the different outcomes of interest (MT vs volumetric changes of the alveolar process) a comparison between the two different methods was not investigated by the authors (Hosseini et al., 2020). Similarly, Papi et al. measured changes in MT with an endodontic file, while optical scanning-based technologies were used for evaluating Vol and LD changes, reflecting the changes in the buccal contour including both the soft tissue and the alveolar ridge. However, a correlation between MT and LD was not performed (Papi et al., 2020).

The risk of bias is discussed in detail in the Appendix.

4. Discussion

The present systematic review evaluated the methods for assessing volumetric and mucosal thickness changes at implant sites. Among them, optical scanning-based digital technologies were the only approach that provided "volumetric changes", reported as volumetric variation in mm³, or the mean distance between the surfaces/mean thickness of the reconstructed volume (ΔD).

Despite a relatively high number of articles using optical scanning-based technologies was found, there is a large heterogeneity in the digital workflow for creating and assessing volumetric variation with this approach. Most of the included articles reported using an indirect technique for generating 3D digital models, that involved taking a conventional impression followed by scanning the casts with laboratory scanners. Other studies relied on intraoral digital impressions, which has the potential to provide higher patient acceptance and comfort, as well as decreased clinical time and increased operator satisfaction compared to conventional impressions (Burhardt et al., 2016, Burzynski et al., 2018, Mennito et al., 2019, Yuzbasioglu et al., 2014, Gallardo et al., 2018).

While some authors have suggested that the indirect technique with the digitalization of the casts using desktop scanners should be considered the recommended workflow process (Wesemann et al., 2017, Sanz-Martín et al., 2016), a recent study concluded that direct digital impression systems can be as accurate as 3D models obtained with conventional impressions which are poured and scanned with a laboratory scanner, if not superior (Mennito et al., 2019). This finding was also confirmed by other authors (Keul and Guth, 2020, Muallah et al., 2017, Guth et al., 2013), suggesting that intraoral scanners

have had a significant improvement in the last years to a point where direct digitalization may soon replace the use of indirect techniques. A recent trial demonstrated that for single-implant sites, the quadrant-like intraoral scanning was more time efficient and more often preferred by the operators compared to the conventional full-arch impression technique (Joda et al., 2017). Intraoral scanners permit a 3D pre-visualization of the area of interest and the opportunity to quickly rescan a missed area, in contrast to conventional impressions where the operator has to repeat the entire procedure if it is incorrect (Lee and Gallucci, 2013, Di Fiore et al., 2018). Indeed, the incidence that a cast may need to be excluded from the analysis due to model artifacts that do not allow STL matching is not a rare event when using the indirect technique (Sanz-Martín et al., 2016). On the other hand, it has to be mentioned that the accuracy of an intraoral scanner is largely affected by operator experience, the type of intraoral scan system and the size of the scanned area (Resende et al., 2020). Therefore, operator calibration is highly recommended. However, in the present review, only few studies mentioned that the examiners for the 3D measurements had been calibrated or blinded to the interventions.

The software of digital scanner as well when generating the casts is also an important variable to consider. Desktop scanners can have different modules/program (i.e., scan fixed restorations or scan orthodontic models) and this can also result in different mesh (exported triangles in STL models) qualities that could affect the final results (Skramstad, 2019, Ender et al., 2019, Richert et al., 2017). Interestingly recent updates in scanner technology with the introduction of artificial intelligence (AI) allows the software to designate different mesh densities to areas that the software considers more or less important (Skramstad, 2019, Ender et al., 2019, Richert et al., 2017).

In addition, the scanning area can also play a role on the accuracy of the digital files. A recent clinical study showed that short-span intraoral scanning led to less deviations than long-span distance scans, even using four current intraoral scanners which were equipped with the latest software version (Schmidt et al., 2020). Six (Galarraga-Vinueza et al., 2020, Parvini et al., 2020, Rojo et al., 2018, Rojo et al., 2020, Tian et al., 2019, Wei et al., 2019) out of the 7 studies which performed intraoral scanning, reported that a short span area was scanned to generate 3D digital models. This reduced scanned area may have ensured higher accuracy of generated digital models (Schmidt et al., 2020, Resende et al., 2020).

The studies included in the present review reported Vol changes, ΔD or LD changes as main volumetric outcomes. It has been advocated that ΔD should be considered the outcome of choice when comparing the volumetric results among different sites and different treatment modalities (Fickl et al., 2009, Schneider et al., 2011, Baumer et al., 2015, Sanz-Martín et al., 2016, Tian et al., 2019, Thoma et al., 2010). Nevertheless, the variability observed in the included studies in terms of digital workflow, type of

software, method of superimposition and ROI determination rend volumetric comparisons among different articles not feasible. It is also worth of mentioning that many of the included studies did not describe the method of model superimposition in detail and did not report the range of errors/tolerance between the two STL files. In the authors' opinion, the superimposition methods should consider anatomic fiduciary regions of interest and/or landmarks that are considered stable and valid to perform the superposition. Lo Russo et al. have also described that trimming digital casts to eliminate peripheral areas not present in both files and nonmatching areas caused by practical aspects related to obtaining digital impressions (mobile tissue stretching) are important steps that can improve alignment and, consequently, measurement accuracy (Lo Russo et al., 2020).

Aside from operator calibration for scan acquisition, it is also important to perform calibration for obtaining the digital measurements. A learning curve is needed for mastering software functions, and once the complete domain is obtained, higher accuracy of the technique can be expected. This aspect is a limitation encountered in published articles at the moment, where only 12 out of 32 studies reported that the examiner was calibrated in terms of reproducibility of the 3D digital measurements (with only 6 of them reporting the coefficient of reproducibility).

Interestingly, none of the included studies compared the volumetric outcomes obtained using optical scanning-based approaches with the other techniques. This is due to the fact that optical scanning-based technologies evaluated the volumetric changes in the buccal/ridge contour rather than MT variation. This was the reason for which the four included studies assessing volumetric changes with both optical scanning-based techniques and transgingival piercing did not explore a correlation between the two methods (Hosseini et al., 2020, Huber et al., 2018, Papi et al., 2020, Thoma et al., 2020).

Nowadays, transgingival probing is one of the most common methods for assessing soft tissue thickness, as typically measured 1 to 3 mm apical to the soft tissue margin (Tavelli et al., 2020a, Barootchi et al., 2020c, Barootchi et al., 2020b). However, this measurement does not represent the overall volumetric changes, but the variation in MT at a specific reference point (plane), which may not be representative of the overall volume gain/loss after a treatment. The obtained ΔD from the digital analysis can however show all the changes in a bucco-lingual direction perpendicular to the labial surface at any chosen reference point, as the mean distance between the two analyzed surfaces (Fickl et al., 2009, Schneider et al., 2011, Sanz-Martín et al., 2016, Baumer et al., 2017, Bienz et al., 2017, Tian et al., 2019). This measurement should be considered for assessment of the entire volumetric change at a particular site, as digital image superimposition due to its accuracy, encompassing scope, and non-invasiveness may

become the gold standard technique for evaluating volumetric variation in the future (Fons-Badal et al., 2019, Rebele et al., 2014).

As for traditional approaches (transgingival piercing methods), the need for a standardized stent, the possibility in bending of the needle/endodontic instrument, patient discomfort and reduced accuracy are among other limitations (Fons-Badal et al., 2019). However, as none of the included studies compared the obtained 3D digital analysis to alternative methods, the results from volumetric analysis should also be interpreted with caution.

Despite this being the first attempt in the literature to qualitative evaluate the digital workflow of the clinical studies assessing volumetric changes among different treatment protocol and techniques, a certain heterogeneity was observed in terms of impression technique, data acquisition, software used and volumetric outcome measures. The lack of a standardized method for identifying ROIs makes quantitative comparisons between studies not feasible. Other limitations of the included studies include a lack of, or limited information on method of model superimposition, range of tolerance between the two STL files and operator calibration (Appendix). As such, the findings from this review can serve as a recommendation for future investigations to be more comprehensive on the above parameters, including patient-reported outcomes.

5. Recommendation for future studies

Superimposing digital models at different time points allows for evaluating soft tissue volume change over time in a non-invasive and accurate method. Nevertheless, the present review highlights that there are not guidelines or recommendations for clinical studies. In order to minimize heterogeneity within the methodologies of future articles, we recommend the use of intraoral scanning for generating digital models or the use of indirect techniques with highly accurate conventional impressions and using a laboratory optical scanner. When using intraoral scanners, reducing the size of the scanned area can ensure higher accuracy of digital surface models and 3D analysis. Methods used for model alignment should be described and precautions have to be taken to guarantee maximum reproducibility. The operator who performs the scanning and the 3D analysis should have an adequate training, follow manufacturers scanning strategy recommendations, be calibrated, and blind to the treatments in case of comparative studies. The intraclass correlation coefficient calculated for consecutive measurements should also be reported. In particular, it has been suggested to perform all the measurements two times with an interval of one week for assessing the reproducibility of the 3D analysis (Sapata et al., 2018). Based on the included studies, for evaluating tissue contour changes in a single implant site, we

recommend defining the region of interest (ROI) as follow: i) mesial and distal papillae not included (Benic et al., 2015), ii) rectangular shape with the gingival/soft tissue margin as coronal border and extending 6 mm apically, iii) two lines perpendicular to the occlusal plane and to the cemento-enamel junction of the adjacent teeth and passing through the mid-point of the mesial and distal papilla as mesial and distal borders. The volumetric outcomes of interest that should be reported in the manuscript are: 1) LD changes (from 1 to 5 mm from the soft tissue margin), 2) mean area of the defect (in mm^2), 3) ΔD (in mm) and 4) Vol change (in mm^3). Volumetric comparisons should be mainly based on ΔD (Fickl et al., 2009, Thoma et al., 2010, Schneider et al., 2011, Baumer et al., 2015, Sanz-Martín et al., 2016, Tian et al., 2019) and follow the proposed guidelines. This has the potential to render optical scanning-based digital analysis more reproducible and comparable among different studies and treatment modalities. Comparison between different techniques in assessing volumetric and linear changes are also encouraged.

6. Conclusions

Based on the currently available evidence, and the limitations within this research, the following conclusions can be drawn:

1. Volumetric and/or mucosal thickness changes around dental implants have been assessed with transgingival piercing techniques, calipers, CBCT, ultrasonography and optical scanning-based approaches.

