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ORIGINAL ARTICLE

Assessment of fully digitalized workflow for implant-prosthetic rehabilitation in temporomandibular disorders patients: A clinical study

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Abstract Digitalized workflow eliminates the need for the tray, impression materials, its decontamination, packaging and shipping, pouring with plaster, cast fabrication, mounting in an articulator, reducing storage spaces, and the risks of any loss or fracture of the plaster model is overcome by archiving on the computer. This clinical investigation aimed to evaluate the effectiveness of the fully digitalized rehabilitation [implant-supported prosthesis] method in partially edentulous patients and with TMD, using advanced software. Twelve patients requiring implant-supported prosthesis in the mandibular molar area with Temporomandibular disorders [TMD] were selected. The fully digitalized rehabilitation method with advanced software was used for rehabilitation. For each subject, Optical impressions, CBCT scan, and Digital recording of jaw movement data. Guided implant surgery and digitalized prosthetic rehabilitation; were performed. The effectiveness of the digitalized workflow was assessed by evaluating the changes in the joint symptoms before and

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after the end of the treatment, changes in the electromyographic tracings, the precision of the prosthetic artefact, assessed through the amount of chair adjustment operating time and the number of retouching/ modifications to be carried out before the completion of the work. The results showed that the mean operative time required in 12 patients was 9.42 min, significantly less than the time recorded in previous studies when the medium mean was 16.00 min. The mean number of touch-ups [adjustments] was less than 3, most of which were on the interproximal surfaces. There were no significant changes recorded in the electromyography tracings. There were also no changes in joint symptoms. It was found that this way of working was entirely reliable and significantly reduced operating times and the number of appointments. Digital flow is beneficial ei dysfunctional patients, not about improvements in temporomandibular symptoms but in times of operability and prosthetic retouching.

1. Introduction

Temporomandibular disorders (TMD) affect how well the temporomandibular joints (TMJ) and the neuro-muscular system that controls them operate. Several factors contribute to these illnesses and their symptoms, such as trauma, systemic, iatrogenic, occlusal, and mental health disorders. Patients in TMD mainly refer to TMJ for pain, abnormal movements and sound (Karakis et al., 2021). There are still more tools to assemble the models accurately using radiodiagnosis. Radiodiagnosis was used to study the anatomical details of the structure. Several TMJ imaging techniques are recommended in the literature, including panoramic radiography, stratigraphy, conventional computed tomography [CT] and Cone beam computed tomography [CBCT]. Most recently, CBCT were introduced. This radiological technique includes observing the articular bone structures on all three planes, manipulating the images at different depths, and creating three-dimensional reconstructions (Liu et al., 2012). Therefore, with the advent of CBCT, it has been possible to study the movements of the temporomandibular joint digitally using Jaw tracking devices. Cone beam computed tomography [CBCT], in combination with jaw motion tracking devices [JMT], enables virtual assessment of occlusion and TMJ and substantially helps overcome these problems (Zimmermann et al., 2020). Diagnostic imaging using CBCT, tracing and representation of jaw movement are some essential techniques developed to record and assess the stomatognathic system's functional state and plan complex prosthodontic restorations. But until today, the two technologies haven't been combined (Revilla-León et al., 2022). Recently, new software [SICAT Function software] has been introduced, which provides a practical and precise solution for directly merging CBCT and JMT datasets. This allows you to visualize the anatomically correct localization of the specific condylar position and the actual movement of the patient within a three-dimensional volume (Kurbad, 2018). This type of application consists of a single device that acts as a trait union between the two detection technologies, ensuring a precise fusion of the CBCT data sets (Millet, 2018). Thus, CBCT, combined with digital impressions and jaw motion tracking devices, allows the virtual evaluation of the occlusion by integrating dynamic representations of functional movements in compliance with the TMJ (Kordaß et al., 2015). Our work aims to evaluate the accuracy of the all-digital workflow and the JMT for use in designing prosthetic rehabilitation in patients with TMD. All of this was evaluated with changes in electromyographic tracing and patient symptom reporting.

