



Assessment of Retention and Resistance Form of Tooth Preparations for All Ceramic Restorations using Digital Imaging Technique

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ABSTRACT

Aim: This *in vitro* study evaluated the resistance form of die preparations for all ceramic restorations and, thereby, explored the concept of effective taper and its correlation between the ideal in theory and actual in the clinical situation by analyzing the digital images of the die preparations.

Materials and methods: Scanned digital images of 114 die preparations for all ceramic restorations (n = 114) were collected from a dental laboratory. All the images were also analyzed digitally using Adobe Photoshop® software to analyze the degree of taper (angle of convergence) of each preparation and then applied the Zuckerman's circle, and the Lewis perpendicular methods were used to measure the resistance form.

Results: For the current study, the overall average degree of taper was found to be 20.9° (range, 2–80°), which is more than what is recommended by most previous studies and also sharply greater than the textbook ideal of 3 to 6°. Mean degree of taper for maxillary was 17.56° (anterior—10.50°, posterior—23.7°), and for mandibular teeth, it was 25.22° (anterior—15°, posterior—28.45°). Out of the 64 analyzed images of maxillary teeth, 61 presented resistance form, while 3 were without it. Out of the 50 mandibular teeth analyzed, 38 possessed resistance form, whereas 12 were without. All the anterior teeth showed resistance form irrespective of the arch.

Conclusion: The degree of taper showed a significant relationship with resistance and retention form, which was inversely

proportional to each other. The recommended “degree of taper” is not always the clinically achievable as advocated in textbooks, as it is modified by various factors in the actual clinical situation.

Clinical significance: The study provides scientific background regarding the relationship between the degree of taper with resistance and retention form, and the relationship was found to be inversely proportional to each other. The recommended “degree of taper” is not always the clinically achievable as advocated in textbooks, and it is modified by various modifying or limiting factors in the actual clinical situation.

Keywords: All ceramic, Degree of taper, Resistance form, Retention form, Tooth preparations.

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INTRODUCTION

Conventionally, clinicians have used resistance form as a basis for determining guidelines for preparation design, which ensures the clinical success of cemented cast restorations. Resistance form is defined as the features of a tooth preparation that enhance the stability of a restoration and resist dislodgment along an axis other than the path of placement.^{1,2} While retention form counteracts tensile stress, resistance form counteracts shearing stress. All tooth preparations require the incorporation of the certain design features, such as parallelism, length, and surface area that are mainly associated with retention and resistance along with other factors, such as axial surface, groove, box, and pinholes to prevent the dislodgment of the restoration by functional stresses.³

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The most retentive preparation is theoretically represented as the one with parallel walls (zero taper). Nevertheless, some of the earlier studies found that some degree of axial wall taper is inevitable and necessary to ensure complete seating of casting, though retention and resistance decreased. Although 6° is widely accepted as the gold standard and criterion of taper for full veneer crown preparation, studies show the actual taper of most preparations to be <12°.4-8 Tylman said that to develop frictional resistance, the near parallelism of axial walls in tooth preparations is necessary, which meant a 2 to 5° taper, an arbitrary figure advocated earlier for cast inlay preparation.9,10 Jørgensen's11 study on the relationship between retention and convergence angle in cemented veneer crowns related taper to retention and determined maximum retention with a 5° taper.8 A subsequent study on factors influencing the retention of cemented gold castings by Kaufman et al9 identified that the 5° taper is the point at which the most significant increase in retention occurs.12 However, Smith et al8 found that the overall mean taper for full veneer crown preparation in preclinical prosthodontics exceeded his targeted criterion of 12°; however, he stated that a 12° criterion is more realistic than a 6° criterion for full veneer crown preparations.

