Marginal Adaptation of Fixed Prosthodontics: A New In Vitro 360-Degree External Examination Procedure

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Purpose: This study evaluated the marginal fit of experimental and custom-made fixed prosthetic restorations through a new 360-degree external examination. The minimum number of gap measurements required to produce relevant results for gap analysis was also investigated. ***Materials and Methods:*** The marginal fit of six experimental and eight custom-made crowns was observed microscopically by means of a mechanical device, and software was employed to measure the gap. Two crowns, chosen from among the 14 previously evaluated, were reanalyzed to determine the minimum number of gap measurements required to produce significant results for gap analysis. ***Results:*** The precision obtained with the custom-made crowns differed from that of the experimental specimens. The minimum number of measurements required to produce a sample mean value within ± 5 µm of the mean, calculated over 360 measurements, taking standard error of the means ≤ 4 µm, was 18 for experimental and 90 for custom-made crowns, for both equidistant measurement spacing and randomly selected points. ***Conclusion:*** Differences in fit between experimental specimens and custom-made ones showed that experimental results might not always be obtained in clinical practice. Within the limitations of the protocol of this study, the minimum number of measurements required to ensure relevant results for gap analysis was 18 for experimental and 90 for custom-made crowns. *Int J Prosthodont 2004;17:218–223.*

An important factor that ensures long-term success of fixed prosthodontics is the precision of the margins. An inadequate fit is potentially damaging to both the abutment and periodontal tissues and causes deterioration of the luting agent in the gap between tooth and restoration.[1–5] No general guidelines exist on how to perform gap measurements on crowns, nor does the term "marginal gap" have a single definition.[6] Various protocols have been proposed to study marginal precision through inspection, exploratory probing, and radiographic examination.[7,8]

Two significant and precise methods analyze crowns microscopically, "internally" and "externally." However, internal cross-sectional measurements, although very accurate, result in the destruction of the crown and consequently are of little use in clinical practice. Furthermore, only a limited number of parallel sections can be cut on any one tooth, and thus only a few points of observation are possible for each specimen.[9–13] Direct viewing with external measurements has the advantage of not being invasive, but it is difficult to repeat the measurements from an identical angle and to distinguish the actual marginal gap from its projection.[14–17] The number of sites measured per tooth varies from study to study.[10,11,15,16] Groten et al[18] claim it is imperative to make at least 50 marginal measurements on a specimen to assess the precision of fit.

The present study analyzed the marginal precision of six experimental crowns and eight custom-made ones

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with a 360-degree external observation. The second aim was to investigate the minimum number of gap measurements, with a total of assumed maximum tolerance limit for the reevaluated means ± standard error values < 10 μm, to ensure a very accurate gap analysis. In fact, the greater the number of gap measurements per specimen, the greater the precision of the analysis, but the time required for a large number of measurements makes that kind of evaluation impractical on a regular basis. To have a valid evaluation of the fit in a reasonable time span, it is important to determine the minimum number of measurements required to produce significant and reliable results for gap analysis. In accordance with previously suggested terminology, the casting misfit investigated was the marginal gap, described as the perpendicular measurement from the internal surface of the casting to the axial wall of the preparation at the margin, or the shortest distance from the coping to the abutment marginal preparation.[6,13]

Materials and Methods

Fourteen complete crown restorations (eight custom-made and six experimental) were evaluated in this study. The eight custom-made crowns, manufactured by different dental technicians, were analyzed, evaluating their fit on the laboratory abutment, before cementation in the patient's mouth. The eight crowns differed in terms of materials (three metal-ceramic, two veneer, one auro-galvan, two all-ceramic), shape (two incisors, three premolars, three molars), and preparation (four chamfer, two 90-degree shoulder, two beveled shoulder).

