# ODOVTOS
International Journal of Dental Sciences

UNIVERSIDAD DE COSTA RICA

FOd Facultad de **Odontología**

https://revistas.ucr.ac.cr/index.php/Odontos

LITERATURE REVIEW:

# Intraoral and Extraoral Scanning Technologies in the Digital Workflow Era: An Integrative Review with Artificial Intelligence

Tecnologías de escaneo intraoral y extraoral en la era del flujo de trabajo digital: una revisión integral con inteligencia artificial

Juliana Lujan Brunetto[1] https://orcid.org/0000-0001-9518-695X
Manuel Martin Adriazola Ique[1] https://orcid.org/0009-0007-0792-5830
Clovis Lamartine de Moraes Melo Neto[2] https://orcid.org/0000-0003-1477-2055
Victor Perinazzo Sachi[3] https://orcid.org/0000-0002-9044-737X
Daniela Micheline dos Santos[4] https://orcid.org/0000-0001-6297-6154
Marcelo Coelho Goiato[5] https://orcid.org/0000-0002-3800-3050

[1]DDS, MSc, PhD student at the Department of Dental Materials and Prosthodontics, Araçatuba Dental School, São Paulo State University, Araçatuba, São Paulo, Brazil.
[2]Profesor at the Department of Dental Materials and Prosthodontics, Araçatuba Dental School, São Paulo State University, Araçatuba, São Paulo, Brazil.
[3]DDS, MSc student at the Department of Dental Materials and Prosthodontics, Araçatuba Dental School, São Paulo State University, Araçatuba, São Paulo, Brazil.
[4]Profesor at the Department of Dental Materials and Prosthodontics, Araçatuba Dental School, São Paulo State University, Araçatuba, São Paulo, Brazil.
[5]Associate Profesor at the Department of Dental Materials and Prosthodontics, Araçatuba Dental School, São Paulo State University, Araçatuba, São Paulo, Brazil.

Correspondence to:  Dr. Marcelo Coelho Goiato - m.goiato@unesp.br

ABSTRACT:  The aim of this integrative review is to investigate the possibility of aligning three-dimensional intraoral scanner data with facial mobile device data, as well as comparing the effectiveness of AI-based search with manual search methods. This investigation adhered to the PRISMA guidelines aiming to answer the PICO question: "Does the facial and intraoral three-dimensional technologies are compatible and clinically applicable in oral rehabilitation?". Was employed a search strategy incorporating specific keywords ("dental", "intraoral", "photogrammetry", "stereo photo", "scanner", "three-dimensional", "stereophotogrammetry", "scan", "virtual articulators", "facebow", "face", "facial") within multiple databases (Pubmed, BVS, and Scielo), including artificial intelligence (Scite.ai). Of the 7128 initially

identified articles, 4 articles of manual search were included but none article of the artificial intelligence website were added. Among the most used: at the intraoral scanners were the TRIOS (3shape) (n=2) and for facial images the Apple Inc. cell phones (n=2). The most frequently reported software was Bellus3D (Bellus3D Inc.) with particular emphasis on the georeferencing tactic software. Several commonalities were observed, including the requirement for a 30cm spacing during cell phone-based extraoral scanning, the necessity for multiple captures, and the inclusion of landmarks and/or perioral and nasal scans. Manual searching is still the gold standard scientific searching data; Both stereophotogrammetry and mobile device scan can be used for facial scanning and the files can be integrated by utilizing georeferencing tactic software.

KEYWORDS: Three-dimensional imaging; Artificial intelligence; Dental articulator; Temporomandibular joint; Photogrammetry.

