Clinicians use tooth preparation principles to maximize the retention and resistance of complete crowns. This in turn is thought to influence the longevity and survivability of the restoration. Manufacturers have provided recommendations for an ideal preparation that maximizes the retention and resistance form of the prepared tooth. According to the “Glossary of Prosthodontic Terms,” retention is the ability to resist removal along the path of insertion, and resistance is the ability to prevent dislodgement by oblique or horizontal forces. In practice, both retention and resistance are closely related and are described as phenomena that cannot be separated. Several factors are under the control of the operator during tooth preparation and known to affect retention and resistance. These include the total occlusal convergence (TOC) angle, total surface area, surface roughness, preparation height and width, and auxiliary features such as boxes or grooves.

Parameters of ceramic lithium disilicate complete crown preparations by general dentists such as TOC, preparation height, and margin width were collected and reported in part 1 of this study. The TOC angles produced were always greater than the recommended angles for both anterior and posterior teeth, and preparation widths were always less than the recommended minimal width of 1 mm. In part 2 of...
Clinical Implications

By implementing an objective measuring method, retention and resistance theories can be applied to make clinically relevant recommendations for success.

In this study, conventional retention and resistance theories and formulae found in the literature were applied to predict clinical serviceability. Total surface area affects the amount of area for the bonding cement and is important in crown retentive tests. The greater this area is, the greater the retention of the restoration will be. Several studies have published surface area of in vitro retention tests of standardized abutments or preparations using adaptation of foil and directly measuring, or weighing the applied foil. A simplified way of measuring surface area is by approximation and the assumption that the preparation abutment resembles a truncated cone/cone frustum (CF) or a right truncated pyramid (RTP) (Fig. 1). To the authors’ knowledge, no clinical studies measuring each individual surface area of crown preparations have discussed their long-term effects on the resulting restoration, despite the fact that the bondable and cementable surface area of an abutment plays a major role in clinical serviceability.

Preparation parameters considered individually cannot predict the success of a restoration. For this reason, combining these features and attempting to discover their combined effects with varying angles and lengths have been the subject of many studies. Currently, a few quantifying methods and theories have been introduced in the literature, with many regarding the quantification of the resistance form as an important factor in the success of a restoration.

Resistance form depends on the direction and magnitude of the oblique force, the preparation geometry, and the luting agent used to cement the crown. Woolsey and Matich evaluated the effect of the preparation height and taper on the resistance form and found that a reduction in the convergence angle increased the resistance form. They also found that the addition of grooves provided resistance to horizontal dislodgment, which was also confirmed by Potts et al.

Dodge et al tested the effect of the convergence angle on the retention and resistance form and found that the resistance form was more sensitive to changes in the convergence angle. Owen reviewed the literature and stated that while proximal grooves contributed to the resistance form, the minimum required clinical taper value was still unknown.

Zuckerman introduced a method of calculating resistance forms by using a boundary circle. This concept is based on the width of the base of the abutment and whether the rotation of the crown.

Figure 1. Formulas used. A, Cone frustum. B, Right truncated pyramid. C, Limiting taper. D, Resistance length.

\[ T(H/B) = 0.5 \sin^{-1}(H/B) \]

If 1/2TOC > T(H/B) = No resistance form

If 1/2TOC < T(H/B) = Resistance form

\[ N = 2(B - W). \sin \theta \]

\[ RL = (H/\cos \theta) - N \]
is higher or lower than the height of the cusp. This was taken further in the concept of the limiting taper, which was introduced by Parker et al.\textsuperscript{19-21} This method applies a mathematical formula based on the height-to-base ratio of a preparation to determine the preparation’s resistance form characterized as the limiting taper. The resistance form is based on an arc of the restoration pivoting about a point on the opposite side. If the TOC value is within the limiting taper, then that side of the restoration is considered to have a resistant form. If it is higher, then that side is considered not to impart resistance to dislodgement of the restoration by oblique forces. The idea is an “on” or “off” concept. Clinical acceptability requires the preparation to have resistance form in all directions: facial, lingual, mesial, and distal.

Trier et al.\textsuperscript{22} showed that failed castings were found on abutments that lacked resistance form and that the clinical success reflected the all or none nature of resistance form in accordance with the limiting taper theory. Cameron et al.\textsuperscript{23} looked at the limiting taper concept versus the linear or progressive relationship and found an abrupt change in the graph of the cycles it took to dislodge the crowns as a function of taper. This suggested that it was reasonable to use the limiting taper as a guideline for minimally acceptable preparation.

The limiting taper concept was disputed by Wiskott et al.\textsuperscript{24,25} who showed that the relationship between the taper and the resistance form and the abutment height and resistance form is approximately linear. The linear relationship was suggested to be directly influenced by the length of the axial wall that provided resistance. A formula for this length is provided by the study of Leong et al.\textsuperscript{26} For the purposes of this study, this theory will be called the resistance length.

In theory, all these factors play their part in increasing retention and resistance. Ideally, measuring clinical crown preparations and finding their values for surface area, limiting taper, or resistance length should indicate

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2}
\caption{Mean surface area of each tooth using cone frustum and right truncated pyramid formula with dividing lateral and occlusal surface area and corresponding 95\% confidence interval. CF, cone frustum; RTP, right truncated pyramid.}
\end{figure}
the retention and resistance of the tooth preparation. The greatest barrier to measuring clinical crown preparations has been the lack of an ideal, simple, objective, and universally accepted measuring method.

