Current applications of computerized occlusal analysis in dental medicine

Technology has given rise to many computer applications in dental medicine. A computer system has been developed that can accurately record, in real time and in a dynamic "movie" form, the timing of occlusal contacts and their sequence and duration and report on the occlusal forces contained within them. By its very nature, this computerized occlusal analysis system is capable of describing occlusion in ways that classical occlusal instrumentation, such as paper, wax, and pastes, cannot.

Articulating paper, occlusal indicator wax, and occlusal registration pastes all have been thought to reveal more information regarding occlusal contact time and force than has ever actually been verified through scientific analysis. A misconception exists throughout the dental profession that articulator paper and ribbon markings and occlusal indicator wax and paste perforations can illustrate time and force information. However, no paper, wax, ribbon, or paste has been proven to have time measurement capacity.

Conversely, a computerized occlusal analysis system has the capacity to reveal quantifiable time data and relative force data to challenge the classic materials for their perceived descriptive capacity. The T-Scan II occlusal analysis system (Tekscan, Inc., South Boston, MA; 800/248-3669) measures occlusal contact events in real time. It is this real-time recording ability that allows the operator to gain an improved understanding of what paper labeling or wax perforations are attempting to describe but cannot.

Because of this time and force measurement capacity, computerized occlusal analysis offers the operator the ability to optimize an occlusal contact pattern precisely, thereby attaining measurable verification of what has been theorized as ideal occlusal parameters in many classical occlusal principles. The table lists some of these classic principles and their associated verifying time and/or force parameters.

Although it has been suggested that occlusal modifiers can affect the tooth-to-tooth relationships present in a given occlusal scheme and lead to stomatognathic stability or instability, in the final analysis (regardless of a chosen occlusal design or philosophy), the teeth need to occlude without damaging themselves, the periodontal structures, the neuromuscular mechanism, or the ligaments, tendons, and articular discs of the temporomandibular joints.

By combining diagnostic T-Scan II recordings with a thorough occlusal history, clinical examination, dental radiographs, and temporomandibular joint functional analyses with joint vibration analysis and/or magnetic resonance imaging, the operator can gain complete pretreatment occlusal data from which to make a proper occlusal diagnosis.

The correct treatment plan then can be developed, implemented, and finished. Case finishing based upon quantifiable time and force analyses that is controlled with computer-guided occlusal adjustments to teeth, dental prostheses, or implant prostheses can optimize the way the teeth interdigitate and disclude during excursive function. This ensures that the tooth-to-tooth
Occlusal data was obtained by instructing patients to occlude through an intraoral recording sensor (Fig. 1), which was connected to a stand-alone computer. The computer screen displayed a force movie, which illustrated a dynamic columnar time and force display of the recorded occlusion for playback and analysis.

In the mid-to-late 1980s, a series of articles reported that the T-Scan I system was difficult to use clinically and its recording sensor yielded unreliable tooth contact location data. It was reported by Patyk, Yamamura, and Harvey et al. that the T-Scan sensor and graphical interface gave varying tooth contact location representations from one recording to the next. The sensor was deemed inflexible, caused episodic mandibular shifting, illustrated a lack of sensitivity on some of its recording surface area, and failed to reproduce tooth contact location reliably after two uses.

Conversely, other authors found consistent measuring capacity when analyzing time data and reported clinical reliability in data analysis. Kerstein reported reliable discusion time means using the T-Scan I sensor in 1991. Both pre- and posttreatment discusion time means were statistically reliable for seven female patients with myofacial pain dysfunction syndrome (MPDS).

In 1995, a Windows-based T-Scan system was created that maintained the real-time recording capacity of the original T-Scan I system.
and added numerous software features that describe the occlusal contact events in various formats. T-Scan II is a Windows-compliant system that has been integrated into a clinical diagnostic computer workstation. An IBM-compatible PC with a Pentium processor and a minimum of 4.0 megabytes of RAM is required to operate the system properly. The graphical interface uses the familiar Windows format to display the recorded occlusal contact information (in two and three dimensions) and a force vs. time graph (Fig. 2). Figure 3 illustrates the toolbar icons that represent the software features that can be utilized to analyze the recordings.

The recording sensor also was redesigned to contain more than 2,000 0.05 in.² force recorders, known as sencells (proprietary to Tekscan, Inc.), that are aligned in an x-y grid. These sencells can measure 256 levels of force in real time; the T-Scan I could measure only 16 levels. Figure 2 illustrates the color-coded legend that describes the 256 force levels.

