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RESEARCH ARTICLE

DIGITAL OCCLUSAL ANALYSIS AND ORAL HEALTH-RELATED QUALITY OF LIFE OF PATIENTS WITH 3D PRINTED COMPLETE DENTURES VERSUS CONVENTIONAL DENTURES

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Abstract

Background: 3D printed complete dentures fabrication with computer-aided designing and computer-aided manufacturing (CAD/CAM) techniques is becoming popular nowadays. However, studies that analyzed the occlusal forces distribution using recent digital methods as T-scan III and further evaluated the denture's effect on patient`s life quality were lacking.

Objectives: Evaluation of the occlusal forces' distribution using T-scan III, and evaluation of the oral health-related quality of life (OHRQoL) using Oral Health Impact Profile for Edentulous Patients (OHIP-EDEN) questionnaire for 3D printed complete dentures and comparing it with conventional denture fabrication techniques.

Methods: Twenty completely edentulous patients were selected and divided randomly into two equal groups according to manufacturing technique; group I (patients who received conventional complete dentures), and group II (patients who received 3D printed complete dentures). For all patients, occlusal force analysis (percentage of applied occlusal force on both sides) was performed using the T-Scan III (digital occlusal analysis system). Also, OHRQoL was assessed using (OHIP-EDENT) questionnaire.

Results: In the digital occlusal analysis, comparison between right and left sides regarding occlusal forces distribution revealed a significant difference in group I (conventional denture), while in group II (3D printed denture), it revealed an insignificant difference. Regarding, OHIP-EDENT; patients in group I (conventional denture) revealed higher scores than group II (3D printed dentures). Also, the correlation between occlusal forces & (OHIP-EDENT) scores revealed a strong negative significant correlation.

Conclusions: The 3D printed complete dentures fabricated using CAD/CAM technology proved to be more superior over conventional methods in terms of digital occlusal force analysis and Oral Health Impact Profile for Edentulous Patients (OHIP-EDENT). However, further studies are required on more patients to decide the exact superiority of one technique over the other after long-term follow-up periods.

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Introduction:-

One of the most important challenges during complete dentures (CDs) treatment is obtaining the bilateral balance due to its great effect on dentures' retention and stability, especially in mandibular dentures. Its importance is attributed to the significant dislodgment effect of unbalanced forces on both upper and lower opposing dentures during function not just for conventional CDs but also for digitally fabricated ones [1]. However, the most frequent obstacle is usually the resiliency of the soft tissues, although using semi-adjustable articulators may be beneficial, nevertheless, it allows only approximation of the occlusal functional movements. [2]

To register the patient's inter-arch relationship, a recording medium is necessary. If the inter-arch registration is wrong, the mounted casts will not reveal accurate patient's maxillo-mandibular relationship which will further result in errors in diagnosis and treatment planning [3]. However, with the use of conventional static occlusal indicators (articulating paper, waxes); the occlusal contact size and location can only be revealed but the intensity and the magnitude measurement of the generated occlusal forces cannot accurately quantified. Furthermore, the size of the marked area using the articulating paper is only an illustrative method of how heavy the occlusal load is. [4]

Fortunately, recent technologies offer a better solution to such problem with computerized occlusal analysis (T-Scan System). It is an occlusal analysis device which has the capability of patient's biting force accurate registration, in addition to showing the occlusal force location and timing, also the T-Scan System can uniquely quantify occlusal contact timings and forces of occlusion for patients with affected occlusion [5]. Moreover, it is used as a diagnostic tool for the intracapsular diseases of temporomandibular joint, where the occlusal forces differ greatly from healthy patients. Accordingly, the invention of the T-scan occlusal analysis system has remarkably eliminated the dentist guesswork. [6]

In the mid-80s of this century, the T-Scan system was used for computerized occlusal force analysis as it allows determination of real-time of the recorded forces using the T-Scan intra-oral sensor. However, the original design of the T-Scan system both software and hardware has been greatly modified and improved until the invention of the latest version of the system (T-Scan III) which is available nowadays. [7]

The T-Scan III (S. Boston, MA, USA) is an advanced occlusal analysis system that can record the distribution of occlusal contact force from the first tooth contact to the maximum inter-cuspal position. It is a thin, readily flexible, pressure-sensitive bite transducer embedded in a dental arch-shaped recording sensor. It allows graphical displaying for analysis in both two or three dimensions. Furthermore, it has various applications in recording patient parameters as the force center, explaining the occlusal forces symmetry, initial contact, maximum bite force and maximum intercuspation. [6-9]

However, edentulous patients almost always seek denture treatment not only to restore function but are also seeking aesthetics in the most comfortable fashion, in addition to, self-esteem in their daily public life. Consequently, people may develop anxiety, decreased self-confidence and depression in cases of improperly constructed complete dentures, which will be further reflected on their psychological behavior, well-being and quality of life. [10]

The OHIP (Oral Health Impact Profile) was made to evaluate the possible dysfunctions, discomfort and disability of oral conditions among elderly populations and geriatric patients. It consists of forty-nine items, based on seven conceptual models which represents the functional limitation as difficulty chewing, Physical pain (teeth sensitivity), Psychological discomfort (self-consciousness), Physical disability (diet changes), Psychological disability (less concentration), Social disability (avoiding interactions) and Handicap (unable to work productively). [11]

