Digital and Analog Analysis of Occlusion in Conventional and Implant-Retained Complete Dentures: Preliminary Results of a Prospective Clinical Trial

Franciele Floriani, DDS, MSc
Gabriela Panca Sabatini, DDS, MSc
Tarla Thaynara Oliveira dos Santos, DDS, MSc
Analucia Gebler Philippi, DDS, MSc, PhD
Department of Dentistry, Federal University of Santa Catarina, Florianópolis, Brazil

Luiz Henrique Gonzaga, DDS, MSc
Department of Oral and Maxillofacial Surgery, College of Dentistry, University of Florida, Gainesville, Florida, USA.

Luis André Mezzomo, DDS, MSc, PhD
Department of Dentistry, Federal University of Santa Catarina, Florianópolis, Brazil.

Purpose: To digitally evaluate the static and dynamic occlusion of patients treated with both removable conventional complete dentures (CCDs) and implant-retained removable overdentures (IODs) and to correlate two different methods of occlusal analysis. Materials and Methods: Eleven totally edentulous patients were treated with bimaxillary CCDs. Later, mandibular CCDs were replaced by IODs retained by either two or four implants. The distribution of the occlusal contacts in static and dynamic occlusion was compared by means of the digital method (DM; T-Scan III) and the analog method (AM; articulating paper). Scores 0, 1, and 2 were assigned for inadequate, satisfactory, and adequate distribution of the occlusal contacts, respectively. The frequencies of scores were compared in relation to the types of denture by means of Fisher exact test ($P < .05$). The correlation between methods was assessed by means of the kappa agreement coefficient ($\kappa$) and the correlation coefficient phi ($\phi$) ($P < .05$). Results: Significant differences between CCDs and IODs were found in the right lateral mandibular movement (DM, $P = .024$; AM, $P = .008$), as well as in the left lateral mandibular movement (DM, $P = .035$). The methods of analysis of the occlusion showed a moderate agreement ($\kappa = 0.604$; $P < .001$) and a moderate correlation ($\phi = 0.605$; $P < .001$). Conclusion: The digital and analog methods showed a significant agreement and moderate correlation, irrespective of the type of complete denture. The T-Scan III digital system seems to be a consistent and reproducible method to analyze occlusion. Int J Prosthodont 2022;35:27–36. doi: 10.11607/ijp.7562

Conventional complete dentures (CCDs) have been used for decades to rehabilitate edentulous patients and to provide improved masticatory function, esthetics, and phonetics, improving the patient’s quality of life.1 Nevertheless, many complete denture wearers suffer from masticatory dysfunction, gastrointestinal problems, and nutritional deficiencies due to instability, lack of retention, or inadequate support affecting the mandibular CCD.2–4 Implant-retained overdentures have been recommended to overcome these deficiencies, as they offer a reliable and predictable solution for restoring esthetic, functional, nutritional, and social parameters in these patients.5,6

Occlusion is one of the many factors influencing denture stability and plays an important role in the dynamic interplay of the stabilizing and destabilizing forces that keep the denture in place. Proper occlusion results in a balanced load distribution and adequate seating of a denture.7 Some occlusion patterns have been suggested in order to achieve this, such as bilateral balanced occlusion,8–10 lingualized occlusion,11 and canine-guided disocclusion.12,13 Tools such as wax, articulating papers,14 films, silk strips, and, more recently, digital tools such as the T-Scan (Tekscan),15,16 are available to locate interferences and equalize the distribution of occlusal contacts.

