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Evaluation of maximum biting force and chewing efficiency in patients with digital complete dentures constructed using two different workflows: A cross-over randomized controlled trial

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Aim: This crossover study was done to evaluate the maximum biting force and chewing efficiency of digital complete dentures constructed using two different workflows: a combination of intra-oral and facial scanning and an indirect technique. Also, the study compared the two measured parameters of both digital workflows against those of conventional complete dentures.
Materials and methods: Twelve completely edentulous patients received three complete dentures: a conventional complete denture (CD1), a digital complete denture constructed using the indirect workflow (CD2), and a digital complete denture constructed using the combined intra-oral and face scan workflow (CD3). The design of the study was a crossover, with patients wearing dentures in a random order. Biting force and chewing efficiency results were evaluated after three months of using each denture type.
Results: There were statistically significant differences in maximum biting force and chewing efficiency between CD1 and each of CD2 and CD3. However, the differences between CD2 and CD3 were statistically insignificant regarding both parameters studied.
Conclusion: Within the limitations of this study, digital complete dentures demonstrated higher maximum biting force and chewing efficiency than conventional complete dentures. Furthermore, the differences between the indirect digital workflow and intra-oral scanning combined with the face scanning workflow were statistically insignificant in both parameters.

Keywords: digital complete denture, face scanning, intra-oral scanning, maximum biting force, chewing efficiency.

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Introduction

Digital technology is revolutionizing prosthodontic rehabilitation, including complete denture construction. Conventional techniques for fabricating complete dentures are time-consuming and prone to errors. The integration of CAD/CAM techniques has simplified and accelerated the denture fabrication process, with the possibility of improving the prostheses characteristics. Digital complete dentures offer a promising alternative to conventional dentures with improved accuracy, efficiency, and patient satisfaction.[1-3]

The edentulous ridge clinical data in digital complete dentures is collected in the form of conventional or digital recordings that are submitted to different CAD/CAM software, which designs, prints, or mills the digital denture. Studies have recommended intraoral scanning for producing a digital complete denture; however, edentulous jaw digitization is a challenging procedure due to soft tissue dynamics issues. Using tissue retractors during intra-oral scanning can improve edentulous ridge digitization and digital denture retention. Intra-oral scanning is recommended for cases where traditional impressions are difficult, such as microstomia or lip tightness; however, more clinical studies are needed before replacing conventional impressions.[4-6]

Clinical studies show that edentulous ridges can be fully digitalized, and intra-oral scanners can be used for digital complete denture manufacturing. This method enhances patient comfort, decreases gag reflexes and chairside time, reduces laboratory procedures, and prevents allergic reactions to impression materials. A proof of concept for the creation of a digital complete denture using intra-oral scanning has been shown, and it has been claimed that these scans are accurate enough for digital denture construction. [7-9]

Digital face scanning is a fast-growing technology used in various fields like industrial design, dentistry, and biomedical engineering. It is applied in dentistry to design and produce virtually complete dentures. Such a procedure provides a 3D simulation of tooth arrangement as opposed to the traditional way in which teeth are clinically evaluated. It minimizes treatment planning errors and enables a higher level of communication with the patient. By giving patient profile data, the face scanning approach creates a virtual patient record that is necessary for prosthesis construction. By combining the advancements in digital data processing with the collection of as much information as possible about the edentulous ridges, anatomical landmarks, and facial profile, a "virtual patient" may be constructed. Without common landmarks across all datasets, combining all the data remains a challenging task. Because there are teeth in a dentulous subject, data alignment is simpler; with an edentulous patient, however, an artificial object is required for alignment. [10,11]

Various manufacturer-dependent technologies and workflows have been created for digital denture design and fabrication. Certain treatment procedures utilize conventional clinical procedures that are then digitalized in an indirect workflow; other workflows use intra-oral scanning alone or combined with face scanning technology. When intra-oral and face scans are used in conjunction to generate a digital complete denture, edentulous patients may have improved denture precision, an improved look, and reduced chair time and treatment costs.[12-14]

Masticatory efficiency is a measure of the quality of mastication by analyzing the distribution of food particles after chewing cycles. Several parameters, including the type of prosthesis, the selected occlusal concept, and the maximal biting force, may impact masticatory efficiency. Natural or synthetic particles are tested. Digital assessment of masticatory efficiency by mixing ability test using two different colors of chewing gum was commonly employed.[15,16] Biting force refers to the force exerted by masticatory muscles on teeth's occlusal surfaces that is significantly affecting the masticatory system. Maximum biting force is measured by pressure-sensitive films, optical fiber, piezoelectric, and strain gauges.[17,18]