RESUMEN: El objetivo de esta revisión fue investigar la posibilidad de alinear los datos de un escáner intraoral tridimensional con los datos de dispositivos móviles faciales, así como comparar la efectividad de la búsqueda basada en Inteligencia Artificial con los métodos de búsqueda manual. Esta investigación se adhirió a las directrices PRISMA con el objetivo de responder a la pregunta PICO: "¿Las tecnologías tridimensionales faciales e intraorales son compatibles y clínicamente aplicables en la rehabilitación oral?". Se empleó una estrategia de búsqueda incorporando palabras clave específicas ("dental", "intraoral", "fotogrametría", "escáner", "tridimensional", "estereofotogrametría", "scan", "articuladores virtuales", " facebow", "rostro", "facial") dentro de múltiples bases de datos (Pubmed, BVS y Scielo), incluída la inteligencia artificial (Scite.ai). De los 7128 artículos identificados inicialmente, se incluyeron 4 artículos de búsqueda manual pero no se agregó ningún artículo del sitio web de inteligencia artificial. Entre los más utilizados: en los escáneres intraorales se encontraban los TRIOS (3shape) (n=2) y para imágenes faciales los teléfonos móviles de Apple Inc. (n=2). El software reportado con mayor frecuencia fue Bellus3D (Bellus3D Inc.), con especial énfasis en el software de georreferenciación. Se observaron varios puntos en común, incluido el requisito de un espacio de 30cm durante el escaneo extraoral con teléfono celular, la necesidad de capturas múltiples y la inclusión de puntos de referencia y/o escaneos periorales y nasales. La búsqueda manual sigue siendo el estándar de oro para la búsqueda de datos científicos. Tanto la estereofotogrametría como el escaneo de dispositivos móviles se pueden utilizar para el escaneo facial y los archivos se pueden integrar mediante el uso de software táctico de georreferenciación.

PALABRAS CLAVE: Imagen tridimensional; Inteligencia artificial; Articulador dental; Articulación temporomandibular; Fotogrametría.

## INTRODUCTION

In a new era of precision, efficiency, and patient-centric care, the progression of the use of scanners has been linked to the growth of CAD/CAM systems and their completely digitalized workflow reality, revolutionizing the diagnostic and treatment planning phases of oral rehabilitation (1).

The transition to a fully digital workflow in dentistry naturally sparked interest in publications related to the development of a virtual articulator aiming their digital high-precision, manufacturing speeding up process and making it more accurate (2).

The mechanical articulators are insufficient to simulate the distortion and deformation of the mandible during loading conditions. They follow the average boundary measurements of the mechanical joint, which never represent the effects of the resilience of the soft tissue (3, 4).

There are numerous types of digital facebow software, and regardless of their type, they are extremely important in both diagnosis and complex treatment planning. It has been reported that the accuracy of virtual patients registered by different methods varies, possibly as a result of errors in registration and digitization (2, 5).

Recently, interest in the use of three-dimensional (3D) depth-sensing smartphone cameras has been spreading for facial scanning. These devices have become popular due to their affordable cost as well as their easy transportation and handle, reducing technical learning time. Another growing 3D system is short-range photogrammetry, but there has been limited existing studies about the integration of extraoral with intraoral data (5).

The gold standard of this individualized combination data is the cone beam computed tomography (CBCT) and intraoral scanning (6). Still, its use, involving unnecessary ionizing radiation and the need to transport patients to a radiology center, makes this standard unfeasible for all dental no-surgical rehabilitation (6).

However, despite the many advantages, there are still obstacles and shortcomings to be resolved. Some systems require a layer of powder on the tooth to recognize the surface during scanning process, which can affect accuracy and most professional stereophotogrammetry scanners are complex and require a long learning curve to optimally execute the scanning protocols (1).

While the accuracy of these systems is still being assessed, additional analysis and comparisons remain essential. When conducting data pursuit, a more expansive search increases the likelihood of discovering articles relevant to the chosen topic, being extremely relevant the artificial intelligence (AI) application (7).

So, this integrative review aims to explore the potential for integrating three-dimensional intraoral scanner data and aligning it with facial mobile device data, as well as comparing the effectiveness of AI-based search with manual search methods.

## MATERIAL AND METHODS

This study was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (8) and presents the hypothesis that:

- The three-dimensional intraoral scanner data may align with extraoral mobile device data;
- And that the AI-based search will discover a greater number of relevant articles on the topic compared to manual search.

### SEARCH STRATEGY AND DATABASE STANDARDIZATION PROTOCOL

The search has been conducted up to 2023 December 19th and the articles were analyzed by a reviewer (J.L.B.) aiming to answered the PICO question: "Does the facial and intraoral three-dimensional technologies are compatible and clinically applicable in oral rehabilitation?".

The manual search strategy in three electronic databases (PubMed, BVS, and Scielo) used a combination of the keywords with Boolean operators (AND/OR): "dental", "intraoral", "photogrammetry", "stereo photo", "scanner", "three-dimensional", "stereophotogrammetry", "scan", "virtual articulators", "facebow", "face", "facial"

For the AI-based search, one site was elected (Scite.ai) and the voice command "Name the articles that correlate..." was added before the same manual strategy keywords.

### INCLUSION AND EXCLUSION CRITERIA

The literature search included articles in all languages in the field of dentistry, published in peer-reviewed journals, and the reference lists of the selected articles were screened.

