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Corresponding author:
ES Grossman
MRC/Wits Dental Research Institute
School of Oral Health Sciences
Faculty of Health Sciences
University of the Witwatersrand
Private Bag 3
WITS
2050
Tel: +27 11 7172137
Fax: +27 11 7172121
E mail: grossmane@dentistry.wits.ac.za

ES Grossman PhD. Senior Specialist Scientist
M Rosen LDS MSc(Dent). Honorary Researcher
PE Cleaton-Jones BDS MB BCh PhD DSc(Dent)
A Volchansky BDS, PhD Honorary Researcher

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SUMMARY

Introduction
Surface roughness of dental restorative materials is most often established with the Ra value obtained using profilometry or by assessing surface topography with the scanning electron microscope (SEM). Both methods should validate each other in confirming surface roughness.

Aims and objectives
The purpose of this study was to compare surface roughness values obtained with a profilometer to the SEM appearance of 6 resin-based restorative materials and assess whether Ra was appropriate as a sole surface roughness measure.

Methods
Six 5mm diameter specimen discs of Prodigy® (Pr); Z100® (Z); Compoglass F® (C); Hytac Aplitip® (H); Photac-Fil® (Pf) and Vitremer® (V) were prepared against Mylar strips and stored in distilled water for 14 days. One side of each disc was sequentially polished with Soflex discs to super fine state, the other side remained unpolished. Three surface roughness measurements were made on each surface (n=18) recording Ra, Rv, Rp and Rt values, this data was subjected to a four way ANOVA and Tukey's Studentised Range Test (p=0.05). Two unpolished and two polished discs per material were prepared for SEM, evaluated and visually grouped for surface roughness.

Results
Approximate ascending order of roughness was Z, Pr, H, C, V, Pf for Ra, Rv, Rp and Rt and un/polished treatment. Polishing increases surface roughness through raised Rp, Rv or both. SEM evaluation grouped the unpolished specimens into a "bland" (Pr, H, Z, C) and "textured" group (Pf and V). The polished specimens gave four groups: (Pr), (Z and C), (H) and (V and Pf) of increasing surface complexity. Polishing caused surface scratching, removed the matrix, reduced or removed filler particles and exposed voids within the material.

Conclusions
This study emphasises the importance of using more than one technique to assess surface roughness. Rv and Rp values should be utilised to better understand polish induced surface feature changes. Rv maximum is a better measure to identify surface defects which could affect restoration longevity.

INTRODUCTION

Polishing of resin based restorative materials is necessary to remove excess material and establish aesthetic contour, form and anatomy. During this procedure a smooth restoration surface is obtained that will reflect light in a similar manner to adjacent tooth structure, feel natural to the tongue and produce a surface that will minimise food debris and plaque accumulation. If air bubbles are entrapped within the material during placement, polishing will expose these, creating hollows, holes and cavities at the polished surface. While an early, in vitro study indicated that bacteria do not accumulate in these voids[1], the in vivo situation with modern resin based restorative materials is unclear. Porosities have also been shown to adversely affect the compressive strength of glass ionomer cements[2] while others[3] have demonstrated that low velocity cracks are propagated through pores within dental resin composites. Both cracks and holes have major implications for restoration longevity.

For close to 30 years a profilometer has been used to measure surface roughness of restorative materials[4]. The instrument gives four measurements of the topography of a specimen along its reading track, based on a mean line drawn between the peaks and valleys of the roughness profile. Rv is the maximum depth of the profile below the mean line within the sampling range ie. the valley, while Rp is the maximum height of the profile above the mean line within the sampling range ie. the peak. These two values are used to calculate Rt or Rmax which is the maximum peak to valley distance of the profile in the assessment length (Rt = Rv + Rp). Ra or average roughness reading is the arithmetic mean of the absolute departures of the roughness profile from the mean line. Ra is often reported as the only measure of roughness and has been used to express the surface roughness or finish in most studies[4-10]. In the few cases where the Rt of a surface has been reported this value has been used to monitor major surface flaws and has not formed part of the overall surface roughness assessment[4 5 11 12]. Rv and Rp values are seldom reported.