Reviewing the literature revealed different methods of merging intra-oral and facial scans have been published, with the aim of developing a CAD/CAM full denture manufacturing process that meets patient requirements. Few studies on the advantages of using facial scanning technology in dental applications have been published. Some of these studies have evaluated combining intra-oral and facial scans in digital denture construction and concluded that this technology is technically reliable. But further research is needed to concentrate on verifying the use of this approach and broadening its possible applications.[19-21]

The purpose of this study was to evaluate the maximum biting force and chewing efficiency of digital complete dentures constructed using two different workflows: a combination of intra-oral and facial scanning and an indirect technique. Also, the study compared the two measured parameters of both digital workflows against those of conventional complete dentures. The first null hypothesis stated that there would be no difference between digital full dentures made using indirect digital construction and those made utilizing intra-oral and facial scanning in terms of maximal biting force and chewing efficiency. The second null hypothesis stated that there would be no difference in maximum biting power and chewing efficiency between digital and conventional complete dentures.

Materials and methods

I- Patients' selection and study design:

This study involved twelve patients from the Removable Prosthodontic Department's outpatient clinic, with an average age of 61.92 ± 4.16 years (range: 57-68 years). The inclusion criteria for the patients' selection were complete edentulism and class I Angle maxillo-mandibular jaw relation. Exclusion criteria were temporomandibular joint dysfunction, systemic illness, hard or resistant tissues in the denture-bearing area, or inability to attend follow-ups.

The sample size was calculated based on a previous study[21] (0.85 effect size, α= 0.05, β = 0.95). The calculated sample size of 10 patients was increased to 12 to accommodate any dropouts. The sample size was calculated using power analysis (G. Power 3.1.5). The ethical committee approved the study procedures. The patients signed informed consent forms after explaining the treatment procedures and follow-up visits to them.

This study used a crossover design to standardize patients' parameters and control treatment outcomes. Participants received three complete dentures: a conventional complete denture (CD1), a digital complete denture constructed using the indirect workflow (CD2), and a digital complete denture constructed using the combined intra-oral and face scan workflow (CD3). They were randomly assigned to either denture set. Then they were instructed to use it for three months before switching to the other set. The order of denture insertion was randomized to limit its influence on measured outcomes. Six blocks of two patients were created randomly using a random generation tool in a Microsoft Excel spreadsheet. Three months after each type of denture was used, biting force, and chewing efficiency results were measured. At the end of the study, patients were asked to select one of the three dentures to continue using.

II-Prosthodontic procedures:
The patients' medical and dental histories, as well as the clinical examination, were completed. The prosthodontic procedures listed below were performed for all patients.

1- Conventional complete denture fabrication (CD1):

The conventional complete dentures (CD1) were constructed using a conventional technique, which involved making upper and lower primary impressions (Alginate, Cavex, Holland), molding the trays' borders with green stick compound (Perfectin, Buenesaires, Argentina), final impressions (3M ESPE St. Paul, USA), boxing the impressions, pouring them into master casts (Zeus Dental Stone, Italy), and registering jaw relations. Both casts were mounted on a semi-adjustable articulator (Hanau wide view, USA), with the upper cast mounted using a facebow record and the lower cast mounted using a centric jaw relation record. The sagittal condylar guidance of the articulator was adjusted using a protrusive record.

After setting the artificial teeth, the trial dentures were checked intraorally for extension, stability, retention, vertical and horizontal relations, esthetics, phonetics, and occlusion. The trial dentures were waxed up and processed using heat-cured resin (Acrostone, Egypt). Remounting and selective grinding were carried out until a balanced occlusion was attained.

2. Fabrication of digital complete denture constructed using the indirect workflow (CD2)

The construction process involved scanning the master cast and jaw relationship performed in CD1 using a desktop scanner (Medit, Seoul, Korea) followed by generating virtual models using CAD/CAM software (Exocad, GmbH., Darmstadt., Germany). Setting the virtual articulator was done using the scanned jaw relation and face bow record. The denture base extension was digitally developed for optimal coverage, and relief areas were determined. The digital design created was saved in Standard Tessellation Language (STL) format.