2. Volumetric outcomes are reported only with optical-scanning digital technologies and are displayed using Vol changes, ΔD or LD changes. Transgingival piercing, calipers, ultrasonography and CBCT report merely the linear changes in MT.

3. Both indirect and direct techniques are currently used for generating 3D digital models following optical scanning. Different software are available for the superimposition of the digital files and 3D analysis, with most of the studies using an automated or semi-automated method of superimposition.

4. Volumetric outcomes from 3D digital analyses should be interpreted with caution given the lack of interventional studies comparing this method with other approaches for assessing peri-implant volume changes at the present moment.

5. The high level of heterogeneity among the studies evaluating 3D volume changes at implant sites in terms of digital impression techniques, types of software, methods of superimposition and ROI determination make volumetric comparison among different studies not feasible at the present moment. Guidelines for generating and analyzing 3D models in a standardized way are therefore needed for obtaining reproducible and comparable volumetric outcomes among different studies and treatment modalities.

Conflict of interest

The authors do not have any financial interests, either directly or indirectly, in the products or information enclosed in the paper. The study was self-supported.

REFERENCES

Anderson, L. E., Inglehart, M. R., El-Kholy, K., Eber, R. & Wang, H. L. (2014) Implant associated soft tissue defects in the anterior maxilla: a randomized control trial comparing subepithelial connective tissue graft and acellular dermal matrix allograft. *Implant Dentistry* **23,** 416-425. doi:10.1097/ID.0000000000000122.

Andreasi Bassi, M., Andrisani, C., Lopez, M. A., Gaudio, R. M., Lombardo, L. & Lauritano, D. (2016) Modified connective tissue punch technique to increase the vestibular/buccal keratinized tissue on flapless implant surgery: A case series. *Journal of Biological Regulators and Homeostatic Agents* **30,** 29-34.

Barootchi, S., Chan, H. L., Namazi, S. S., Wang, H. L. & Kripfgans, O. D. (2020a) Ultrasonographic characterization of lingual structures pertinent to oral, periodontal, and implant surgery. *Clin Oral Implants Res* **31,** 352-359. doi:10.1111/clr.13573.

Barootchi, S., Tavelli, L., Gianfilippo, R. D., Eber, R., Stefanini, M., Zucchelli, G. & Wang, H. L. (2020b) Acellular Dermal Matrix for root coverage procedures. 9-year assessment of treated isolated gingival recessions and their adjacent untreated sites. *J Periodontol*. doi:10.1002/JPER.20-0310.

Barootchi, S., Tavelli, L., Zucchelli, G., Giannobile, W. V. & Wang, H. L. (2020c) Gingival phenotype modification therapies on natural teeth: A network meta-analysis. *J Periodontol*. doi:10.1002/JPER.19-0715.

Barootchi, S., Wang, H. L., Ravida, A., Ben Amor, F., Riccitiello, F., Rengo, C., Paz, A., Laino, L., Marenzi, G., Gasparro, R. & Sammartino, G. (2019) Ridge preservation techniques to avoid invasive bone reconstruction: A systematic review and meta-analysis: Naples Consensus Report Working Group C. *Int J Oral Implantol (Berl)* **12,** 399-416.

Bashutski, J. D., Wang, H. L., Rudek, I., Moreno, I., Koticha, T. & Oh, T. J. (2013) Effect of flapless surgery on single-tooth implants in the esthetic zone: A randomized clinical trial. *Journal of Periodontology* **84,** 1747-1754. doi:10.1902/jop.2013.120575.

Basler, T., Naenni, N., Schneider, D., Hammerle, C. H. F., Jung, R. E. & Thoma, D. S. (2018) Randomized controlled clinical study assessing two membranes for guided bone regeneration of peri-implant bone defects: 3-year results. *Clin Oral Implants Res* **29,** 499-507. doi:10.1111/clr.13147.

Baumer, D., Zuhr, O., Rebele, S. & Hurzeler, M. (2017) Socket Shield Technique for immediate implant placement - clinical, radiographic and volumetric data after 5 years. *Clin Oral Implants Res* **28,** 1450-1458. doi:10.1111/clr.13012.

Baumer, D., Zuhr, O., Rebele, S., Schneider, D., Schupbach, P. & Hurzeler, M. (2015) The socket-shield technique: first histological, clinical, and volumetrical observations after separation of the buccal tooth segment - a pilot study. *Clin Implant Dent Relat Res* **17,** 71-82. doi:10.1111/cid.12076.

Benic, G. I., Elmasry, M. & Hammerle, C. H. (2015) Novel digital imaging techniques to assess the outcome in oral rehabilitation with dental implants: a narrative review. *Clin Oral Implants Res* **26 Suppl 11,** 86-96. doi:10.1111/clr.12616.

Benic, G. I., Ge, Y., Gallucci, G. O., Jung, R. E., Schneider, D. & Hammerle, C. H. (2017) Guided bone regeneration and abutment connection augment the buccal soft tissue contour: 3-year results of a prospective comparative clinical study. *Clin Oral Implants Res* **28,** 219-225. doi:10.1111/clr.12786.

Bertl, K., Gotfredsen, K., Jensen, S. S., Bruckmann, C. & Stavropoulos, A. (2017) Can hyaluronan injections augment deficient papillae at implant-supported crowns in the anterior maxilla? A randomized controlled clinical trial with 6 months follow-up. *Clin Oral Implants Res* **28,** 1054-1061. doi:10.1111/clr.12917.

Bhaskar, V., Chan, H. L., MacEachern, M. & Kripfgans, O. D. (2018) Updates on ultrasound research in implant dentistry: a systematic review of potential clinical indications. *Dentomaxillofac Radiol* **47,** 20180076. doi:10.1259/dmfr.20180076.

Bienz, S. P., Sailer, I., Sanz-Martín, I., Jung, R. E., Hämmerle, C. H. & Thoma, D. S. (2017) Volumetric changes at pontic sites with or without soft tissue grafting: a controlled clinical study with a 10-year follow-up. *Journal of Clinical Periodontology* **44,** 178-184. doi:10.1111/jcpe.12651.

Bittner, N., Schulze-Spate, U., Silva, C., Da Silva, J. D., Kim, D. M., Tarnow, D., Ishikawa-Nagai, S. & Gil, M. S. (2020) Comparison of Peri-implant Soft Tissue Color with the Use of Pink-Neck vs Gray Implants and Abutments Based on Soft Tissue Thickness: A 6-Month Follow-up Study. *Int J Prosthodont* **33,** 29-38. doi:10.11607/ijp.6205.

Borges, T., Fernandes, D., Almeida, B., Pereira, M., Martins, D., Azevedo, L. & Marques, T. (2020) Correlation between alveolar bone morphology and volumetric dimensional changes in immediate maxillary implant placement: A 1-year prospective cohort study. *J Periodontol*. doi:10.1002/JPER.19-0606.

Bosniac, P., Rehmann, P. & Wostmann, B. (2019) Comparison of an indirect impression scanning system and two direct intraoral scanning systems in vivo. *Clin Oral Investig* **23,** 2421-2427. doi:10.1007/s00784-018-2679-4.

Burhardt, L., Livas, C., Kerdijk, W., van der Meer, W. J. & Ren, Y. (2016) Treatment comfort, time perception, and preference for conventional and digital impression techniques: A comparative study in young patients. *Am J Orthod Dentofacial Orthop* **150,** 261-267. doi:10.1016/j.ajodo.2015.12.027.

Burzynski, J. A., Firestone, A. R., Beck, F. M., Fields, H. W., Jr. & Deguchi, T. (2018) Comparison of digital intraoral scanners and alginate impressions: Time and patient satisfaction. *Am J Orthod Dentofacial Orthop* **153,** 534-541. doi:10.1016/j.ajodo.2017.08.017.

Cabanes-Gumbau, G., Pascual-Moscardo, A., Penarrocha-Oltra, D., Garcia-Mira, B., Aizcorbe-Vicente, J. & Penarrocha-Diago, M. A. (2019) Volumetric variation of peri-implant soft tissues in convergent collar implants and crowns using the biologically oriented preparation technique (BOPT). *Med Oral Patol Oral Cir Bucal* **24,** e643-e651. doi:10.4317/medoral.22946.

Cairo, F., Barbato, L., Tonelli, P., Batalocco, G., Pagavino, G. & Nieri, M. (2017) Xenogeneic collagen matrix versus connective tissue graft for buccal soft tissue augmentation at implant site. A randomized, controlled clinical trial. *Journal of Clinical Periodontology* **44,** 769-776. doi:10.1111/jcpe.12750.

Canullo, L., Pesce, P., Tronchi, M., Fiorellini, J., Amari, Y. & Penarrocha, D. (2018) Marginal soft tissue stability around conical abutments inserted with the one abutment-one time protocol after 5 years of prosthetic loading. *Clin Implant Dent Relat Res* **20,** 976-982. doi:10.1111/cid.12683.

Cardaropoli, G., Lekholm, U. & Wennstrom, J. L. (2006) Tissue alterations at implant-supported single-tooth replacements: a 1-year prospective clinical study. *Clin Oral Implants Res* **17,** 165-171. doi:10.1111/j.1600-0501.2005.01210.x.

Chan, H. L. & Kripfgans, O. D. (2020) Ultrasonography for diagnosis of peri-implant diseases and conditions: a detailed scanning protocol and case demonstration. *Dentomaxillofac Radiol***,** 20190445. doi:10.1259/dmfr.20190445.

Chappuis, V., Rahman, L., Buser, R., Janner, S. F. M., Belser, U. C. & Buser, D. (2018) Effectiveness of Contour Augmentation with Guided Bone Regeneration: 10-Year Results. *Journal of Dental Research* **97,** 266-274. doi:10.1177/0022034517737755.

Clementini, M., Agostinelli, A., Castelluzzo, W., Cugnata, F., Vignoletti, F. & De Sanctis, M. (2019) The effect of immediate implant placement on alveolar ridge preservation compared to spontaneous healing after tooth extraction: Radiographic results of a randomized controlled clinical trial. *J Clin Periodontol* **46,** 776-786. doi:10.1111/jcpe.13125.