Relying on a single method to assess surface roughness may lead to misleading results and conclusions. For this reason it is recommended[13] that a second surface roughness evaluation be used to validate the results of the first. Scanning electron microscopy (SEM) has often been selected because of its resolution, ease of use and depth of field[4 6 10 12 14-16].

A previously reported study[17] compared the Ra surface roughness values of six aesthetic resin-based restorative materials obtained using a profilometer. This investigation examines the SEM appearance of these six restorative materials[17] and utilises Rv, Rp and Rt to assess whether the commonly used Ra value is sufficiently discriminating to identify surface features which could have major implications for restoration longevity in modern restorative materials.

MATERIALS AND METHODS

Specimens were prepared from two brands of hybrid composites: Prodigy® (Kerr, Orange USA) and Z100® (3M, St Paul, USA); two brands of compomers: Compoglass F® (Vivadent Schaan, Lichtenstein) and Hytac Aplitip® (ESPE, Norristown, USA) and two brands of resin modified glass ionomers: Photac-Fil® (ESPE, Norristown, USA) and Vitremer® (3M, St Paul, USA) according to manufacturer's recommendations. For each brand six discs 5mm in diameter and 1.5mm thick were prepared in clear perspex moulds. Following placement of the material both upper and lower surfaces were covered with Mylar strips (Buffalo Dental Mfg. Co., Brooklyn USA) which in turn were covered with glass microscope slides and compressed with finger pressure to express surplus material. Each disc was light cured for 40 seconds per side with a Dentsply QHL 75 curing light (Dentsply Caulk, Milford, USA) to give a total of 12 surfaces for each brand. After storage in distilled water for 14 days one surface of each specimen disc was polished. One individual carried out all polishing after standardising the technique on practise specimens. Medium, fine and super fine Soflex discs (3M, St Paul, USA) were used sequentially for 30 seconds each in a slow hand piece with light intermittent pressure. New discs were used for each specimen, which was polished in a north-south direction for 15 seconds and an east-west for a further 15 seconds. This method was used to simulate clinical polishing in an incisogingival and mesiodistal direction. The other surface of the specimen disc was untouched and served as a control. The specimens were stored for a further seven days in distilled water until surface profiles were recorded with a Rank Taylor Hobson Ltd., Form Talysurf Series 2 instrument (Taylor Hobson, Leicester, UK) with a 2mm tip, a standard cut-off of 0.8mm and a traverse length of 3.2mm. The specimens were dabbed dry, but not desiccated and placed randomly in the Talysurf. Once seated, three replicate measurements were made across the surface of each specimen disc; all traverses were in the same direction and parallel to each other. The stylus tracks were approximately equidistant on all specimens. The three replicate measurements gave a total of 18 tracks per treatment surface. The data from these 18 tracks yielded the Ra, Rv, Rp and Rt values recorded for each treatment. The data were subjected to a four way analysis of variance ANOVA and Tukey's Studentised Range test at p=0.05 using SAS (SAS for Windows Version 8.2, SAS Institute Inc., Cary, NC: USA). Specimens were returned to distilled water immediately after surface profile assessment for a further week prior to SEM preparation.

A total of 24 discs were removed from the perspex strips, four for each material, and prepared for SEM examination. Each disc was air dried and mounted on aluminium specimen stubs using colloidal graphite (DAG 580 Colloidal Graphite in denatured Alcohol. Acheson Colloids Company. Prince Rock, Plymouth PL4 OSP, UK) so that the polished surface was uppermost in two specimens and the unpolished surface uppermost for the other two specimens for each material. All specimens were coated with a thin layer of carbon (25nm) and viewed in a JSM-840 SEM (JEOL Ltd, 1-2 Musashino 3-chome, Akishimo, Tokyo 196, JAPAN) at 5-10kV and suitable tilt and magnifications to emphasize surface profile. Viewing was done by an electron microscopist, blind to the surface roughness profile measurements. Representative surfaces of the material were photographed at x200 and x1000 magnification printed and assessed. Surface roughness was judged on the absence or presence of scratches, grooves, pitting, matrix loss, filler particle loss, surface fragmentation, cracks and incorporated voids. Filler particle sizes for all six materials were sought from the manufacturer. This was not provided in all cases therefore exposed filler particles were measured from electron micrographs (Table I).