1.1. Workflow process

1) Optical scan 2) CBCT with JMT 3) Surgical guide 4) Optical scan 5) End of work.

2. Materials and methods

The present cross-sectional study was designed and analyzed at King Khalid University, in the Department of Prosthodontics, College of Dentistry and was approved by the institute's ethical committee [IRB/KKUCOD/ETH/2022–23/009; Approval Date: 18/09/2022]. To standardize the study protocol, a synchronized flowchart [Fig. 1]. The patients data were computerized in the outpatient department, reporting for replacing missing teeth in the mandibular jaw using an implant-supported prosthesis. Before being enrolled in the study, all patients were informed about it and allowed to provide written consent. A single examiner used the following inclusion criteria to screen Participants data: complaining of jaw pain or dysfunction, earache, headache, muscle fatigue and orofacial pain. Patients undergoing TMD treatment [based on the bite, physical therapy performed through Transcutaneous Electrical Nerve Stimulation TENS and counselling] are momentarily not symptomatic. Patients without joint problems suffering from autoimmune arthritis were excluded. The change in the symptomatology of TMJ between pre and post-treatment, the precision of the prosthetic artefact, assessed through the amount of chair adjustment operating time and the number of retouching/ modifications to be carried out before the completion of the work and the possible change in the electromyographic EMG tracings, were evaluated in patients.

The workflow adopted in the study to collect digital information was as follows:

1. Optical impressions [with Cerec, Primescan AC Sirona];
2. CBCT scan [with Fusion Bite, Sirona Sidexis];
3. Digital recording of jaw movement data [with Jaw Motion Tracking JMT, Sicat Function]. [Fig. 2]
4. Guided implant surgery and digitalized prosthetic rehabilitation. [Fig. 3]

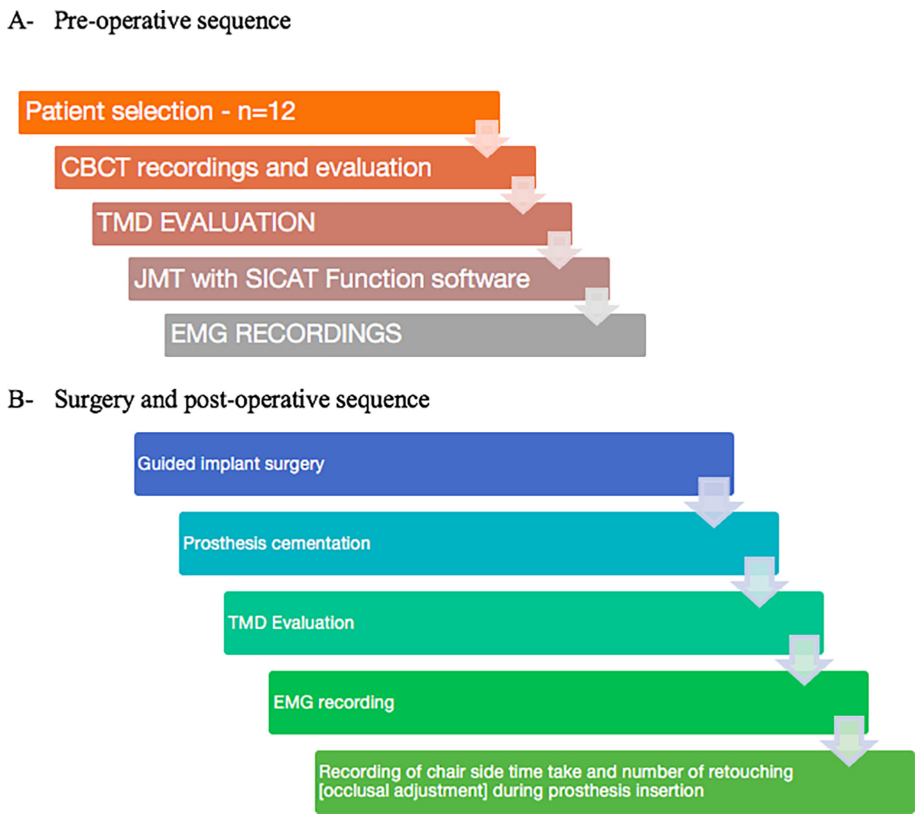

Fig. 1 Flow chart of the study.