Clementini, M., Castelluzzo, W., Ciaravino, V., Agostinelli, A., Vignoletti, F., Ambrosi, A. & De Sanctis, M. (2020) The effect of immediate implant placement on alveolar ridge preservation compared to

spontaneous healing after tooth extraction: soft tissue findings from a randomized controlled clinical trial. *J Clin Periodontol*. doi:10.1111/jcpe.13369.

D'Elia, C., Baldini, N., Cagidiaco, E. F., Nofri, G., Goracci, C. & de Sanctis, M. (2017) Peri-implant Soft Tissue Stability After Single Implant Restorations Using Either Guided Bone Regeneration or a Connective Tissue Graft: A Randomized Clinical Trial. *The International journal of periodontics & restorative dentistry* **37,** 413-421. doi:10.11607/prd.2747.

De Bruyckere, T., Cabeza, R. G., Eghbali, A., Younes, F., Cleymaet, R. & Cosyn, J. (2020) A randomized controlled study comparing guided bone regeneration with connective tissue graft to reestablish buccal convexity at implant sites: A 1-year volumetric analysis. *Clin Implant Dent Relat Res*. doi:10.1111/cid.12934.

De Bruyckere, T., Eeckhout, C., Eghbali, A., Younes, F., Vandekerckhove, P., Cleymaet, R. & Cosyn, J. (2018) A randomized controlled study comparing guided bone regeneration with connective tissue graft to re-establish convexity at the buccal aspect of single implants: A one-year CBCT analysis. *J Clin Periodontol* **45,** 1375-1387. doi:10.1111/jcpe.13006.

De Bruyckere, T., Eghbali, A., Younes, F., De Bruyn, H. & Cosyn, J. (2015) Horizontal stability of connective tissue grafts at the buccal aspect of single implants: a 1-year prospective case series. *J Clin Periodontol* **42,** 876-882. doi:10.1111/jcpe.12448.

Di Fiore, A., Vigolo, P., Graiff, L. & Stellini, E. (2018) Digital vs Conventional Workflow for Screw-Retained Single-Implant Crowns: A Comparison of Key Considerations. *Int J Prosthodont* **31,** 577-579. doi:10.11607/ijp.5938.

Eeckhout, C., Bouckaert, E., Verleyen, D., De Bruyckere, T. & Cosyn, J. (2020) A 3-Year Prospective Study on a Porcine-Derived Acellular Collagen Matrix to Re-Establish Convexity at the Buccal Aspect of Single Implants in the Molar Area: A Volumetric Analysis. *J Clin Med* **9**. doi:10.3390/jcm9051568.

Eghbali, A., De Bruyn, H., Cosyn, J., Kerckaert, I. & Van Hoof, T. (2016) Ultrasonic Assessment of Mucosal Thickness around Implants: Validity, Reproducibility, and Stability of Connective Tissue Grafts at the Buccal Aspect. *Clin Implant Dent Relat Res* **18,** 51-61. doi:10.1111/cid.12245.

Eghbali, A., Seyssens, L., De Bruyckere, T., Younes, F., Cleymaet, R. & Cosyn, J. (2018) A 5-year prospective study on the clinical and aesthetic outcomes of alveolar ridge preservation and connective tissue graft at the buccal aspect of single implants. *Journal of Clinical Periodontology* **45,** 1475-1484. doi:10.1111/jcpe.13018.

Eisner, B., Naenni, N., Hüsler, J., Hämmerle, C., Thoma, D. & Sailer, I. (2018) Three-Year Results of a Randomized Controlled Clinical Trial Using Submucosally Veneered and Unveneered Zirconia

Abutments Supporting All-Ceramic Single-Implant Crowns. *The International journal of periodontics & restorative dentistry* **38,** 645-652. doi:10.11607/prd.3669.

Ender, A., Zimmermann, M. & Mehl, A. (2019) Accuracy of complete- and partial-arch impressions of actual intraoral scanning systems in vitro. *Int J Comput Dent* **22,** 11-19.

Farina, V. & Zaffe, D. (2015) Changes in Thickness of Mucosa Adjacent to Implants Using Tissue Matrix Allograft: A Clinical and Histologic Evaluation. *The International journal of oral & maxillofacial implants* **30,** 909-917. doi:10.11607/jomi.3611.

Fickl, S., Schneider, D., Zuhr, O., Hinze, M., Ender, A., Jung, R. E. & Hurzeler, M. B. (2009) Dimensional changes of the ridge contour after socket preservation and buccal overbuilding: an animal study. *J Clin Periodontol* **36,** 442-448. doi:10.1111/j.1600-051X.2009.01381.x.

Fischer, K. R., Testori, T., Wachtel, H., Muhlemann, S., Happe, A. & Del Fabbro, M. (2019) Soft tissue augmentation applying a collagenated porcine dermal matrix during second stage surgery: A prospective multicenter case series. *Clin Implant Dent Relat Res* **21,** 923-930. doi:10.1111/cid.12817.

Fons-Badal, C., Alonso Perez-Barquero, J., Martinez-Martinez, N., Faus-Lopez, J., Fons-Font, A. & Agustin-Panadero, R. (2019) A novel, fully digital approach to quantifying volume gain after soft tissue graft surgery. A pilot study. *J Clin Periodontol*. doi:10.1111/jcpe.13235.

Friberg, B. & Jemt, T. (2012) Soft tissue augmentation in connection to dental implant treatment using a synthetic, porous material--a case series with a 6-month follow-up. *Clin Implant Dent Relat Res* **14,** 872-881. doi:10.1111/j.1708-8208.2010.00320.x.

Frizzera, F., Moreno De Freitas, R., Muñoz-Chávez, O. F., Cabral, G., Shibli, J. A. & Marcantonio, E. (2019) Impact of soft tissue grafts to reduce peri-implant alterations after immediate implant placement and provisionalization in compromised sockets. *International Journal of Periodontics and Restorative Dentistry* **39,** 381-389. doi:10.11607/prd.3224.

Froum, S. J., Khouly, I., Tarnow, D. P., Froum, S., Rosenberg, E., Corby, P., Kye, W., Elian, N., Schoor, R. & Cho, S. C. (2015) The use of a xenogeneic collagen matrix at the time of implant placement to increase the volume of buccal soft tissue. *The International journal of periodontics & restorative dentistry* **35,** 179-189. doi:10.11607/prd.2226.

Fu, J. H., Oh, T. J., Benavides, E., Rudek, I. & Wang, H. L. (2014) A randomized clinical trial evaluating the efficacy of the sandwich bone augmentation technique in increasing buccal bone thickness during implant placement surgery: I. Clinical and radiographic parameters. *Clinical Oral Implants Research* **25,** 458-467. doi:10.1111/clr.12171.

Galarraga-Vinueza, M. E., Obreja, K., Magini, R., Sculean, A., Sader, R. & Schwarz, F. (2020) Volumetric assessment of tissue changes following combined surgical therapy of peri-implantitis: a pilot study. *J Clin Periodontol*. doi:10.1111/jcpe.13335.

Gallardo, Y. R., Bohner, L., Tortamano, P., Pigozzo, M. N., Lagana, D. C. & Sesma, N. (2018) Patient outcomes and procedure working time for digital versus conventional impressions: A systematic review. *J Prosthet Dent* **119,** 214-219. doi:10.1016/j.prosdent.2017.07.007.

Gargallo-Albiol, J., Barootchi, S., Tavelli, L. & Wang, H. L. (2019) Efficacy of Xenogeneic Collagen Matrix to Augment Peri-Implant Soft Tissue Thickness Compared to Autogenous Connective Tissue Graft: A Systematic Review and Meta-Analysis. *Int J Oral Maxillofac Implants* **34,** 1059-1069. doi:10.11607/jomi.7497.

Guarnieri, R., Di Nardo, D., Gaimari, G., Miccoli, G. & Testarelli, L. (2019) Implant-gingival unit stability around one-stage implant with laser-microgrooved collar: Three-year result of a prospective study. *International Journal of Periodontics and Restorative Dentistry* **39,** 875-882. doi:10.11607/prd.3983.

Guth, J. F., Keul, C., Stimmelmayr, M., Beuer, F. & Edelhoff, D. (2013) Accuracy of digital models obtained by direct and indirect data capturing. *Clin Oral Investig* **17,** 1201-1208. doi:10.1007/s00784-012-0795-0.

Hanser, T. & Khoury, F. (2016) Alveolar Ridge Contouring with Free Connective Tissue Graft at Implant Placement: A 5-Year Consecutive Clinical Study. *The International journal of periodontics & restorative dentistry* **36,** 465-473. doi:10.11607/prd.2730.

Harris, D., Horner, K., Grondahl, K., Jacobs, R., Helmrot, E., Benic, G. I., Bornstein, M. M., Dawood, A. & Quirynen, M. (2012) E.A.O. guidelines for the use of diagnostic imaging in implant dentistry 2011. A consensus workshop organized by the European Association for Osseointegration at the Medical University of Warsaw. *Clin Oral Implants Res* **23,** 1243-1253. doi:10.1111/j.1600-0501.2012.02441.x.

Higgins, J. P., Altman, D. G., Gotzsche, P. C., Juni, P., Moher, D., Oxman, A. D., Savovic, J., Schulz, K. F., Weeks, L., Sterne, J. A., Cochrane Bias Methods, G. & Cochrane Statistical Methods, G. (2011) The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ* **343,** d5928. doi:10.1136/bmj.d5928.

Hinze, M., Janousch, R., Goldhahn, S. & Schlee, M. (2018) Volumetric alterations around single-tooth implants using the socket-shield technique: preliminary results of a prospective case series. *Int J Esthet Dent* **13,** 146-170.

Hosseini, M., Worsaae, N. & Gotfredsen, K. (2020) Tissue changes at implant sites in the anterior maxilla with and without connective tissue grafting: A five-year prospective study. *Clin Oral Implants Res* **31,** 18-28. doi:10.1111/clr.13540.

Huber, S., Zeltner, M., Hammerle, C. H. F., Jung, R. E. & Thoma, D. S. (2018) Non-interventional 1-year follow-up study of peri-implant soft tissues following previous soft tissue augmentation and crown insertion in single-tooth gaps. *J Clin Periodontol* **45,** 504-512. doi:10.1111/jcpe.12865.