The following prosthodontic procedures involved: artificial tooth selection from the teeth library, virtual setting-up of teeth on denture bases (Fig. 1. A), balancing the occlusion using a digital articulator, exporting the STL file of the digital denture to a 3D printer (Elegoo ultra mono, 3D printer), and printing the trial denture (Next, Dent Try In). Trial dentures were checked intraorally for extension, stability, retention, phonetic aesthetics, jaw relationship, and occlusion, and corrections were made.

The final digital file was created by utilizing a reverse engineering tool (Meshmixer, USA) to subtract teeth from denture bases and create tooth sockets. This was followed by printing both denture bases and artificial teeth separately (Next Dent 3D Print). Bonding the teeth to the base was performed using adhesive (Visio Bredent, Germany), then washed with 95% alcohol and dried before being subjected for 15 minutes to UV radiation. The printed dentures were finished and polished, and the occlusion was fine-tuned.

3. Fabrication of digital complete denture using combined intra-oral and face scan workflow (CD3):

The study used an intra-oral scanner (TRIOS3, 3Shape, Denmark) to create digital impressions of edentulous ridges. The ridge areas were washed and dried before scanning, and a cheek retractor was used to support the tissues, preventing overextension. The scanning began with the upper arch at the tuberosity areas, followed by the posterior palatal seal area until the rugae region, buccal and labial vestibules, and finally the palatal area in a zigzag pattern. The lower edentulous

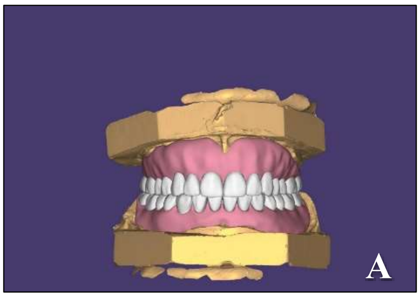

Fig. 1 A: Designing the digital complete denture in CD2 group using CAD software

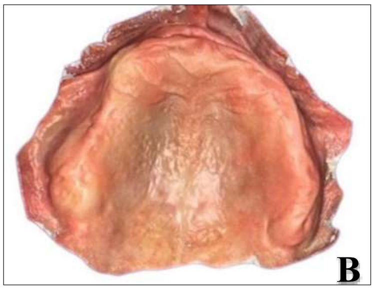

Fig. 1 B: Intra-oral scanning of maxillary edentulous ridge.

Fig. 1 C: Intra-oral scanning of mandibular edentulous ridge.

ridge was scanned starting at the retromolar pad areas bilaterally across the ridge, followed by the labial and buccal vestibules, and finally the lingual vestibule with tongue retraction. The scanned images were transferred to an STL file, after which virtual casts were created. (Fig. 1. B, C)

The jaw relation record bases were designed over the virtual casts and printed (Elegoo Mars 3 ultra 4k mono LCD 3D printer). Occlusion rims were added to the record bases, and functional impression was performed using tracing compound and rubber base impression material (Impregum Penta; 3M ESPE). The jaw relation-impression assembly was scanned and stored as STL file. Virtual models were aligned to the impression-jaw relation STL file using the designing software.

A 3D "virtual patient" replica was created using a three-dimensional face scan. The patient's face was scanned (Proface Face Scanner, Pro Max 3DMid, Planmeca, Helsinki, Finland) three times: at rest, while smiling, and while wearing a reference stent as an oral scan body fixed to record blocks. The three scans were aligned using software (Planmeca Romeis Viewer, Planmeca, Helsinki, Finland) using the forehead and the stent as references and then transferred to an STL file. (Fig. 2. A)

The following prosthodontic procedures were performed: Aligning the face scan STL file with the virtual model resulted from aligning the intra-oral scan with functional impression, virtual articulation to balance the occlusion, and designing dentures with maximum coverage and extension. Afterward, virtual tooth selection was done from the digital library, and teeth arrangement was aided with data obtained from intra-oral and face scans. (Fig. 2. B) The resulting file was sent to be printed into a trial denture (Next-Dent Try-in) for try-in assessment. (Fig. 3. A) The rest of the procedures were performed as done in CD2.