Table I. Particle sizes of resin-based restorative materials used in this study

Material	Manufacturers average particle size	Manufacturers average particle size	Measured particle size
Glass ionomers			
Photac-Fil	Not available	50% = 5.5-7.0µm 100% = <42.0µm	7.5 - 50.0µm
Vitremer	Not available	Not available	5.0 - 50.0µm
Compomers			
Compoglass F	Not available	0.2 - 3.0µm	1.0µm >
Hytac Aplitip	5.0µm	50% = <5.2µm 90% = <16.9µm	7.5 - 25.0µm
Hybrid composite			
Prodigy	0.5µm	Not available	2.5µm >
Z100	0.6µm	0.01 - 3.5µm	2.0µm >

Table II. Means and standard deviations in µm of Ra, Rv, Rp and Rt for unpolished surfaces of the six resin-based restorative materials studied. Means with the same letter in each column indicate that the materials are not significantly different. (Ra values[17])

Material	Ra	Rv	Rp	Rt
Photac-Fil	0.71 ± 0.83 ab	3.34 ± 2.17 b	3.06 ± 4.24 a	6.41 ± 7.27 ab
Vitremer	0.42 ± 0.25 b	6.62 ± 3.93 a	1.29 ± 0.85 ab	7.92 ± 4.42 a
Compoglass F	1.15 ± 1.44 a	2.17 ± 2.46 bc	2.03 ± 3.02 ab	3.91 ± 4.65 bc
Hytac Aplitip	0.15 ± 0.19 b	0.45 ± 0.40 c	0.95 ± 1.67 ab	1.41 ± 1.87 c
Prodigy	0.14 ± 0.10 b	0.31 ± 0.18 c	0.46 ± 0.47 b	0.77 ± 0.52 c
Z100	0.22 ± 0.36 b	0.30 ± 0.32 c	0.35 ± 0.46 b	0.51 ± 0.36 c

Table III. Means and standard deviations in µm of Ra, Rv, Rp and Rt for polished surfaces of the six resin-based restorative materials studied. Means with the same letter in each column indicate that the materials are not significantly different. (Ra values[17])

Material	Ra	Rv	Rp	Rt
Photac-Fil	1.51 ± 1.44 a	12.18 ± 6.84 a	3.99 ± 3.37 a	16 18 ± 9.55 a
Vitremer	0.65 ± 0.48 ab	5.77 ± 2.88 b	1.67 ± 1.75 b	7.54 ± 4.14 b
Compoglass F	1.33 ± 1.93 ab	2.21 ± 2.25 c	1.79 ± 2.34 b	3.98 ± 3.81 bc
Hytac Aplitip	0.60 ± 1.10 ab	2.30 ± 2.49 c	1.18 ± 0.78 b	3.48 ± 2.82 bc
Prodigy	0.47 ± 0.33 ab	2.16 ± 2.38 c	1.14 ± 1.54 b	3.30 ± 3.84 bc
Z100	0.35 ± 0.37 b	0.88 ± 0.75 c	0.71 ± 0.72 b	1.60 ± 1.23 c