2.1. Optical impressions

The method was introduced in 1985, but only in recent years has its use become common: it took more than twenty years to produce machines able to give acceptable clinical results in terms of precision (Rutkūnas et al., 2017). This method eliminates traditional impressions and trays, often unwelcome to the patient and poorly tolerated regarding pharyngeal reflex.

2.2. CBCT scan

For recording the CBCT scan, a CBCT device with a scan time of 14 s, which acquires the maxillary-mandibular region in a rotation of 210° and has a manufacturer-reported radiation dose of 29 µSv at 54 µSv, was used. The voxel size is between 0.15 mm and 0.30 mm, and the grayscale is 12 bits. The field of view has a spherical volume of 11x10 cm. The CBCT data was transferred from the scanner to a workstation, in which the software created 3D images, saved in DICOM [digital imaging and communication in medicine] format (Çakmak et al., 2022).

2.3. Digital recording of jaw movement data

The Jaw Motion Tracking system was used to record the jaw movements. It uses an ultrasonic transmitter, magnetically connected to a metal support called "T-Attachment". The T-Attachment is positioned in the anterior vestibular region of the mandible and carefully individualized to the dental surfaces so as not to interfere with the movements of the mouth (Hanssen et al., 2014).

The next registration phase begins after the chair phase, where all assembly connections are made. The correct positioning of the arch was done considering the Frankfurt plane and the supraorbital line [Fig. 4].

2.4. Surgical procedure: Guided implant surgery

After antibiotic prophylaxis, patients underwent implant surgery through the guided positioning of 2 or 4 implants [as per the requirement for missing teeth replacement in the patient.]. The standard surgical protocol for dental implant placement was followed. After a four-month recovery period, the fixed type of prosthesis was planned for each patient. The fabrication of the prosthesis was done by using the digitalized workflow. All the data were acquired through the software, and the prosthetic design was carried out by combining the various data acquired through digital aids to re-establish the correct occlusal relationships and vertical dimensions of the patients.

2.5. Electromyography

During the study, pre-and post-treatment electromyography was performed to assess how the joint would respond to implant placement. It was evaluated using a sheet showing the movements' accuracy and occlusal and eccentric adjust-

Fig. 2 Evaluation of mandibular movements by JMT, SICAT FUNCTION SOFTWARE.

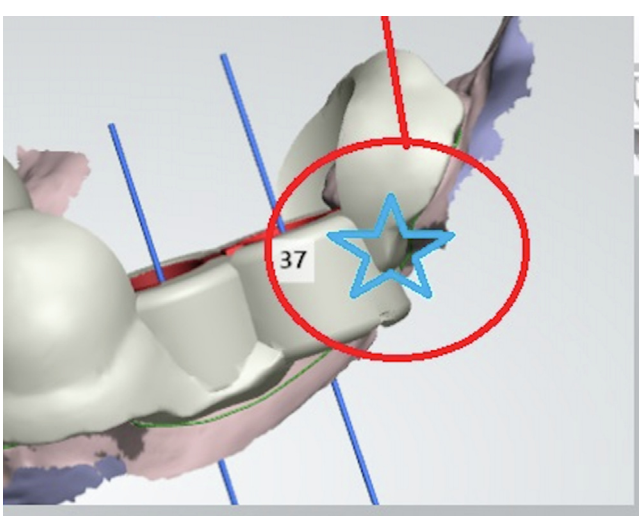

Fig. 3 Guided implant surgery.

ments to be carried out in the chair. The muscles analyzed were: the right anterior temporalis [RAT], the left anterior temporalis [LAT], the right masseter [RMAS], and the left masseter [LMAS].