Each patient received three dentures (CD1, CD2, and CD3) according to the randomly selected sequence. Patients recalling performed three days, then one week after receiving dentures, to address any problems. Adjustments were performed to ensure comfortable denture wearing during follow-ups. Participants were told to use each denture for three months. Maximum biting force and chewing efficiency results were

Fig. 2 A: Face scanning

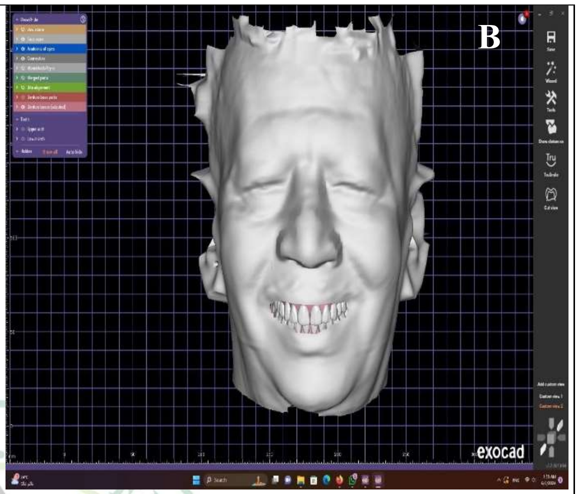

Fig.2. B: Designing the digital denture in CD3 group using face scans and CAD software

evaluated after three months of using each denture type.

III- Outcomes measurements:

1.Evaluation of maximum biting force:

The maximum biting force (Newton) was assessed using a load sensor (Load Star Sensor, Ravendal Drive, USA), which was positioned horizontally to guarantee vertical force application and prevent errors from rotational force vectors. The sensor was wrapped and positioned in the premolar-molar region on both sides of the patient, who was sitting upright. The patient was told to exert maximum vertical biting force, and readings were obtained on average ten times. (Fig 3 B)

2. Evaluation of chewing efficiency:

An assessment of chewing efficiency was performed using a color mixing ability test. Chewing gum in two distinct colors (trident spearmint and watermelon tastes) was used to produce the samples. Participants were given five samples (each 45 x 10 x 3 mm), chew it for different strokes (five (St1), ten (St2), twenty (St3), thirty (St4), and fifty (St5)), separated by thirty minutes of rest. The samples were then dried, placed between cellophane sheets, and pressed to a consistent one mm thickness. A digital camera (Nikon, Sony, Thailand) was used to photograph both sides of each sample under controlled lighting conditions. The image dimensions were set at 4800 x 7200 pixels with a 600-dpi resolution. The software (View Gum) was used to calculate the average number of pixels of blended color. High hue deviations showed insufficient color mixing, while low values specified proper mixing with superior chewing efficiency. (Fig 3 C)

IV- Statistical analysis:

The Shapiro-Wilk test revealed the normal distribution of the results. The ANOVA test was used to compare chewing efficiency and maximal biting force between groups. The Tukey multiple comparison test was used for multiple comparisons after revealing a significant difference by ANOVA. Data analysis was conducted using SPSS

Fig. 3 A: Try in the trial denture

Fig. 3 B: Measuring the maximum biting force

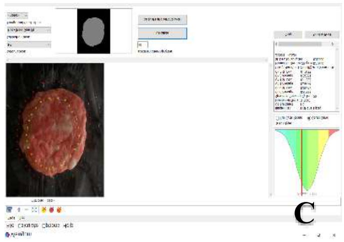

Fig. 3 C: Evaluating the hue deviation of the chewing sample with software.

software, with a statistical significance level of $p < 0.05$.

Results

All the participants completed the study and no patients dropped out of the follow-up visits.

1- Results of maximum biting force:

Table 1 compares the maximum biting force between groups as measured in newtons (N). There were insignificant differences in maximum biting force between the right and left sides, so the average of both sides was used. There were statistically significant differences in maximum biting force between CD1 and each of CD2 and CD3, while the differences between CD2 and CD3 were statistically insignificant.

2- Results of chewing efficiency:

Table 2 compares chewing efficiency between groups, as measured by hue deviation at different chewing stroke count. There was a statistically significant increase in the maximum biting force during different follow-up periods in the three groups. The comparison between groups showed that the differences in hue deviation between CD2 and CD3 were statistically insignificant ($p > 0.05$). However, there were statistically significant differences between CD1 and each of CD2 and CD3 for each masticatory stroke.

Table 1: Mximum biting force across different types of complete dentures

	X	SD	Median	Minimum	Maximum
CD1	43.58 A	3.41	42.85	38.80	50.30
CD2	56.00 B	3.94	56.00	49.50	65.00
CD3	54.98 B	3.01	55.65	50.00	59.20
P value	P<0.0001				

X: mean ; D: standard deviation; * Significant at P≤ 0.05. Vertically, differences in letters denote statistically significant variations between groups.

