Validation procedures in computerized dentistry
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Link to publication

Citation for published version (APA):

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CHAPTER 2

Accuracy of Dental Scanners

Keywords: Dental CAD/CAM, Surface digitization device, Laser-triangulation scanning, Dental imaging, Scanning accuracy
2.1 Abstract

Statement of the problem: The need for proper validation and verification methodology for CAD/CAM systems is imminent. CAD/CAM systems existing of an optical impression system, design software and a fabrication machine have to perform to a certain level, whereby manufacturers need to prove the effectiveness of the system as a whole. However, especially when dental surface digitization devices are used as open, stand-alone applications in dental outsourcing, a reliable standard test for comparison is necessary.

Purpose: This study evaluates a proposed test method to be used to quantify “digitizing quality” with respect to accuracy and reproducibility of two dental surface digitization devices. Comparability of the characteristics should become ensured.

Method: Two laser light section scanners: “DentaScope II” (3D Alliance GmbH, Germany) [D] and “D200” (3Shape A/S, Copenhagen, Denmark) [S] were evaluated by means of the “Sphere Test”, that involved repeated measurements (N >= 5) of a precision ball (radius: 6.00 mm) according to a pre-defined protocol. The surface information was received as unmatched, overlapping point clouds and statistically processed with CYRTINA® software package (Oratio B.V., Hoorn, The Netherlands). The standard deviation of all points as well as a measure for undercutting the equator were determined.

Results: The standard deviation for the radius for D and S were 7.7 (± 0.8) and 13.7 (± 1.0) μm respectively. The equator undercut elevations were –2.0⁰ and –0.25⁰ for scanner D and S respectively. Conclusion: Scanner D had a significantly higher accuracy than S (p<0.05), corresponding with the smaller pixel distance of the sensor. Both devices show adequate accuracy and reproducibility and have an adequate ability to detect the equator. The test is also suitable for calibration purposes.

1 For the software package the name “CYRTINA®” is used instead of “CICERO®”, which was the former name. CICERO® is a registered trade mark owned by Elephant Dental B.V., Hoorn-NL.
2.2 Introduction

The emergence of different modalities for the computerized production of custom dental devices, proper validation and verification methodology for CAD/CAM systems becomes of interest to dental professionals and custom dental device manufacturers. CAD/CAM components such as the digitization system, design software and fabrication machine are medical devices that have to perform to a certain level, whereby dental device manufacturers need to prove with reasonable assurance the safety and effectiveness of the devices [1].

In order to manufacture a custom prosthetic device with an automatic CAD/CAM procedure the preparation surface and surroundings need to be digitized using a mechanical [2,3] or optical [4,5] surface measuring device. During the entire manufacturing process, each sequential step will add to final inaccuracies, which has its limits set on 50-75 μm [6-14]. In evaluating the performance of integrated, closed CAD/CAM-systems results have been obtained that fulfilled this limit. May et al. [15] measured the precision of fit of the crown fabricated with CAD/CAM technology for the premolar and molar teeth fit to a die and found that the mean gap dimensions for marginal openings, internal adaptation, and precision of fit for the crown groups were below 70 μm. These findings showed that the crowns studied can be prescribed with confidence knowing that the precision of fit will consistently be less than 70 μm. To remain within this generally accepted precision the accuracy and reproducibility of the first step of surface digitization needs to be considerably lower than this value. A dental surface digitization device can be defined as: a device used to record the topographical characteristics of teeth, dental impressions, or stone models by analog or digital methods for use in the computer assisted design and manufacturing of dental restorative prosthetic devices.

Accuracy is a measure for the digitizing quality of the measured points. An existing standard for characterizing “Digitizing quality” of coordinate measuring machines has already been devised in an international standard [16], but the test methods are laborious and not dedicated to the geometries and undercut measurements that are encountered in dental surface digitization.

The first objective of the study is to find a value for the measurement error of digitized dental surfaces by testing a new statistical evaluation method on two laser light section triangulation scanners.

A second objective is to evaluate whether the proposed test method using a standard artefact can serve as a dental standard for dental surface digitization devices. The test method should further provide a possibility to objectively test and compare vendor specifications.
2.3 Materials and Methods

The surface digitizers in this study are used to measure a replica gypsum model. Dental surface digitizers use different sensors with different physical measurement methods to get physical measurement of the surface [5]. Depending on the sensor one point, a line of points or a field of points are measured at a time. To measure a larger area the digitizer can be equipped with an extra axis that translates, rotates or tilts the sensor or object. The software on the computer transforms the measured points to a virtual 3D surface.