Hutton, C. G., Johnson, G. K., Barwacz, C. A., Allareddy, V. & Avila-Ortiz, G. (2018) Comparison of two different surgical approaches to increase peri-implant mucosal thickness: A randomized controlled clinical trial. *J Periodontol* **89,** 807-814. doi:10.1002/JPER.17-0597.

Jiang, X., Di, P., Ren, S., Zhang, Y. & Lin, Y. (2020) Hard and soft tissue alterations during the healing stage of immediate implant placement and provisionalization with or without connective tissue graft: A randomized clinical trial. *J Clin Periodontol* **47,** 1006-1015. doi:10.1111/jcpe.13331.

Joda, T., Lenherr, P., Dedem, P., Kovaltschuk, I., Bragger, U. & Zitzmann, N. U. (2017) Time efficiency, difficulty, and operator's preference comparing digital and conventional implant impressions: a randomized controlled trial. *Clin Oral Implants Res* **28,** 1318-1323. doi:10.1111/clr.12982.

Kaminaka, A., Nakano, T., Ono, S., Kato, T. & Yatani, H. (2015) Cone-Beam Computed Tomography Evaluation of Horizontal and Vertical Dimensional Changes in Buccal Peri-Implant Alveolar Bone and Soft Tissue: A 1-Year Prospective Clinical Study. *Clin Implant Dent Relat Res* **17 Suppl 2,** e576-585. doi:10.1111/cid.12286.

Kato, T., Nakano, T., Fujita, Y., Kobayashi, T. & Yatani, H. (2018) Influence of different implant operative procedures on morphologic changes in peri-implant alveolar bone and soft tissue: a one-year prospective clinical study. *J Prosthodont Res* **62,** 490-496. doi:10.1016/j.jpor.2018.07.003.

Keul, C. & Guth, J. F. (2020) Accuracy of full-arch digital impressions: an in vitro and in vivo comparison. *Clin Oral Investig* **24,** 735-745. doi:10.1007/s00784-019-02965-2.

Ko, K. A., Lee, J. S., Kim, J. H., Park, J. M., Gruber, R. & Thoma, D. S. (2020) Changes in mucogingival junction after an apically positioned flap with collagen matrix at sites with or without previous guided bone regeneration: a prospective comparative cohort study. *Clin Oral Implants Res*. doi:10.1111/clr.13665.

Lee, J. S., Jeon, Y. S., Strauss, F. J., Jung, H. I. & Gruber, R. (2020) Digital scanning is more accurate than using a periodontal probe to measure the keratinized tissue width. *Sci Rep* **10,** 3665. doi:10.1038/s41598-020-60291-0.

Lee, S. J. & Gallucci, G. O. (2013) Digital vs. conventional implant impressions: efficiency outcomes. *Clin Oral Implants Res* **24,** 111-115. doi:10.1111/j.1600-0501.2012.02430.x.

Lehmann, K. M., Kasaj, A., Ross, A., Kammerer, P. W., Wagner, W. & Scheller, H. (2012) A new method for volumetric evaluation of gingival recessions: a feasibility study. *J Periodontol* **83,** 50-54. doi:10.1902/jop.2011.110143.

Linkevicius, T., Puisys, A., Linkeviciene, L., Peciuliene, V. & Schlee, M. (2015) Crestal Bone Stability around Implants with Horizontally Matching Connection after Soft Tissue Thickening: A Prospective Clinical Trial. *Clinical Implant Dentistry and Related Research* **17,** 497-508. doi:10.1111/cid.12155.

Lo Russo, L., Caradonna, G., Troiano, G., Salamini, A., Guida, L. & Ciavarella, D. (2020) Three-dimensional differences between intraoral scans and conventional impressions of edentulous jaws: A clinical study. *J Prosthet Dent* **123,** 264-268. doi:10.1016/j.prosdent.2019.04.004.

Loubele, M., Bogaerts, R., Van Dijck, E., Pauwels, R., Vanheusden, S., Suetens, P., Marchal, G., Sanderink, G. & Jacobs, R. (2009) Comparison between effective radiation dose of CBCT and MSCT scanners for dentomaxillofacial applications. *Eur J Radiol* **71,** 461-468. doi:10.1016/j.ejrad.2008.06.002.

Mandelaris, G. A., Scheyer, E. T., Evans, M., Kim, D., McAllister, B., Nevins, M. L., Rios, H. F. & Sarment, D. (2017) American Academy of Periodontology Best Evidence Consensus Statement on Selected Oral Applications for Cone-Beam Computed Tomography. *J Periodontol* **88,** 939-945. doi:10.1902/jop.2017.170234.

Mendes, S., Rinne, C. A., Schmidt, J. C., Dagassan-Berndt, D. & Walter, C. (2020) Evaluation of magnetic resonance imaging for diagnostic purposes in operative dentistry-a systematic review. *Clin Oral Investig* **24,** 547-557. doi:10.1007/s00784-019-03103-8.

Mennito, A. S., Evans, Z. P., Nash, J., Bocklet, C., Lauer Kelly, A., Bacro, T., Cayouette, M., Ludlow, M. & Renne, W. G. (2019) Evaluation of the trueness and precision of complete arch digital impressions on a human maxilla using seven different intraoral digital impression systems and a laboratory scanner. *J Esthet Restor Dent* **31,** 369-377. doi:10.1111/jerd.12485.

Migliorati, M., Amorfini, L., Signori, A., Biavati, A. S. & Benedicenti, S. (2015) Clinical and Aesthetic Outcome with Post-Extractive Implants with or without Soft Tissue Augmentation: A 2-Year Randomized Clinical Trial. *Clin Implant Dent Relat Res* **17,** 983-995. doi:10.1111/cid.12194.

Muallah, J., Wesemann, C., Nowak, R., Robben, J., Mah, J., Pospiech, P. & Bumann, A. (2017) Accuracy of full-arch scans using intraoral and extraoral scanners: an in vitro study using a new method of evaluation. *Int J Comput Dent* **20,** 151-164.

Papapetros, D., Vassilis, K., Antonis, K. & Danae, A. A. (2019) Interim tissue changes following connective tissue grafting and two-stage implant placement. A randomized clinical trial. *Journal of Clinical Periodontology* **46,** 958-968. doi:10.1111/jcpe.13159.

Papi, P., Di Murro, B. & Pompa, G. (2019) Use of a xenogenic collagen membrane in peri-implant soft tissue augmentation. *Dental Cadmos* **87,** 150-157. doi:10.19256/d.cadmos.03.2019.05.

Papi, P., Penna, D., Murro, B. D. & Pompa, G. (2020) Clinical and volumetric analysis of peri-implant soft tissue augmentation using an acellular dermal matrix: A prospective cohort study. *J Periodontol.* doi:10.1002/JPER.20-0219.

Parvini, P., Gallaraga-Vinueza, M. E., Obreja, K., Magini, R., Sader, R. & Schwarz, F. (2020) A prospective study assessing three-dimensional changes of mucosal healing following soft tissue augmentation using free gingival grafts. *J Periodontol*, 1-9. doi:https://doi.org/10.1002/JPER.19-0640.

Poli, P. P., Maridati, P. C., Stoffella, E., Beretta, M. & Maiorana, C. (2019) Influence of Timing on the Horizontal Stability of Connective Tissue Grafts for Buccal Soft Tissue Augmentation at Single Implants: A Prospective Controlled Pilot Study. *J Oral Maxillofac Surg* **77,** 1170-1179. doi:10.1016/j.joms.2019.02.030.

Puisys, A., Vindasiute, E., Linkevciene, L. & Linkevicius, T. (2015) The use of acellular dermal matrix membrane for vertical soft tissue augmentation during submerged implant placement: a case series. *Clinical Oral Implants Research* **26,** 465-470. doi:10.1111/clr.12401.

Puzio, M., Błaszczyszyn, A., Hadzik, J. & Dominiak, M. (2018) Ultrasound assessment of soft tissue augmentation around implants in the aesthetic zone using a connective tissue graft and xenogeneic collagen matrix – 1-year randomised follow-up. *Annals of Anatomy* **217,** 129-141. doi:10.1016/j.aanat.2017.11.003.

Puzio, M., Hadzik, J., Błaszczyszyn, A., Gedrange, T. & Dominiak, M. (2020) Soft tissue augmentation around dental implants with connective tissue graft (CTG) and xenogenic collagen matrix (XCM). 1-year randomized control trail. *Ann Anat* **230,** 151484. doi:10.1016/j.aanat.2020.151484.

Rebele, S. F., Zuhr, O., Schneider, D., Jung, R. E. & Hurzeler, M. B. (2014) Tunnel technique with connective tissue graft versus coronally advanced flap with enamel matrix derivative for root coverage: a RCT using 3D digital measuring methods. Part II. Volumetric studies on healing dynamics and gingival dimensions. *J Clin Periodontol* **41,** 593-603. doi:10.1111/jcpe.12254.

Resende, C. C. D., Barbosa, T. A. Q., Moura, G. F., Tavares, L. D. N., Rizzante, F. A. P., George, F. M., Neves, F. D. D. & Mendonca, G. (2020) Influence of operator experience, scanner type, and scan size on 3D scans. *J Prosthet Dent*. doi:10.1016/j.prosdent.2019.12.011.

Richert, R., Goujat, A., Venet, L., Viguie, G., Viennot, S., Robinson, P., Farges, J. C., Fages, M. & Ducret, M. (2017) Intraoral Scanner Technologies: A Review to Make a Successful Impression. *J Healthc Eng* **2017,** 8427595. doi:10.1155/2017/8427595.

Rojo, E., Stroppa, G., Sanz-Martin, I., Gonzalez-Martín, O., Alemany, A. S. & Nart, J. (2018) Soft tissue volume gain around dental implants using autogenous subepithelial connective tissue grafts harvested from the lateral palate or tuberosity area. A randomized controlled clinical study. *Journal of Clinical Periodontology* **45,** 495-503. doi:10.1111/jcpe.12869.

Rojo, E., Stroppa, G., Sanz-Martin, I., Gonzalez-Martin, O. & Nart, J. (2020) Soft tissue stability around dental implants after soft tissue grafting from the lateral palate or the tuberosity area - a randomized controlled clinical study. *J Clin Periodontol*. doi:10.1111/jcpe.13292.

