Validity and reliability of the T-Scan®III for measuring force under laboratory conditions

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SUMMARY
Although measuring bite force is an important indicator of the health of the masticatory system, few commercially available transducers have been validated for routine clinical use. T-Scan®III Occlusal Analysis System allows to record the bite force distribution, indicating its relative intensity and occlusal timing. Nevertheless, even fewer studies have evaluated the validity and reliability of the latest generation of the T-Scan® occlusal analysis system. To determine the validity and reliability of the T-Scan®III system when measuring total absolute bite force under laboratory conditions. Known forces were applied to 18 T-Scan®III sensors, which were classified into two groups differentiated by their production series. Both Lin’s concordance correlation coefficient (CCC) and the intra-class correlation coefficient (ICC) were used to assess the system’s reliability and validity. Considering all the sensors studied, a substantial level (Lin’s CCC 0.969) and a very good level of reliability (CCI 0.994) were obtained. When evaluating the validity of the system, a poor (Lin’s CCC 0.530) and moderate (ICC 0.693) agreement were also obtained. The main factor that negatively influenced the validity of the T-Scan®III under these study conditions was the significant difference in the behaviour of the two sensor groups. The T-Scan®III showed a high degree of reliability when used to perform consecutive measurements. However, the system showed an insufficient degree of validity for measuring absolute force when estimating total occlusal force under laboratory conditions.

KEYWORDS: validity, reliability, T-Scan®III, bite force, bite registration, dental occlusion

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Introduction
Bite force (BF) is an important indicator of masticatory function. Some authors have emphasised the value of assessing BF for both research and clinical purposes (1). Although BF has been measured extensively in research for almost 40 years, it is still not used routinely for clinical assessment. This is partly because the few transducers available have not been commercially validated for routine clinical use (2).

When used clinically, the computerised occlusal analysis becomes a high-tech tool with which it is possible to analyse the functional and parafunctional occlusal contact forces to determine the contact time sequences and observe occlusal pressure surfaces (3). Among the commercially available devices is the T-Scan®III Occlusal Analysis System*, reported by Maness in its first version at the end of the 1980s (4), which can graphically record BF distribution, indicating its relative intensity and occlusal timing. According to the manufacturer, it is an ideal complement to

*Tekscan Inc., Boston, MA, USA.
articulating paper, identifying premature contacts and interferences in the occlusion dynamics. Various studies have evaluated the performance of the several generations of T-Scan® that exist (2, 5–13, while others have applied it as a reference instrument (14–17). The T-Scan® system measures relative force, that is, in arbitrary units corresponding to the internal digital (or ‘raw’) level. According to Throckmorton, clinical situations do not justify the time and effort needed to perform the calibration, which is why the T-Scan®/C226 and other systems based on similar thin film sensors have not been factory calibrated to measure absolute forces (2).

In the few studies that have investigated the validity or reliability of the T-Scan® to quantify absolute BF, it has been suggested that this system generally does not perform adequately. Conversely, several authors have studied the capacities of this system to detect the number and location of occlusal contacts, concluding that the T-Scan® performs well, particularly if used in conjunction with traditional methods (2, 5, 12). Although under conditions of standard use the T-Scan®/C226 provides only relative force values that cannot be used directly to estimate occlusal force (2), it does allow a fast and easy recording of the occlusal contacts, the exact moment when they occur, and the consequent distribution of force (7). Nevertheless, even fewer studies have evaluated the validity and reliability of the latest generation of the T-Scan® occlusal analysis system.

Therefore, it is necessary to ascertain whether the T-Scan III is valid and reliable system for measuring the exerted forces and times for the different types of occlusal motions, to establish with certainty the magnitude of the occlusion and thus avoid the negative consequences of an unbalanced occlusion, such as treatment failures or recurrences (6).

The aim of this study was to determine the validity and reliability of the T-Scan®/C226 occlusal analysis system when measuring total absolute BF under laboratory conditions.

Materials and methods

In the conducted in vitro study, 18 new large HD sensors (code #2001) were used, obtained from two production series (2011 and 2012). Series A was comprised of 8 series 31911T1 sensors and Series B of 10 series 29013T1 elements. Series A-B is the total sample of all 18 sensors. The basic equipment used was an Evolution Handle EH-2, series 102-B445.