Figure 2.1: “DentaScope II” (3D Alliance GmbH, Germany) (left) and “D200” scanner (3shape A/S, Denmark) (right).

Figure 2.2: Test sphere in holder (left) and a result of one pass scan lines on the sphere (right).
Table 2.1 compiles a type selection of dental surface digitizers with respect to the sensor used. The table has been structured according to the number of dimensions of the sensors and the underlying physical principle of measurement.

The two scanners under evaluation in this study use a two-dimensional method and make use of a laser light section. This method is based on the triangulation principle. By widening a laser beam using a special cylinder lens or an oscillating mirror, a “light curtain” is generated. For laser light section, the linear CCD array known from point triangulation, e.g., is replaced by a sensor matrix. Image-processing algorithms are used to determine the position of the light line, diffusely reflected by the test object, on the sensor matrix. The distance between the laser light section sensor and the test object surface is calculated as for the triangulation method, extending the evaluation of a point to that of a line.

<table>
<thead>
<tr>
<th>Type</th>
<th>Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>One-dimensional methods (involving at least two mechanical axes for three-dimensional measurements)</td>
</tr>
<tr>
<td>Ia</td>
<td>Tactile method</td>
</tr>
<tr>
<td></td>
<td>Focusing method</td>
</tr>
<tr>
<td></td>
<td>Video autofocus method</td>
</tr>
<tr>
<td>Ib</td>
<td>Methods based on triangulation</td>
</tr>
<tr>
<td></td>
<td>Point triangulation</td>
</tr>
<tr>
<td></td>
<td>Holographic methods</td>
</tr>
<tr>
<td></td>
<td>Holographic conoscopy</td>
</tr>
<tr>
<td></td>
<td>Chromatic focusing method</td>
</tr>
<tr>
<td>II</td>
<td>Two-dimensional methods (involving at least one mechanical axis for three-dimensional measurements)</td>
</tr>
<tr>
<td></td>
<td>Methods based on triangulation</td>
</tr>
<tr>
<td></td>
<td>Laser light section</td>
</tr>
<tr>
<td></td>
<td>Interferometry methods</td>
</tr>
<tr>
<td></td>
<td>White-light interferometry</td>
</tr>
<tr>
<td></td>
<td>Focusing methods</td>
</tr>
<tr>
<td></td>
<td>Confocal microscopy</td>
</tr>
<tr>
<td></td>
<td>X-Ray</td>
</tr>
<tr>
<td></td>
<td>CT, DVT</td>
</tr>
<tr>
<td>III</td>
<td>Three-dimensional methods (w/o external frame of reference)</td>
</tr>
<tr>
<td></td>
<td>Methods involving structured lighting</td>
</tr>
</tbody>
</table>

Table 2.1: Type of dental surface digitizing system.

A dental digitization device should measure enough points with a certain accuracy (digitizing quality) to define the surface and especially the preparation line. This means that sufficient points spread across the surface (point density) have to be determined, so that the software of the next step can create a complete and accurate surface with enough reproduction of detail.
Dental objects have a continuously changing surface with sharp edges, steep walls and undercuts, this is especially true for the most important area, the preparation line. The characteristics of the scanners are listed in Table 2.2.

For testing the point cloud mathematically we need to test them against a mathematical surface. The most basic 3D surface is a sphere which has an equator line just like the one we can see in teeth. The sphere has, like a dental preparation, a continuously changing surface and is therefore the perfect object to quantify the undercut as a measure how far a scanner can measure steep walls and undercuts. This study was directed to a simpler method using a standard certified sphere as artifact with a specially developed software package Cyrtina® CSD (Oratio B.V., Hoorn, The Netherlands) to analyze the aquired point cloud from two laser line scanners from different manufactures (Fig. 2.1).