2.6. Temporomandibular disorders evaluations

Diagnostic Criteria for Temporomandibular Disorders [DC/TMD] were submitted to assess any change or onset of joint symptoms for each patient (Eto et al., 2022). The DC/TMD comprises two domains, a physical Axis I [clinical condition] and a psychosocial Axis II [psychosocial distress] [Table. 1].

A questionnaire is required to assess the patient's pain history as part of the clinical examination for Axis I diagnoses. The patient's psychosocial function, level of distress, and pain-related impairment are all evaluated by the DC/TMD Axis II. It has tools for measuring pain behaviour, jaw function, psychosocial functioning, and distress (Yang et al., 2022).

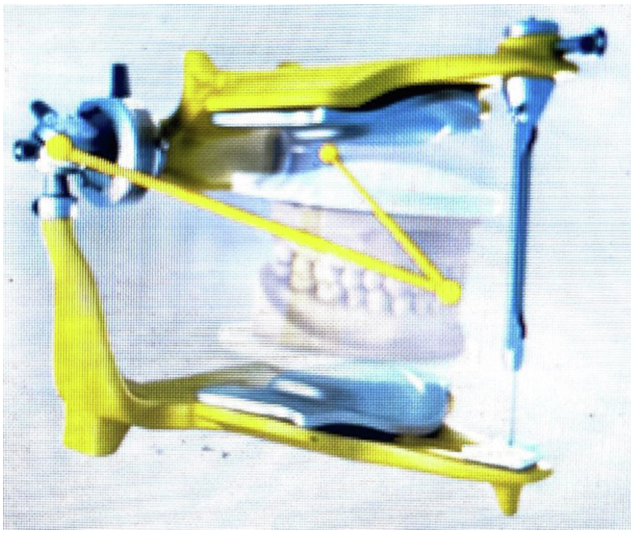

Fig. 4 Integration with joint structures.

3. Results

Symptoms assessed by DC/TMD were joint pain and soreness on chewing; almost all patients suffer from headaches and never had blockages in both opening and closing. A pre-operative cone beam and digital recordings were performed to evaluate the movement. All patients underwent molar rehabilitation with guided implant surgery. The surgical sites were reopened after 3–4 months to insert the healing screws. There were no complications during the early healing period. The prosthetic phase was digitally performed. The artefact was evaluated using a card to evaluate the congruity with the patient's occlusion during the test. After [delivery], electromyography was performed to compare any changes. The prosthetic precision was assessed by the clinician's operating time in the chair, the adjustments made during the clinical chair side time and the comfort experienced by the patient upon delivery of the product.

The mean operative time reported in a previous study for a final implant-supported prosthesis delivery was 16 min, while in this study, it was 9.42 min (Kühnöl et al., 2019). The mean number of touch-ups [adjustments] was less than 3, most of which were on the interproximal surfaces. There were no significant changes recorded in the electromyography tracings. There were also changes in joint symptoms [Table 2].