Assembly

The specific assembly design consisted of an ideal dental arch model (American Orthodontics), the maxillary arch of which can be displaced vertically by simple lever system diagrammed in Fig. 1c. The occlusal force is generated by acting on the handle manually, enabling its measurement by means of a dynamometric system made up of three identical CI-6537 Pasco force sensors, the individual range of which goes from 0 to 50 Newtons in compression or traction. When locating the three sensors at the same time in mechanical form, the range of the system was expanded up to 150 Newtons, with a resulting sensitivity better than 0.1 Newtons, adequate to conduct this study. To compare the force exerted with T-Scan®/C226, the sensors were connected to data acquisition hardware, the Pasco CI-7650 750 Interface, which measures the force directly in Newtons. This in turn was controlled by the DataStudio 1.9.8r10 software. The system, conveniently located to measure occlusion force, was controlled using the T-Scan®/C226 v.7.01 software. The three force sensors were calibrated using a set of standard weights and a Scout Pro SPE2001 non-analytical digital scale. The mass of the weights measured with each sensor was contrasted with the values calculated from the measurements given by the scale (Weight = mass gravitational acceleration), generating a straight line of correlation possible for use in calibration.

Procedure

Following the instructions in the User’s Manual (v. 7.0x, Rev P, 05/24/2010), the T-Scan®/C226 was carefully positioned so that its sensor would remain centred and prepared to measure (Fig. 1a,b). Of the eight levels of relative sensitivity adjustment offered by the T-Scan®/C226, the ‘default’ option was selected because in previous clinical use of this equipment, this scale was the most frequently used. A force of adequate intensity was applied on this ‘default’ scale...
An adequate intensity has an intermediate value between the minimum and maximum values measured in the T-Scan®III scale, and using the 3-D and 2-D windows of the T-Scan®III software, it was verified that the resulting centre of force (COF) was located in the central zone of the sensor, indicating that the occlusion was adequate; otherwise, the position of the mandibular arch of the model was adjusted using a mount with fine-pitch micrometric screws that enabled its careful displacement and orientation in space (Fig. 1b). Next, using the handle, an increasing occlusion force was applied, which rapidly decreased at the end of the measurement process. Both the applied force and the signal generated in the T-Scan®III sensor were recorded, first by the Pasco system calibrated in units of absolute force (‘Newtons’), and second directly in the (‘raw’) digital levels given by the T-Scan®III internal digital/analog converter (Fig. 2). The abrupt reduction of the force applied at the end of the measurement interval served as reference during the data processing, enabling synchronisation of the temporary curves obtained from both systems. The measurement process takes 10 s, defined by the time that the T-Scan®III uses by default.

With each of the 18 sensors, two consecutive measurements were taken. All the sensors were measured under equal environmental conditions, with the same instruments, assembly, software and operators during the same experimental session.

Both the Pasco system as well as T-Scan®III worked with a sampling rate of 50 measurements per second, and as the actual measurement process took about 7 s (minus dead and desynchronisation times), about 360 data were obtained by measurement system, totalling approximately 13 000 data, 5694 data from the 8 sensors of Series and 7319 data from the 10 Series B.

Data processing

Although T-Scan®III software control can export numeric data in universal ASCII format, this optional feature was not available in the version used in this study. Therefore, the ‘raw’ curve versus the time obtained from the T-Scan®III system was exported as a picture file (png) for each measurement. Then using a routine implemented in Matlab 7.6-R2008a,§ this digital image was converted into the series of numeric data corresponding to the relative force.

However, controlling the Pasco Interface 750 using the DataStudio software, it was possible to obtain the numeric data directly from the three force sensors in each of the measurements taken. Using Matlab, these three signals were added and the resulting value was adjusted according to the calibration curve of the Pasco sensors obtained previously, thereby obtaining the absolute force applied to the dental arch model.

§Mathworks, Inc., Natick, MA, USA.
As the resulting data – ‘raw’ versus time from the T-Scan®III and force versus time from the Pasco Interface – were obtained from independent systems, it was necessary to synchronise them in time. To do this, particular characteristics of the curves to be adjusted were observed, especially the reference of the final drop, moving one in relation to the other until they coincided. Excel 2003 SP3¶ software was used because it permitted control over the process, thus ensuring its correct application. Finally, by eliminating the time parameter, a scatter plot of relative ‘raw’ force versus absolute force was obtained for each measurement.