The standard ISO 10360 describes the method to measure the error of coordinate measuring machines (CMM’s), as the measuring uncertainty of the part measured. For validating CMM’s with optical sensors the guide line VDI/VDE 2617 part 6.2 [17] can be used. According to this guideline, the probing error characterizes the three-dimensional errors of the entire system consisting of digitization system, distance sensor, and accessories (like articulators) within a very small measurement volume. In order to exclude extremes using a small number of measurements, one in 35 measured errors may be re-measured 10 times. When digitizing the complete surface, a lot more points (>1000) are digitized. This gives the possibility to analyze the error in a more statistical way. Especially when the error is distributed with a ‘normal’ distribution (Fig. 2.3) the error in one measured point is given with a certainty. By determining the mean value (Rmn) and the standard deviation (RSD) the measurement error for one point can be given with a 99.7% (3σ) certainty. Accuracy for the user can be defined as: RsdE = |(Rmn-Rk)| + Rsd + U. Rk stands for the calibrated radius of the sphere and U stands for the expanded measurement of uncertainty according to ISO 13060.

The method to give the measurement uncertainty for the whole measure volume according to ISO 10360 / VDI2617 [17] is complex and time consuming. For customers and vendors and for calibration purposes a more practical method is needed. Given the huge amount of measured points a statistical analysis of a single artifact should be enough to give a practical test to validate the accuracy (measuring uncertainty).

An Aluminium Oxide precision ball (Fig. 2.2) Grade 10 with a nominal radius of 6.000 ± 0.0005 mm (Saphirwerk AG, Switzerland) was used as artefact, mimicking the size of a molar. Balls are specified according to ISO3290. By using Grade 25 or better the diameter
and surface error is smaller than +/- 1 μm and can be assumed discarded. The Grade 10 ball has a roundness (diameter) deviation of maximum 0.25 μm (G μ inch) and a surface roughness of 0.02 μm.

The shiny sphere is glued onto a post and then sprayed with titanium dioxide powder finer than 1μm (Met-L-Check Developer 70, Matcon, The Netherlands) for retro-reflectivity and opacity of the surface. Spraying the surface gives an error but when applied correctly this will be small compared to the measured error. A beginners’ mistake is the application of too little or too much powder causing uneven coating thickness and overlaps. This is directly visible in the measured error distribution.

Before scanning both scanners were calibrated according to the manufacturers instruction.

![Normal Gaussian distribution of the radius standard deviation (histogram).](image)

**Figure 2.3: Normal Gaussian distribution of the radius standard deviation (histogram).**
### Table 2.2: Scanner characteristics.

The ball is digitized from 8 views by rotating the rotation table by 45°. The linear axis moves the laser line to −7 mm from the center of the sphere. With a set speed the linear axis is moved to + 7 mm, thereby moving the entire sphere through the laser curtain. Each step of 0.05 mm a measurement is taken by the sensor camera and the reflected surface points are calculated.
The speed of movement is calculated by the step size times the number of lines per second the camera can measure (Frame rate): \( v = L_{\text{step}} \times f \). \([\text{mm/s} = \text{mm} \times 1/\text{s}]\).

The total scan time is measured, this includes the time needed for the movements, capture, calculation into 3D world points and the loading into the work memory. From this we can calculate the effective frame rate:

\[
     f_{\text{eff}} = \frac{N}{t_{\text{tot}}} = 8 \times \frac{L}{L_{\text{step}}} \times \frac{t}{t_{\text{tot}}} = 8 \times \frac{14}{0.05} \times \frac{1}{t_{\text{tot}}} = 2240 \times \frac{1}{t_{\text{tot}}} \text{ (lines/second)}
\]

\[\text{Figure 2.4: Sphere in world and polar coordinate system.}\]

To get a representative value for the accuracy and a measure for undercut it is important to scan with the same global settings, like laser power, camera line detection threshold, as used for digitizing a die except for the area scanned. The complete sphere must be digitized because the measurement error is most likely be larger at the edge of the sphere which has the greatest slope with respect to the sensor. The number of points measured on near vertical areas is influenced by the laser power, camera line detection threshold and surface reflection ability. It is possible to use a gypsum replicate sphere but it will have an larger error due to the duplication process. The data point cloud of the scanner is used in its most raw form with overlapping parts and without extra filtering. Filtering the data with software will generally improve the tested accuracy by smoothing the ‘surface’ and loosing fine surface structure. Matching software can sometimes improve the accuracy by minimizing the overlap error between different views (19). When the scanner uses a matching algorithm to merge the different views, it is important to scan an irregular surface of the surroundings of the ball to facilitate matching. Otherwise the result is unpredictable due to the fact that sphere parts are rotation symmetrical along 3 axis.