Using the T-Scan II system, Kerstein in 1997 reported statistically
significant comparable multiple daily disculsion time measurements for individual subjects and subject group mean values. These disculsion time means were reproduced on four or five distinct measurement dates and were statistically consistent between subjects, within individual subjects, and across subject groups.15

Three studies by Sequeiros et al have illustrated that consistent force and contact location data can be obtained with the T-Scan II sensor.16-18 All three studies concluded that the T-Scan II sensor could be utilized at least four times and reliably match differing bites recorded from the same subject. This finding is twice the usage reported by Harvey et al while recording significantly more data.11 One study reported a sensor precision level of 90-93% reliability through four uses.17 The authors reported that the T-Scan system is simple methodology to measure and reproduce tooth contact positions. Other authors also have reported the valuable diagnostic capability of the T-Scan system.19,22

Clinical applications

There are numerous clinical applications for the T-Scan II system.1,2,15,23-26 Occlusal adjustment procedures performed on differing dental prostheses or natural teeth can be guided by computer analysis to accomplish the ideal occlusal endpoints already described.

Bilateral time simultaneous occlusal contacts

Numerous authors and textbooks have advocated the concept of bilateral simultaneous occlusal contacts as one of the necessary components of an optimum occlusal condition.15,28 All occluding surfaces
Fig. 19. Full-arch implant-supported prosthesis with COF icon positioned poorly, indicating a 79%/21% force imbalance. Force vs. time graph shows force imbalance—the red and green arch half lines do not overlap.

Fig. 20. Full-arch implant-supported prosthesis with COF icon positioned properly, indicating a near 50%/50% force balance. Force vs. time graph shows force balance—the red and green arch half lines overlap.

Fig. 21. Differing tooth and implant mobility chart.

should meet at the same time when, during mandibular closure, the mandibular teeth reach occlusal contact with their opposing maxillary counterparts.

have illustrated that zero seconds is an unrealistic and unachievable clinical result. However, a time frame of 0.1–0.3 seconds between first and last contact is possible to achieve clinically.

Developing bilateral simultaneous contacts on natural teeth and a variety of dental prostheses is a desirable clinical endpoint. Time simultaneity can be evaluated by viewing the center of force (COF) icon and trajectory software features. An example of a nonsimultaneous contact sequence can be seen in the T-Scan II two-dimensional display in Figures 4–7.

In these figures, the trajectory is long and completely outside the COF ellipse. More teeth on the right side of the arch make contact before those on the left, which causes the trajectory to move posterior and right first, then slightly to the left, without crossing the midline (0.469 seconds). This trajectory illustrates a right-sided premature contact sequence, which ends with a right side-to-left side force imbalance of 62% right/38% left.

Conversely, Figures 8–10 illustrate a centered closure COF trajectory, which travels close to the arch midline as both halves of the arch load together. This bilateral simultaneous contact sequence requires 0.260 seconds to elapse from first to last contact with near 50% right side-to-left side balance during the entire closure sequence.

**Immediate posterior discison**

Prolonged posterior discison time (>0.5 seconds per excursion) indicates an occlusal scheme that contains posterior interferences in lateral excursions. The shorter the elapsed time required for posterior teeth to disclude, the faster the anterior guidance takes complete control over excursive function.

Lengthy discison time has been determined to be etiologic for MPDS. In an electromyographic study, it was observed that lengthy discison time (>1.39 seconds) created elevated levels of contractions in the masseter and temporalis muscles. Shortening
the discision time to less than 0.5 seconds per excursion resulted in

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\[ \text{Fig. 22–26. Three-dimensional time delay sequence of maxillary left distal extension implant prosthesis.} \]

With the T-Scan II system, it is possible to record a mandibular excursion commencing with mandibular closure into complete interdigitation, followed by an excursive movement made in one direction (right, left, or protrusion). Playing back the resulting force movie will illustrate where posterior teeth do not disengage in a short time. Appropriate occlusal adjustments can greatly shorten the time required for discision. An example of lengthy posterior discision time (nearly 2.0 seconds) can be seen in Figures 11–14.

The resultant occlusal force distribution is far less destructive to the prosthesis and the implant-bone interface by negating the reliance on poor subjective confirmation of implant occlusal correctness by the patient. A study by Hammerle revealed that, without periodontal ligament (PDL) feedback, patient perceptions of occlusal contacts with implants are eight times less reliable than those with natural teeth.\footnote{14}

Managing the occlusal force loading on a totally implant-supported prosthesis with computerized occlusal analysis can ensure that all implants are loaded with bilateral simultaneity and are loaded uniformly with forces that are directed axially.\footnote{15} This type of occlusal result shares the functional loading among all the underlying implants.