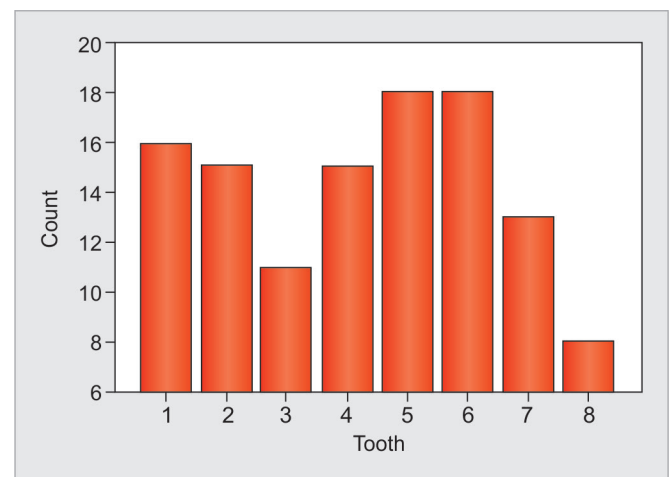
Retention and resistance forms are the characteristics of a preparation that prevent castings from becoming uncemented, debonded, or cement failures, which are one of the top three reasons for the replacement of castings.13,14 Tier et al's12 study on dislodged crowns and retainers revealed that there was a fundamental relation between clinical success or failure and the all-or-none nature of resistance form. They proved dislodged crowns came almost exclusively from preparations with tapers that did not provide resistance form and over 95% of all castings that failed by becoming uncemented lacked resistance form.13,15,16 Furthermore, Walton13 evaluated the modes of failure and the influence of various clinical characteristics on the outcome of the metal-ceramic fixed dental prosthesis and observed that 13% of them failed due to loss of retention.17

This study aims to discern an actually achieved degree of taper in a clinical situation, and the textbook recommended degree of taper. Furthermore, it also assessed how resistance and retention form correlate with the degree of taper of tooth preparation.

MATERIALS AND METHODS

Scanned digital impressions of die preparations used for all ceramic restorations were collected from a dental laboratory. Images included die preparations of all ceramic single crowns (79 preparations) and bridge (35 preparations) restorations only. All the available images (n = 114) from the laboratory were included in the study sample (Graph 1). Samples were grouped into maxillary and mandibular, and again subgrouped, based on tooth type, for making intergroup as well as intragroup comparisons (Table 1).

All the available images were analyzed with the help of Adobe Photoshop CS6® photo editing software. To find out the degree of taper of each image, two straight lines extended from base of the preparation in a coronal direction along the mesial and distal margins of the preparation until they meet at a common point (Fig. 1). The resultant angle was measured for each preparation



Graph 1: Distribution of samples into subgroups

Table 1: Sample distribution

| Maxillary teeth | | | Mandibular teeth | | |
|-----------------|-----------------|-------|------------------|-----------------|-------|
| Tooth | | Total | Tooth | | Total |
| Incisors | Central incisor | 12 | Incisors | Central incisor | 4 |
| | Lateral incisor | 11 | | Lateral incisor | 4 |
| Canine | | 7 | Canine | | 4 |
| Premolars | First premolar | 8 | Premolars | First premolar | 7 |
| | Second premolar | 12 | | Second premolar | 6 |
| Molars | First molar | 6 | Molars | First molar | 12 |
| | Second molar | 4 | | Second molar | 9 |
| | Third molar | 4 | | Third molar | 4 |
| Total | | 64 | Total | | 50 |

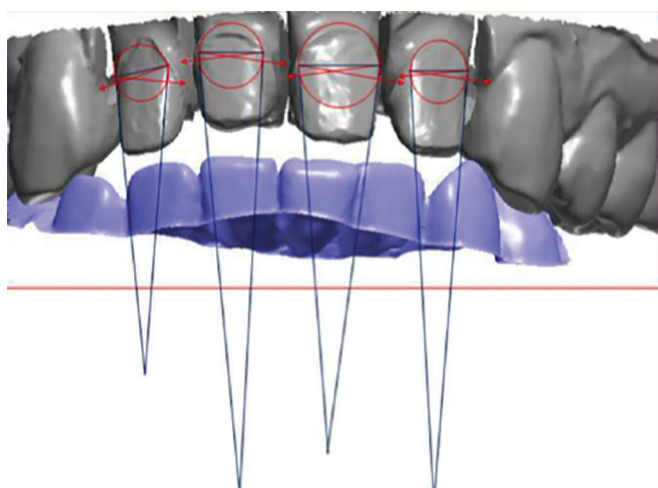


Fig. 1: Analysis of the degree of taper and resistance using Adobe Photoshop

and recorded as the “degree of taper” or “degree of convergence” (Tables 2 and 3).