4. Discussion

Rehabilitating the TMD patient with missing teeth requires an accurate diagnosis and proper planning. The conventional method of replacement of teeth by implant-supported prosthesis requires a lot of time, effort, and clinical visits for the patient. Ultimately, the clinician skills variant is a factor which will affect the result, and these factors are more accentuated in TMD patients. Every area of dentistry has changed thanks to the development of digital dentistry, and so is the case while replacing missing teeth in TMD patients. The development of the digitalized workflow for the rehabilitation of the TMD patient makes the work more objective, reduces the clinical visit, reduces the overall time required for the completion and dependency on the skill is also reduced to an extent (Aslanidou et al., 2017). This study was planned to assess the efficiency of the digitalized workflow for replacing missing teeth with an implant-supported prosthesis in TMD patients. The first step was intraoral impressions to acquire the data; CBCT was combined with the SICAT Fusion Bite and Jaw Motion Tracking System (Lauren, 2014). This study shows a significant decrease in chair operating time in each session, with an average of 9.42 min. According to other studies, the average operative time is 16 min. This study, therefore, showed the predictability and reliability of this technique regarding operative time; also, the number of readjustments needed in the final prosthesis was less. In the present study, the fully digitalized workflow was followed, starting with impressions recorded for the selected patients using an intraoral scan (Aslanidou et al., 2020; Costantinides et al., 2020). The intraoral digital impression is time savings [which inevitably translates into economic savings] and proved to be significant, compared to the traditional method, both in terms of minutes used to detect the scan of an arch [average time 3–5 min] and in terms of the gain in the following phases: development of impressions [plaster cast of the model and squaring] and their physical displacement between the dental clinic and the laboratory (van der Zel, 2008). The 3D models can be instantly sent via e-mail to an STL [Standard Triangulation Language] file, even in clinics equipped with computer-guided design and production machines to create "chair-side" prosthetic products (Jacobs et al., 2018).

Jaw motion tracking, Sicat software has permitted the creation of prosthetic products suitable for mandibular movements and adaptable to the shape and movements of the temporomandibular joint (da Cunha et al., 2017; Jucevičius et al., 2021). The clinician is offered the opportunity to see and study the proper relationship between occlusal morphology and joint dynamics, not extrapolated or approximated, but respecting the anatomy and function. Further scientific tests are necessary, but from the study conducted, it is evident that the condylar and mandibular position of the patient in the "digital reconstruction" are perfectly superimposable to the actual position of the structures detected by the CBCT data without the need for further invasive radiographic or MRI magnetic resonance (Scarfe et al., 2006).

Through the method described in the present study, the modern computerized approach, it is possible to "completely digitize the patient" by collecting all the information necessary for the case study, the initial planning and the subsequent finalization without the patient always being physically present in the office (Mani et al., 2019). In fact, in selected TMD patients in the present study, there was no worsening of the symptoms of temporomandibular dysfunction. Considering these results, this fully digitalized workflow for rehabilitation protocol can be applied in the designing of prostheses in patients with TMD; it can also be helpful in patients with reduced mobility, as it requires fewer operating sessions and a chair time reduction (Moriuchi et al., 2019).

5. Limitations

Certain limitations of the study included the less sample size, time of adjustment given to patients after prosthesis cementa-

Table 1 Diagnostic Criteria for Temporomandibular Disorders.

TMD - Axis I	Physical Axis [Clinical Condition]	
Myalgia	1. Local Myalgia [localization of pain only at the site of palpation] 2. Myofascial Pain [pain spreading beyond the site of palpation, but within the boundary of the muscle] 3. Myofascial Pain with Referral [referral of pain beyond the boundary of the muscle being palpated]	Positive for both of the following: – Pain in the jaw, temple, ear, or in front of ear – Pain modified with jaw movement, function, or parafunction
Disc displacement	1. Disc Displacement with Reduction [in the closed mouth position, the disc is in an anterior position relative to the condylar head, and the disc reduces upon opening of the mouth] 2. Disc Displacement without Reduction, with Limited Opening [in the closed mouth position, the disc is in an anterior position relative to the condylar head, and the disc does not reduce with opening of the mouth. This disorder is associated with persistent limited mandibular opening]. 3. Disc Displacement without Reduction, without Limited Opening [in the closed mouth position, the disc is in an anterior position relative to the condylar head, and the disc does not reduce with opening of the mouth. This disorder is not associated with current limited opening].	1. Positive for at least one of the following: - In the last 30 days, any TMJ noise[s] present with jaw movement or function - Patient report of any noise present during the exam 2. Positive for both of the following: - Jaw locked so that the mouth would not open all the way - Limitation in jaw opening severe enough to limit jaw opening and interfere with ability to eat 3. Positive in the past for both criteria in point 2.
Arthralgia/ degenerative joint changes	1. Arthralgia [pain of joint origin that is affected by jaw movement, function, or parafunction] 2. Degenerative Joint Changes: - TMJ Osteoarthritis [chronic inflammatory disease, characterized by the concomitant presence of clinical signs of continuous crackling noises in the joint, accompanied by arthralgia]. - TMJ Osteoarthrosis [a degenerative disorder involving the joint characterized by deterioration of articular tissue with concomitant osseous changes in the condyle and/or articular eminence].	1. Positive for both of the following: - Pain in the jaw, temple, in the ear, or in front of the ear - Pain modified with jaw movement, function, or parafunction. 2. Positive for at least one of the following: - In the last 30 days any TMJ noise[s] present with jaw movement or function - Patient report of any noise present during the exam.
TMD - Axis II	Psychosocial Axis II [Psychosocial distress]. Distress and pain disability	
Application	**Clinical**	**Clinical or research**
Screening Test	PHQ-4 and GCPS	PHQ-9, GAD-7, PHQ-15 and GCPS
Confirmatory test	Consultation with mental health provider	Structured psychiatric or behavioral medicine interview