Correspondence to: Dr Analucia Gebler Philippi
Department of Dentistry, Postgraduate Program in Dentistry, University of Federal de Santa Catarina, Santa Catarina, Brazil 88040-370
Email: analucia.p@ufsc.br
Submitted December 18, 2020; accepted April 22, 2021. ©2022 by Quintessence Publishing Co Inc.
The T-Scan system has been claimed to overcome many limitations of articulating papers. This device quantifies occlusal contact information and displays it on the computer screen through topographic images and determines the pattern and quality of the occlusion, as well as the magnitude of time and relative force. This digital system has been used in the analysis of occlusion in dentate patients undergoing orthodontic treatment with or without orthognathic surgery. Another study compared the occlusal contacts obtained with either carbon paper strips or with the T-Scan II system in maximum intercuspsation in Angle Class I dentate patients without signs and symptoms of temporomandibular disorders (TMDs). The number and location of the occlusal contacts were found to be equal with both methods in all subjects.

However, there is a lack of evidence on the use of the digital device in patients treated with removable complete dentures, either conventional or implant-retained. Furthermore, no clinical study in prosthodontics has correlated the digital (T-Scan) and analog (articulating paper) methods of analysis of occlusion. Therefore, this study aimed to correlate the findings of occlusion records obtained with a digital method to those of the analog method and to compare the occlusion in patients treated with CCDs and subsequently with implant-retained removable overdentures (IODs). The null hypothesis was that there would be no difference between the occlusal analysis of the conventional and implant-retained removable complete dentures as assessed by means of the digital method in lateral mandibular movement.

**MATERIALS AND METHODS**

This study was developed from a major clinical study that compared the performance of CCDs and mandibular IODs supported by either two conventional (≥ 8-mm) interforaminal implants or four (two conventional [≥ 8-mm] interforaminal implants and two extra-short [4-mm] implants) in the posterior region. The present clinical trial was approved by the Institutional Human Research Ethics Committee in February 2016 (protocol 1.452.492).

Sample size calculation was based on the results of a pilot study comparing the two types of prosthetic restoration (CCDs vs IODs) during lateral mandibular movement assessed using the digital method in 13 patients ($\chi^2 = 9.66; df = 2; probability \alpha = .05$). To achieve an 80% test power, the minimum sample size required was 21 participants (21 participants and 42 removable complete dentures). The methodology for the pilot study was the same as that used for the patients included in the statistical analysis.

**Eligibility Criteria**

The inclusion criteria were male and female patients with fully edentulous arches, from 40 to 75 years of age, American Society of Anesthesiologists (ASA) Classification I or II, intermaxillary relationship Class I, who were not satisfied with their old CCDs.

The exclusion criteria were previous episodes of failure of osseointegration in the region of interest for implant placement, bone augmentation sites, reduced interarch distance (< 15 mm), severe resorption of the mandible (classes V–VI), skeletal malocclusion Class II or III patients, heavy smoking (> 10 cigarettes/day), decompensated type II diabetes mellitus, use of bisphosphonates, head and neck radiotherapy, immunodeficiency, presence of a cyst or neoplasia in the region of interest for implant placement, and presence of bruxism, as assessed with the American Academy of Sleep Medicine (AASM) questionnaire.

**Fabrication of CCDs**

Treatment of the patients included in the study began with the replacement of their old CCDs with new CCDs. Functional impressions were taken with customized trays and monophase polyvinyl siloxane (Examix NDS, GC Europe). The occlusal plane was reestablished based on extraoral references, including the Camper plane and bipupillary line. Stone casts were articulated in a semi-adjustable articulator (Bio-Art). The prosthetic treatment was performed in centric occlusion (CO). This has been defined as the occlusion of opposing teeth when the mandible is in centric relation (CR). CR, in turn, is defined as the condyle disc joint articulating in the most anterior position against the posterior wall of the temporal joint eminence. CR was obtained by using the physiologic swallowing method: when the saliva is swallowed, the tongue is raised, and the mandible is retracted to the position of CR (method of autonomous retraction).

Based on this position, the vertical dimension of occlusion (VDO) was determined, and it was confirmed by the Willis method. The artificial acrylic resin anatomical teeth (33-degree cuspal inclination; Trilux, Vipi) were assembled up to the first molar on each side (six anterior and six posterior teeth) and in a Class I tooth arrangement.