The six experimental crowns (135-degree shoulder) were chosen from among those analyzed in a previous study conducted by the authors' department,[16] in which 75 gypsum dies were fabricated from a master steel die. They were randomly divided into three groups of 25 dies each. A metal coping was prepared on each die using a different technique for each group: composite alloy, electroforming, and cast high-noble alloy. Ceramic was baked on all of the samples following the same protocol and simulating the shape and size of a maxillary incisor. The six crowns were chosen at random, two from each group.

To evaluate crown fit during laboratory preparation, a device was developed (Mussino, Alpignano) that enabled the entire perimeter of the margin of a fixed prosthodontic restoration to be maintained at an identical distance from the microscope, and consequently to remain in focus. This device consists of a solid base on which a vertical rod is fixed; an adjustable upper arm is free to rotate both horizontally and vertically. The arm holds a feeler pin, adjustable for angle and height. A second arm, which can rotate from 0 degrees (horizontal) to 45 degrees upward or downward to align the focal plane of the microscope with the plane of any kind of marginal preparation, is articulated via a protractor scale to a spring unit. The spring piston bears a ring, within which the specimen holder unit (clamp) rotates. A graded knob enables the clamp to be rotated. The whole device is mounted on a sliding rail and can be moved backward or forward by means of a cogwheel (Fig 1).

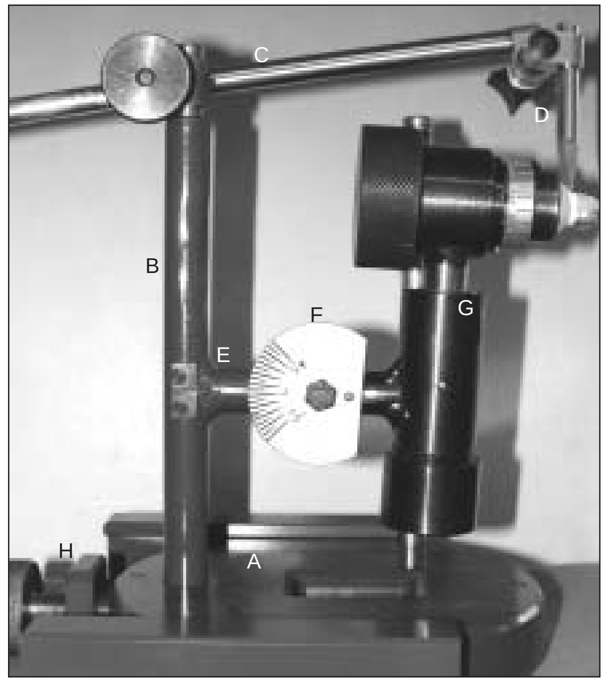

Fig 1 Device: *A* = base; *B* = vertical rod; *C* = adjustable upper arm free to rotate horizontally and vertically; *D* = feeler pin adjustable for angle and height; *E* = horizontal arm; *F* = protractor scale; *G* = spring unit; *H* = sliding rail and cogwheel.

Each of the eight removable laboratory abutments and the six gypsum dies, together with their crowns, was inserted centrally and perpendicularly in a small block of plaster shaped to fit into the clamp of the device. The blocks were made using a silicone mold; the margin of the specimen had to protrude at least 3 mm from the block. The block was then transferred to the clamp, where a screw was tightened to fix it in place. The crowns were not cemented in any way; their friction on the abutments was sufficient to keep them in place. After alignment of the plane of each type of marginal preparation with the focal plane of the microscope (Wild TYP) by means of the protractor scale, the upper arm was adjusted, bringing the feeler pin into contact with the abutment about 1 mm from the block surface; the spring unit had to be slightly depressed so that the feeler pin exercised light pressure on the abutment. The feeler pin adjustments were then tightly fastened.

The feeler pin maintains the upper surface of the specimen constantly at the same height, and consequently always in focus, irrespective of the portion of the crown being examined, while the spring unit compensates for irregularities in the shape of the abutment. By means of the graded knob, the specimen was made to rotate around its longitudinal axis. (A full turn of the knob is equivalent to a 360-degree rotation.) To compensate for the convexity and concavity of the margin (especially of the custom-made crowns) and keep the analyzed portion always within the microscope focus under the same light at a high magnification, the device was made to move backward or forward via the cogwheel.