The inclusion criteria applied in the search strategy for choosing the studies were: 1. *in vivo* studies; 2. adults without facial deformities or syndrome; 3. that performed intraoral scanning; 4. that performed extraoral scanning with a mobile device and with stereophotogrammeter or Cone Beam computed tomography or scanner and 5. that were published until December 19, 2023. And were not included: 1. studies that did not cover the topic in question; 2. duplicate studies; 3. literature reviews or conference abstracts; and 4. exclusively using only one of the scan techniques.

### DATA COLLECTION AND EXTRACTION PROCESS

The selection of articles was carried out by the same reviewer with blind and independent analysis, following the steps: 1. reading the title and abstract; 2. complete reading; 3. data collect. And then organized in a spreadsheet using Microsoft Excel® Professional Plus version 2016 (Microsoft Corporation, USA), standardized for later qualitative comparison between the studies.

### RESULTS

The initial search retrieved 3648 records from various databases, supplemented by an additional 3480 records sourced from artificial intelligence, resulting in a total of 7128 studies. None of the 114 articles identified through artificial intelligence (www.scite.ai) were included due to failure to meet inclusion criteria or duplication.

After the selection of titles and removal of duplicates, the articles underwent full-text review. Manual inclusion within selected articles led to the final inclusion of 4 publications (Figure 1).

The qualitative data in Table 1 provides a comprehensive and detailed overview of the technologies, procedures, and equipment utili-

zed in dental and facial 3D scanning applications (9-12). All studies feature small sample sizes and successful alignment of intraoral and extraoral STL and OBJ file formats. This integration was facilitated by various software platforms, with particular emphasis on the georeferencing tactic employed by Geomagic X (3D Systems).

Despite variations in brands and products, all articles underscore the necessity of georeferencing tactics, even in the absence of added landmarks and occlusal devices. Notably, Jreige (2022) (11) stands out as the only author to produce a video without incorporating landmarks and/or occlusal devices, resulting in an animated projection of the rehabilitation process.

Among intraoral scanners, the most frequently cited device was the TRIOS (3Shape) (n=2) (10, 11), followed by the CS3600 (Cares-tream)9 and the Medit i50012. In the realm of extraoral scanning via mobile devices, the iPhone (Apple Inc.) (10, 11) and the Bellus3D (9, 12) App were prominently mentioned. Among other 3D extraoral analyzers, Li (2023) (11) was the only researcher to compare a Cone Beam Computed Tomography (CBCT) file with a cellphone scan, while others utilized industrial scanners (9) and stereophotogrammetry (10, 12).

Several commonalities were observed, including the requirement for a 30cm spacing during cell phone-based extraoral scanning, the necessity for multiple captures, and the inclusion of landmarks and/or perioral and nasal scans when employing intraoral scanners (9-12). In contrast to other studies, which scanned at maximal intercuspal position, Li *et al.* (2023) (11) designed a customized Gothic arch, reporting the centric relation and vertical dimension of occlusion.
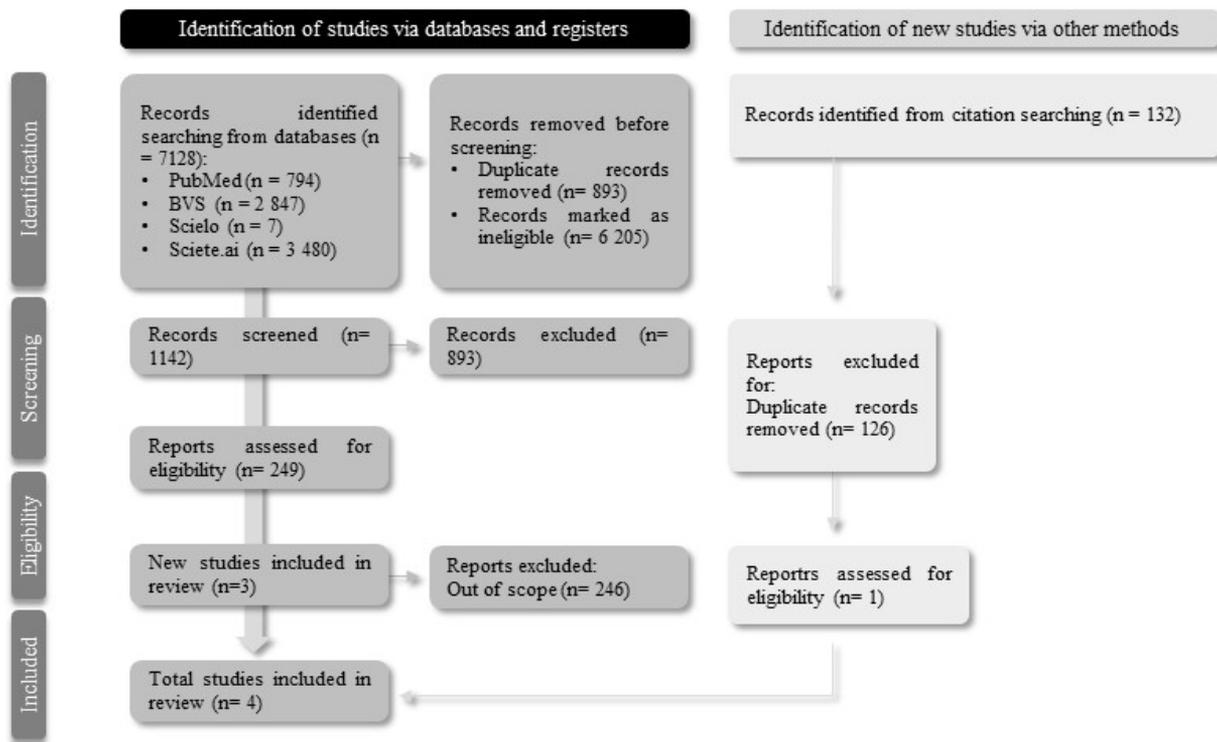