However, the OHIP full forty-nine items are not practical clinically because of its length. Therefore, (OHIP-14) was developed which consists of only 19 questions, obtained from the main seven conceptual domains of the original OHIP. Seven domains' questions were responded on: 0 = never, 1= hardly ever, 2 = occasionally, 3 = fairly often, 4 = very often. Thus, better OHRQoL is markedly represented by lower scores. The response code of each question was calculated among the seven domains to give seven subscale scores. The total ranges from 0-76. On the other hand, higher OHIP-EDENT summary scores indicate OHRQoL impairment. [12, 13]

Although, milled dentures are more popular than 3D printed dentures, very soon this concept will be reversed as the milling method has the well-known problems of machining tools wear and causes a large amount of denture base material wastage. However, the 3D printed dentures are more economical where the unemployed material can be further used again and also,, many dentures with accurate details reproduction can be printed. [14, 15]

Different features of both techniques have been evaluated and reported in various clinical and in laboratory studies regarding, dentures‘ retention, trueness, patient and dentist satisfaction, fabrication simplicity, properties of materials and mechanical performance. However, the occlusal analysis was not much reviewed, which should be with no doubt of high precision for digital CDs success. Nevertheless, the presence of deflective occlusal contacts, poor occlusal forces distribution might result in undesirable torque and possible dentures‘ dislodgement affecting its stability, in addition to, patients’ discomfort, anxiety and unacceptance. Accordingly, this study was performed to evaluate the occlusal forces distribution in complete dentures, fabricated by the conventional technique and 3D printed method using the computerized occlusal force analysis system (T-Scan III). [16-21]

Materials & Methods:-

Study design:

This study was carried out in the Department of Removable prosthodontics Faculty of Oral and Dental Medicine, MSA University, and in the Department of Fixed & Removable Prosthodontics at National Research Centre, Cairo-Egypt. The participants of this study were twenty randomly distributed equally among two groups according to the technique of complete denture construction: (1) Conventionally constructed complete denture, (2) 3D printed complete denture.

Ethical Approval:

This study was designed and approved by Research Ethics Committee-Cairo university (1798 registration number), Cairo-Egypt, which is in accordance with Helsinki Declaration of 1975. All patients were informed about the practical steps of the study and signed written approval consent.

Sample size calculation

Sample size calculated depending on a previous study by **Azza Farahat Metwally, (2019)** as reference. According to this study, the response within each subject group was normally distributed with standard deviation (7.94), the true difference in the experimental and control means is (7.85), minimally the study needed 17 subjects in each group when the probability (power) was 0.8 & the type I error (α) was 0.05. The total sample size increased to 20 subjects per group to compensate for 20 % dropout. [22]

Inclusion & exclusion criteria:

All selected participants were completely edentulous patients fulfilling inclusion criteria by the recording of full medical and dental histories in addition to, intra-oral and extra-oral examinations. All included patients should be cooperative, males, 45-60 years old patients with healthy and firm mucosa. On the other hand, the exclusion criteria included the following: Alzheimer's or Parkinson's disease patients who were already experiencing a decline in their quality of life, patients with uncontrolled psychological or psychiatric conditions. Also, any condition that may affect muscular activity should be excluded as bruxism, temporomandibular disorders, or any neuromuscular condition. Only patients who showed cooperation and acceptance for compliance to treatment were accepted in the study.

Patients grouping:

Denture construction:

Group I (Conventional heat-cured dentures):

Primary impressions were made using irreversible hydrocolloid impression material, followed by border molding with Putty-C-Silicone. Then final impressions were made using Silicone impression material (poly-C-silicone impression material, thixoflex M, medium, Zhermack, Italy) to obtain casts. Then maxillary and mandibular casts were mounted on the articulator at the predetermined vertical dimension of occlusion using the wax wafer technique. Setting-up of acrylic resin teeth was performed after proper selection according to the patient`s demands, then waxing up was performed and checked in the patient’s mouth.

Denture’s fabrication was performed by using heat-cured acrylic resin (Acron Duo, Associated Dental Products Ltd., Kemdent, Purton, Swindon, Wiltshire, UK). Denture processing was done using a long polymerization cycle, 9

hours in a water bath at 73°C ±1°C, followed by 30 minutes in boiling water as recommended by the manufacturer then, deflasking, finishing, and polishing of the dentures were done following the conventional routine method.

Finally, denture delivery was made after checking proper extension, retention and stability. The patient was informed about the proper oral hygiene measures.

Group II (3D printed complete dentures):
For the 3D-printed workflow, preliminary impressions, final impressions, and bite record blocks, face-bow records and jaw relations were carried out as in a conventional way obtaining upper and lower master casts with their bite blocks mounted on the semi-adjustable articulator. Upper and lower master casts with the mounted casts were scanned by the desktop 3D scanner (3shape E2, Holmens kanal 7 Copenhagen) and exported into three STL files for upper, lower master casts, and bite scan respectively. The scanned denture STL files were designed using (3shape DENTAL SYSTEM PREMIUM design software) and the designed preview was sent to the patients for approval and incorporation of any changes suggested by the clinician as shown in figure (1). Once the design was approved, the files were exported into four newly designed STL files defined as upper, lower denture bases, upper and lower set of teeth to be manufactured as socketed dentures having the teeth to be bonded in their perspective sockets in the denture. The designed STL files were then sent to the 3D printer to be ready for manufacturing. The denture bases were fabricated from a printable resin (NextDent Denture 3D+; NextDent B.V.) by using a 3D-printer (NextDent 5100; NextDent B.V.) that utilizes Digital Light Projection Manufacturing (DLPM) equipment shown in figure (2).