To assess the retention and resistance form by Zuckerman’s method,^{16,18} a circle is extended around each preparation with the width of the base of preparation taken as diameter. The point at which the circle intersects the mesial or distal margin (extended line or taper line) of the preparation indicates the demarcating point between areas with and without retention and resistance form (Fig. 1). Points of the preparation outside of the circle have resistance form. Whereas, when the point of intersection is on the extended line above or occlusal to the top of the preparation, the preparation lacks resistance form (Tables 2 and 3).

In the Lewis perpendicular method,^{16,18} the dividing point between the resistive and nonresistive sections of a preparation wall is taken as the point of intersection with the perpendicular line from the center of rotation on the opposing margin (Graphs 2 and 3). All points occlusal to the point of the intersection have resistance form, and all points gingival to it. Both the methods provide the same point of intersection and, thereby, the same results. Based on these measurements, preparations were recorded as preparations with or without resistance form (Tables 2 and 3).

Table 2: Degree of taper and resistance form—maxillary teeth

| Tooth | Degree of taper | Resistance form |
|-------|-----------------|-----------------|
| CI-1 | 9 | Yes |
| CI-2 | 12 | Yes |
| CI-3 | 12 | Yes |
| CI-4 | 14 | Yes |
| CI-5 | 2 | Yes |
| CI-6 | 13 | Yes |
| CI-7 | 17 | Yes |
| CI-8 | 9 | Yes |
| CI-9 | 2 | Yes |

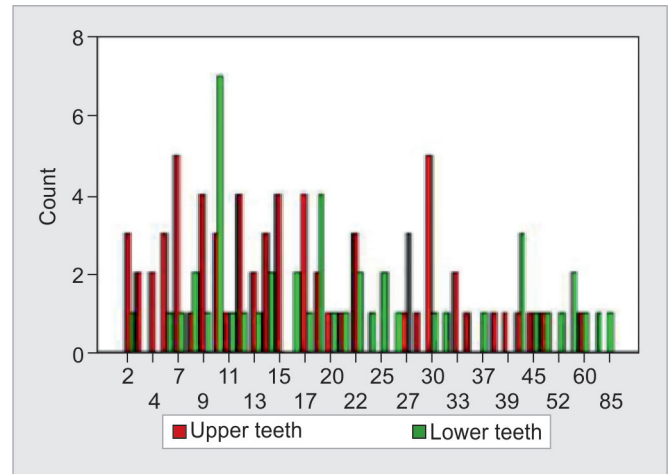
| Tooth | Degree of taper | Resistance form |
|---------|-----------------|-----------------|
| CI-10 | 7 | Yes |
| CI-11 | 9 | Yes |
| CI-12 | 6 | Yes |
| LI-1 | 10 | Yes |
| LI-2 | 8 | Yes |
| LI-3 | 3 | Yes |
| LI-4 | 3 | Yes |
| LI-5 | 6 | Yes |
| LI-6 | 11 | Yes |
| LI-7 | 14 | Yes |
| LI-8 | 7 | Yes |
| LI-9 | 18 | Yes |
| LI-10 | 6 | Yes |
| LI-11 | 17 | Yes |
| C-1 | 14 | Yes |
| C-2 | 12 | Yes |
| C-3 | 13 | Yes |
| C-4 | 33 | Yes |
| C-5 | 12 | Yes |
| C-6 | 9 | Yes |
| C-7 | 7 | Yes |
| IPM-1 | 30 | Yes |
| IPM-2 | 7 | Yes |
| IPM-3 | 38 | Yes |
| IPM-4 | 4 | Yes |
| IPM-5 | 15 | Yes |
| IPM-6 | 40 | Yes |
| IPM-7 | 21 | Yes |
| IPM-8 | 4 | Yes |
| IIPM-1 | 20 | Yes |
| IIPM-2 | 17 | Yes |
| IIPM-3 | 30 | Yes |
| IIPM-4 | 30 | Yes |
| IIPM-5 | 10 | Yes |
| IIPM-6 | 17 | Yes |
| IIPM-7 | 30 | Yes |
| IIPM-8 | 60 | No |
| IIPM-9 | 7 | Yes |
| IIPM-10 | 39 | No |
| IIPM-11 | 30 | Yes |
| IIPM-12 | 10 | Yes |
| IM-1 | 22 | Yes |
| IM-2 | 18 | Yes |
| IM-3 | 36 | Yes |
| IM-4 | 15 | Yes |
| IM-5 | 28 | Yes |
| IM-6 | 15 | Yes |
| IIM-1 | 33 | Yes |
| IIM-2 | 27 | Yes |
| IIM-3 | 2 | Yes |
| IIM-4 | 22 | Yes |
| IIIM-1 | 15 | Yes |
| IIIM-2 | 45 | No |
| IIIM-3 | 50 | No |
| IIIM-4 | 22 | Yes |