RESULTS

Profilometer measurements

Tables II and III show the mean values and standard deviations of the four surface profile readings for each of the six materials examined in the unpolished and polished condition. While the means for the different surface roughness parameters vary, the relative order of roughness for each material remains largely similar within each test. The maximum and minimum range, mean and median in polished and unpolished surface roughness values are shown for Ra (Fig. 1) arranged from least to greatest maximum value. In this case the relative order of the materials varies. This was also true for Rp, Rv and Rt – these values are not shown because of space constraints. Polishing tended to increase all maximum R values, but in two cases (Photac-Fil and Hytac Aplitip) the maximum Rp values decreased markedly. Overall, polishing caused an increase in Rt values which could be due to increases in the peaks, valleys or both as shown in Fig. 2. Compoglass F, Prodigy and Z100 experienced increases in both Rv and Rp maximums when polished; Rv maximum increased and Rp maximum decreased in Photac-Fil and Hytac Aplitip; Vitremer experienced an increase in Rp maximum and a decrease in Rv maximum. A similar pattern was apparent if mean, as opposed to maximum Rv and Rp values were used.

Figure 1 shows that means and medians do not coincide indicating the skewness in the data. This skewness is best illustrated when the means and medians are plotted as cumulative percentages of specimens (Fig. 3). In this figure the polished and unpolished surface roughness values for Ra, Rp, Rv and Rt are reflected as cumulative percentages for each of the restorative materials. The median is given as a straight line at 50% of the specimen group. The position of the means indicates the cumulative aggregate of specimens incorporated within that roughness value as a percentage of the entire specimen group. Percentage departure from the median ranges from a minimum of 0% where mean and median coincide (as in the case of Rv for unpolished Vitremer) to 39% (Ra for polished Hytac Aplitip). The magnitude of the percentage departure between median and mean values indicate the presence of significant outliers within the data set which influence the mean value. For example the Ra maximum value of polished Hytac Aplitip is 5.05mm with the next greatest being 0.74mm. The Ra median value is 0.34mm and Ra mean = 0.60mm. While the plotted graphic distance between mean and median for polished Hytac Aplitip appears minor in terms of the maximum and minimum values (Fig. 1), the notable maximum value outlier has effectively doubled the mean value relative to the median. In addition the mean value falls at the 90% cumulative level of the specimen group.

Scanning electron microscopy

All unpolished specimen surfaces had a smooth, matrix rich surface layer indicating that the flowable resin component was forced up against the Mylar strip during specimen placement. Shallow scratches or grooves were visible on all specimen surfaces (Fig. 4). Placement defects or voids were present in Photac-Fil and Vitremer from 150mm> in diameter (the large voids are not illustrated due to space constraints), as well as surface cracks (Fig. 5). SEM suggested that unpolished specimens could be divided into two based on the additional presence of surface cracks and voids: the "bland" (Pr, H, Z, C) and "textured" (Pf and V) groups.

Polishing caused scratching of the surface and resulted in four surface appearances: Prodigy was the smoothest with scratches of varying depth and small pits irregularly scattered on the surface (Fig. 6). Compoglass F and Z100 (Fig. 7) had similar clusters of pits but were more heavily scratched, with some small voids present in Compoglass F. Hytac Aplitip (Fig. 8) was heavily scratched and had numerous pits or areas of gouged out material. Polishing of Vitremer and Photac-Fil showed a distinct removal of the matrix rich surface layer exposing the filler particles and particle-matrix interface; in addition scratches, cracks and exposed voids were present (Fig. 9). Most voids were present in polished specimens. They were mainly 50mm> in diameter, although larger bubbles up to a maximum of 450mm were present. Polished specimens gave four groups: (Pr), (Z and C), (H) and (V and Pf) based on the complexity and variability of surface topography.

The order of surface roughness as determined by R values and the groupings of similar surfaces by SEM showed an arrangement closest to the Rv maximum value, more so for the unpolished (from greatest to least V, Pf, C, Z, H, Pr) than polished (from greatest to least Pf, H, Pr, V, C, Z) treatment. The materials with the largest particle sizes had the most complex surface topography at SEM level.