Scanner D has no filtering and the points measured by the sensor are transformed (moved and rotated) to the 3D world coordinates according to the position of the axis. Scanner S uses the
points of both camera’s by selecting the ‘best’ point on the line. The points are save as ASCII coordinate files. The resulting point cloud is read into the “Cyrtina® CSD” (Oratio B.V., Hoorn, The Netherlands) software package.

From the point cloud the ‘best fitted’ sphere is calculated. This is done by an iterative method (pseudo code 1), starting from a starting center, given in by clicking in a reference marker, and start radius. Each point in the cloud, belonging to the sphere, is transformed to a polar coordinate (Fig 2.4: \( P_r-P_c = \{ Az, El, Ri \} \)) giving a radius and a direction. From this the three dimensional errors of the point are calculated \( \{ Az, El, Ri-Rmn \} \). The center is moved by a fractional part of the mean error and this is repeated until the change in mean radius and center is smaller then a given value (Fig. 2.5).

With the acquired sphere centre (Pc) the mean (Rmn), standard deviation (Rsd), minimum (RMIN) and maximum radius (RMAX) can be calculated (Fig. 2.6).

---

```plaintext
// pseudo code 1: estimating sphere center and radius

Pc₀, start point center (marker P1)
Rmn₀, start value radius
n = number of points in point cloud \{ P₁, .., Pₙ \}
j = 0

repeat
j = j + 1

dPᵢ = Pᵢ - Pcⱼ⁻¹
Rᵢ = | dPᵢ |
Rmnⱼ = ( \( \sum \) Rᵢ ) / n

dPmnⱼ = ( \( \sum \) (dPᵢ / |dPᵢ|) * (Rᵢ - Rmnⱼ⁻¹)) / n // mean error in point

Pcⱼ = Pcⱼ⁻¹ + dP * 0.5 // next iteration
Rmnⱼ⁻¹ + 0.5 * (Rmnⱼ + Rmnⱼ⁻¹) // centre sphere + radius

// tempered - smoothing iteration

until | Rmnⱼ - Rmnⱼ⁻¹ | < \( \triangle R \)
and | dP | < \( \triangle dP \) // end criteria iteration
```

---

*Figure 2.5: Pseudo code 1 for estimating sphere center and radius.*
Figure 2.6: Pseudo code 2 for calculating statistics.

With the found minimum and maximum values the distribution of the radius can be plot as a histogram by dividing the range in 200 intervals and counting the number of occurrences of a radius in the interval. At the same time the number of radius that deviate one \( R_{SD} \) and 3 \( R_{SD} \), from the mean radius, can be counted.

```
// pseudo code 2: calculating statistics: mean and standard deviation

Pc = center sphere
n = number of points in point cloud \{P_1, ..., P_n\}

dP_i = P_i - Pc
R_i = \mid dP_i \mid

\text{Rmn} = (\sum R_i) / n \quad // \text{mean radius}

\text{Rsd} = \sqrt{\frac{\sum (R_i - \text{Rmn})^2}{n}} \quad // \text{standard deviation}

\text{RMin} = \text{MIN}(R_i) \quad // \text{minimum radius}
\text{RMax} = \text{MAX}(R_i) \quad // \text{maximum radius}
```

Figure 2.7: Pseudo code for calculating histogram distribution.

The error distribution of the radius can also be plotted against the surface. For this the surface of the sphere is overlayed by a grid with the azimuth \((-180^\circ ... 180^\circ)\) and elevation \((E_{\text{min}} ...\)
90°) range divided into small intervals. For each interval of azimuth and elevation the number of points, mean radius, minimum and maximum radius can be determined. This can be compared as dividing the earth in degrees longitude and latitude and determine the median, minimum and maximum heights of measured point by e.g. a satellite. With a high enough point density each interval of azimuth-elevation should be filled with points until the undercut blocks the sensor view at a certain elevation. The elevation that still has points at the complete circumference (equator) is the slope angle that the scanner is capable to digitize. The lowest elevation that has one and three points in each interval for azimuth is noted as ElN=1 and ElN=3. When ElN=3 is negative the scanner is capable to scan the surface with enough points to capture vertical surfaces and even partial undercuts needed to detect the equator.