CI: Central incisor; LI: Lateral incisor; C: Canine; IPM: First premolar; IIPM: Second premolar; IM: First molar; IIM: Second molar; IIIM: Third molar

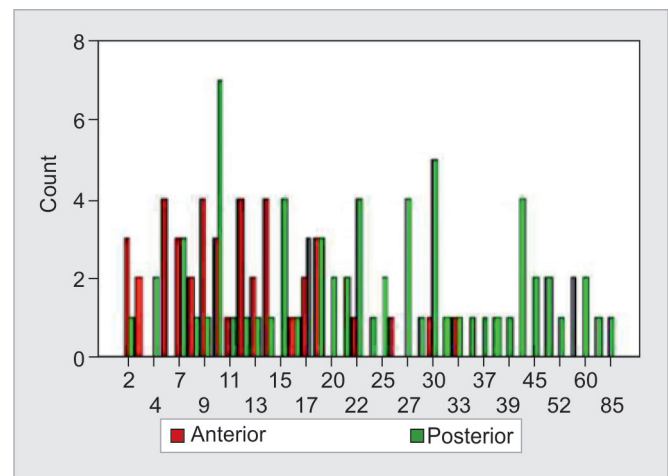
Table 3: Degree of taper and resistance form—mandibular teeth

| Tooth | Degree of taper | Resistance form |
|--------|-----------------|-----------------|
| CI-1 | 10 | Yes |
| CI-2 | 6 | Yes |
| CI-3 | 16 | Yes |
| CI-4 | 18 | Yes |
| LI-1 | 14 | Yes |
| LI-2 | 10 | Yes |
| LI-3 | 8 | Yes |
| LI-4 | 2 | Yes |
| C-1 | 22 | Yes |
| C-2 | 30 | Yes |
| C-3 | 26 | Yes |
| C-4 | 18 | Yes |
| IPM-1 | 37 | No |
| IPM-2 | 10 | Yes |
| IPM-3 | 16 | Yes |
| IPM-4 | 7 | Yes |
| IPM-5 | 9 | Yes |
| IPM-6 | 10 | Yes |
| IPM-7 | 8 | Yes |
| IIPM-1 | 17 | Yes |
| IIPM-2 | 14 | Yes |
| IIPM-3 | 12 | Yes |
| IIPM-4 | 11 | Yes |
| IIPM-5 | 21 | Yes |
| IIPM-6 | 20 | Yes |
| IM-1 | 27 | Yes |
| IM-2 | 27 | Yes |
| IM-3 | 40 | No |
| IM-4 | 10 | Yes |
| IM-5 | 60 | No |
| IM-6 | 32 | Yes |
| IM-7 | 52 | No |
| IM-8 | 56 | No |
| IM-9 | 85 | No |
| IM-10 | 40 | No |
| IM-11 | 25 | Yes |
| IM-12 | 56 | No |
| IIM-1 | 77 | No |
| IIM-2 | 27 | Yes |
| IIM-3 | 25 | Yes |
| IIM-4 | 18 | Yes |
| IIM-5 | 45 | No |
| IIM-6 | 22 | Yes |
| IIM-7 | 10 | Yes |
| IIM-8 | 40 | No |
| IIM-9 | 10 | Yes |
| IIIM-1 | 24 | Yes |
| IIIM-2 | 13 | Yes |
| IIIM-3 | 50 | No |
| IIIM-4 | 18 | Yes |

CI: Central incisor; LI: Lateral incisor; C: Canine; IPM: First premolar; IIPM: Second premolar; IM: First molar; IIM: Second molar; IIIM: Third molar