**Figure 1**. Flowchart showing the selection process for the studies analyzed.

**Table 1**. Qualitative data collected from the articles.

| Author (Year) | N | Intraoral | Extraoral | LandMark | Occlusal Device | Occlusal Position | Analysis software ANALYSIS SOFTWARE | Steps | Files format | Alignment |
|---|---|---|---|---|---|---|---|---|---|---|
| Mai and Lee (2021) | 1 | SCAN (CS3600, Carestream) | SPG (Canon EOS 100D com lente Canon EF 50 mm f1.8 STM, Canon Corp.) with MetraSCANR (Creaform) + C (Iphone X, Apple store) with Bellus3D (version 1.8.6, Bellus3D) | Periorai scans with intraoral scanner + 3 Anatomic Landmarks (Proximal contact area between teeth 11 and 21 + the cusp tip of teeth 13 and 23) | NR | Maximal intercuspal position | Facial: Di3D capture (version 6,8.17.4490, Dimensional Imaging, UK) + Bellus3D (version 1.8.6, Bellus3D Inc) + industrial laser scanner (MetraSCANR, Creaform) and Image integration: Geomagic Design X (3D systems) | 6 | Export the extraoral SPG in OBJ file format and the intraoral SCAN in STL file format | Successful |
| Li et al. (2023) | 1 | SCAN (TRIOS 3, 3Shape A/S) | CBCT + C (iPhone 11 Pro, Apple Inc) with Hege 3D scanner | Digital Frankfort and middle plane + Prion and hinge axis shaft | 3D customized gothic printed arch (SprintRay Pro 95, SprintRay) + surgical guide (SprintRay Surgical guide 2, SprintRay) | Centric relation and vertical dimension of occlusion | Intraoral design: Exocad (exocad GmbH) + Gothic arch tracer: Blender (version 2.83, The Blender Foundation) + Extraoral scan: Hege 3D scanner (Apple App Store) + planning sofware BlueSkyPlan (version 4.70, Blue Sky Bio LLC) + 3D Facebow: Blender (version 2.83) | 10 | Export the intraoral scans into STL files + CBCT DICOM files + export the PLY extraoral scan files + from the BlueSkyPlan were exported a bone model as STL file | Successful |
| Jreige et al. (2022) | 1 | SCAN (TRIOS 3 color, 3Shape A/S) | C (iPhone, Apple Inc) video + SPG (cIOner, Done 3D) | Facial landmarks | NR | Maximal intercuspal position | Software program for georeferencing tactic (3DF Zephyr, 3DFLOW) to transform 2D to 3D files + DSD app for iPad (Apple Corp) + an animation software (Maya, Autodesk) | 9 | Export the SPG images using the JPG format + Export the 3DF Zephyr file in OBJ format + Export the intraoral scanner and the DSD files in STL format | Successful |
| Hong and Noh (2021) | 1 | SCAN (Medit i500, Medit) | C (Galaxy Note 10 Plus; Samsung Electronics Co) + SPG (Bellus3D Face Camera Pro, Bellus3D Inc) + desktop SCAN (Rainbow Scanner Prime, Dentium) for the device | Facial: Round stickers at Beyron points (13mm anterior to tragus and the inferior outer canthus of the eye)+ Software: Lines connecting the Frankfort horizontal plane with Beyron ponits os the 2 facial scan images + midsagittal plane line | 3D printer (ZENITH D, Dentis) | Maximal intercuspal position and protrusive interocclusal record | Geomagic Control X, 3D Systems | 10 | Does not mention file export and import formats | Successful |