DISCUSSION

SEM showed that surface defects were almost exclusively confined to flaws extending below the surface rather than those which protruded above the restorative material surface. While surface scratches and areas of gouged out material were evident in mainly polished specimens (and could be the result of poor polishing technique), voids of various sizes formed the most visible part of surface defects present in both specimen treatments. Porosities in resin composite restorative materials have been noted for many years[9,10,12] and are ascribed to air bubbles incorporated at various stages within the material[18]. Such voids are implicated in decreased compressive strength[2]; crack propagation[3,19]; surface roughness[20] and microleakage[1]. While the increased surface area represented by voids and scratches may augment plaque accumulation it is well known that the relationship between surface roughness and enhanced retention is not necessarily parallel[21,22].

Opinion differs as to the acceptable clinical level of surface roughness. Kaplan et al.[15] have suggested that a Ra mean value of less than 10mm is clinically undetectable and therefore clinically acceptable. On the other hand, Borchers et al.[8] supports a target Ra threshold of 0.2mm

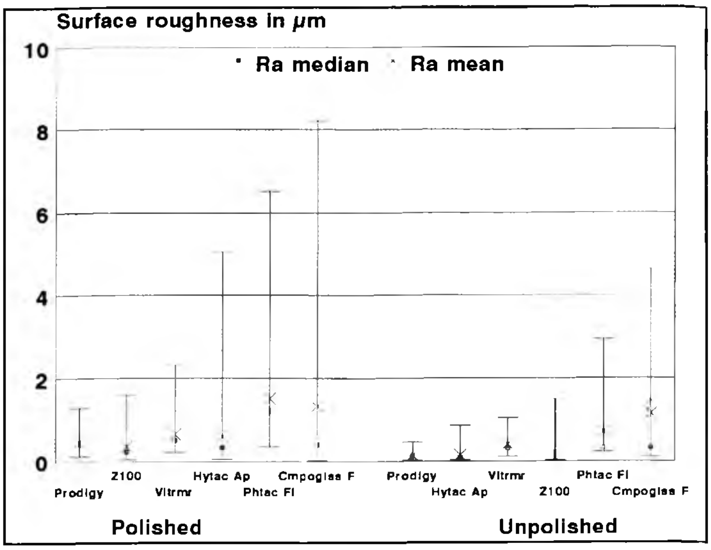

Figure 1: Maximum and minimum range (line and whisker), means and medians, are shown for Ra. The six materials are arranged from least to greatest maximum value in polished and unpolished groups.

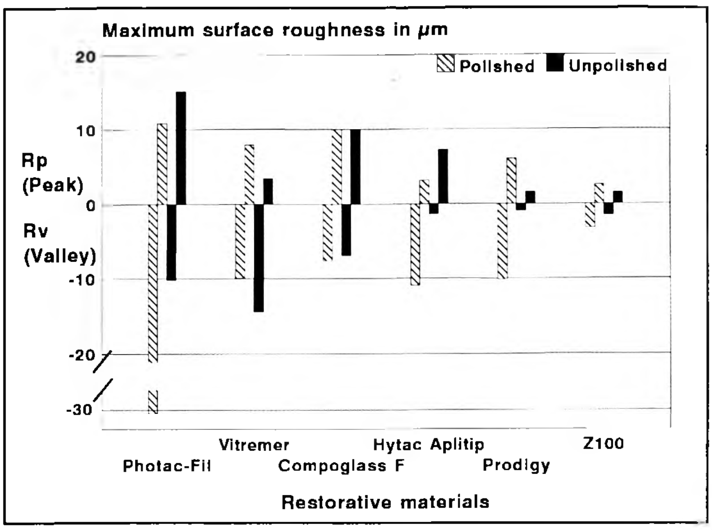

Figure 2: Histogram showing the effect of polishing on Rt maximum values for the six restorative materials. All values above zero indicate Rp maximum values, those below zero show Rv maximum values.