After fabrication and prior to deflasking, the dentures were remounted in the articulator and adjusted in order to remove possible occlusal interferences resulting from processing and to achieve CO and balanced articulation. CO was considered adequate when there were simultaneous bilateral contacts in the posterior teeth with simultaneous contact in the anterior teeth (ie, canines). A balanced articulation scheme was achieved when there was bilateral and simultaneous occlusal contact of the anterior and posterior teeth in excursive movements.

At placement, CCDs underwent all of the necessary basal and occlusal adjustments. First, basal adjustments were made to ensure that the prosthesis was correctly seated in order to provide satisfactory retention and
stability. This adjustment was made by applying a homogenous layer of pressure-indicating paste (zinc oxide–eugenol paste, Lysanda) on the intaglio surface of the prosthesis and placing the prosthesis in the patient’s mouth. The patient was given a piece of cotton to chew. After chewing, the prosthesis was removed, and the areas of excess compression were relieved. After confirmation of an adequate seating, the intraoral occlusal assessment was performed. The occlusion was considered acceptable for adjustment only if a minor interference (less than 0.5 mm of a deflective occlusal contact) was found. The subsequent adjustments were made with the use of digital and analog tools in order to achieve CO and balanced articulation. The final quality of the dentures was assessed by the modified Kapur criteria. Patients were followed up on a weekly basis for a period of up to 1 month to check comfort, handling, chewing, and oral hygiene instructions.

Occlusion Analysis
Patients were left to adapt to the new CCDs for 1 month. After this period, their occlusion was analyzed by two independent and experienced examiners (F.F. and J.S.F.) by means of the T-Scan Novus digital occlusal analysis system (Fig 1a) and the articulating paper (Contacto, Angelus; Fig 2), both with the same thickness. The tests were performed with the patient seated in an upright position in the dental chair. Every precaution was taken to avoid functional movement of the head and neck area.

The distribution of the occlusal contacts was categorized for both the digital and analog methods using the same criteria to allow for a plausible comparison between the two methods.

Digital Occlusal Analysis Method
For the digital method (DM), horseshoe-shaped sensors 130 mm wide and 100 μm thick (Novus Sensor, TekScan, Fig 3) were positioned between the patient’s dental arches. Then the patients were asked to occlude three times in CO (static occlusion) at maximum biting force for 4 seconds with 2-second intervals between each clench. The video generated from the distribution of occlusal contacts in the TekScan 9.0 software ranged from the first dental contact obtained to the maximum of the distributed contacts. A-B was the time of occlusion, and C-D was the time of no occlusion (ie, disocclusion). Point B was selected to symbolize the maximum contact (Fig 4). After selecting a specific point B, the distribution of occlusal contacts was classified by an independent examiner (F.F.) attributing a score of 0, 1, or 2 for inadequate, satisfactory, and adequate contacts, respectively (Table 1).

In addition, patients were asked to perform each mandibular excursive movement (dynamic occlusion) three times, with the sensor in the same position: left lateral mandibular movement, right lateral mandibular movement, and protrusive movement. Then, the distribution of occlusal contacts was analyzed using the T-Scan Novus digital device and TekScan 9.0 software (Fig 1b). For the three measurements of each mandibular movement, the point selected for data extraction was the point with the largest contact area, the same as that used for CO. Scores were attributed by examiner 1 (F.F.) as score 0, 1, or 2 for inadequate, satisfactory, or adequate distribution of occlusal contacts, respectively, for the movements (Table 1).