CBCT: Cone Beam Computed Tomography; NR: Not Reported; SPG: Stereophotogrammeter; SCAN: Scanning; C: Cellular; DSD: Digital Smile Design.

## DISCUSSION

The hypothesis of this study has been validated as the research shows that it is posible to align images obtained at different times using various software and equipment, given that equivalent file formats are employed.

The integration of diverse technologies is crucial for technological advancements from traditional oral rehabilitation to fully digital solutions. Being compatible the intraoral and facial digital files for effective implementation in Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) (13). In connection to these technologies, the potential of artificial intelligence (AI) has been increasingly evident in expediting and efficiently replicating intermaxillary relationships, predict decimation through intraoral scanning, and to other functions such as workflow enhancement and image retrieval and linking (7).

Nevertheless, despite significant progress, a systematic review (7) indicates that AI's application in rehabilitation remains limited (1.61%), highlighting the need for further refinement and human assistance in AI-driven data extraction.

Even though the CBCT is currently considered the gold standard imaging method (14), Bechtold et al. (15) shows close accuracy values between CBCT and SPG. While most facial SPG have an accuracy within 500μm, the CBCT have shown variances ranging from 106 to 760μm due to the influence of exposure parameters.

This discrepancy prompted an analysis of interoperative and intraoperative measurements. Gallardo et al. (2023) (16) studied twelve patients with SPG system (LifeViz™) to capture facial images, which were then analyzed using Derma-Pix™ software. Operators recorded distances between reference points, and the measurements were repeated after one week to assess reliability. The data from this study indicated that there were no significant differences in interoperative and intraoperative measurements when using the aforementioned equipment.

Additionally, Mai et al. (2021) (9) demonstrated the significance of landmarks for aligning intraoral scans with cell phone and SPG, supported by the findings of Ritchl et al. (17), putting emphasis to the need for parameter lines to facilitate precise alignment.

Ritschl et al. (17) conducted a geometric comparison between spherical and cross geometries devices, concluding that spherical geometries achieved more precise intraoral and extraoral alignments and were easier to superimpose. In the discussions of the cited articles (9-12), the cell phones exhibited clinically acceptable accuracy but was lacking in capturing finer details, corroborating with the findings of Andrews et al. (18).

It's crucial to highlight the variability in the number of steps taken by different authors (9-12) in their methodologies, potentially leading to variations in the total working time for each technique and equipment, despite following a similar flow. Notably, while these steps do not directly impact the final results, the incorporation of required landmarks is crucial for accurate outcomes.

This integrative review offers valuable insights into diverse clinical approaches for procedures utilizing intraoral and facial scans, paving the way for potential integration of these imaging examinations into daily oral rehabilitation practice, including the use of virtual patients and articulators. However, it's important to note that further clinical studies are necessary to validate the clinical accuracy of this information.

## CONCLUSION

From the data reported, we can conclude that:

- Manual searching is still the gold standard for scientific searching data;
- Both stereophotogrammetry and mobile device scan can be used for facial scanning, but this capability does not extend to intraoral image;
- Facial (SPG and mobile device) and intraoral scan files can be integrated by utilizing georeferencing tactic software.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## SOURCE OF FUNDING

## AUTHOR CONTRIBUTION STATEMENT

Conceptualisation, methodology, software and validation: J.L.B.
Formal analysis, investigation, data curation, Writing-original draft: J.L.B., M.M.A.I. and C.L.M.M.N.
Writing-review and editing: J.L.B., M.M.A.I., V.P.S., M.C.G. and D.M.d.S.
Visualisation: C.L.M.M.N and V.P.S.
Supervision and project administration: M.C.G.