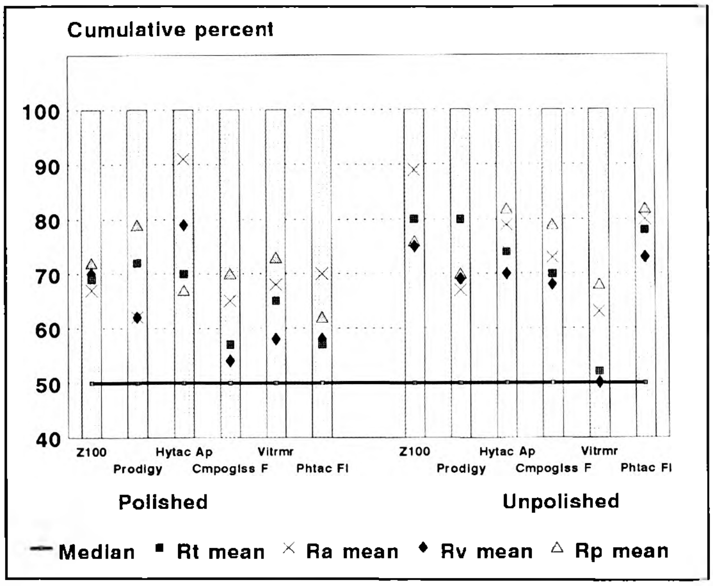

Figure 3: Histogram of cumulative percentages of specimen spread in polished and unpolished conditions. The mean and median is given for Ra, Rv, Rp and Rt

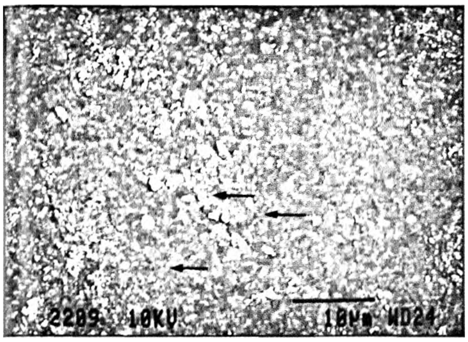

Figure 4: Shallow scratches (arrowed) are visible on the unpolished, matrix-rich Prodigy surface.

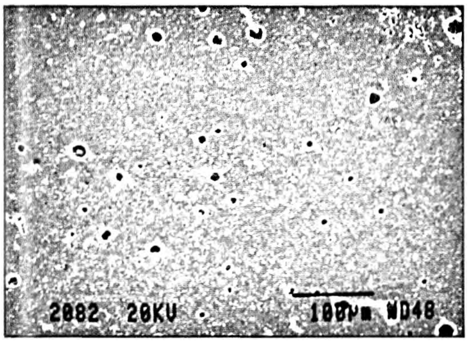

Figure 5: The matrix rich surface layer of this unpolished Vitremer specimen is broken by numerous voids which have been incorporated within the material. Some cracks can be seen extending from the voids.

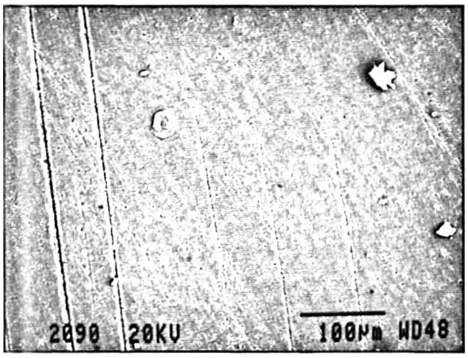

Figure 6: Deep grooves, shallow scratches and areas of pitting are visible on this polished Prodigy surface.

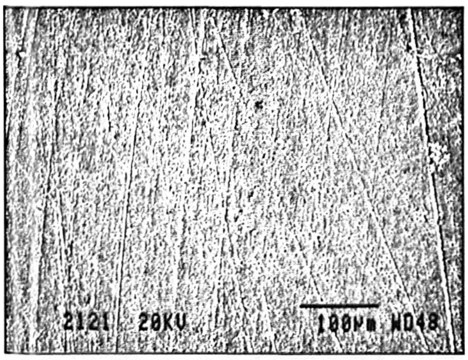

Figure 7: Polished Z100 surface showing scratches, grooves and pits.