The value for N_AZ and N_EL are arbitrary but must be chosen in accordance to the surface reconstruction need of point density (Fig. 2.8). The Cyrtina® CAD software converts the point cloud into a meridian wire model. The highest number of meridians used was 200.

```plaintext
// pseudo code 4: calculating surface (Azimuth, Elevation) distribution
N_AZ = 200 // arbitrary value, equal to plot area
N_EL = 200 // arbitrary value, equal to plot area

dAz = (A2MAX - A2MIN) / N_AZ

dEl = (ElMAX - ElMIN) / N_EL

dP_l = P_l - P_C

polevec( Az, El, R_l ) = dP_l

l_i = (Az_i - A2MIN) * dAz

m_i = (El_i - ElMIN) * dEl

N_{lm} = COUNT( l = l_i, m = m_i ) // count number of equal pair( l, m )

R_{mn_{lm}} = SUM_{lm} ( R_l ) / N_{lm} // mean radius for each grid [l][m]

R_{MIN_{lm}} = MIN_{lm} ( R_l ) // minimum radius for each grid [l][m]

R_{MAX_{lm}} = MAX_{lm} ( R_l ) // maximum radius for each grid [l][m]
```

Figure 2.8: Pseudo code 4 for calculating surface distribution of points.
2.4 Results

The results are shown in two screens. On the statistics dialog screen (Fig. 2.9 left) the starting point for the center and radius can be given in together with the iteration stop criteria. The center and radius of the sphere are then optimized by iterating until the stop criteria are met. With the found center the sphere, statistical data can be calculated and the histogram and surface error can be shown.

The surface error distribution is drawn as a grid of colors (Fig. 2.9 right) indicating the value out of the range \{ R_{\text{min}} .. R_{\text{mn}} - R_{\text{sd}} .. R_{\text{mn}} .. R_{\text{mn}} + R_{\text{sd}} .. R_{\text{max}} \}. With the [+]/[-] buttons it is possible to walk through the grid of intervals getting the local value.

![Figure 2.9: Sphere statistics (R_{\text{mn}}, R_{\text{sd}}, E_{\text{l N=3}})(left) and a graphical representation (right) for scanner D.](image)

The sphere test results are listed in table 2.3. Scanning only one side of the sphere (1 view, 0°) gives an indication of the basic capabilities of the scanner using only the sensor and one axis. The influence (error) of the rotation table and the other axis are constant and have no influence on the measurement.

Both surface digitization systems show adequate accuracy, but scanner D was significantly more accurate in the measurement of the ball geometry \(R_{\text{sd E}} = 7.7 \pm 0.8\mu m\) than scanner S \(R_{\text{sd E}} = 13.9 \pm 1.0\mu m\)(p<0.05). This is as expected because the field of view and the corresponding sensor pixel size are smaller. A measure \(E_{\text{l N=3}}\) for the ability to digitize steep walls and undercuts \(E_{\text{l N=3}}<0\) indicating if enough points are present to be used in the next phase of surface reconstruction, for the production of dental CAD/CAM restorations were –2.0° and -0.25° for scanner D and S respectively.
# Chapter 2

<table>
<thead>
<tr>
<th>Scanner</th>
<th>D</th>
<th>D</th>
<th>S (B=30°)</th>
<th>S (B=30°)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nr of views</td>
<td>0°</td>
<td>8 x 45°</td>
<td>0°</td>
<td>8 x 45°</td>
<td></td>
</tr>
<tr>
<td>Scan length at step size</td>
<td>mm</td>
<td>14 ± 0.05</td>
<td>14 ± 0.05</td>
<td>14 ± 0.05</td>
<td>14 ± 0.05</td>
</tr>
<tr>
<td>Radius nominal, Rk</td>
<td>mm</td>
<td>6.0000</td>
<td>6.0000</td>
<td>6.0000</td>
<td>6.0000</td>
</tr>
<tr>
<td>Radius mean, Rmm</td>
<td>mm</td>
<td>6.0002</td>
<td>5.9998</td>
<td>5.9998</td>
<td>6.0000</td>
</tr>
<tr>
<td>Radius deviation, Rsd</td>
<td>mm</td>
<td>0.00047</td>
<td>0.0065</td>
<td>0.0130</td>
<td>0.0129</td>
</tr>
<tr>
<td>Radius accuracy</td>
<td>mm</td>
<td>0.00059</td>
<td>0.0077</td>
<td>0.0142</td>
<td>0.0139</td>
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<tr>
<td>Radius accuracy deviation</td>
<td>mm</td>
<td>±0.0002 (N=400)</td>
<td>±0.0008 (N=85)</td>
<td>±0.0005 (N=40)</td>
<td>±0.0010 (N=40)</td>
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<td>Measured points N</td>
<td>53521</td>
<td>432770</td>
<td>21019</td>
<td>167895</td>
<td></td>
</tr>
<tr>
<td>Points in ±/3 Rad</td>
<td>%</td>
<td>99.0</td>
<td>99.1</td>
<td>99.5</td>
<td>99.5</td>
</tr>
<tr>
<td>Radius undercut El, N=1°</td>
<td>°</td>
<td>-2.087</td>
<td>-0.25</td>
<td>1</td>
<td>1</td>
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<tr>
<td>Radius undercut El, N=3°</td>
<td>°</td>
<td>3.38</td>
<td>10.45</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Scan time</td>
<td>s</td>
<td>164</td>
<td>208</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>effective lines / sec</td>
<td>l/s</td>
<td>13.6</td>
<td>10.7</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