Rungcharassaeng, K., Kan, J. Y., Yoshino, S., Morimoto, T. & Zimmerman, G. (2012) Immediate implant placement and provisionalization with and without a connective tissue graft: an analysis of facial gingival tissue thickness. *The International journal of periodontics & restorative dentistry* **32,** 657-663.

Sanz Martin, I., Benic, G. I., Hammerle, C. H. & Thoma, D. S. (2016) Prospective randomized controlled clinical study comparing two dental implant types: volumetric soft tissue changes at 1 year of loading. *Clin Oral Implants Res* **27,** 406-411. doi:10.1111/clr.12579.

Sanz-Martin, I., Encalada, C., Sanz-Sanchez, I., Aracil, J. & Sanz, M. (2019) Soft tissue augmentation at immediate implants using a novel xenogeneic collagen matrix in conjunction with immediate provisional restorations: A prospective case series. *Clin Implant Dent Relat Res* **21,** 145-153. doi:10.1111/cid.12696.

Sanz-Martín, I., Sailer, I., Hämmerle, C. H. & Thoma, D. S. (2016) Soft tissue stability and volumetric changes after 5 years in pontic sites with or without soft tissue grafting: a retrospective cohort study. *Clinical Oral Implants Research* **27,** 969-974. doi:10.1111/clr.12743.

Sapata, V. M., Sanz-Martin, I., Hammerle, C. H. F., Cesar Neto, J. B., Jung, R. E. & Thoma, D. S. (2018) Profilometric changes of peri-implant tissues over 5 years: A randomized controlled trial comparing a one- and two-piece implant system. *Clin Oral Implants Res* **29,** 864-872. doi:10.1111/clr.13308.

Schallhorn, R. A., McClain, P. K., Charles, A., Clem, D. & Newman, M. G. (2015) Evaluation of a porcine collagen matrix used to augment keratinized tissue and increase soft tissue thickness around existing dental implants. *Int J Periodontics Restorative Dent* **35,** 99-103. doi:10.11607/prd.1888.

Schmidt, A., Klussmann, L., Wostmann, B. & Schlenz, M. A. (2020) Accuracy of Digital and Conventional Full-Arch Impressions in Patients: An Update. *J Clin Med* **9**. doi:10.3390/jcm9030688.

Schneider, D., Ender, A., Truninger, T., Leutert, C., Sahrmann, P., Roos, M. & Schmidlin, P. (2014) Comparison between clinical and digital soft tissue measurements. *J Esthet Restor Dent* **26,** 191-199. doi:10.1111/jerd.12084.

Schneider, D., Grunder, U., Ender, A., Hammerle, C. H. & Jung, R. E. (2011) Volume gain and stability of peri-implant tissue following bone and soft tissue augmentation: 1-year results from a prospective cohort study. *Clin Oral Implants Res* **22,** 28-37. doi:10.1111/j.1600-0501.2010.01987.x.

Skramstad, M. J. (2019) Welcome to Cerec Primescan AC. *Int J Comput Dent* **22,** 69-78.

Stefanini, M., Felice, P., Mazzotti, C., Marzadori, M., Gherlone, E. F. & Zucchelli, G. (2016) Transmucosal Implant Placement with Submarginal Connective Tissue Graft in Area of Shallow Buccal Bone Dehiscence: A Three-Year Follow-Up Case Series. *The International journal of periodontics & restorative dentistry* **36,** 621-630. doi:10.11607/prd.2537.

Stefanini, M., Mounssif, I., Barootchi, S., Tavelli, L., Wang, H. L. & Zucchelli, G. (2020a) An exploratory clinical study evaluating safety and performance of a volume-stable collagen matrix with coronally advanced flap for single gingival recession treatment. *Clin Oral Investig* **24,** 3181-3191. doi:10.1007/s00784-019-03192-5.

Stefanini, M., Rendon, A. & Zucchelli, G. (2020b) Porcine-Derived Acellular Dermal Matrix for Buccal Soft Tissue Augmentation at Single Implant Sites: A 1-Year Follow-up Case Series. *Int J Periodontics Restorative Dent* **40,** 121-128. doi:10.11607/prd.4477.

Stillwell, S. B., Fineout-Overholt, E., Melnyk, B. M. & Williamson, K. M. (2010) Evidence-based practice, step by step: asking the clinical question: a key step in evidence-based practice. *Am J Nurs* **110,** 58-61. doi:10.1097/01.NAJ.0000368959.11129.79.

Strebel, J., Ender, A., Paque, F., Krahenmann, M., Attin, T. & Schmidlin, P. R. (2009) In vivo validation of a three-dimensional optical method to document volumetric soft tissue changes of the interdental papilla. *J Periodontol* **80,** 56-61. doi:10.1902/jop.2009.080288.

Tattan, M., Sinjab, K., Lee, E., Arnett, M., Oh, T. J., Wang, H. L., Chan, H. L. & Kripfgans, O. D. (2019) Ultrasonography for chairside evaluation of periodontal structures: A pilot study. *J Periodontol*. doi:10.1002/JPER.19-0342.

Tavelli, L., Barootchi, S., Avila-Ortiz, G., Urban, I. A., Giannobile, W. V. & Wang, H. L. (2020a) Peri-implant soft tissue phenotype modification and its impact on peri-implant health: A systematic review and network meta-analysis. *J Periodontol*. doi:10.1002/JPER.19-0716.

Tavelli, L., Barootchi, S., Di Gianfilippo, R., Modarressi, M., Cairo, F., Rasperini, G. & Wang, H. L. (2019) Acellular dermal matrix and coronally advanced flap or tunnel technique in the treatment

of multiple adjacent gingival recessions. A 12-year follow-up from a randomized clinical trial. *J Clin Periodontol* **46,** 937-948. doi:10.1111/jcpe.13163.

Tavelli, L., McGuire, M. K., Zucchelli, G., Rasperini, G., Feinberg, S. E., Wang, H. L. & Giannobile, W. V. (2020b) Extracellular matrix-based scaffolding technologies for periodontal and peri-implant soft tissue regeneration. *J Periodontol* **91,** 17-25. doi:10.1002/JPER.19-0351.

Tavelli, L., Ravida, A., Barootchi, S., Chambrone, L. & Giannobile, W. V. (2020c) Recombinant Human Platelet-Derived Growth Factor: A Systematic Review of Clinical Findings in Oral Regenerative Procedures. *JDR Clin Trans Res***,** 2380084420921353. doi:10.1177/2380084420921353.

Thoma, D. S., Bienz, S. P., Payer, M., Husler, J., Schmidlin, P. R., Hammerle, C. H. F., Jakse, N. & Jung, R. E. (2019) Randomized clinical study using xenograft blocks loaded with bone morphogenetic protein-2 or autogenous bone blocks for ridge augmentation - A three-dimensional analysis. *Clin Oral Implants Res* **30,** 872-881. doi:10.1111/clr.13492.

Thoma, D. S., Gasser, T. J. W., Jung, R. E. & Hammerle, C. H. F. (2020) Randomized controlled clinical trial comparing implant sites augmented with a volume-stable collagen matrix or an autogenous connective tissue graft: 3-year data after insertion of reconstructions. *J Clin Periodontol*. doi:10.1111/jcpe.13271.

Thoma, D. S., Jung, R. E., Schneider, D., Cochran, D. L., Ender, A., Jones, A. A., Gorlach, C., Uebersax, L., Graf-Hausner, U. & Hammerle, C. H. (2010) Soft tissue volume augmentation by the use of collagen-based matrices: a volumetric analysis. *J Clin Periodontol* **37,** 659-666. doi:10.1111/j.1600-051X.2010.01581.x.

Thoma, D. S., Zeltner, M., Hilbe, M., Hämmerle, C. H., Hüsler, J. & Jung, R. E. (2016) Randomized controlled clinical study evaluating effectiveness and safety of a volume-stable collagen matrix compared to autogenous connective tissue grafts for soft tissue augmentation at implant sites. *J Clin Periodontol* **43,** 874-885. doi:10.1111/jcpe.12588.

Tian, J., Wei, D., Zhao, Y., Di, P., Jiang, X. & Lin, Y. (2019) Labial soft tissue contour dynamics following immediate implants and immediate provisionalization of single maxillary incisors: A 1-year prospective study. *Clin Implant Dent Relat Res* **21,** 492-502. doi:10.1111/cid.12786.

Torkzaban, P., Arabi, S. R., Roshanaei, G., Rostami, M. & Soheilifar, S. (2015) A comparative study of clinical parameters in submerged and non submerged implants. *Journal of Clinical and Diagnostic Research* **9,** ZC26-ZC29. doi:10.7860/JCDR/2015/11317.5653.

Ustaoğlu, G., Paksoy, T. & Gümüş, K. Ç. (2020) Titanium-Prepared Platelet-Rich Fibrin Versus Connective Tissue Graft on Peri-Implant Soft Tissue Thickening and Keratinized Mucosa Width: A Randomized, Controlled Trial. *Journal of Oral and Maxillofacial Surgery* **78,** 1112-1123. doi:10.1016/j.joms.2020.02.019.

van Nimwegen, W. G., Raghoebar, G. M., Zuiderveld, E. G., Jung, R. E., Meijer, H. J. A. & Muhlemann, S. (2018) Immediate placement and provisionalization of implants in the aesthetic zone with or without a connective tissue graft: A 1-year randomized controlled trial and volumetric study. *Clin Oral Implants Res* **29,** 671-678. doi:10.1111/clr.13258.

Verardi, S., Orsini, M., Lombardi, T., Ausenda, F., Testori, T., Pulici, A., Oreglia, F., Valente, N. A. & Stacchi, C. (2019) Comparison between two different techniques for peri-implant soft tissue augmentation: Porcine dermal matrix graft versus tenting screw. *J Periodontol*. doi:10.1002/jper.19-0447.

Wang, I. C., Chan, H. L., Kinney, J. & Wang, H. L. (2019) Volumetric facial contour changes of immediately placed implants with and without immediate provisionalization. *J Periodontol*. doi:10.1002/jper.19-0308.

Wei, D. H., Zhao, Y. J., Di, P., Tian, J. H., Jiang, X. & Lin, Y. (2019) [Quantitative three-dimensional methodology based on intraoral scan to assess the soft tissue contour alterations following single immediate implant and immediate provisionalization in maxillary central incisor: a 1-year prospective study]. *Zhonghua Kou Qiang Yi Xue Za Zhi* **54,** 3-9. doi:10.3760/cma.j.issn.1002-0098.2019.01.002.