Table 2: Hue variation between different types of complete dentures at different chewing strokes.

	St1		St2		St3		St4		St5	
	X	D	X	D	X	D	X	D	X	D
CD1	0.5648 A	0.0594	0.4937 A	0.0685	0.4282 A	0.0547	0.4097 A	0.0445	0.3628 A	0.0324
CD2	0.2772 B	0.0158	0.2286 B	0.0555	0.1695 B	0.0222	0.1572 B	0.0119	0.1421 B	0.0099
CD3	0.2876 B	0.0534	0.2472 B	0.0396	0.1870 B	0.0628	0.1753 B	0.0682	0.1599 B	0.0465
P value	<0.0001*		<0.0001*		<0.0001*		<0.0001*		<0.0001*	

X: mean ; D: standard deviation; * Significant at P≤ 0.05. Vertically, differences in letters denote statistically significant variations between groups.

Discussion

Recent advancements in prosthetic dentistry with the advent of CAD/CAM technology have significantly improved the restoration of edentulous patients. Digital denture construction, combined with the use of intra-oral facial scanning techniques, can improve the interaction between prosthetic and aesthetic planning, benefiting both patients and the prosthodontist. However, more clinical studies are needed to investigate the potential of this technology.

This study's cross-over design made it possible to standardize denture and patient characteristics. Additionally, it enhanced the precision of the comparison of maximum biting force and chewing efficiency between the three types of dentures. The utilization of fewer patients is another advantage of this design. Furthermore, the patients independently experienced and contrasted the three denture types.

The study aimed to evaluate the impact of combining 3D facial scanning data with intra-oral scanning for construction of digital complete dentures. Recently, there have been a lot of studies detailing the process for producing digital complete dentures using intra-oral scanners. Since it was reported that intra-oral scanners can scan the dentulous ridges without the requirement for markers, no markers were employed during intra-oral scans. [7] To integrate conventional and digital workflow, an intra-oral record containing the impression-occlusal rim assembly was collected in addition to the intra-oral scan of the dentulous ridges. This action was taken since it resulted in better retention of digital dentures, as digital impressions when used alone failed to create a peripheral seal. [19,22]

The study used face scans three times: at rest, while smiling, and while wearing a reference stent for virtual tooth arrangement guided by the extra-oral anatomical landmark in the "virtual patient" that was created. The integration of virtual tooth arrangements with face scans allows for immediate prosthesis inspections, considering facial appearance. This allows for modification of tooth, position, size, and occlusal scheme while observing the facial appearance. This enhances the aesthetic try-in clinical approach, reduces chairside time, and improves communication between dentists and labs. Additionally, the digitally saved virtual setup can be reused for new prosthesis creation, reducing treatment time and cost.[12,13,23]

The results of the current study revealed that the first null hypothesis, that there would be no difference between digital full dentures made using indirect digital construction and those made utilizing intra-oral and facial scanning in terms of maximal biting force and chewing efficiency, was accepted. Both dentures are fabricated using the same digital manufacturing method, design program, 3D printer, printing process, and printed resin type.

The study found that using a facial scanner aligned with an intra-oral scanner did not improve outcomes compared to the indirect workflow. This could be due to the absence of cheek retraction while wearing the intra-oral stent during facial scanning. This may lead to inaccurate records and a change in facial line position during the smile scan. The cheek-retraction facial scanner was recommended by Schweiger et al[25] for better alignment with the intra-oral scan.

The second null hypothesis that there would be no difference in maximum biting power and chewing efficiency between digital and conventional complete dentures, was rejected. The study found an improvement in maximum biting force and masticatory efficiency for digitally fabricated dentures compared to conventional dentures. The significant improvement in both outcomes was attributed to superior adaptation of digital denture bases compared to conventionally constructed dentures, which resulted in better retention and function. Moreover, the more efficient cutting of cups through food due to the stable denture base, results in more comfortable chewing and higher biting forces. Digital dentures have been shown in several trials to be more retentive than conventional ones, due to its improved fit against the tissues beneath, [26,27] However, Kattadiyil et al.[28] noted the inadequate retention of the digital dentures', which was thought to be caused by digital impressions' inability to produce the peripheral seal of the selective pressure impression technique as suggested by D'Arienzo et al.[29]

Digital dentures have shown higher maximum biting force and masticatory efficiency compared to conventional dentures due to their superior retention and stability. This is due to the use of CAD/CAM design and production, which reduces inaccuracies in conventional denture fabrication techniques. The dimensional accuracy of the printed digital dentures is achieved through additive manufacturing and consecutive resin layering, which compensates for dimensional shifts and allows for material conservation. Ragheb and Ibrahim [30] have found that digital complete dentures have much higher maximum biting force and masticatory efficiency than conventional complete dentures.