The denture bases were printed in a vertical orientation with a layer thickness of 100 microns, with the location and number of support struts being automatically generated by the software program. After each layer was cured, the 3D printer's platform with the cured structure attached moved upper and another layer of uncured liquid resin was spread over the bottom until the final construction was built as demonstrated in figure (3). After printing, the denture bases were separated from the build platform with a putty knife and the support struts were removed. The bases were ultrasonically cleaned in isopropyl alcohol for 5 minutes, dried, and then placed in an ultraviolet light unit (LC-3DPrint Box; NextDent B.V.) for 30 minutes for post-polymerization. Teeth set STL files were milled from PMMA (Polymethyl Methacrylate) blocks and bonded to their perspective sockets in the printed denture bases according to the manufacturing instructions as shown in figures (4a and 4b).

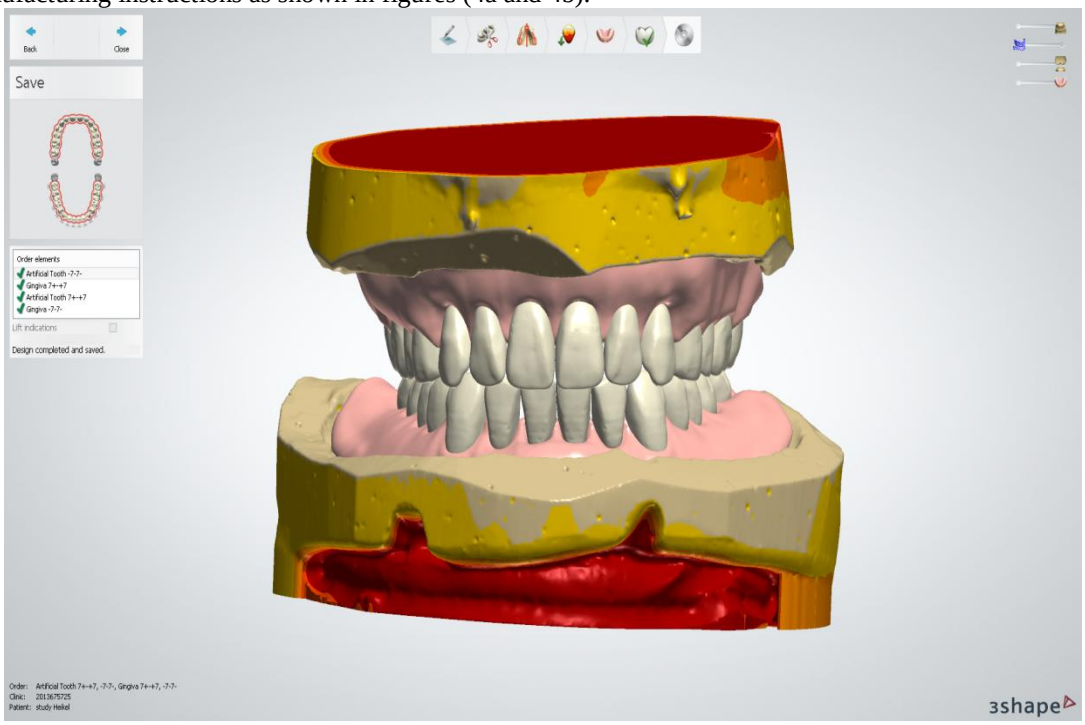

Figure (1):- CAD designed dentures using scanned denture STL files.