## REFERENCES

1. Khurshid Z. Digital Dentistry: Transformation of Oral Health and Dental Education with Technology. Eur J Dent 2023; 17: 943-4
2. Perez-Giugovaz M.G., Park S.H., Revilla-Leon M. Three-dimensional virtual representation by superimposing facial and intraoral digital scans with an additively manufactured intraoral scan body. J Prosthet Dent 2020; 126: 459
3. Kordaß B., Gärtner C., Söhnel A., Bisler A., Voß G., Bockholt U., Seipel S., et al. The virtual articulator in dentistry: concept and development. Dent Clin 2002; 46 (3): 493-506
4. de Caxias F.P., Dos Santos D.M., Bannwart L.C., de Moraes Melo Neto C.L., Goiato M.C. Classification, history, and future prospects of maxillofacial prosthesis. Int J Dent 2019; 1: 8657619
5. Ye H., Ye J., Wang S., Wang Z., Geng J., Wang Y., Zhou Y. Comparison of the accuracy (trueness and precision) of virtual dentofacial patients digitized by three different methods based on 3D facial and dental images. J Prosthet Dent 2022; 3913 (22): 99-3. https://doi.org/10.1016/j.prosdent.2022.01.035
6. Mangano F., Mangano C., Margiani B., Admakin O. Combining Intraoral and Face Scans for the Design and Fabrication of Computer-Assisted Design/Computer-Assisted Manufacturing (CAD/CAM) Polyether-Ether-Ketone (PEEK) Implant-Supported Bars for Maxillary Overdentures. Scanning 2019; 2019: 1-14. https://doi.org/10.1155/2019/4274715
7. Alshadidi A.A.F., Alshahrani A.A., Aldosari L.I.N., Chaturvedi S., Saini R.S., Hassan S.A.B., et al. Investigation on the application of artificial intelligence in prosthodontics. Appl Sci 2023; 13 (8): 5004
8. Page M.J., McKenzie J.E., Bossuyt P.M., Boutron I., Hoffmann T.C., Mulrow C.D., et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. J Clin Epidemiol 2021; 134: 178-89
9. Mai H., Lee D.H. The Effect of Perioral Scan and Artificial Skin Markers on the Accuracy of Virtual Dentofacial Integration: Stereophotogrammetry Versus Smartphone Three-Dimensional Face-Scanning. Int J Environ

Res Public Health 2021; 18 (1):229. https://doi.org/10.3390/ijerph18010229

10. Li J., Att W., Chen Z., Lepidi L., Wang H.L., Joda T. Prosthetic articulator-based implant rehabilitation virtual patient: A technique bridging implant surgery and reconstructive dentistry. J Prosthet Dent 2023; 130 (1): 8-13

11. Jreige C.S., Kimura R.N., Segundo Â.R.T.C., Coachman C., Sesma N. Esthetic treatment planning with digital animation of the smile dynamics: A technique to create a 4-dimensional virtual patient. J Prosthet Dent 2022; 128 (2): 130-8

12. Hong S.J., Noh K. Setting the sagittal condylar inclination on a virtual articulator by using a facial and intraoral scan of the protrusive interocclusal position: A dental technique. J Prosthet Dent 2021; 125 (3): 392-5.

13. Sun A., Yang Y., Gao H., Lin W.S., Chen L., Tan J. Integrating facial and intraoral scans for digital esthetic and occlusal design: a technical report. J Prosthet Dent 2021; 30 (8): 729-33.

14. Conejo J., Dayo A.F., Syed A.Z., Mupparapu M. The digital clone: intraoral scanning, face scans and cone beam computed tomogra-phy integration for diagnosis and treatment planning. Dental Clinics 2021; 65 (3): 529-53. https://doi.org/10.1016/j.cden.2021.02.011

15. Bechtold T.E., Goz T.G., Schaupp E., Koss B., Godt A., Reinert S., Berneburg M. Integration of a maxillary model into facial surface stereophotogrammetry. J Orofac Orthop 2012; 73 (2): 126-37.

16. Gallardo Y.N., Salazar-Gamarra R., Bohner L., De Oliveira J.I., Dib L.L., Sesma N. Evaluation of the 3D error of 2 face-scanning systems: An in vitro analysis. J Prosthet Dent 2023; 129 (4): 630-636

17. Ritschl L.M., Wolff K.D., Erben P., Grill F.D. Simultaneous, radiation-free registration of the dentoalveolar position and the face by combining 3D photography with a portable scanner and impression-taking. Head Face Med 2019; 15 (1): 1-9

18. Andrews J., Alwafi A., Bichu Y.M., Pliska B.T., Mostafa N., Zou B. Validation of three-dimensional facial imaging captured with smartphone-based photogrammetry application in comparison to stereophotogrammetry system. Heliyon 2023; 9 (5). https://doi.org/10.1016/j.heliyon.2023.e15834