Statistical analysis

The validity was determined by means of the agreement between the measurements taken with the T-Scan®III system and those from the Pasco system (gold standard), and the reliability was evaluated using the agreement between measurements obtained from the same T-Scan®III system. Through the linear correlation model, using all the data from each of the series studied, the total force quantified by the T-Scan®III system was estimated from the measured ‘raw’ values. The validity was evaluated by quantifying the degree of agreement between the values of force estimated for the T-Scan®III and those measured for the Pasco system. Both validity and reliability were evaluated using the concordance correlation coefficient of Lin (CCC) (18) and the intra-class correlation coefficient (ICC). The statistical calculation was carried out using SPSS-PC v. 20.0.** The level of significance was set at \( P < 0.05 \).

Results

Figure 3 illustrates the total of 13 013 pieces of data collected, together with the regression lines from the three series.

Reliability of the T-Scan®III system

Both Lin’s CCC and the ICC were calculated for each sensor using the two measurements taken with each. Additionally, using the standard error (SE), the corresponding confidence interval was determined at 95%. Table 1 shows a summary of the CCC and ICC values of the three study categories obtained from the values of the coefficients for each sensor. Series A-B includes

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*Microsoft Corp., Redmond, WA, USA.

**SPSS, Chicago, IL, USA.
all the sensors and thus represents the general performance of the T-Scan/C226 III system; Series A only includes the behaviour of 8 sensors and Series B the other 10.

**Validity of the T-Scan® III system**

Given the trend observed in the dispersion of the data in Fig. 3, a linear equation was used to fit Series A-B, Series A and Series B: \( \text{Force}_{\text{estimated}} (F_e) = m \times (T-Scan) + c \), where \( m \) represents the slope of the correlation line and \( c \) is the intercept with the vertical axis (ordinate). The estimated force \( F_e \) is expressed in Newtons (N), and the values quantified using the T-Scan® III are represented with total (raw) digital value. Thus, it was possible to acquire the estimated force values once the raw values were ascertained.

**Error generated by the prediction of force**

Using the linear regression lines, the absolute force value was estimated from the raw values provided by the T-Scan® III. Then, the prediction error was determined by comparing this estimated force with the reference force provided by the Pasco system. Figure 4 shows the error obtained using the regression line from Series A-B, predicting all the data from Series A-B, and finally comparing this estimation with the real force values given by Pasco for Series A-B. The same procedure was repeated for Series A and Series B.

**Agreement between the prediction and the real force value**

The agreement between the prediction of the force from the raw values given by the T-Scan® III, and the absolute force values measured by Pasco were analysed using Lin’s CCC and the ICC. Table 2 summarises the values found together with the corresponding evaluation.

**Discussion**

The aim of this study was to determine the validity and reliability of the T-Scan® III system under laboratory conditions. The most important category is Series A-B as this represents the real clinical use of the T-Scan® III system, where no distinction is made between sensors from various sources. Consequently, we considered the system should be evaluated for its
clinical use in measuring occlusal force based on its general performance using sensors from different series.

Figure 3 illustrates the marked differences in the behaviour of the two series of sensors used in this study. Under the study conditions, Series B exhibited average sensitivity approximately 2.5 times greater than Series A, given the same total applied force, the sensors in group B showed raw values several times higher than Series A. During real clinical use of the T-Scan®III, sensors with different series are used; therefore, this result shows that it would not be possible to use the T-Scan®III to measure absolute BF accurately with a single generic calibration for the system.

Nevertheless, considering each series of sensors separately, it was possible to find higher levels of agreement, concluding that it is possible to use the T-Scan®III to adequately quantify the level of occlusal force as long as a specific calibration for each sensor or series of sensors is performed from each individual regression curve. Obviously, this process would not be very practical during clinical use of the system, particularly with patients with natural teeth, being reserved only for studies under laboratory conditions, like this study, or with patients with removable teeth as proposed by Throckmorton (2). Although under clinical conditions, T-Scan®III provides relative values only force that cannot be used directly to estimate occlusal force (2), this information may be useful for the clinician, as it allows quick and easy registration of occlusal contacts, the exact instant they occur, and with a consistent force distribution (7).