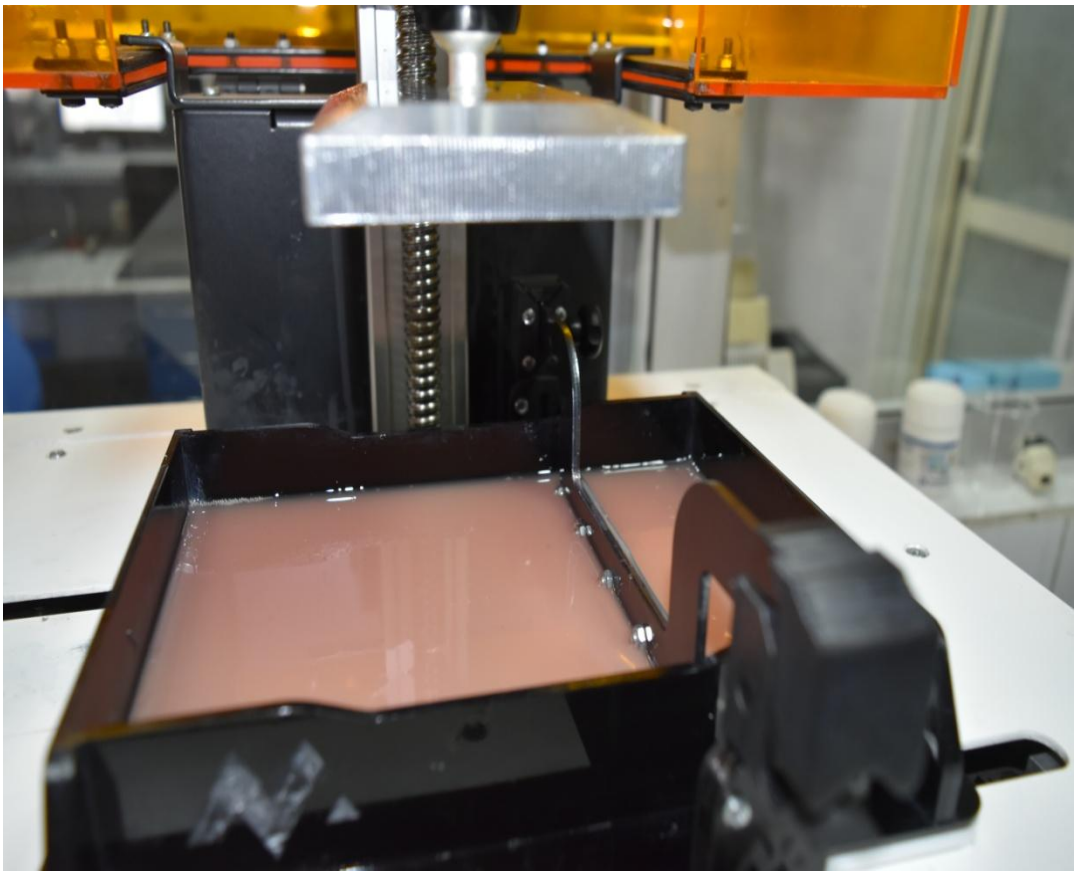

Figure (2):- 3D printing operation using the photopolymerizable liquid resin.

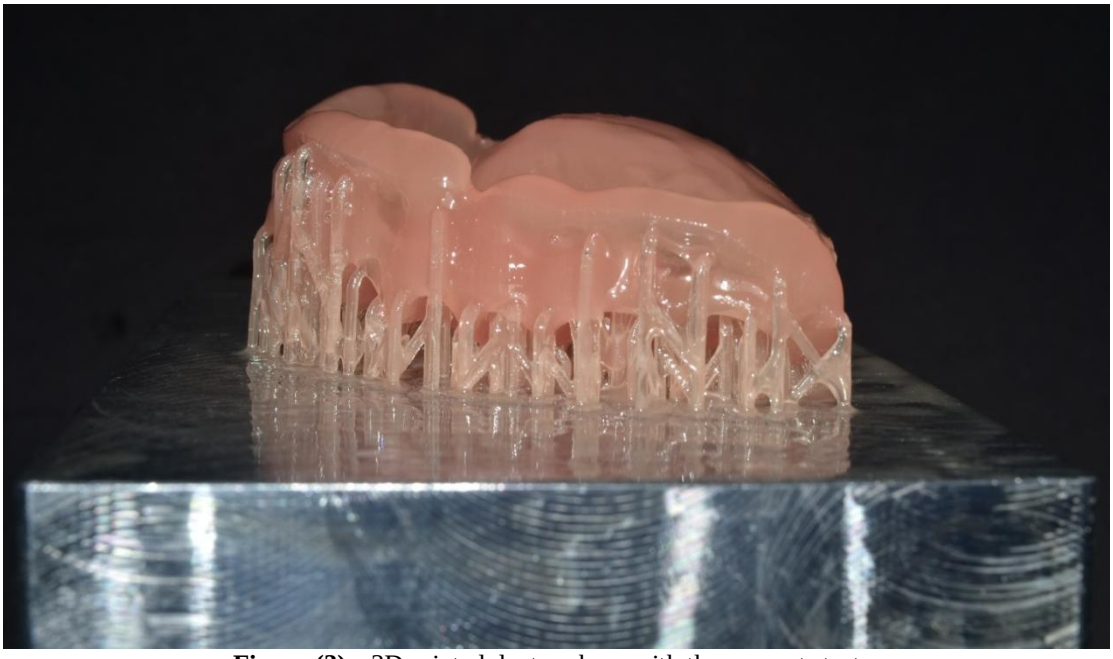

Figure (3):- 3D printed denture base with the support struts.

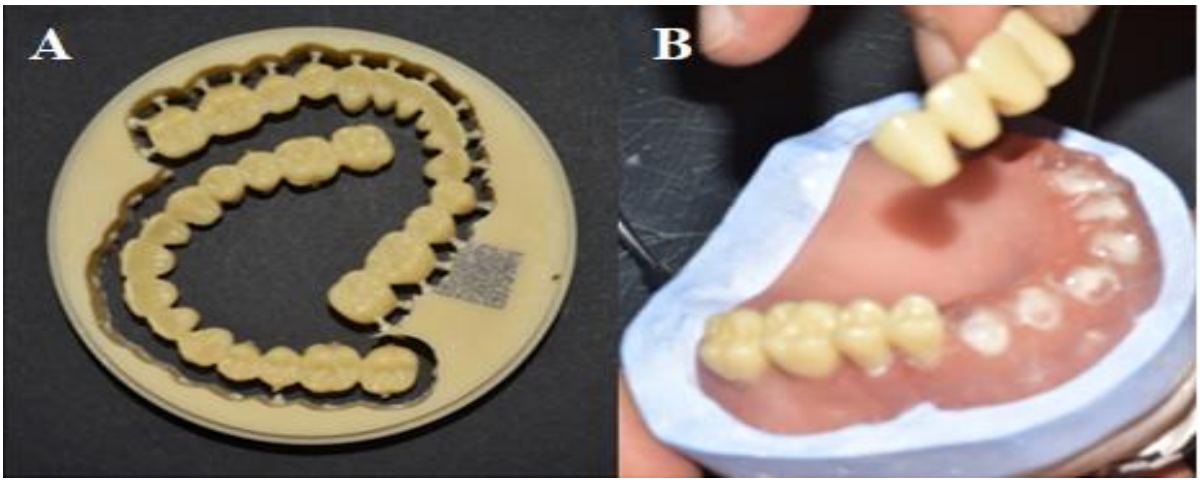

Figure (4):- (A): Milled denture teeth, (B): Bonding the milled teeth in their printed denture sockets.