Wesemann, C., Muallah, J., Mah, J. & Bumann, A. (2017) Accuracy and efficiency of full-arch digitalization and 3D printing: A comparison between desktop model scanners, an intraoral scanner, a CBCT model scan, and stereolithographic 3D printing. *Quintessence Int* **48,** 41-50. doi:10.3290/j.qi.a37130.

Wiesner, G., Esposito, M., Worthington, H. & Schlee, M. (2010) Connective tissue grafts for thickening peri-implant tissues at implant placement. One-year results from an explanatory split-mouth randomised controlled clinical trial. *Eur J Oral Implantol* **3,** 27-35.

Windisch, S. I., Jung, R. E., Sailer, I., Studer, S. P., Ender, A. & Hammerle, C. H. (2007) A new optical method to evaluate three-dimensional volume changes of alveolar contours: a methodological in vitro study. *Clin Oral Implants Res* **18,** 545-551. doi:10.1111/j.1600-0501.2007.01382.x.

Wittneben, J. G., Brägger, U., Buser, D. & Joda, T. (2016) Volumetric Calculation of Supraimplant Submergence Profile After Soft Tissue Conditioning with a Provisional Restoration. *The International journal of periodontics & restorative dentistry* **36,** 785-790. doi:10.11607/prd.2742.

Yuzbasioglu, E., Kurt, H., Turunc, R. & Bilir, H. (2014) Comparison of digital and conventional impression techniques: evaluation of patients' perception, treatment comfort, effectiveness and clinical outcomes. *BMC Oral Health* **14,** 10. doi:10.1186/1472-6831-14-10.

Zafiropoulos, G. G., Deli, G., Hoffmann, O. & John, G. (2016) Changes of the peri-implant soft tissue thickness after grafting with a collagen matrix. *J Indian Soc Periodontol* **20,** 441-445. doi:10.4103/0972-124X.181245.

Zeltner, M., Jung, R. E., Hämmerle, C. H., Hüsler, J. & Thoma, D. S. (2017) Randomized controlled clinical study comparing a volume-stable collagen matrix to autogenous connective tissue grafts for soft tissue augmentation at implant sites: linear volumetric soft tissue changes up to 3 months. *Journal of Clinical Periodontology* **44,** 446-453. doi:10.1111/jcpe.12697.

Zucchelli, G., Felice, P., Mazzotti, C., Marzadori, M., Mounssif, I., Monaco, C. & Stefanini, M. (2018) 5-year outcomes after coverage of soft tissue dehiscence around single implants: A prospective cohort study. *European journal of oral implantology* **11,** 215-224.

Zucchelli, G., Mazzotti, C., Mounssif, I., Mele, M., Stefanini, M. & Montebugnoli, L. (2013) A novel surgical-prosthetic approach for soft tissue dehiscence coverage around single implant. *Clin Oral Implants Res* **24,** 957-962. doi:10.1111/clr.12003.

Zucchelli, G., Tavelli, L., McGuire, M. K., Rasperini, G., Feinberg, S. E., Wang, H. L. & Giannobile, W. V. (2020) Autogenous soft tissue grafting for periodontal and peri-implant plastic surgical reconstruction. *J Periodontol* **91,** 9-16. doi:10.1002/JPER.19-0350.

Zucchelli, G., Tavelli, L., Stefanini, M., Barootchi, S., Mazzotti, C., Gori, G. & Wang, H. L. (2019) Classification of facial peri-implant soft tissue dehiscence/deficiencies at single implant sites in the esthetic zone. *J Periodontol* **90,** 1116-1124. doi:10.1002/JPER.18-0616.

Tables and figures.

Table 1. Characteristics of the included studies assessing volumetric outcomes with optical scanning-based digital technologies

Figure 1. Digital workflow of optical scanner-based technologies for generating Standard Tessellation Language (STL) files and for analyzing volumetric changes

Figure 2. PRISMA flowchart

Table 1. Characteristics of the included studies assessing volumetric outcomes with optical scanning-based digital technologies

Publication	Study design	Country, Setting, Funding	Treatment	Follow-up time (months)	Participant (n), age (years), sites (n)	Type of impression	Type of digital scanner and software used	3D volumetric measurements	Transgingival piercing assessment	Calibration and blinding of the examiner(s) of the 3D analysis
(Basler et al., 2018)	RCT	Switzerland, University, sponsored	Implant placement and simultaneous GBR (resorbable membrane) Implant placement and simultaneous GBR (non-resorbable membrane)	12, 36	23, 56.6, 23	Silicon impressions, then dental stone casts scanned	Laboratory scanner (Imetric 3D SA, Courgenay, Switzerland), SMOP (Swissmeda, Zurich, Switzerland)	ΔD, LD	No	NR
(Benic et al., 2017)	Prospective non-randomized comparative study	Switzerland, University, self-supported	GBR No augmentation	36 36	10, 49.5, 10 18, 52.2, 18	Silicon impressions, then dental stone casts scanned	Laboratory scanner (Imetric 3D Gmbh, Courgenay, Switzerland), SMOP (Swissmeda, Zurich, Switzerland)	LD	No	NR

Study	Study design	Country, setting	Intervention	Time points	N, Age	Impression	Device/software	Outcome		Calibration
(Bertl et al., 2017)	RCT	Denmark, University, self-supported	Peri-implant papilla augmentation with HY injection	6 (3 for the 3D analysis)	11, 26.7, 11	Intraoral digital impression	Intraoral scanner (Trios, 3-shape, Copenhagen, Denmark), Convince Standard (3-shape, Copenhagen, Denmark) and Photoshop CS 5 (Adobe Systems, San Jose, CA, USA)	Differences in the area	No	NR
			Peri-implant papilla augmentation with saline solution (control group)	6 (3 for the 3D analysis)	10, 33.1, 10					
(Bittner et al., 2020)	RCT	USA, University, sponsored	IIP + IP with conventional titanium implant	6	40, 46.9, 40	Alginate impression and then the casts were scanned	Intraoral scanner (Romexis, Planmeca, Helsinki, Finland), Compare (Planmeca, Helsinki, Finland)	LD	No	NR
			IIP + IP with a pink-neck implant							
(Borges et al., 2020)	Prospective case	Portugal, Universit	IIP	1, 4, 12	26, 53.04,	Intraoral digital	Intraoral scanner (CEREC OMNICAM,	Vol, ΔD	No	Calibrated (k=0.91) and

series	y, self-supported			26	impression	Sirona, Salzburg, Austria), Geomagic Control (3D Systems, Rock Hill, USA)			blinded
(Cabanes-Gumbau et al., 2019)	Prospective case series	Spain, University, sponsored	Implant placement and soft tissue conditioning with the abutment and the provisional crown	10	14, 60.4, 32	Intraoral digital impression	Intraoral scanner (CEREC OMNICAM, Sirona, Salzburg, Austria), OraCheck application (CEREC OMNICAM, Sirona, Salzburg, Austria)	Vol, ΔD	No	NR
(Canullo et al., 2018)	Prospective case series	Italy, Private practice, self-supported	Peri-implant soft tissue conditioning with abutments and crowns	60	22, 68.3, 22	Impressions (material NR) and then the casts were scanned	Laboratory scanner (Sinergia, Bologna, Italy), ExoCad (Exocad gmbh, Darmstadt, Germany)	ΔD	No	NR
(Clementini et al., 2020)	RCT	Italy, University, sponsored	IIP with XCM vs ARP or spontaneous healing (with delayed implant placement)	4	10, 52.5, 10 (in the immediate implant placement)	Polyether impressions and then the casts were scanned	Optical scanner (CEREC Omnicam, Dentsply Sirona, USA), SMOP (Swissmeda, Zurich, Switzerland)	Vol, ΔD, LD	No	Calibrated and blinded

Study	Design	Country/Setting	Intervention	Follow-up (months)	n, age, teeth	Impression/Scanning method	Scanner	Outcomes	Blinding	Examiner
					with XCM group)					
(De Bruyckere et al., 2020)	RCT	Belgium, University and private practice, materials donated	Implant placement with GBR Implant placement with CTG	12	21, 51, 21 21, 48, 21	Alginate impressions. Casts scanned with an optical scanner	Laboratory scanner (LS 3 scanner, Kavo, Biberach an der Riss, Germany), SMOP (Swissmeda, Zurich, Switzerland)	Vol, ΔD	No	NR
(Eeckhout et al., 2020)	Prospective case series	Belgium University, materials donated	Implant placement with PADM	3, 12, 36	51, 51.4, 15	Alginate impressions. Casts scanned with an optical scanner	Laboratory scanner (LS 3 scanner, Kavo, Biberach an der Riss, Germany), SMOP (Swissmeda, Zurich, Switzerland)	ΔD	No	NR
(Fischer et al., 2019)	Prospective case series	Germany and Italy, Private practice, self-supported	Peri-implant soft tissue augmentation with PADM	24	20, 50.2, 24	Silicone impressions. Dental stone casts scanned with an optical 3D scanner	Optical scanner (CEREC scan utility, inEos, Sirona Dental System, Bensheim, Germany), SMOP (Swissmeda, Zurich, Switzerland)	ΔD	No	Calibrated and blinded
(Friberg and Jemt, 2012)	Prospective case series	Sweden, University, sponsore	Peri-implant soft tissue augmentation with a	6	10, 27, 12	Impressions (material NR). Study casts scanned	Optical 3D scanner (Atos, GOM International AG, Switzerland), NR	Vol, ΔD	No	NR