The marginal fit was analyzed using software (IM 50, Leica Microsystems) connected to the microscope, magnification 50×, by means of a digital camera (Power Shot S40, Canon). Thirty digital photographs were taken of each of the 14 crowns, each spanning 12 degrees of the circumference, and stored in the computer. On each photograph, three operators, working separately, chose 12 equally spaced points, one every degree, on the margin of the abutment together with the corresponding point on the margin of the crown. The 12 points per photograph differed slightly among the operators because the initial point was not identical. The computer then measured the gap between each pair of points. The marginal precision was consequently evaluated through 360 degrees with 360 external points of observation (30 photographs per specimen, 12 points per photograph). The results were analyzed (statistics software package, version 8.2, SAS Institute) to evaluate: *(1)* arithmetic mean of the marginal gap of each crown over 360 measurements; and *(2)* differences among the three operators.

The second aim of the present study was to investigate the minimum number of gap measurements required to produce reliable results for gap analysis. A sample mean value was required to lie within ± 5 μm around the true mean (calculated over 360 measurements) and a standard error of the means ⩽ 4 μm. The total maximum tolerance limit for mean ± standard error was thus 9 μm (5 μm mean ± 4 μm standard error) around the true mean. A similar level of precision was reported by others.[10,18]

This analysis was carried out on two crowns: one custom-made and one experimental. The two specimens were chosen from among the ones evaluated in the present study, excluding those with the best and worst marginal gaps, to evaluate crowns with an average fit (mean value of 360 measurements: custom-made crown 49 μm, experimental crown 22 μm). The minimum number of measurements required to produce a sample mean within ± 5 μm of the mean, calculated over 360 measurements, was determined by sequentially reducing the number of evaluated points from 360 to 8 (360, 180, 120, 90, 60, 36, 24, 18, 12, 8). These numbers were chosen so as to always obtain integer numbers in dividing 360 degrees for the number of measurements. It was thus possible to evaluate the marginal fit at increasing intervals. The same number of measurements was then analyzed again, this time taking randomly selected points. The standard error and confidence interval were calculated for each set of measurements. The acceptable standard error of the mean was limited to a maximum of 4 μm. To exclude any variations produced by the choice of the starting point (point 1), it was decided to recalculate the means by changing point 1, moving it on by 1 degree until point 2 of the first measuring was encountered. The total time required for the measurements of one specimen was also recorded.

Results

The precision of the eight custom-made crowns and that of the six experimental specimens differed. The mean precision of the experimental crowns varied from 10 to 46 μm, while that of the custom-made ones varied from 35 to 98 μm. No significant differences between the measurements made by the three operators were found: The interoperator variance of the mean values calculated over 360 measurements of the 14 crowns ranged from 1 to 2 μm.

The analysis of the minimum number of measurements required to have a sample mean value within ± 5 μm from the mean value of 360 measurements must be divided into two sections. First, there was a considerable difference between the data relating to the experimental and custom-made crowns. Second, measurements at equidistant intervals were on average less variable, with lower error than when points were selected randomly. Taking 4 μm as the maximum acceptable standard error, the minimum number of measurements maintaining the mean value within ± 5 μm was 18 for the experimental crowns and 90 for the custom-made ones whether the points were selected equidistantly or at random (Fig 2).