Patient instructions:

All patients were recalled 24 hours after dentures delivery and one week later, to eliminate any patient complaints that might arise during the initial period of prosthesis adaptation. At the time of denture insertion, patients were motivated to follow proper oral and denture hygiene instructions.

Evaluation of occlusion by using digital occlusal analysis:

Digital occlusal analysis was performed for both groups utilizing the T-Scan III computerized system (Tekscan system Tekscan Inc., South Boston, MA, USA) immediately after processing without laboratory/clinical remount and after finishing of the study records, further occlusal adjustments were performed following basic protocols of remounting to satisfy the patients and make CDs comfortable.

This system is composed of a computer with a specific board and software capable of converting information recorded by the sensor to visual and numerical information on tooth contact. The size of the sensor was selected according to the arch size & form of dentures in all patients in both groups. The patient was instructed to seat in an upright position & the sensor was positioned parallel to the upper denture occlusal plane & the midline was placed between the central incisor denture teeth. The patient was instructed to bite on the sensor 2-4 times for adjusting the sensitivity of the sensor before recording. The percentage of occlusal force distribution in the anterior & posterior areas was obtained on each quadrant & saved for data analysis as presented in figure (5).

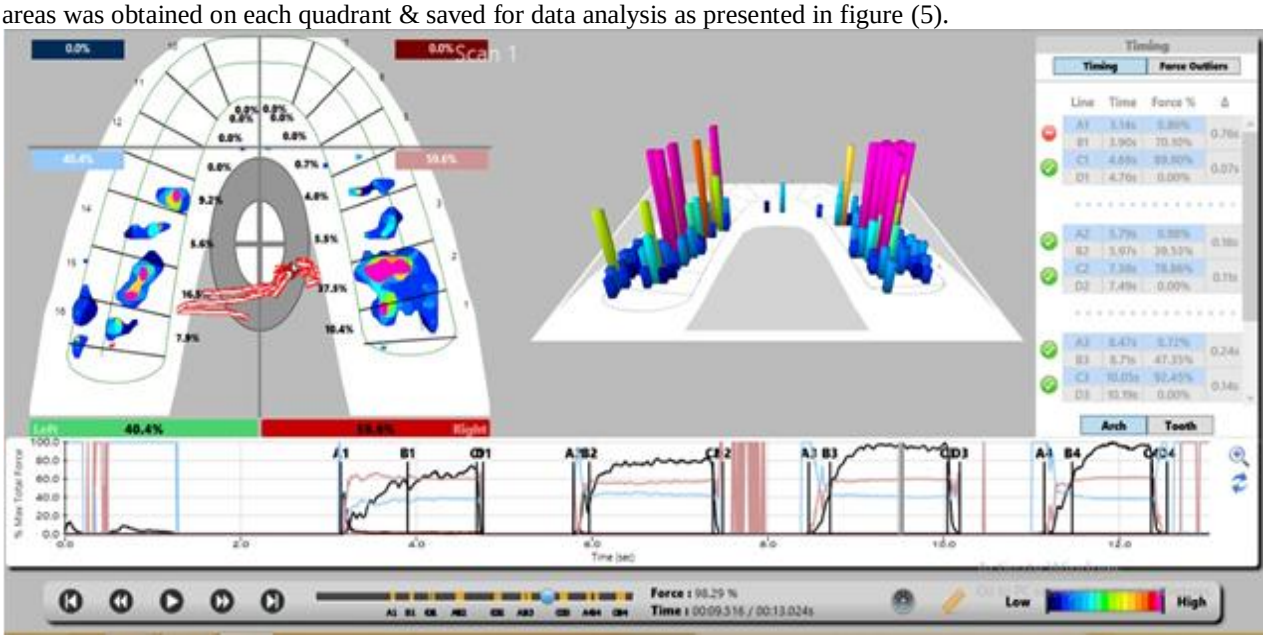

Figure (5):- Distribution of occlusal force in each quadrant.

Evaluation of Oral Health Quality of Life (OHRQoL):

The Oral Health Impact Profile for Edentulous Patients (OHIP-EDENT) consists of 19 questions which were obtained from each of the seven conceptual domains of the OHIP (functional limitation, physical pain, psychologic discomfort, physical disability, psychologic disability, social disability, and handicap) as shown in table (1).

The OHIP-EDENT questionnaire was translated into Arabic by linguistic professionals who worked in collaboration with the authors to prepare the final version, the five categories of response for each item were never (= 1), hardly ever (=- 2), occasionally (=3), fairly often (= 4), and very often (= 5) The sum ranges from 0-76. Higher OHIP-EDENT summary scores indicate OHRQoL impairment.

Table (1):- Questions for the Oral Health Impact Profile for Edentulous Patients.