Study	Design	Country/Setting/Funding	Intervention	Follow-up	N, age	Impression	Scanner/Software	Outcomes		Calibration
		d	synthetic scaffold			with an optical 3D scanner				
(Galarraga-Vinueza et al., 2020)	Prospective case series	Germany, University, sponsored	Peri-implantitis treatment with implantoplasty (supracrestally) and GBR (intrabony component)	1, 6	20, 65, 28	Intraoral digital impression	Intraoral optical scanner (3 shape TRIOS MOVE, GmbH, Germany), GOM inspect 2018, Zeiss Company, Germany) and Meshlab (ISTI, Italy)	SCTA contraction rate, ΔD, LD	No	Calibrated
(Hinze et al., 2018)	Prospective case series	Germany, Private practice, sponsored	IIP + IP with socket shield technique	3	15, 49.25, 17	Impressions (material NR) and then the casts were scanned	Optical 3D scanner (Scanner S600 ARTI, Zirkonzahn, Germany), SMOP (Swissmeda, Zurich, Switzerland)	ΔD	No	Calibrated
(Hosseini et al., 2020)	Prospective non-randomized comparative study	Denmark, University, self-supported	Implant placement with CTG at second stage / Implant placement without soft tissue augmentation	12, 36, 60	10, 20, 10 / 15, 23, 23	Alginate impressions. Casts scanned in an optical model scanner	Opical model scanner (Q 800, 3Shape), OrthoAnalyzer (3Shape)	LD	Yes	NR
(Huber et al., 2018)	RCT	Switzerland,	Peri-implant soft tissue	12	10, 43.4,	Alginate with an A-silicone	Desktop 3D scanner (Imetric 3D, Courgenay,	ΔD	Yes	NR

Study	Design	Setting	Intervention	N	Values	Impression	Scanner/Software	Outcomes		Calibration
		University, Sponsored	augmentation with CTG		10	impression material.	Switzerland), SMOP (Swissmeda, Zurich, Switzerland)			
			Peri-implant soft tissue augmentation with XCM	12	10, 44.1, 10	Casts scanned with a desktop 3D scanner				
(Jiang et al., 2020)	RCT	China, University, self-supported	IIP + IP with CTG	6	20, 34.3, 20	Intraoral digital impression	Intraoral optical scanner (3 shape TRIOS MOVE, GmbH, Germany), Geomagic Qualify 12 (3D Systems, Rock Hill, USA)	LD	No	NR
			IIP + IP without soft tissue augmentation		20, 37.7, 20					
(Papi et al., 2020)	Prospective case series	Italy, University, materials donated	Peri-implant soft tissue augmentation with PADM	12	12, 51.6, 12	Intraoral digital impression	Intraoral optical scanner (Carestream CS3600, Carestream Dental, Atlanta, USA), GOM inspect 2018, Zeiss Company, Germany)	Vol, LD	Yes	Calibrated (k>0.85)
(Parvini et al., 2020)	Prospective case series	Germany, University, sponsored	Peri-implant soft tissue augmentation with FGG	3	12, 60, 19	Intraoral digital impression	Intraoral optical scanner (3 shape TRIOS MOVE, GmbH, Germany), GOM inspect 2018, Zeiss Company, Germany)	Surface area, shrinkage rate, ΔD	No	Calibrated (k between 0.81 and 1)
(Rojo et al., 2018)	RCT	Spain, University	Peri-implant soft tissue	3	16, 50.47,	Intraoral digital	Intraoral optical scanner (Lava Chairside Oral	LD	No	Blinded

			augmentation with CTG		18	impression	Scanner C.O.S., 3M ESPE, Seefeld, Germany), Geomagic Control (3D Systems, Rock Hill, USA)			
		y, self-supported	Peri-implant soft tissue augmentation with tCTG		16, 54.44, 18					
(Rojo et al., 2020)	RCT	Spain, University, self-supported	Peri-implant soft tissue augmentation with CTG	4, 12	13, 50.47, 15	Intraoral digital impression	Intraoral optical scanner (Lava Chairside Oral Scanner C.O.S., 3M ESPE, Seefeld, Germany), Geomagic Control (3D Systems, Rock Hill, USA)	LD	No	Blinded
			Peri-implant soft tissue augmentation with tCTG	4, 12	14, 54.44, 16					
(Sanz Martin et al., 2016)	RCT	Switzerland, University, self-supported	One-piece dental implants	12	15, NR, 15	Alginate impressions, stone casts fabricated and scanned with a desktop 3D scanner	Desktop 3D scanner (Imetric 3D, Courgenay, Switzerland), SMOP (Swissmeda, Zurich, Switzerland)	ΔD, LD	No	Calibrated and blinded
			Two-piece implants		18, NR, 18					
(Sanz-Martin et al., 2019)	Prospective case series	Spain, University, Sponsored	IIP + XCM + IP	12	12, 53, 12	Silicone impressions. Dental stone casts scanned with a	Desktop 3D scanner (Zfx Evolution Scanner, Zimmer Dental, Bolzano, Italy), SMOP (Swissmeda, Zurich,	Vol, ΔD, LD	No	Calibrated

Study	Study type	Setting	Intervention	N	n, age, ...	Impression	Scanner	Outcome		
						desktop 3D scanner	Switzerland)			
(Sapata et al., 2018)	RCT	Switzerland, University, self-supported	One-piece dental implants	60	14, NR, NR	Alginate impressions. Stone casts scanned with a desktop 3D scanner	Desktop 3D scanner (Imetric 3D, Courgenay, Switzerland), SMOP (Swissmeda, Zurich, Switzerland)	ΔD, LD	No	Calibrated (k=0.93) and blinded
			Two-piece implants		12, NR, NR					
(Schneider et al., 2011)	Prospective case series	Switzerland, University, NR	Implant placement with hard and soft tissue augmentation	6, 7, 19	16, 47.5, 16,	Alginate impressions. Stone casts scanned with a desktop 3D scanner	3D camera (Cerec 3D, Sirona Dental Systems GmbH, Bensheim, Germany), Cerec 3 (Sirona Dental Systems GmbH, Bensheim, Germany) and Match3D (University of Munich, Munich, Germany)	ΔD	No	NR
(Thoma et al., 2020)	RCT	Switzerland, University, Sponsored	Peri-implant soft tissue augmentation with CTG	36	9, 43.4, 9	Alginate with an A-silicone impression material. Casts scanned with a desktop 3D scanner	Desktop 3D scanner (Imetric 3D, Courgenay, Switzerland), SMOP (Swissmeda, Zurich, Switzerland)	ΔD	Yes	Blinded
			Peri-implant soft tissue augmentation with XCM	36	8, 44.1, 8					
(Tian et al., 2019)	Prospective case	China, Universit	IIP + IP	12	27, 34.6,	Intraoral digital	Intraoral scanner (3Shape Trios, 3Shape, Denmark),	ΔD	No	NR

Study	Design	Setting	Intervention	Follow-up	N	Impression	Device/Software	Outcomes		Calibration
	series	y, self-supported			27	impression	Geomagic Control (3D systems, Rock Hill, SC, USA)			
(van Nimwegen et al., 2018)	RCT	The Netherlands, University, Sponsored	IIP + IP + CTG	12	25, 45.4, 25	Alginate impressions. Dental stone casts scanned with a laboratory optical scanner	Laboratory optical scanner (IScan D301i, Imetric, Cougenay, Switzerland), SMOP (Swissmeda, Zurich, Switzerland)	Vol, ΔD	No	Calibrated (k=0.821)
			IIP + IP		25, 47.8, 25					
(Wang et al., 2019)	RCT	USA, University, Sponsored	IIP + IP	12	18, NR, 18	Digital models obtained by scanning the stone models (impression material NR) using a laboratory optical scanner	Laboratory optical scanner (Activity 101 Dental 3D Scanner, Smart Optics, Germany), Geomagic Control (3D systems, Rock Hill, SC, USA)	Vol, LD	No	Calibrated (k>0.8) and blinded
			IIP without IP		20, NR, 20					
(Wei et al., 2019)	Prospective case series	China, University, self-supported	IIP + IP	12	29, 34.3, 29	Intraoral digital impression	Intraoral scanner (3Shape Trios, 3Shape, Denmark), Geomagic control (3D systems, Rock Hill, SC, USA)	ΔD, LD	No	NR

(Wittneben et al., 2016)	Prospective case series	Switzerland, University, sponsored	Peri-implant soft tissue conditioning with provisional restorations	NR	20, 42.9, 20	Polyether impressions. Casts were scanned with optical scans	iTero System (Align Technology), Final Surface version 4.010 (GFal)	Vol	No	NR
(Zeltner et al., 2017)	RCT	Switzerland, University, sponsored	Peri-implant soft tissue augmentation with CTG Peri-implant soft tissue augmentation with XCM	3	10, 42.7, 10 10, 43.8, 10	Alginate with an A-silicone impression material. Casts scanned with a desktop 3D scanner	Desktop 3D scanner (Imetric 3D, Courgenay, Switzerland), SMOP (Swissmeda, Zurich, Switzerland))	ΔD	No	Blinded

Legend. ARP: alveolar ridge preservation. CTG: connective tissue graft. FGG: free gingival graft. GBR: guided bone regeneration. HY: hyaluronan. IIP: immediate implant placement. IP: immediate provisionalization. LD: linear dimensional changes. NR: not reported. PADM: porcine-derived acellular dermal matrix. PS: platform switching. RCT: randomized clinical trial. SCTA: peri-implant soft tissue contour area. tCTG: connective tissue graft from the maxillary tuberosity. Vol: volumetric change in mm³. XCM: xenogeneic collagen matrix. ΔD: mean distance between the surfaces/mean thickness of the reconstructed volume. 3D: Three-dimensional.