The dimensional instability of conventional complete dentures can account for their poor maximum biting force and masticatory efficiency. Alterations in the denture base, which are often brought on by curing shrinkage during manufacturing, internal stress release, and water sorption-induced expansion. These alterations may result in decreased stability and retention. Contrary to previous studies, conventional dentures have been found to retain significantly more than digital dentures.[31] The study has several limitations, such as the need for a facial scan using a cheek retractor to enable a shared fixed reference to be aligned between the virtual cast and the face scans. The study's short follow-up time and limited sample size are further drawbacks. To validate the findings of this study, more research taking these outcomes into account is advised.

Conclusion

Within the limitations of this study, digital complete dentures demonstrated higher maximum biting force and chewing efficiency than conventional complete dentures. Furthermore, the differences between the indirect digital workflow and intra-oral scanning combined with the face scanning workflow were statistically insignificant in both parameters.

Declarations

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Ethical approval and consent to participate

This study was conducted according to the Declaration of Helsinki guidelines and approved by the Ethical Committee of Faculty of Oral and Dental Medicine, Misr International University
with IRB Number: MIU-IRB-2223-236
Informed consent was obtained from the participants.

Competing interests

The authors declare that there is no conflict of interest.

References

1. Kattadiyil MT, AlHelal A. An update on computer-engineered complete dentures: A systematic review on clinical outcomes. J Prosthet Dent 2017; 117:478-85.
2. Steinmassl PA, Klaunzer F, Steinmassl O, Dumfahrt H, Grunert I. Evaluation of currently