Functional limitation	**Q1**	**Have you had difficulty chewing any foods?**
	Q2	**Have you had food catching in your dentures?**
	Q3	**Have you felt that your dentures have not been fitting properly?**
Physical pain	**Q4**	**Have you had painful aching in your mouth?**
	Q5	**Have you found it uncomfortable to eat any foods because of problems with your dentures?**
	Q6	**Have you had sore spots in your mouth?**
	Q7	**Have you had uncomfortable dentures?**
Psychological discomfort	**Q8**	**Have you been worried by dental problems?**
	Q9	**Have you been self-conscious because of your dentures?**
Physical disability	**Q10**	**Have you had to avoid eating some foods because of problems with your dentures?**
	Q11	**Have you been unable to eat with your dentures because of problems with them?**
	Q12	**Have you had to interrupt meals because of problems with your dentures?**
Psychological disability	**Q13**	**Have you been upset because of problems with your dentures?**
	Q14	**Have you been a bit embarrassed because of problems with your dentures?**
Social disability	**Q15**	**Have you avoided going out because of problems with your dentures?**
	Q16	**Have you been less tolerant of your spouse or family because of problems with your dentures?**
	Q17	**Have you been a bit irritable with other people because of problems with your dentures?**
Handicap	**Q18**	**Have you been unable to enjoy other people's company as much because of problems with your dentures?**
	Q19	**Have you felt that life, in general, was less satisfying because of problems with your dentures?**

Statistical analysis:

Statistical analysis was performed using Statistical Package for Social Science (IBM SPSS) version 23 and Graph Pad Prism version 8.0.2 (263). All quantitative were presented as mean ± standard deviation & explored for normality by using Shapiro Wilk and Kolmogorov-Smirnov normality test which revealed that all data is parametric data (P-value > 0.05). Accordingly, comparison between two groups was performed by Independent t-test, and comparison between 3 different areas was performed by using the One-Way ANOVA test followed by Tukey`s Post Hoc test for multiple comparisons. On the other hand, qualitative data were presented as frequency & percentages and comparisons between the 2 groups were performed by using the Chi square test and the p-value ≤0.05 was considered a significant value.

Results:-

In occlusal forces distribution, comparison between both groups revealed a significant difference as $P < 0.05$ in the anterior area as group I (Conventional denture) was significantly higher than group II (3D printed denture), and in the left posterior area as the group I (Conventional denture) was significantly lower than group II (3D printed denture), while there was insignificant difference between them regarding the right posterior area. Also, comparison between different areas for each group revealed a significant difference between all areas in group I (conventional denture), while in group II (3D printed denture) anterior area was significantly the lowest as $P<0.05$, while there was an insignificant difference between right & left posterior areas as $P>0.05$, as presented in table (2) and figure (6)

Regarding the OHIP-EDENT questionnaire, comparison between both groups regarding seven conceptual domains of the OHIP revealed an insignificant difference between both groups as P > 0.05 in all domains and overall OHIP-EDENT as P > 0.05 except functional limitation, psychological discomfort & social disability (group I was insignificantly higher than group II) as presented in table (3) and figure (7).

Moreover, the correlation between values of occlusal forces & OHIP-EDENT scores was performed and revealed a strong, negative, significant correlation between them in both groups as presented in table (4).

Table (2):- Mean ± standard deviation of values of occlusal force and their distribution in all areas regarding group I (Conventional denture) & group II (3D printed denture) and comparison between them:

Area	**Total N**	**Group I**		**Group II**		**P value (Independent t-test)**
		M	**SD**	**M**	**SD**	
Anterior	**20**	14.1 [a]	2.82	8.2 [a]	1.85	<0.0001*
Right Posterior	**20**	45.3 [b]	7.31	46.3 [b]	7.12	0.66
Left posterior	**20**	40.6 [c]	4.5	45.5 [b]	4.61	0.001*
P value (One Way ANOVA test)		<0.001*		<0.0001*		

N; count M; mean SD: standard deviation CI: confidence interval at 95%
*Significant difference as P < 0.05

Means with the same superscript letters in the same column were insignificantly different as P>0.05
Means with different superscript letters in the same column were significantly different as P<0.05

Table (3):- Mean ± standard deviation of OHIP-EDENT score in group I (Conventional denture) and group II (3D printed denture) and comparison between them:

	N	**Group I (conventional denture)**		**Group II (3 D printed denture)**		**P value (Independent t-test)**	**CI**	
		M	**SD**	**M**	**SD**		**U**	**L**
Functional limitation	20	8.7	1.62	7.5	1.5	0.01*	-2.193	-0.207
Physical Pain	20	8	1.6	7.2	1.44	0.107	0.1744	-1.744
Psychological discomfort	20	4.4	0.82	3.8	0.76	0.02*	-1.106	-0.093
Physical disability	20	7.1	1.42	6.4	1.28	0.109	0.1654	-1.565
Psychological disability	20	3.1	0.82	2.7	0.54	0.076	0.0444	-0.844
Social Disability	20	2.5	0.53	2.1	0.62	0.03*	-0.769	-0.031
Handicap	20	1.9	0.38	2.3	0.89	0.072	0.8381	-0.038
Overall OHIP-EDENT	20	35.7	7.19	32	7.03	0.1	-8.252	0.859

N; count M; mean SD: standard deviation CI: confidence interval at 95%

Table (4):- Correlation between values of occlusal force and OHIP-EDENT score in both groups:

OHIP-EDENT score	**Values of occlusal force**		
	r	**P value**	**Indication**
Group I (conventional denture)	-0.91	0.03*	Strong / |Negative / Significant correlation
Group II (3D printed denture)	-0.93	0.01*	Strong / Negative / Significant correlation