According to the research protocol, to exclude any variations produced by the choice of the starting point, the means of the experimental crowns were recalculated 19 times (for a total of 20 different samples), and 3 times for the custom-made crowns (for a total of four different samples) (experimental crown: 18 measurements, one every 20 degrees; custom-made crown: 90 measurements, one every 4 degrees). The starting point (point 1) was found to be of no importance: The recalculations confirmed the data obtained from the initial measuring. The time necessary to make the 360 measurements was about 30 minutes, including 15 minutes to take 30 photographs and a further 15 minutes to

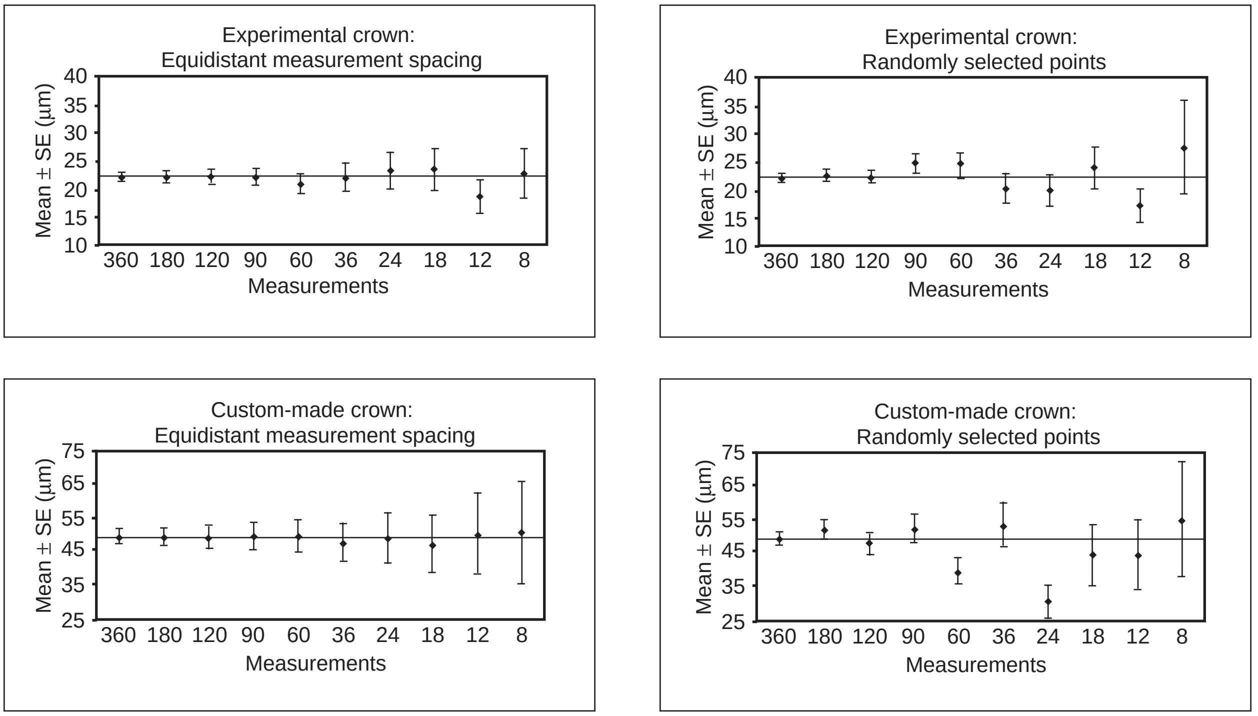

Fig 2 Comparison between equidistant measurements and randomly selected points: Measurements at equidistant intervals were on average less variable, with lower error. The minimum number of measurements required to produce a sample mean value within ± 5 µm of the true mean, with standard error of the means *(SE)* ≤ 4 µm, is 18 for experimental and 90 for custom-made crowns, for both equidistant measurement spacing and randomly selected points.

evaluate the gap. The time required to make the 90 or 18 measurements is clearly shorter than that for 360 measurements: Both the number of photographs and the number of measurements per photograph decrease. For 90 points, there are 10 photographs (each covering 36 degrees) and nine measurements per photograph (one every 4 degrees); for 18 points, there are nine photographs (each covering 40 degrees) and two measurements per photograph (one every 20 degrees).