Determining the agreement between the two measurements taken with each sensor, the T-Scan®III showed a reliability level between substantial and very good (Lin’s CCC 0.961 and ICC 0.994 in Table 1) for each of the three series. Thus, all the sensors consistently quantified the applied relative force when used in two successive measurements.

The linear regression curves in Fig. 3 enabled modelling of Series A and B; however, perfect fits were not obtained. The coefficients of determination found (0.964 and 0.859 for Series A and B, respectively) reveal differences between sensors from the same series, especially in the case of Series B. Thus, for

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**Table 2.** Lin’s CCC and the ICC values for the three series

<table>
<thead>
<tr>
<th>Series</th>
<th>Lin’s CCC</th>
<th>CI (95%)</th>
<th>Agreement</th>
</tr>
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<tbody>
<tr>
<td>A-B</td>
<td>0.5302</td>
<td>0.5199–0.5405</td>
<td>Poor</td>
</tr>
<tr>
<td>A</td>
<td>0.9815</td>
<td>0.9806–0.9825</td>
<td>Substantial</td>
</tr>
<tr>
<td>B</td>
<td>0.9242</td>
<td>0.9209–0.9274</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Series</th>
<th>ICC</th>
<th>Sig.</th>
<th>Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-B</td>
<td>0.693</td>
<td>0.000</td>
<td>Moderate</td>
</tr>
<tr>
<td>A</td>
<td>0.991</td>
<td>0.000</td>
<td>Very good</td>
</tr>
<tr>
<td>B</td>
<td>0.961</td>
<td>0.000</td>
<td>Very good</td>
</tr>
</tbody>
</table>

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example, when a total force of 120 N was applied, the sensors in Series A showed raw responses between 1000 and approximately 2300, as those in Series B responded with raw values approximately between 4100 and 5200. The differences in the measurement ranges and the dispersion of the responses between the two series of sensors can thus be clearly observed.

The results of this study agree with the few previous studies evaluating the capacity of the T-Scan®III system to quantify BF. Throckmorton concluded that the T-Scan®III sensors used directly without any type of covering did not sufficiently exhibit the degree of validity when measuring absolute occlusal forces. It was also mentioned that given the variability between sensors, these should be calibrated individually if the absolute force is to be estimated from raw values (2).

Working with the first version of the T-Scan®, Lyons evaluated the degree of accuracy of the system when measuring force in arbitrary units. He found that the T-Scan® did not measure force accurately but did adequately detect the presence of occlusal contacts (12). The significant reliability that the T-Scan®III showed when measuring relative force in the complete arch is consistent with the results published recently by da Silva, who investigated the behaviour of a sensel (minimum unit of sensitivity that comprises each sensor, 0.1 x 0.1 in size), and determined that the reliability was adequate but that further research is needed to verify the variability in the properties of the total surface of the sensor (5). However, our study worked with a significantly higher number of applied force levels and pressing sensels in a manner and amount very similar to real use.

Future investigation will endeavour to study the reliability the sensors exhibit during repeated use to assess the manufacturer’s recommendation that a particular sensor be assigned to a specific patient for the purposes of follow-up. It would also be useful to characterise other aspects of the system such as response times, sensor hysteresis and saturation, the effect of performing a preloading process, and determining the behaviour of the rest of the T-Scan® sensitivity scales. Finally, in accordance with da Silva (5), it would be important to conduct validity and reliability studies on the behaviour of the sensel to establish the precision with which the T-Scan®III detects the number, position and intensity of occlusal contacts across the sensor surface.

Conclusions
The authors conclude that when estimating the total occlusal force under laboratory conditions, the T-Scan®III did not show an appropriate degree of validity, thereby rendering it inadequate for this function in clinical use. The reliability of the system was high when used for two consecutive measurements, which might improve its validity by individually calibrating each sensor. The main factor encountered that negatively affects the validity of the T-Scan®III for measuring total absolute force under the conditions of this study was the great difference in behaviour between the sensors of the two series; however, it must be noted that there were also differences noted between sensors in the same series.

Disclosures
The authors declare they received no funding for this investigation. The authors declare they have no conflict of interests.

References

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