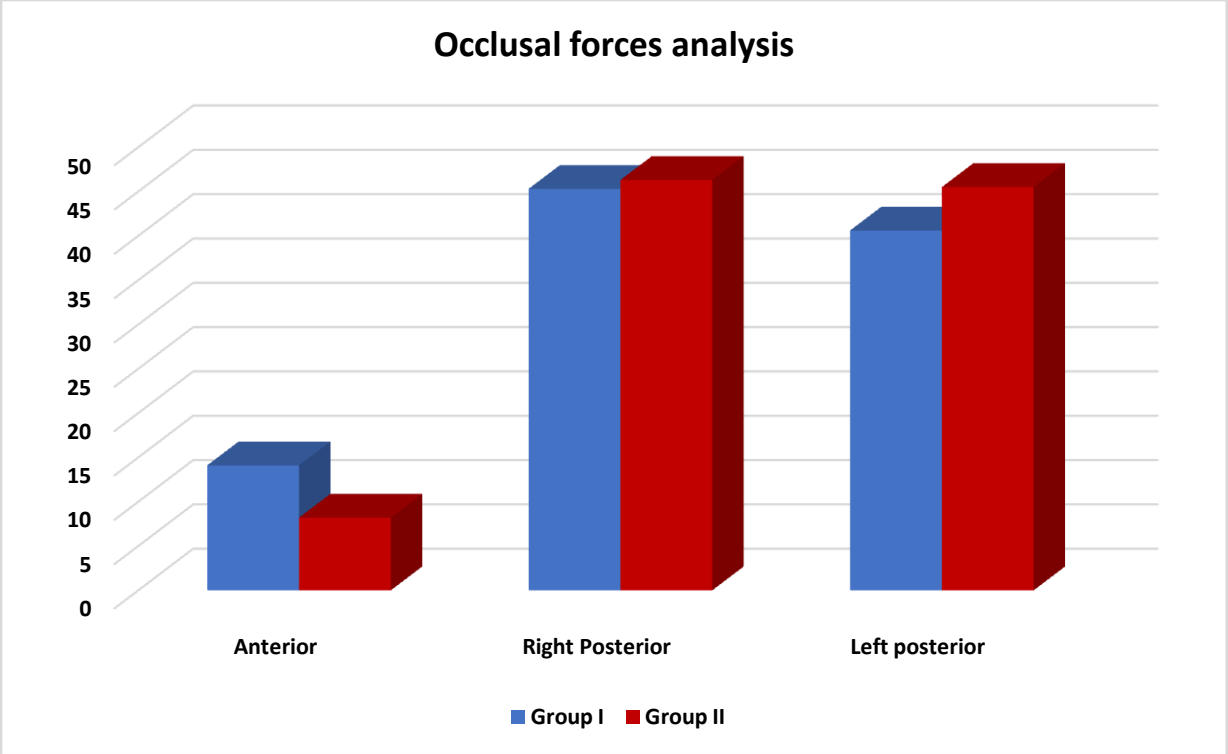

Figure (6):- Bar chart representing values of occlusal force in all areas regarding group I (Conventional denture) & group II (3D printed denture).