Graph 2: Degree of taper comparisons of upper and lower teeth



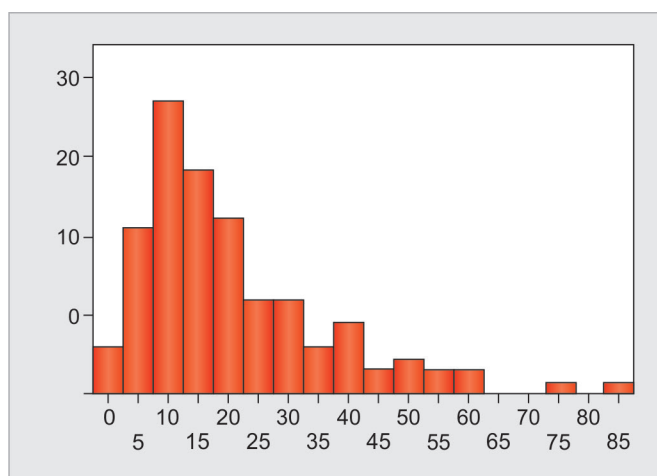
Graph 3: Degree of taper comparisons of anterior and posterior teeth

Collected data were analyzed using Statistical Package for the Social Sciences for Windows 7, and descriptive tables and cross-tabs were prepared. A variance ratio test carried out (F-test) before comparing the degree of taper between maxillary and mandibular teeth as the standard deviations for these groups were unequal.

Modified t-test applied for the analysis and it showed a significant difference between these groups with $t = 2.49$ and $p = 0.015$. Similar tests used for anterior–posterior teeth comparison within maxillary ($t = -5.090$ and $p = 0.0001$) and mandibular ($t = -6.89$ and $p = -0.002$) groups also showed significant difference in degree of taper. Kruskal–Wallis one-way analysis of variance test for comparing the degree of taper among different teeth also showed the highly significant difference in taper with $p = 0.0001$.

RESULTS

For the present study, the overall average (mean) degree of taper is 20.9° (range, 2–80°; Graph 4). The mean degree



Graph 4: Distribution of degree of taper

of taper for maxillary was 17.56° (anterior—10.50°, posterior—23.7°) (Graph 3). For mandibular teeth, the mean degree of taper was 25.22° (anterior—15°, posterior—28.45°). Chi-squared test used for comparing resistance form showed highly significant differences between maxillary and mandibular teeth ($p = -0.007$) and also between anterior and posterior teeth ($p = -0.001$; Graph 2 and 3). Out of the 64 analyzed images of tooth preparations of maxillary teeth, 60 preparations (93.8%) were found to have sufficient resistance form, and 4 were found to be without it. Tooth preparations without resistance and retention form were from the posterior teeth group (Tables 2 and 3).

Out of 50 mandibular tooth preparations analyzed, 38 were found to be with resistance form (76%), and 12 were found to be without resistance form. As observed in the maxillary arch, those preparations without resistance and retention form were again from the posterior (77.8%) teeth group.

As observed in the study, the majority of the tooth preparations which had a degree of taper $\geq 35^\circ$ showed lack of resistance and retention form, but a few preparations even with 40° of convergence angle showed sufficient retention and resistance form. All the anterior teeth showed resistance form irrespective of the arch (100%). Significantly, the maximum number preparations without retention and resistance form were posteriors with first molar group having 61.1% resistance form followed by third molar group (63.5%), second molar group (76.9%), second premolar group (88.9%), and first premolar group (93.3%).

DISCUSSION

In the literature, there are many studies available that evaluate the resistance and retention form, but most of them are based on measurements on die preparations and simulated models.^{5,7,13-19} In the era of digital diagnostic

aids, digital imaging, and computer-aided design (CAD)/computer-aided manufacturing (CAM)-based restorative treatments, the study on resistance and retention form based on measurements on digital impressions of clinical tooth preparations, to best of our knowledge, have very rarely been undertaken. Apart from that, the study also utilized two methods simultaneously to assess the resistance and retention form to provide an unbiased result.

Mean degree of taper (20.9°) observed in the present study is more than what was recommended by most previous studies and also greater than the textbook ideal of 3 to 6°. All the anterior teeth showed resistance form irrespective of the arch, which may be attributed to reasons, such as increased accessibility and greater preparation height to base width ratio.