Analog Occlusion Analysis Method
For the analog method (AM), conventional carbon-stained, horseshoe-shaped articulating papers (Contacto, Fig 2) 100 μm thick were placed between the patient’s dental arches with the aid of Miller tweezers. Patients were asked to occlude in a CO position and to perform right lateral mandibular movement, left lateral mandibular movement, and protrusive movement with maximum force for 4 seconds. After each mandibular movement, the maxillary and mandibular stained dentures were photographed with a digital single-lens reflex camera (D7200, 105-mm macro objective lens and “twin-type” flashes, Nikon), in a small studio box, with a standardized focal distance and the occlusal plane perpendicular to the ground (Fig 1c).

Images were then saved in jpeg format and coded to maintain patient’s data confidentiality and to be analogous with the results of the digital analysis. An independent and blinded examiner (J.S.F.) classified the distribution of occlusal contacts for all mandibular movements, attributing scores 0, 1, or 2 for inadequate, satisfactory, or adequate contacts, respectively, in the same way as adopted for the digital method (Table 1).

Fabrication of IODs
Mandibular CCDs were duplicated in acrylic resin for the fabrication of a multifunctional radiographic and surgical stent. Four months after the randomized placement of either two or four implants in the mandible, mandibular CCDs were replaced by implant bar-clip overdentures. The maxillary CCD was kept in place, and a facebow registration was made directly over it for the purpose of subsequent articulation of the stone casts in the semi-adjustable articulator. The occlusal plane, CO, and VDO references were all obtained with the same techniques as previously used for the CCDs, and the artificial teeth model and setup strictly adhered to the same pattern adopted for the CCDs.

In both groups, prosthetic abutments (synOcta, Straumann) were tightened with 35-Ncm torque to the implants. An egg-shaped, distal extension–free Dolder bar fabricated in chromium-cobalt was tightened with a 15-Ncm torque, splinting either the two- or the four-implant...
Fig 1  (a) Digital occlusion analysis (T-Scan). (b) Distribution of occlusal contacts in lateral and protrusive movements with the digital method. (c) Occlusal photography of the distribution of occlusal contacts in centric occlusion and lateral and protrusive movements (left to right, respectively) with the analog method.
IODs. After a period of mucosal adaptation to the new denture, one single clip, regardless of the number of implants placed, was attached to the intaglio surface of the overdenture at the midline, and the implants were finally loaded. Likewise, IODs were given basal and occlusal adjustments up to the point of achieving the CO and a balanced articulation scheme by performing the same techniques as previously used for the CCDs.9

Digital and Analog Occlusal Analysis Methods for IODs
For the IODs, the same digital and analog methods used for CCDs were used for the registration of occlusal contacts in CO in right lateral mandibular movement, left lateral mandibular movement, and protrusive movement. Thus, intersubject comparisons between the two types of removable complete dentures were possible.

Statistical Analysis
The statistical analysis was performed using SPSS software (IBM) to examine the intraindividual (type of denture) and interindividual (two vs four implants retaining the mandibular overdenture) variables, the occlusal analysis (digital and analog), and the occlusal movements (CO relation, right lateral mandibular movement, left lateral mandibular movement, and protrusive movement). Comparisons were performed using Fisher exact test (exact sig. 2-tailed; P < .05). The methods of occlusal analysis (digital vs analog) were analyzed in two separate ways for the type of prosthesis and the different occlusal movements, considering all evaluations, using Cohen’s kappa (P < .05) and correlation coefficient (φ).

Fig 2  Articulating paper used for the analog method.
Fig 3  T-Scan Novus Sensor.
Fig 4  Distribution of occlusal contacts in centric occlusion.
**RESULTS**

Eleven (n = 11) patients, 9 women (mean age: 67 ± 8.5 years) and 2 men (mean age: 64.3 ± 8.8 years), met the eligibility criteria and were included in the study. A total of 11 bimaxillary CCDs and 11 mandibular IODs (two-implant–supported: n = 7; four-implant–supported: n = 4), accounting for 85 analysis of the occlusion (CO: n = 22; right lateral: n = 21; left lateral: n = 21; protrusive: n = 21), were available for comparison purposes. Overall, 30 implants were placed (conventional: n = 22; extra-short: n = 8), with a survival rate of 100%.