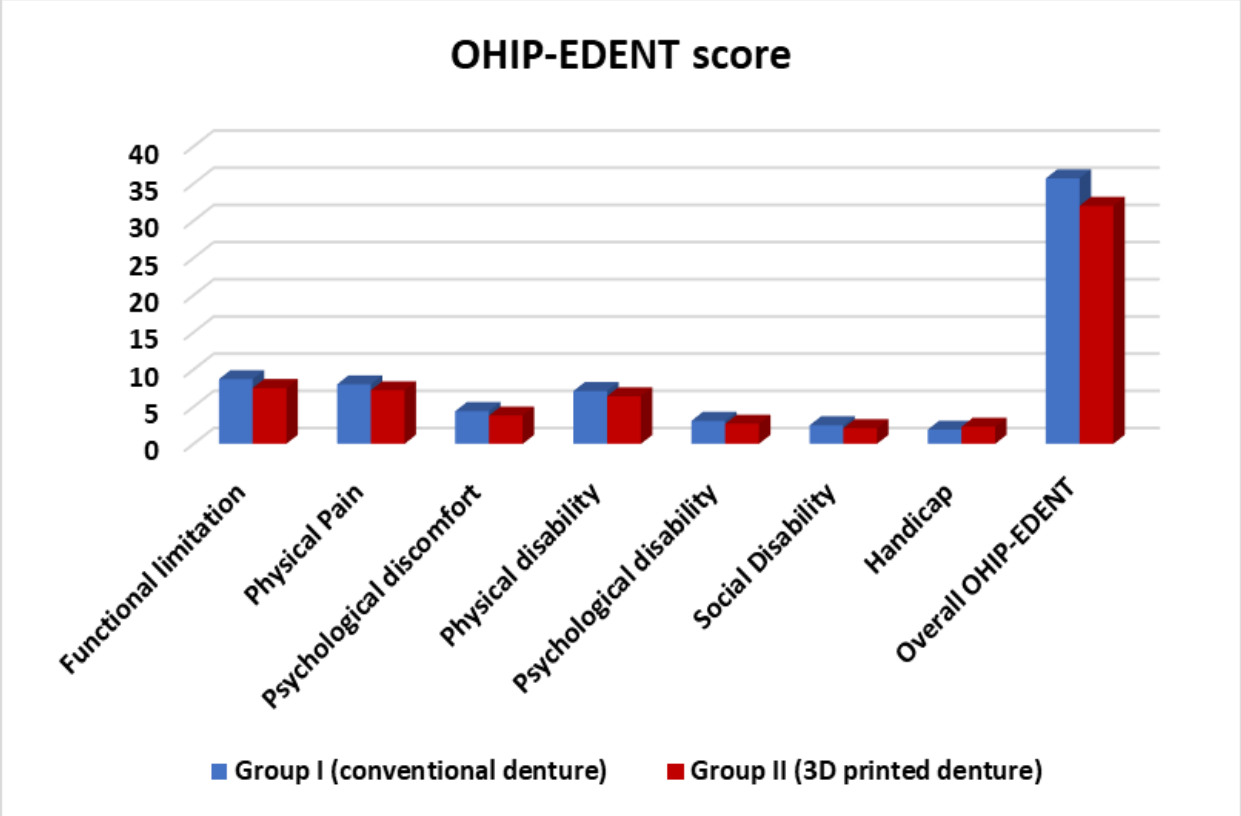

Figure (7):- Bar chart representing OHIP-EDENT score in group I (Conventional denture) and group II (3D printed denture).

Discussion:-

The computerized occlusal analysis was performed using the T-Scan III system because of its good sensitivity and unique usage as a diagnostic tool that shows higher reliability and consistency, even in the presence of saliva intra-orally. Also, it utilizes a 100 mm thick recording sensor that eliminates problems related to occlusal registration materials thickness. Moreover, T-Scan III quantifies the amount of relative occlusal force to initially identify areas of ununiform occlusion and helps the clinician to ensure homogenous occlusal force distribution which would be impossible to be carried out by using articulating paper as it is used to be the most popular conventional methods of detecting occlusal discrepancies clinically. This technique was accurate, dependable, simply repeatable and had been reported positively in other studies. [23, 24]

The results of this study have revealed that, the percentage of force distribution was not balanced on the anterior and posterior sides of the dentures in both groups. On the other hand, comparison between right and left sides revealed a significant difference in group I (conventional group), while revealed insignificant difference in group II (3D printed) that showed better bilateral balanced occlusion, which may be attributed to the less occlusal errors & less occlusal adjustments required for the 3D printed dentures. Moreover, the better the denture base thickness and the properly designed denture borders; the better the fitness and the overall retention of the 3D printed dentures as compared to conventional ones.

Moreover, occlusal adjustments were made on the software several times during artificial teeth virtual set-up to ensure minimal premature contacts, enhanced occlusal balance and accordingly, better dentures stability. This was in accordance with **McLaughlin et al. (2015)** who reported the CAD/CAM record bases usage in fabrication of conventional complete dentures to help in producing better-fitting dentures with fewer occlusal errors. [25]

Furthermore, CDs fabrication using the conventional fabrication techniques has inherent drawbacks and limitations; as polymerization shrinkage, the release of stresses incorporated in the modeling waxes during manipulation, undesirable residual monomer content, high packing pressure and uncontrolled expansion of dental plaster resulting in movement of denture teeth. These technical mistakes may greatly change the established occlusal scheme, and this was further proved by the present study reported results. On the other hand, the 3D printing fabrication technique of CDs takes place from a photosensitive liquid resin which is repetitively layered on a support structure and finally polymerized. Also, teeth and denture bases were precisely bonded with each other; thus, the final occlusion was not subjected to possible polymerization shrinkage errors & the adjusted occlusal scheme was better retained than conventional CDs. [26]

In this study, evaluation of oral health quality of life was of prime importance as edentulous patients are always concerned about their general appearance in all communities, and teeth loss affects the normal functional activities with great impact on their self-confidence. However, patients' satisfaction and oral health quality of life were directly affected by the denture stability, which depends mainly on the presence of balanced occlusal contacts. Thus, this study was conducted to compare the oral health quality of life of patients with conventional CDs and 3D printed dentures using the OHIP and correlating it with balanced occlusion. [27, 28]

The results of this study have shown that patients of both groups were satisfied with their dentures, but patients of group II had a non-significant more dentures usage satisfaction than those of group I in all domains except functional limitation, psychological discomfort& social disability. These results may agree with **Kattadiyil et al. (2015)** who compared the clinical outcomes and patient satisfaction with CAD/CAM & conventional CDs, and reported that CAD/CAM dentures had shown a more promising outcome. However, these better results of group II (3D printed) agreed with the study of **Kattadiyil et al,** who compared two fabrication techniques treatment outcomes (conventional and CAD/CAM), and further, stated that patients revealed significantly better overall satisfaction with CAD/CAM complete dentures which may be attributed to better dentures' retention and stability. [29]

Conclusion:-

Within the limitations of this study, regarding number of patients, evaluation period and occlusal analysis device used, it can be concluded that:

1. The occlusal forces on CDs were affected by the technique of fabrication utilized.

2. 3D printed CDs provide better oral health-related quality of life (OHRQoL) and better occlusal force distribution than conventional complete dentures.
3. T-Scan technology helps in assessing treatment outcomes; it provides detailed information about the patient's occlusion and helps in the visualization of occlusal equilibration during dentures' delivery.

Conflicts of interest
There are no conflicts of interest to be declared.

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