Table 2 This table showing Operating time, number of occlusal retouching, changes in EMG tracing and TMD symptoms, in patients enrolled in the study.

PATIENTS	OPERATING TIME	OCCLUSION RETOUCHING	EMG CHANGES	TMD CHANGES
1	9 min	0	None	None
2	7 min	1	None	None
3	12 min	2	None	None
4	8 min	1	None	None
5	9 min	2	None	None
6	10 min	3	None	None
7	7 min	3	None	None
8	11 min	1	None	None
9	7 min	3	None	None
10	10 min	2	None	None
11	13 min	3	None	None
12	10 min	4	None	None
Mean	9.42 min	2.08 [> 3]	—	——

tion, absence of recall visits and assessment, long-term follow-up and assessment of the quality-of-life improvement after rehabilitation in TMD patients. Also, it is recommended to assess this protocol for complete occlusal rehabilitation cases. The limitations of this study are the number of patients and the fact that compared with other studies, we measured by ECG and symptoms by DC/TMD. In addition, we can conclude that this study evaluated symptomatology even post-intervention, and we noticed no worsening in symptomatology and electromyographic tracing. Therefore, the prosthesis designed via digital flow is perfectly integrated into the stomatognathic system. However, further adjustments and refinement of the technology are needed to also allow for improved symptomatology and muscle contractility.

6. Conclusions

From the results of this preliminary study, it can be affirmed that the use of the JMT software has high accuracy in prosthetic precision; it also reduces operating times and allows fewer appointments to create the prosthesis. Furthermore, as seen from the EMGs, no changes in the tracing and symptoms are evident. As can be seen from the data collected in the 12 patients, fewer operative sessions were required, fewer occlusion adjustments were required, no significant changes in the dysfunctional symptoms, and no alterations in the electromyographic trace. Therefore, our practice proposes digital flow to reduce operative time and the number of appointments. It also creates a prosthesis that is perfectly integrated with the stomatognathic system. In fact, unlike other studies where there was an improvement even in terms of dysfunction, in our study, there was no improvement in this regard, probably due to the type of TMD; it might be helpful to investigate the cause of TMD and see on which type of TMD digital flow is most appropriate.

All this testifies that the new software [JMT, SICAT Function software] combined with acquiring images via CBCT is a valid aid and is perfectly superimposable to conventional prosthetic techniques. Also, they allow the clinician a shorter operating time and less discomfort for the patient, especially with systemic pathologies.

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Institutional Review Board Statement

This study was conducted in accordance with the Declaration of Helsinki, was performed in King Khalid University, in the Department of Prosthodontics, College of Dentistry and was approved by the institute's ethical committee [IRB/KKU COD/ETH/2022–23/009; Approval Date: 18/09/2022].

Informed Consent Statemen

Informed consent was obtained from all subjects involved in the study.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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