available CAD/CAM denture systems. Int J Prosthodont 2017;30: 116-22.
3. Alhallak, K., & Nankali, A. A review on clinical use of CAD/CAM and 3D printed dentures. British Dental Journal 2023, 1-5.
4. Carneiro Pereira AL, Bezerra de Medeiros AK, de Sousa Santos K, Oliveira de Almeida É, Seabra Barbosa GA, da Fonte Porto Carreiro A. Accuracy of CAD-CAM systems for removable partial denture framework fabrication: A systematic review. J Prosthet Dent. 2021;125(2):241-248.
5. Wagner SA, Kreyer R. Digitally Fabricated Removable Complete Denture Clinical Workflows using Additive Manufacturing Techniques. J Prosthodont. 2021;30(S2):133-138.
6. Kouveliotis G, Tasopoulos T, Karoussis I, Silva NR, Zoidis P. Complete denture digital workflow: Combining basic principles with a CAD-CAM approach. J Prosthet Dent. 2022;127(4):550-555.
7. Fang JH, An X, Jeong SM, Choi BH. Digital intraoral scanning technique for edentulous jaws. J Prosthet Dent. 2018;119(5):733-735.
8. Unkovskiy A, Wahl E, Zander AT, Huettig F, Spintzyk S. Intraoral scanning to fabricate complete dentures with functional borders: a proof-of-concept case report. BMC Oral Health. 2019;19(1):46.
9. Kontis P, Güth JF, Schubert O, Keul C. Accuracy of intraoral scans of edentulous jaws with different generations of intraoral scanners compared to laboratory scans. J Adv Prosthodont. 2021;13(5):316-326.
10. Hassan B, Gimenez Gonzalez B, Tahmaseb A, Jacobs R, Bornstein MM. Three-dimensional facial scanning technology: applications and future trends. Forum Implantol 2014; 10:78-6.
11. Hassan B, Gimenez Gonzalez B, Tahmaseb A, Greven M, Wismeijer D. A digital approach integrating facial scanning in a CAD-CAM workflow for complete-mouth implant-supported rehabilitation of patients with edentulism: A pilot clinical study. J Prosthet Dent. 2017;117(4):486-492.
12. Granata S, Giberti L, Vigolo P, Stellini E, Di Fiore A. Incorporating a facial scanner into the digital workflow: A dental technique. J Prosthet Dent. 2020;123(6):781-785.
13. Hassan B, Greven M, Wismeijer D. Integrating 3D facial scanning in a digital workflow to CAD/CAM design and fabricate complete dentures for immediate total mouth rehabilitation. J Adv Prosthodont. 2017;9(5):381-386.
14. Park JH, Lee GH, Moon DN, Yun KD, Kim JC, Lee KC. Creation of Digital Virtual Patient by Integrating CBCT, Intraoral Scan, 3D Facial Scan: An Approach to Methodology for Integration Accuracy. J Craniofac Surg. 2022;33(4): e396-e398.
15. Schimmel M, Christou P, Miyazaki H, Halazonetis D, Herrmann FR, Muller F. A novel colourimetric technique to assess chewing function using two-coloured specimens: validation and application. J Dent.2015;43:955-964.
16. Salami ZA, Jasser EM, Makzoumé JED, Boulos PJA. Masticatory efficiency of implant-supported mandibular overdentures retained with attachments compared with conventional dentures: an in vitro digital colorimetric image analysis. Gen Dent. 2020;68(6):60-64.
17. Youssef, H. Masticatory efficiency and maximum bite force of patients using two- implant mandibular overdentures retained by equator or locator attachments: a crossover study. Advanced Dental Journal, 2022; 4(4): 322-338.
18. Gu Y, Bai Y, Xie X. Bite force transducers and measurement devices. front bioeng biotechnol. 2021; 9:665081.
19. Lo Russo L, Caradonna G, Salamini A, Guida L. A single procedure for the registration of maxillo-mandibular relationships and alignment of intraoral scans of edentulous maxillary and mandibular arches. J Prosthodont Res 2020; 64:55-9.
20. Lo Russo L, Di Gioia C, Salamini A, Guida L. Integrating intraoral, perioral, and facial scans into the design of digital dentures. J Prosthet Dent 2020; 123:584-8.
21. Youssef, H., Alaswad, R. Quality of life and masseter muscle activity in patients with digital complete dentures constructed using combined intra-oral and face scanning versus the indirect method as compared to conventional dentures: a crossover study. Ain Shams Dental Journal, 2022; 25(1): 44-55.
22. Lo Russo L, Salamini A, Troiano G, Guida L. Digital dentures: A protocol based on intraoral scans. J Prosthet Dent. 2021;125(4):597-602.
23. Lee H J, Jeon J, Moon H S, Chul Oh K Digital Workflow to Fabricate Complete Dentures for Edentulous Patients Using a Reversing and Superimposing Technique. *Appl. Sci.* 2021, *11*(13), 5786
24. Kortam, S., Abdeen, R. Treatment Outcomes of Indirect Versus Direct Digitally Constructed Complete Dentures as Compared to Conventionally Constructed Complete Dentures: Cross-Over Clinical Study. Egyptian Dental Journal, 2022; 68(2): 1741-1756.
25. Schweiger J, Güth JF, Edelhoff D, Stumbaum J. Virtual evaluation for CAD-CAM-fabricated complete dentures. J Prosthet Dent. 2017;117(1):28-33.

26. Steinmassl O, Dumfahrt H, Grunert I, Steinmassl PA. CAD/CAM produces dentures with improved fit. Clin Oral Investig. 2018;22(8):2829-2835.
27. B.J. Goodacre, C.J. Goodacre, N.Z. Baba, M.T. Kattadiyil, Comparison of denture base adaptation between CAD-CAM and conventional fabrication techniques, J. Prosthet. Dent. 116 (2) (2016) 249–256
28. Kattadiyil MT, AlHelal A, Goodacre BJ. Clinical complications and quality assessments with computer-engineered complete dentures: A systematic review. J Prosthet Dent. 2017;117(6):721-728.
29. D'Arienzo LF, Casucci A, Manneh P, D'Arienzo A, Borracchini A, Ferrari M. Digital workflow in complete dentures: a narrative review. Journal of Osseointegration. 2020;12(4):743-50.
30. Ragheb, N., Ibrahim, W. Biting Force and chewing efficiency of Conventional and CAD/CAM complete dentures. A Cross-over Study. Egyptian Dental Journal, 2021; 67(4): 3323-3335.
31. Alkhodary, M. Effect of digital and conventional workflows on complete denture retention. Egyptian Dental Journal, 2022; 68(2): 1685-1693.