for effective plaque prevention on restorative surfaces. The Ra = 10mm threshold for acceptability means that all six resin based restorative materials whether polished or unpolished, have clinically satisfactory surfaces as regards plaque prevention. However

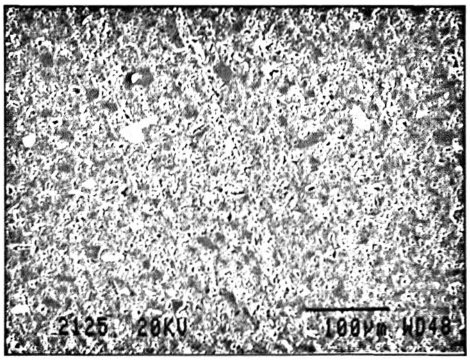

Figure 8: Irregular surface of a polished Hytac Aplitip specimen showing numerous pits and scratches.

Figure 9: Polishing of Vitremer specimens removed the matrix rich surface layer exposing filler particles and voids, both of which in this field can be up to 50mm at the widest point. Grooves and scratches can be seen with large crack on the right. An area of roughened matrix is within the angle of the crack. Compare this surface to that in Fig. 5.

the SEM assessment of surface roughness clearly indicates differences between the materials within each treatment. The Ra threshold of 0.2mm was more in keeping with SEM discrimination of surfaces seen in this study. All polished surfaces had a complex topography at the ultramicroscope level as did the unpolished Photac-Fil and Vitremer: all had Ra's well over 0.2mm and would be regarded as having unacceptable plaque prevention surfaces[8].

The inconsistency between SEM and Ra surface roughness measures in this study suggests that other surface roughness values, generated during profilometry, may be more appropriate when examining the effect of polishing. It seems strange that Rv, which ascertains the valley depth of measured surfaces and as such records a pivotal aspect of restorative material topography, appears to be overlooked in surface roughness studies. We therefore suggest that Rv maximum values are a useful measure as pointers for possible areas of threat to restoration longevity. After all, the site of restoration breakdown will be initiated through the weakest region of the material, in most cases the site of the largest defect.

Rp values of the restorative materials studied were not as large as Rv values. It is not known to what extent peaks could affect the physical and mechanical properties of the restoration, after all mastication would tend to grind down surface protrusions with time. However, projections above the restoration would offer less shelter from the swirling oral tide than the valleys and may be insignificant in the accumulation of oral debris. The above does not imply that Rp values are inconsequential as regards restoration longevity, this can only be assessed in further work.

The Rt value could represent an exaggeration of the topography in as much as the Ra values represents a flattening of the surface. This has been recognised previously[11 12], but both studies seem to regard the sensitivity of Rt to a single large surface defect along the traverse path as a shortcoming of the method rather than adding to information on potential vulnerabilities of the material. The present data shows that polishing may increase or decrease the valleys and peaks depending on the resin based restorative material. While the overall effect may be to increase Rt, the consequence this has on the material may differ whether Rp or Rv is more affected by the process: and thereby the interpretation of the data.

Surface roughness of restorative materials is a term which is loosely applied to the surface roughening effects of finishing and polishing on the material itself. It seems that over the years other equally important consequences of this procedure have been overlooked such as the exposing of voids and cracks within the bulk of the material. While these features were seen in the SEM the Ra values appear not to be sufficiently sensitive, whether analysed by statistical methods or differentiated by threshold values, to reflect these irregularities.

CONCLUSION

This study highlights once again the importance of examining polished and finished restorative material surfaces using more than one technique as false conclusions can be drawn from just one set of data. While the use of Ra mean values appears to have adequately quantified dental material surfaces in the past it may be that the nature of present day resin based restorative materials require the use of all R values to fully portray the topography of such surfaces when assessing materials for clinical outcomes. The added use of Rv and Rp maximum values would surely assist in a greater understanding of placement and wear phenomena unique to modern restorative materials.

References

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The rest of this aricle's references (2 - 22) will be published in the online August SADJ, www.sada.co.za