Table 2 shows the results of analyses of both static and dynamic occlusion performed with CCDs vs IODs as assessed by digital and analog methods in the same patient.

In CO and protrusive movements, there was no statistically significant difference between CCDs and IODs between the occlusal analysis methods. There was also no statistically significant difference in the left lateral movement scores between CCD and IOD scores for the analog method; however, a significant difference was found for the digital method (P = .035; Table 2). A significant difference was found between CCDs and IODs in the right lateral movement scores for both the digital (P = .024) and analog (P = .008) methods. There was no statistically significant difference in any of the occlusal positions for two-implant vs four-implant IODs (Table 2), and for this reason, they were considered as a single group.

No significant correlations between the two methods of occlusal analysis were found for CCDs or IODs in CO. For right lateral movement, the correlation between methods was significant for CCDs (P = .002), but not for IODs (P = .201). For left lateral mandibular movement, the correlation was significant for both CCDs (P = .000) and IODs (P = .006). Finally, for the protrusive mandibular movement, the correlation between methods was significant for both CCDs (P = .002) and IODs (P = .026) (Table 2). Considering all data for occlusion analyses (n = 85), the digital and analog methods presented substantial agreement and significance (κ = 0.604; P < .001; Table 3).

**DISCUSSION**

In this investigation, both types of occlusal analysis and both types of complete dentures showed a substantial correlation. This consistency was expected, given that measures were taken to standardize the occlusal scheme and the method of analysis; ie, bilaterally balanced articulation in both types of dentures, the same thickness of the sensor and the articulating paper (100 μm), the patient’s position in the chair, the time of registration of the occlusion, the scores for occlusal contact distribution, and the acquisition of photographs for the analog method.