In part 1, a custom program was created based on the coordinate geometry method (CGM). This methodology objectively measures abutment geometry parameters in a convenient manner by using computer-aided design scanned images of the abutments. Simple geometric parameters of a large number of clinical treatments are easily attainable with the CGM method. The purpose of this study was to show how the CGM methodology can also obtain information for calculating the surface areas by using both CF and RTP methods and for determining the resistance forms of each crown abutment by implementing the most accepted crown resistance theories—that is, the limiting taper and resistance length theories.

MATERIAL AND METHODS

A total of 236 ceramic lithium disilicate (IPS e.max Press; Ivoclar Vivadent) complete crown preparations made by general dentists were prepared and scanned in 3 dimensions (3D), as described in part 1. Stereolithography (STL) data sets were extracted from the software and inserted into a general-purpose 3D viewer (3D-Tool-Free: http://www.3d-tool-usa.com). Two cross-sectional images from each preparation were captured (faciolingual and mesiodistal views) with the 2 planes 90 degrees around the assumption of a central axis. The images were uploaded onto custom computer software using the CGM, which automatically tracked the outline of the images into x- and y-coordinates.

Surface areas using the CF and RTP approximations were calculated with their respective confidence intervals and limiting taper and resistance length were calculated with formulas as seen in Figure 1.

RESULTS

The pooled mean surface area as seen in Figure 2 and individual numeric values are presented in Table 1. Each tooth had approximated values using the CF and RTP, with clear differentiation of the top surface area and the lateral surface areas. Mean surface areas for mandibular preparations from central incisors to second premolars are less than their maxillary counterparts, whereas the maxillary and mandibular molars have close mean values. Incisors have less occlusal/top surface areas compared with premolars and molars. The lowest mean surface area is seen in mandibular central incisors (CF=33.97

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CF, cone frustum; RTP, right truncated pyramid; Lat, lateral surfaces; Top, top surface area; CI, confidence interval.

Table 1. Mean surface area (mm²)
mm², RTP=41.75mm²), while the largest mean surface area is seen in the maxillary second molar (CF=105.44 mm², RTP=117.50 mm²). The lateral surface area for maxillary incisors and maxillary molars is similar, as the increase is attributed to a larger top surface area.

The resistance length and limiting taper for premolars were calculated as seen in Figure 3, and molars are presented as seen in Figure 4. The resistance length is presented individually as dots on the left, while the limiting taper is represented as percentages on the right. The highest overall percentage of preparations showing resistance form are the maxillary premolars, with at least 30% of all maxillary premolar preparations showing resistance form. The facial aspect of all posterior teeth showed the highest percentage resistance forms compared with all other aspects.

**DISCUSSION**

These results provide the numeric data for surface areas, limiting tapers, and resistance lengths for a large number (n=236) of clinically produced complete crown preparations. The method used in this study is useful in determining and quantifying the parameters of a preparation without the need for conventional sectioning and tracing processes. The method takes theories presented in the literature and provides the values for actual clinical preparations by using a simple 3D scan. These retention and resistance theories, based on the geometric parameter of a preparation, can be tested to determine their correlation with clinical preparations and their supposed survival potential.

The findings for surface area showed that using the RTP formula always resulted in a higher overall surface area. The top and lateral surface areas are affected by different forces, which is why they were presented separately, as shown in a previous publication. The lateral surface area values for molars were very similar those in the study by Chan et al., but the top surface area was noticeably less. This is because the molars used in this study had higher TOC values, resulting in less occlusal surface area. This in turn leads to a smaller top surface area available for bonding.
This study presents the limiting tapers and the resistance lengths together for premolars and molars. Many of the premolars and molars failed to provide any resistance form for both theories. The reason can be traced to the TOC values, as both formulas rely on this value. Furthermore, the percentages and plots do not add up across all 4 sides, showing that on a single preparation there are areas of no resistance and areas that provide resistance. Because clinically acceptable preparations require all 4 sides to exhibit resistance, the percentage of unacceptable teeth is much higher. The effect this has on a preparation and the resulting restoration with uneven distribution of resistance area is unknown.

Clinicians should be aware of the effect a larger TOC angle has on the amount of surface area available for bonding and the resulting resistance form of a preparation. This study gives an alarming indication that many clinical complete crown preparations are failing to provide any resistance and are relying on other factors (such as the bonding system) to provide the majority of the resistance.

Much debate is evident in the literature as to the absoluteness of the limiting taper and the more linear indication of resistance length. Their correlation is evident, but can a higher resistance length indicate a superior clinical performance? The custom software created in this study provides an excellent way of measuring clinical crowns and applying these theories. Clinical studies could include measuring preparation parameters so that one day the debate about resistance theories can be put to rest.

The authors recommend clinical trials implementing the methodology used in this study or a similar objective measuring method to record and observe these parameters in order to understand how to maximize retention and resistance for the long-term success of a restoration.

CONCLUSIONS

Although this study does not provide clinical implications of such retention and resistance theories, the CGM methodology does provide an ideal platform and useful tool in determining such implications for future in vitro retention tests and clinical trials.

REFERENCES


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