Discussion

Two factors prompted the study presented in this article: the need to verify the marginal precision of fixed prosthodontic restorations by means of external observation, and the claim[18] that it is necessary to have a considerable number of measurements to be able to evaluate with precision the fit of a fixed restoration.

The measurements of the eight custom-made and six experimental crowns did not differ in a significant manner among the operators. The interoperator variance was much lower than has been reported in other studies.[10] However, all measurements were made on the same set of photographs; it is possible that if the three operators had worked on different sets of photographs of the same specimens, the results would have been different. The picture-taking process may create interoperator error even if the device maintains the crown margin steadily in focus, but the actual measuring was also subject to error; the operators not only decided which points were to be measured, but they also had to choose the points on the crown and the corresponding ones on the abutment, thus risking projection errors. It may be said that measurements are reproducible when working on identical photographs.

It is difficult to be certain that only the marginal gap has been measured: It is possible that a vertical or horizontal marginal discrepancy or an absolute marginal discrepancy may at times have been measured. A variation of the alignment between the plane of the marginal preparation and the focal plane of the microscope, especially in the custom-made specimens that did not always have a precise shoulder angle, or over- or undercontoured crown margins, has been noted to cause projection errors.[18] This could in part explain the better results obtained with the experimental crowns, which had a better-defined and more regular margin, and were thus easier to align with the focal plane of the microscope.

The minimum number of measurements required to produce a sample mean value within ± 5 µm of the mean, calculated over 360 measurements, varied considerably in the experimental crowns versus the custom-made ones. The tolerance limits were predefined to allow precision levels similar to those reported by others.[10,18] It is possible that if the cut-off points had been different, our results could have changed. The present study did not analyze the precision of different materials, techniques, or preparations; however, the difference in fit between experimental and custom-made specimens indicated that experimental data may not always be obtained in day-to-day practice.

It was to be expected that the data would differ slightly if points were selected equidistantly or at random: Mean variability and error size have been reported to be greater with random data selection.[18] Measurements appeared to be more uniform with equidistant points, and, since the entire margin is analyzed, they provide a better overall view of the gap. Furthermore, having decided the number of measurements and selected the first point, the others follow in consequence. With a random technique, point definition may be more time consuming. For these reasons, we prefer the equidistant points.

The results of the present study confirm that measuring experimental crown margins at fewer than 18 points might be misleading, as reported previously.[18] This potential lack of information would need to be compensated for by analyzing a large number of specimens. Custom-made crowns should be measured in at least 90 points.

External measurements are not invasive and can therefore be useful in clinical practice to determine the precision of the marginal fit of single custom-made crowns before cementation in the patient's mouth. Unfortunately, it is not possible to evaluate clinically just how satisfactory the measurements are to establish the effective precision of prosthodontic restorations on the natural abutment. In any case, there is no clinical evidence for a reliable criterion. The debate over the maximum acceptable gap size includes a wide range of values, from about 50 to 120 µm.[7,8]

Other studies will be necessary to verify and improve this technique and to confirm the results obtained with further data. In fact, some of our conclusions can be drawn on the basis of an analysis of only two crowns, chosen excluding those with the best and the worst marginal gaps of the total group of studied castings to evaluate crowns (especially the custom-made ones) with an average fit that are probably more representative of everyday practice.

Conclusions

Within the limits of this investigation, the following conclusions for fit evaluation may be drawn:

1. The measurements were reproducible if the same set of photographs was analyzed.
2. Differences in fit between the experimental specimens and the custom-made ones showed that the experimental results might not always be obtained in clinical practice.
3. With the mentioned protocol, the minimum number of measurements required to produce a sample mean value within ± 5 µm of the mean, calculated over 360 measurements, taking standard error of the means ≤ 4 µm, was 18 for experimental and 90 for custom-made crowns.
4. If measurements to determine marginal fit are made at equidistant points, the starting point is of no importance.
5. Measuring experimental crown margins at fewer than 18 points might be misleading.

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