This correlation has important clinical implications. The digital device accurately records the number of teeth, the distribution of contacts in the arches, intensity as a percentage of pressure (for the most up-to-date version, in Ncm), and duration of the occlusal contacts. It records a video of the entire movement, from beginning to end, outside the mandible. This video can be paused, and the contacts can be analyzed in percentage for each tooth. It is also possible to analyze the quality of the mandibular movement. Last, the sensor can be used for 15 sets of occlusal analyses. Thus, it may be assumed that
<table>
<thead>
<tr>
<th>Centric occlusion (n = 22)</th>
<th>IODs, n (%)</th>
<th>CCD, n (%)</th>
<th>P value^a</th>
<th>P value^b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital</td>
<td>1.000</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfactory</td>
<td>2 (18)</td>
<td>2 (18)</td>
<td>1 (14)</td>
<td>1 (25)</td>
</tr>
<tr>
<td>Adequate</td>
<td>9 (82)</td>
<td>9 (82)</td>
<td>6 (86)</td>
<td>3 (75)</td>
</tr>
<tr>
<td>Analog</td>
<td>.659</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfactory</td>
<td>5 (46)</td>
<td>3 (27)</td>
<td>2 (29)</td>
<td>1 (25)</td>
</tr>
<tr>
<td>Adequate</td>
<td>6 (54)</td>
<td>8 (73)</td>
<td>5 (71)</td>
<td>2 (50)</td>
</tr>
<tr>
<td>κ (P value)</td>
<td>0.035 (.887)</td>
<td>0.233 (.425)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>φ</td>
<td>0.043</td>
<td>0.241</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right lateral (n = 21)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digital</td>
<td>.024</td>
<td>.576</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfactory</td>
<td>1 (10)</td>
<td>7 (64)</td>
<td>5 (71)</td>
<td>2 (50)</td>
</tr>
<tr>
<td>Adequate</td>
<td>9 (90)</td>
<td>4 (36)</td>
<td>2 (29)</td>
<td>2 (50)</td>
</tr>
<tr>
<td>Analog</td>
<td>.008</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfactory</td>
<td>1 (10)</td>
<td>8 (73)</td>
<td>5 (71)</td>
<td>3 (75)</td>
</tr>
<tr>
<td>Adequate</td>
<td>9 (90)</td>
<td>3 (27)</td>
<td>2 (29)</td>
<td>1 (25)</td>
</tr>
<tr>
<td>κ (P value)</td>
<td>1.000 (.002)</td>
<td>0.377 (.201)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>φ</td>
<td>1.000</td>
<td>0.386</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left lateral (n = 21)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digital</td>
<td>.035</td>
<td>.545</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfactory</td>
<td>0 (0)</td>
<td>5 (45)</td>
<td>4 (57)</td>
<td>1 (25)</td>
</tr>
<tr>
<td>Adequate</td>
<td>10 (100)</td>
<td>6 (55)</td>
<td>3 (43)</td>
<td>3 (75)</td>
</tr>
<tr>
<td>Analog</td>
<td>.090</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfactory</td>
<td>0</td>
<td>4 (36)</td>
<td>3 (43)</td>
<td>1 (25)</td>
</tr>
<tr>
<td>Adequate</td>
<td>10 (100)</td>
<td>7 (64)</td>
<td>4 (57)</td>
<td>3 (75)</td>
</tr>
<tr>
<td>κ (P value)</td>
<td>– (.000)</td>
<td>0.814 (.006)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>φ</td>
<td>–</td>
<td>0.828</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protrusive (n = 21)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digital</td>
<td>.361</td>
<td>.242</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfactory</td>
<td>2 (20)</td>
<td>5 (45)</td>
<td>2 (29)</td>
<td>3 (75)</td>
</tr>
<tr>
<td>Adequate</td>
<td>8 (80)</td>
<td>6 (55)</td>
<td>5 (71)</td>
<td>1 (25)</td>
</tr>
<tr>
<td>Analog</td>
<td>1.000</td>
<td>.491</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfactory</td>
<td>2 (20)</td>
<td>3 (27)</td>
<td>1 (14)</td>
<td>2 (50)</td>
</tr>
<tr>
<td>Adequate</td>
<td>8 (80)</td>
<td>8 (73)</td>
<td>6 (86)</td>
<td>2 (50)</td>
</tr>
<tr>
<td>κ (P value)</td>
<td>1.000 (.002)</td>
<td>0.621 (.026)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>φ</td>
<td>1.000</td>
<td>0.671</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

^a CCDs = conventional complete dentures. ^b IODs = implant overdentures.
^c P value for comparison between CCDs and IODs. Fisher exact test.
^d P value for comparisons between 2-implant (control) and 4-implant (test) implant groups.

Bolded values are statistically significant (P < .05).

Agreement (κ) and phi correlation (φ) between the digital and analog methods according to the type of removable denture (n = 10) were calculated for each mandibular movement.
the T-Scan has confirmed many findings of the analog method, increasing its reliability in daily practice.

These results agree with a clinical study by Cabral et al.\(^3\) regarding the reliability and reproducibility of the T-Scan device and the number of occlusal contacts, which were equal for both the articulating paper and the T-Scan. However, in that study, the authors did not clearly describe the methodology used with the T-Scan device, such as the time for occlusion and disocclusion, how the data were interpreted, and the time used for data collection, thus impairing any type of comparison between the methods used.\(^3\)

Despite the efforts to guarantee acceptable retention and stability during fabrication of the new CCDs, it was easier to assess the occlusal contacts with IODs due to the greater retention and stability provided by the implants.\(^3,5,6\) Regardless of their number. No statistical difference was found between CCDs and IODs with either occlusal analysis method (AM and DM) in CO. This result was expected, since little centrifugal force is involved in CO. On the other hand, in dynamic occlusion, a significant difference was observed between the two types of dentures during right and left lateral movements with the digital method, showing more adequate contacts for CCDs. This type of denture is more likely to be subjected to centrifugal forces from the muscles involved in both mastication and speech during excursive mandibular movements. The little dislodgement caused by the lack of retention of the CCDs resulted in a greater number of contacts in excursive movements and in a significant difference observed between the two types of dentures during right and left lateral movements with the digital method.