The T-Scan II COF analyses can aid the operator in orienting the occlusal forces during the implant insertion occlusal adjustment procedure.\footnote{1,23,27,28} By adjusting the forces to summate within the centering target area (Fig. 18), the sum vector of the occlusal forces is oriented to seat the prosthesis evenly, both medio-laterally and antero-posteriorly. This force orientation will tend to drive the prosthesis in an axially oriented loading direction.

An example of poor force summation can be seen in the insertion of a maxillary full arch implant reconstruction fabricated from a fixed/detachable prosthesis.
OCCLUSAL ADJUSTMENT

Fig. 27. Unbalanced centric relation bimanual manipulation T-Scan force analysis with force vs. time graph.

Fig. 28. Balanced centric relation bimanual manipulation T-Scan force analysis with force vs. time graph.

anchored to seven endosseous implants [Fig. 19]. There is very poor right-to-left balance (21% right/79% left), which will torque the prosthesis with nonaxially directed occlusal forces.

After a series of corrective adjustment sequences guided by the T-Scan II force analyses, a balanced occlusal result is obtained [Fig. 20]. There is near 50% right side/50% left side balance distributed throughout the arch. The COF icon is located at the midline and is equidistant from the anterior and posterior limits of the occlusal contact distribution. (To place the COF icon within the white portion of the centering ellipse, the occlusal contact distribution needs to extend posteriorly to include second and third molar teeth).

Implants and excursive interferences
Posterior interferences in excursions place extreme leverage on implant prostheses and their materials. Fractured restoratives, prosthesis dislodgment, and screw loosening often are the direct result of lateral forces applied to implant restorations during excursions. Additionally, lateral interferences will torque the prosthesis and induce tension and shear stresses to the underlying bone support. Therefore, it is beneficial to remove all lateral interference contacts from the posterior quadrants of implant restorations and create short posterior discusion time.

Mixed implants and natural tooth occlusal schemes
Natural teeth move vertically and horizontally significantly more than implants do because of the resiliency of the PDL [Fig. 21].

In mixed implant/natural tooth occlusal schemes, this discrepancy in movement can result in an occlusal force transmission problem. Under simultaneous occlusal loading of natural teeth and an implant prosthesis, the implants will interfere with the ability of the natural teeth to depress completely into their PDL fibers. This concentrates the occlusal forces on the implant prosthesis.

The treatment objectives with a segmental or single tooth implant fixed prosthesis are to set up a time delay so that the implant segments occlude just after the natural teeth do. This small time differential allows the natural teeth to load and to depress into their PDL fibers before the implant prosthesis occludes. In this way, time can be used to compensate for the differing mobility of teeth and implants.

By employing this nonsimultaneous occlusal scheme, natural teeth can move physiologically in response to the applied occlusal contact force before the implant prosthesis begins to occlude, which will reduce the force concentration on the implant prosthesis. Clinical cases that employ implants to restore partially edentulous arches that are independent from natural tooth regions are candidates for the establishment of a nonsimultaneous occlusal scheme.

An example of this can be seen in Figures 22–26, where a maxillary left distal extension implant prosthesis is a neighbor to porcelain-fused-to-metal crowns on teeth No. 2–10. The three-dimensional sequential force plots illustrate the desired implant prosthesis delayed occlusal result, beginning with the earliest tooth and implant prosthesis occlusal contacts [Fig. 22]; followed by the natural tooth depression into the PDL, resulting in a natural tooth occlusal force increase [Fig. 23]; then the end of intrasocket tooth movement, resulting in natural tooth maximum force [Fig. 24]; followed by the first significant implant prosthesis force increase [Fig. 25]; and ending with moderately forceful occlusal contacts on the implant prosthesis [Fig. 26]. The time delay is approximately 0.4 seconds [0.530 - 0.122 = 0.408].
Locating the centric relation prematurity

The importance of isolating the centric relation prematurity when performing an occlusal equilibration has been advocated by numerous authors. It is believed that when the condyles are positioned properly in centric relation, both articular discs are positioned properly between the head of the mandibular condyle and the inferior aspect of the eminence.