Trier et al¹² described about the concept of limiting taper, as it has been described as a boundary between tapers that do and those that do not provide resistance form for preparation. Their study revealed a relationship between clinical success or failure and the all-or-none nature of resistance form as the dislodged crowns come almost exclusively from preparations with tapers that did not provide resistance form. Ayad et al¹⁷ confirmed through his study that tooth preparation taper and type of luting cement had a direct effect on the bond strength of complete metal crowns.¹⁹ In a computer-aided evaluation of preparations for CAD/CAM-fabricated all-ceramic crowns done by GÜth et al,²⁰ they concluded that mean convergence angle was determined to be 26.7°, which was much higher than the recommended taper and similar to the results of the present study.

In an interesting study by Tiu et al,²¹ they presented a coordinate geometry method of capturing and evaluating crown preparation geometry in which they used limiting taper theory based on the mathematical formula described by Parker et al.^{22,23} If H is the occlusion cervical dimension, B is the base of preparation, and T1 is the average taper, then the limiting taper is $T(H/B) = \frac{1}{2} / \sin(H/B)$. If T1 is greater than this value, the preparation has no resistance form. However, none of the preparations had total occlusal convergence values close to 12°, which are the current manufacturer guidelines.^{22,23}

Criteria related to the permissible degree of taper of preparations in current Prosthodontic Textbooks, such as Rosenstiel et al,¹⁹ and Shillingburg et al²⁴ recommend that the taper should be within the range of 2 to 6°. However, various studies conducted by different authors, such as Olm and Silness,³ Weed and Baez,²⁵ Noonan and Goldfogel,⁴ GÜth et al,²⁰ and Tiu et al²¹ show that in a clinical setting, the degree of taper ranges from 12 to 26.7°. This also justifies the mean degree of taper observed in the present study, which is 20.9°.

Even though as a foundation principle of fixed prosthodontics, 2 to 6° has been taught for years as a standard for preparation taper, unfortunately, it is not consistent with reality. Owen states, "Most teeth are prepared with tapers in excess of 12° and still function adequately."²¹ It is not known what retentive figure is the minimum required clinically. An explanation for the inability of retention to provide a minimum standard is that it is a continuous function of taper. There is no exact demarcation to separate acceptable taper from unacceptable taper as it differs in different clinical situations. The most that can be deduced is that less taper gives better retention.²¹

The diameter for every preparation is controlled somewhat by tooth size. However, length and occlusal convergence are subject to modification.²⁵ Before crown preparations are made, factors, such as length, diameter, and occlusal convergence angle must be evaluated. In general, these factors have been considered in relation to retention form only. It has been reported that an occlusal convergence angle of 16° or less provides adequate resistance form for a complete cast crown 3.5 mm long.²⁵ Hence, further studies are necessitated to conclusively decide on how to develop a guideline, which is more reliable and more efficient to assess the resistance and retention form.

One limitation of the assessment methods used in the present study is that it can only be used in straight-walled preparations and also that the resistance and retention form are assessed from point-to-point rather than from any one aspect of the tooth. However, this study has been able to establish that the morphological factors of individual teeth and tooth position in the arch have an overall bearing on the retention and resistance form as evaluated by Zuckerman's and Lewis perpendicular methods. Indication for the next study is to extend the analysis to the entire preparation, to determine an average taper value that guarantees that the entire preparation is resistive and, therefore, clinically sound. For the average dimensions of each tooth, molars to incisors, values can be calculated as guidelines for preparation taper.

CONCLUSION

Within a few mentioned limitations, the study can conclude that:

- There is a significant relationship between the degree of taper with resistance and retention form, and the relationship was inversely proportional to each other.
- The recommended "degree of taper" is not always the clinically achievable as advocated in textbooks, as it is modified by various factors in the actual clinical situation.
- Optimal retention and resistance form for extracoronary restorations should be established or assessed based on the inclusive analysis that takes into consideration the

geometric configuration of tooth preparations, including aspects, such as, convergence, surface area of the preparations, internal surface roughness of castings, auxiliary grooves, tooth surface preparation, and type of cement used and not exclusively any one of them.

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