In this study, two comparisons were made: first, the type of complete denture, and second, the number of implants retaining the IODs, in an attempt to minimize any likely difference in terms of dynamics. In this regard, the mucosal-supported mandibular overdenture itself retained by a single midline clip attached to a Dolder bar splinting all implants, regardless of their number, was considered as the unit of analysis for statistical purposes. Due to the intra-individual comparison (CCD vs IOD), it is acceptable that a lower number of IODs were available for comparison in this ongoing clinical investigation. Therefore, the actual role of the distal addition of implants in retaining an overdenture and of the widening of the anteroposterior spread within the arch on the long-term stability of the occlusion, on the further prevention of bone resorption, and on the reduced need for prosthesis relinings is still to be answered. This is corroborated by the proof-of-concept study by Van Assche et al.,\(^3\) in which additional extra-short implants were placed in the posterior region of the maxilla. These issues are expected to be better addressed with a larger sample size and a longer follow-up period.

In the present study, although the agreement between digital and analog methods was significant, there was a slight tendency toward a higher frequency of satisfactory occlusal contact distribution score for the analog method. This could be explained by the subjective nature of this method, which may be prone to different environmental conditions and different interpretations by the examiner. Moreover, this trend could also be explained by the fact that the T-Scan Novus system provides more information than the analog contact registration system and eliminates possible patient- and examiner-related biases.

Another advantage of the digital method is the possibility of easily accessing previous data of the same patient. Filter\(^3\) observed that two occlusal registrations from the same dentate patient performed at different times had different contact areas; that is, the occlusal registration performed with the T-Scan is likely to show changes when performed at different times. This result is particularly relevant for edentulous patients, especially in this ongoing prospective study, as it is well documented that artificial acrylic resin teeth suffer abrasion as a result of friction of occlusal surfaces and the action of toothbrushes. That may result in change in the occlusal balance achieved at the time of placement of the denture.

The methods of occlusal analysis showed a positive and strong agreement; however, it should be highlighted that this agreement occurred only in that information in which the tools repeat themselves. The T-Scan shows

### Table 3 Agreement Between Digital and Analog Methods Within All Evaluations (N = 85) Regardless of Type of Complete Denture and Mandibular Movement

<table>
<thead>
<tr>
<th>Digital</th>
<th>Satisfactory</th>
<th>Adequate</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satisfactory</td>
<td>18 (21)</td>
<td>6 (7)</td>
<td>24 (28)</td>
</tr>
<tr>
<td>Adequate</td>
<td>8 (9)</td>
<td>53 (63)</td>
<td>61 (72)</td>
</tr>
</tbody>
</table>

Kappa coefficient (P value) Phi coefficient (P value)

0.604 (< .001) 0.605 (< .001)

Data are reported as n (%) unless otherwise indicated. Bolded values are statistically significant (P < .05).
more information and offers more clinical solutions than the analog method, and these were not necessarily addressed in the present study. These include, but are not limited to, the location of the first point of premature contact and the sequence with which occlusal contacts occur, in addition to allowing easy access of previous information of the patient’s occlusion for comparative purposes. Perhaps the encouraging clinical results achieved in the present study with the T-Scan will, in addition to the scientific validation, shorten the current distance that still exists to the clinician, expanding the knowledge and reducing the cost of the digital device.

One of the limitations of this study was how to properly describe, reproduce, and score the achieved occlusion. To the best of the authors’ knowledge, there is no study in the literature that categorizes occlusion in prosthodontics and assesses occlusal quality. Therefore, the authors had to develop a thorough descriptive and reproducible score system that has not yet been validated to compare the data from this ongoing study. The categorization of inadequate, satisfactory, and adequate contacts was proposed based on scientific evidence of the ideal occlusion in complete dentures and balanced articulation. This is particularly relevant as this is a prospective study, where more data will be collected.