1. Measured with a fixed 30° angle camera / vertical for comparison, Scanner S can tilt its axis and can get an extra 30° by scanning from the side.
2. Scan time includes all movement and calculations until scan data is available as point cloud. Scanner S has 2 camera’s and could scan the same surface with less views (e.g. 6x60°).
3. Error in the sphere radius do not change much, even at warm up the change is smaller then 0.001 mm. To include errors due to mathematical and printing an extra error of 0.001 mm was included.
4. The measurement uncertainty has been set to 0.001 mm to differentiate the error measured between manufacture and user.
5. CSD software can automatically test Scanner D for N sphere tests, spread mostly due to temperature drift. Value of scanner S is a combination of several short series.

### Table 2.3: Sphere test results.

#### 2.5 Discussion

Dahlmo et al (18) developed and evaluated a system for measuring the magnitude of the variation between a computer-aided design (CAD) object created on the computer screen and a replicated object produced by computer-aided manufacturing (CAM), using controlled geometric forms, a square and a cone. For all objects, the systematic error was at most 15.5 microns. Interoperator difference was small. The variation of measurement error was greater for the square object compared to the cone. However, the variation of object was higher for the cone object than for the square. The total standard deviation was 7.7 microns. Thus, the...
total random error caused by object variation and measurement error was in approximately 95% of all measurements less than 15 microns. This is approximately the same order of magnitude as with scanner S. Denissen et al [10] studied the precision of the same scanner D, measuring chamfered and bevelled margins of partial coverage tooth preparations for computer-aided design/computer-aided manufacturing (CAD/CAM). Instrument precision was defined as the ability to reproduce the same margin in repeated measurements and expressed as the coefficient of variation as a percentage. Instrument accuracy for chamfered and beveled margins was estimated by correlating their measurements to the measurement of the margin of a spherical calibration "phantom" with known dimensions. Accuracy was expressed as the standard deviation. The precision errors for the box- and cusp-chamfered margins and cusp-bevelled margins were 3.9%, 3.4%, and 2.4%, respectively. With regard to accuracy the standard deviations of the measurements of the box- and cusp-chamfered margins and cusp-bevelled margins were 19 microns, 21 microns, and 24 microns, respectively, compared to 15 microns for the phantom. This study shows, when comparing the results with those of the present study that “real life” accuracy at difficult edges are two to three times the accuracy of the scanning device. The guidance [1] provides FDA's recommendations to manufacturers for evaluating and labelling optical impression systems for CAD/CAM of dental restorations. An optical impression system for CAD/CAM of dental restorations is a device used to record the topographical characteristics of teeth, dental impressions, or stone models by analogue or digital methods for use in the computer assisted design and manufacturing of dental restorative prosthetic devices. Such systems may consist of a camera, scanner or equivalent type of sensor and a computer with software. The manufacturer need only show that its device meets the recommendations of the guidance or in some other way provides equivalent assurances of safety and effectiveness (1). The values for scanner D are similar of those reported for a similar scanner (Preciscan, DCS, Switzerland) mentioned in a publication of Mehl (19), who mentioned the accuracy to be +/- 13.2 +/- 3.6 micrometers.
2.6 References


7. Van der Zel JM. Ceramic-fused-to-metal restorations with a new CAD/CAM system, Quintessence 1993;24, 11:35-42.