Figure 1. Digital workflow of optical scanner-based technologies for generating Standard Tessellation Language (STL) files and for analyzing volumetric changes

Impressions

Traditional Impressions   Study Cast   Laboratory Optical Scanner
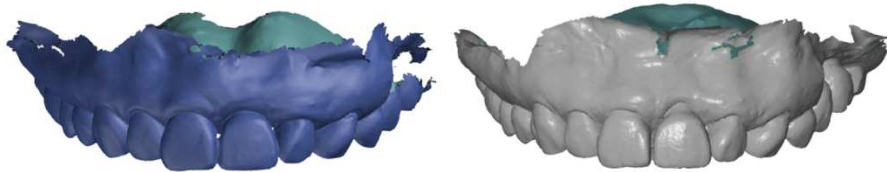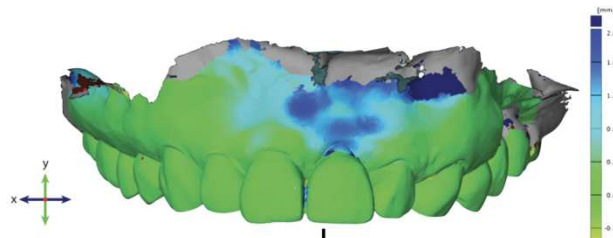
or

Digital Intraoral Impressions
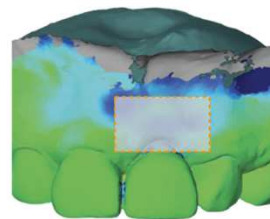
STL Files Importing in Specific Softwares

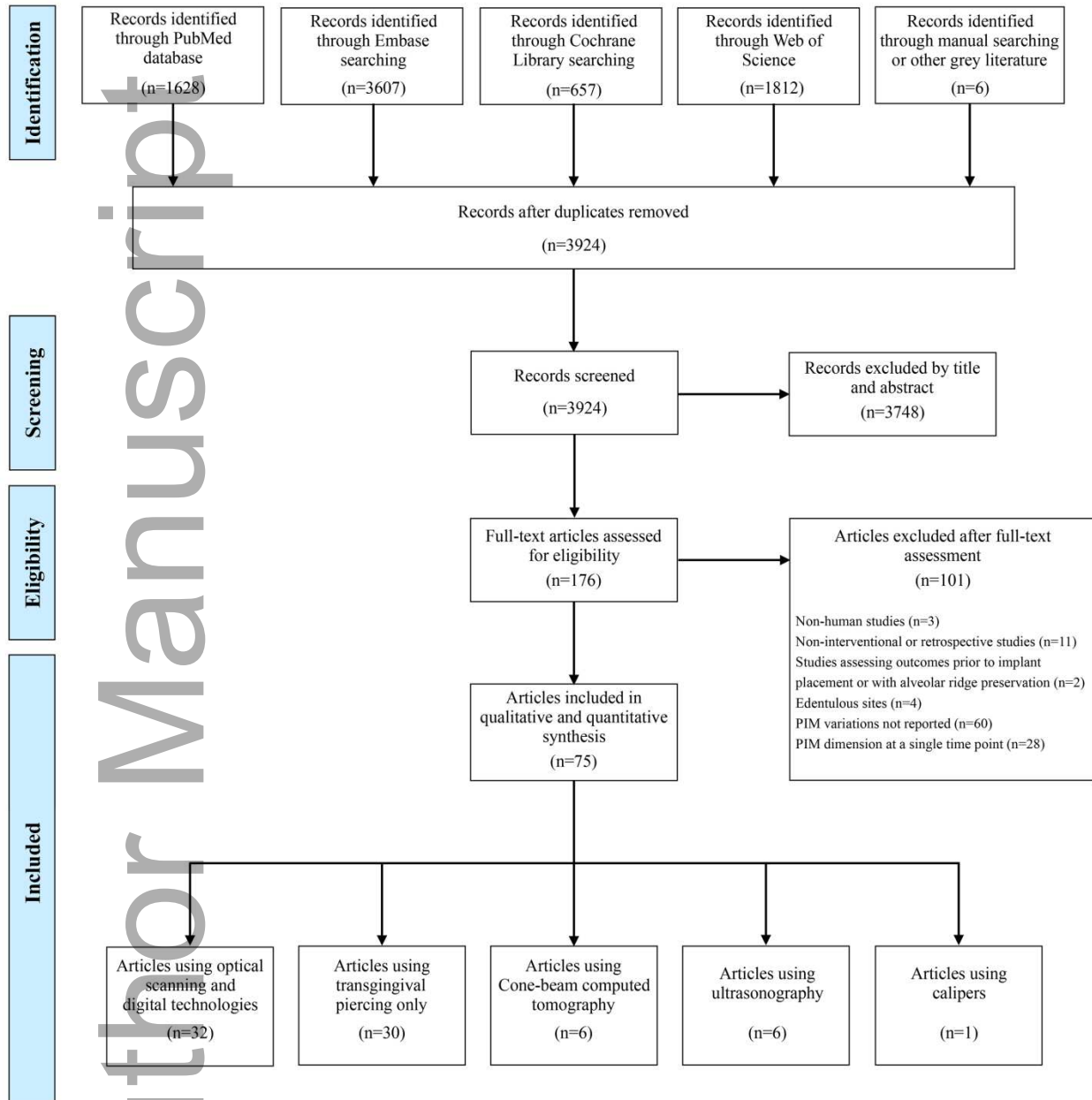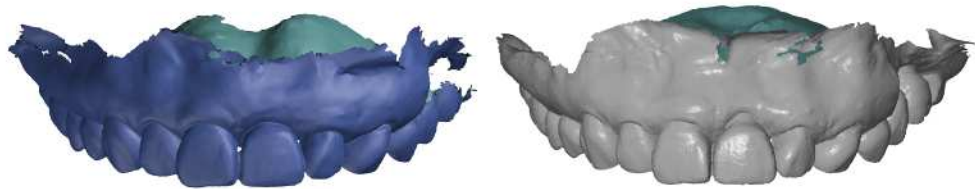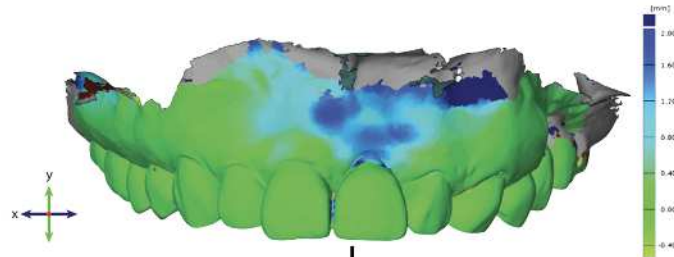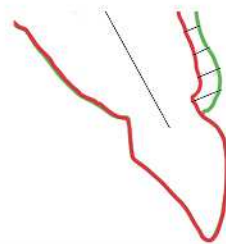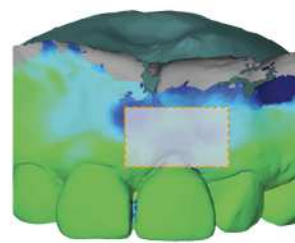STL Files Alignment and Superimposition

Volumetric Analysis

Linear Changes   Mean distance between the surfaces   Volumetric Changes

Figure 2. PRISMA flowchart.

Impressions

Traditional Impressions   Study Cast   Laboratory Optical Scanner

or

Digital Intraoral Impressions

STL Files Importing in Specific Softwares

STL Files Alignment and Superimposition

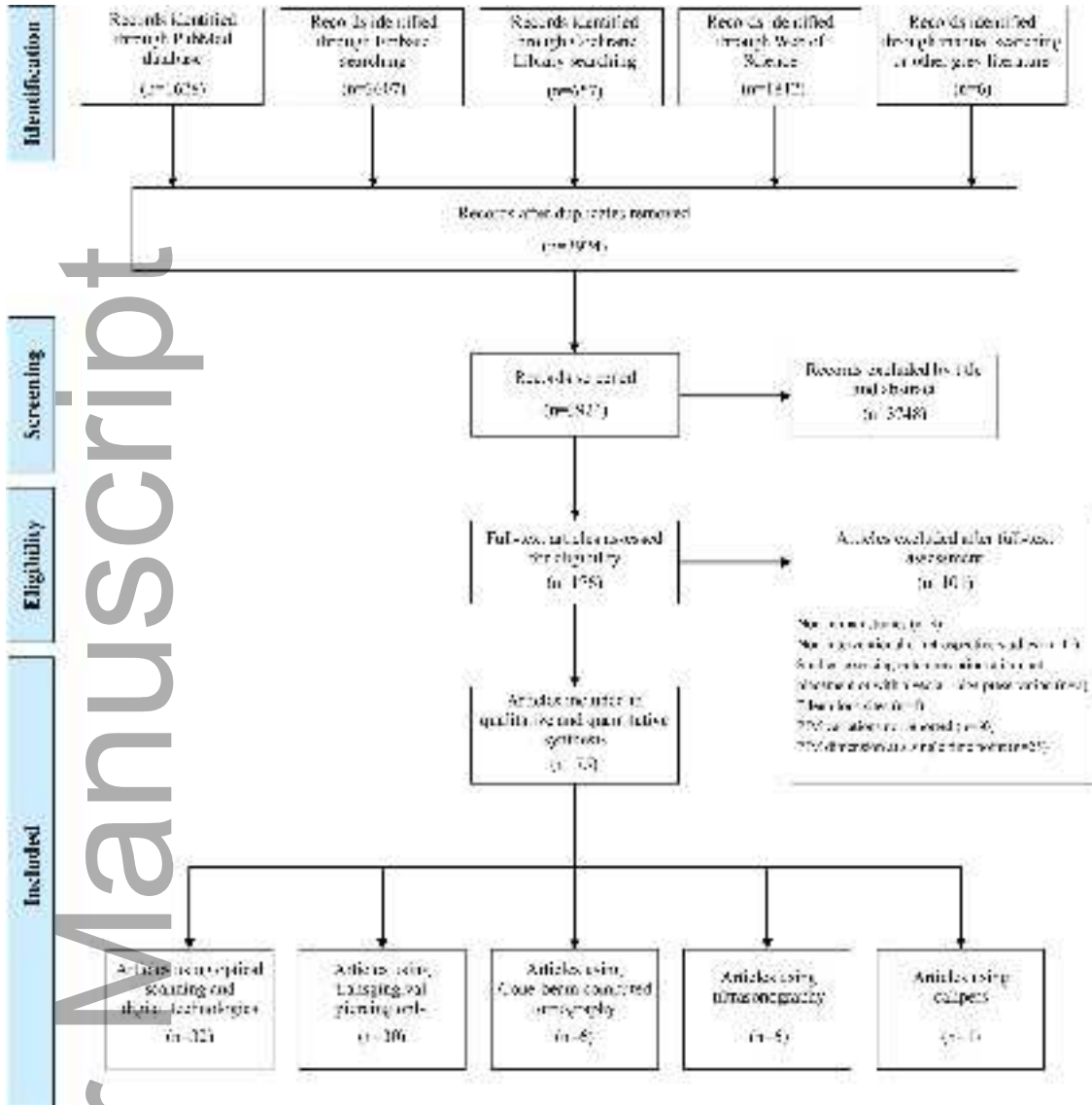Volumetric Analysis

Linear Changes   Mean distance between the surfaces   Volumetric Changes

jcpe_13401_f1.tif

jcpe_13401_f2.tif