To the authors’ knowledge, there is no previous study assessing this digital tool in edentulous patients with CCDs and IODs. Furthermore, the experimental design used in the present study had the main advantage of eliminating possible confounding factors at patient enrollment and reducing the risk of selection bias. In another study design, these analyses could have yielded divergent results. Major shortcomings include that the intrarater and interrater variability (k values) between the two independent examiners were not calculated, and neither were the preliminary or cross-sectional characteristics of the data, as well as the fact that no methodologic parameters were found to enable a plausible comparison to be drawn with previous studies using the T-Scan device.

This paper describes the preliminary results of a prospective clinical trial. Since the minimum sample size was not reached, the conclusions must be interpreted with caution. Therefore, a longitudinal follow-up with a larger sample size is necessary in order to confirm these findings and to assess the long-term maintenance of bilateral balanced contacts. Furthermore, the impact of these possible occlusal changes on the balance of the restorative system, showing clinical complications such as chewing deficiency, overload of the prosthetic components, fracture of artificial teeth and/or the acrylic saddle, marginal bone loss of implants, and volumetric changes in the mandibular bone, are still under investigation.

CONCLUSIONS

Within the limitations of this ongoing experimental clinical study, it could be concluded that:

1. The digital (T-Scan) and analog (articulating paper) methods of occlusal analysis in CCDs and in IODs showed a substantial correlation.
2. CO showed no difference between CCDs and IODs with either the analog or the digital occlusal analysis method.
3. In dynamic occlusion, CCDs showed a significantly higher number of adequate scores during right and left lateral movements with the digital method.

ACKNOWLEDGMENTS

The authors would like to thank Dr. Jerônimo Santiago Floriani for help in the occlusion analysis. The authors report no conflicts of interest.

REFERENCES


CAD-CAM Complete Denture Resins: An Evaluation of Biocompatibility, Mechanical Properties, and Surface Characteristics

The objective of this study was to evaluate the biocompatibility, mechanical properties, and surface roughness of CAD/CAM-milled and rapidly prototyped/3D-printed resins used for manufacturing complete dentures. Six groups of resin specimens were prepared: milled base (MB); milled tooth shade (MT); printed tooth shade (PT); printed base with manufacturer-recommended 3D-printer (PB1); printed base with third-party 3D printer (PB2); and printed base in a vertical orientation (PB2V). Human epithelial (A-431) and gingival (HGF-1) cells were cultured and tested for biocompatibility using resazurin assays. Three-point bending and nanoindentation tests were carried out to measure the mechanical properties of the resin groups. Surface roughness was evaluated using a high-resolution laser profilometer. ANOVA and post hoc tests were used for statistical analyses. There were no significant differences in biocompatibility between any of the investigated groups. MB revealed a higher ultimate strength (P = .008), elastic modulus (P = .002), and toughness (P = .014) than PB1. MT had a significantly higher elastic modulus than PT (P < .001). Rapidly prototyped resin samples with a manufacturer-recommended 3D printer (PB1) demonstrated higher ultimate strength (P = .008), elastic modulus (P < .001), hardness (P < .001), and a reduced surface roughness (P < .05) compared to both prototyped groups using a third-party 3D printer (PB2). Rapidly prototyped samples manufactured with a vertical printing orientation (PB2V) revealed a significantly lower elastic modulus than samples from the group manufactured using a horizontal printing orientation (PB2; P = .011). Within the limits of the present study, CAD/CAM–milled and rapidly prototyped complete denture resins performed similarly in terms of biocompatibility and surface roughness. However, the milled denture resins were superior to the rapidly prototyped denture resins with regard to their mechanical properties. Printing orientation and type of 3D printer can affect the resin strength and surface roughness. 