The centric relation prematurity can be located using various methods involving operator-guided mandibular positioning. The method advocated by Dawson, known as bimanual manipulation, has been accepted as a predictable way to assure the correctness of a mandibular closure into the centric relation position. The first occlusal contact that results from this bimanual manipulation procedure is known as the centric relation prematurity.

Computer analysis generally will reveal a first tooth contact that precedes the patient-perceived first tooth contact. This is because the sensor responds to and records many glancing, light force-contacts of short duration that do not depress the involved teeth deeply enough into the PDL for a patient to "feel" the contact. The T-Scan II system can improve the precision of locating first contact over patient feel and subjective response. An example of a centric relation T-Scan sequence of case finishing adjustments can be seen in Figures 27 and 28. Figure 27 is an example of an unbalanced guided centric relation occlusal contact sequence.

Bimanual manipulation using the Dawson technique will create a COF trajectory that is significantly shorter than the one obtained when a patient self-closes into maximum intercuspation, as it begins more posterior than a self-closure trajectory does. It has a prolonged total time from start to finish due to the slow speed that is actualized during a bimanual manipulation procedure.

Table. Classic occlusal principles and associated verifying times and/or force parameters.

<table>
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<th>Principle</th>
<th>Verification Time/Force</th>
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<tr>
<td>All teeth should contact at the same time—Bilateral simultaneous occlusal contacts where all occluding teeth meet in 0.2 seconds or less with 50% right side/50% left side force balance.</td>
<td>3.777 seconds</td>
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<tr>
<td>All posterior teeth disclude instantaneously once a mandibular excursion is commenced—Immediate posterior disclusion where all occluding teeth disengage and reach, solely, anterior teeth in 0.5 seconds or less from excursive commencement.</td>
<td>4.135.2629.37</td>
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<tr>
<td>All occlusal forces should be directed through the long axes of the teeth—Axial loading and force centering so that there is total occlusal force summation centered precisely within all occluding teeth.</td>
<td>5.402 - 3.777</td>
</tr>
<tr>
<td>Locating and eliminating the centric relation prematurity—There should be no presence of a prolonged first tooth contact (&gt;0.2 seconds in advance of all other teeth) while performing precise occlusal equilibration.</td>
<td>6.363.67</td>
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<tr>
<td>When implants and teeth are located within the same dental arch, the teeth should hit first and move within the PDL fibers to reach the socket wall before the implant prosthesis makes occlusal contact—This is a relatively new concept in which a nonsimultaneous occlusal scheme is employed to compensate for differing tooth and implant mobility.</td>
<td>7.500 - 3.777</td>
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In Figure 27, the first contact occurs at 3.777 seconds. The COF trajectory is positioned in the premolar region on the left side of the dental arch, where it has "squiggled" to the posterior because both halves of the arch are alternatively adding contacts. However, the forces are rising on the left faster than on the right, so the trajectory maintains a position to the left side of the arch. By 5.400 seconds, the trajectory has reached its most posterior position, indicating the end of the bimanual manipulation procedure. The force balance is 67.3% left/32.7% right, with the total duration of this unbalanced centric relation closure equaling 1.623 seconds (5.400 - 3.777).

After a series of corrective centric relation guided force movie recordings and corresponding occlusal adjustments are performed, improved timing and force balance are developed (Fig. 28). The entire closure sequence is brief. The first contact occurs at 2.487 seconds, with the sequence ending at 2.859 seconds. The total time required to complete the sequence is 0.378 seconds (2.859 - 2.481). Note that the COF trajectory is contained completely within the COF ellipse target and that it stays on the midline through the entire sequence, indicating that a bilateral force balance results as more teeth make contact. The overall occlusal balance is 48% left/52% right through the corrected guided contact sequence.

Conclusion

Performing occlusal adjustments with the T-Scan II system can significantly improve the precision of various occlusal adjustment procedures with optimal occlusal results. There are applications for computerized occlusal analysis in conventional prosthodontics, implant prosthodontics, temporomandibular disorders therapy, and in the performance of natural tooth occlusal adjustment therapies.

With the real-time recording capability of the T-Scan II system, tooth contact timing data can be sampled in 0.01 second increments, which predictably will reveal the correct sequence of tooth contacts and their contained forces. This valuable and previously undetectable information provides the operator with dramatically improved predictability over the alternative methodology (without computer analysis) that relies only...
on patient subjective occlusal assessments and paper markings, past perforations, or occlusal indicator wax perforations.

**Disclaimer**
Dr. Kerstein is a clinical consultant for Tekscan, Inc. and Atlantis Components.

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