Research Square

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A base-line study of the wear of burs used for chairside milling of ceramic crowns of different hardness: effect on internal fit and surface roughness

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Research article

Keywords: CAD/CAM milling burs, Internal fit, Surface roughness, Ceramics

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Abstract

Background: In the CAD/CAM environment, wear of the milling burs may affect the accuracy of the milled crown. However, no studies have related bur wear to both the resultant internal fit of the crown or to the surface roughness. The aim of this study was to study this, using diamond burs and a feldspathic ceramic (Sirona Blocs C, Dentsply Sirona, Germany) and tungsten carbide burs and Zirconia (inCoris TZI puck, Dentsply Sirona, Germany).

Methods: Thirty of each of the two materials were milled from the same standard preparation. One set of diamond burs was used for the feldspathic ceramic and one set of tungsten-carbide burs for the Zirconia. Before and after the 10th, 20th and 30th milling times, diamond particle loss was counted and cutting blade changes of the tungsten-carbide burs measured. Internal fit was measured using a silicone replica technique and surface roughness with a 3D measuring laser microscope.

Results: Increasing wear of the diamond burs as measured by an average 26% loss of diamond particles after 30 crowns, which resulted in a 6% decrease in internal luting space and a 16% increase in surface roughness. Increasing wear of the tungsten-carbide burs resulted in a 13% decrease in the luting space, but there was an overall 16% increase in surface roughness.

Conclusions: This is the first study to compare the wear of diamond and tungsten-carbide milling burs with the internal fit and surface roughness of the crown. The wear of milling burs affects the luting space, reducing it as the burs wear, and therefore the milling parameters must be adjusted to compensate for this.

Background

In recent years, many dental Computer Aided Design and Computer Aided Manufacture (CAD/CAM) systems have been developed and introduced to the market both for chairside milling as well as laboratory fabrication, and restorations made this way have become more affordable and increasingly accurate. [1]

Milling systems, however, still have some constraints, related to movements of the axes but also to the size of the burs, which in turn influences the preparation form. This is also influenced by the need for the scanner to see all parts of the preparation without undercuts. The diameter of the smallest bur is 1 mm in most systems, so structures smaller than 1 mm cannot be milled precisely. [2]

A number of researchers have investigated the repeated machining up to 30 and sometimes 50 crowns using one diamond bur and the effect on the accuracy of the milled crowns and the loss of diamond particles from the bur. Yara and colleagues in 2005 [3] found that a diamond bur could be used to fabricate up to 21 crowns when using two different milling systems. Furthermore, they showed that the crowns' average surface roughness ranged from 1.1 to 2.1 μm for the one system and from 0.8 to 1.6 μm for the other. There were significant diamond losses of 34% and 8% respectively. They concluded that the

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Vickers Hardness of the ceramic blocks used influenced the diamond particle loss as well as the surface roughness. [3]

Tomita and colleagues (2005) [4] found that one diamond bur could be used to fabricate up to 51 crowns using their milling system but that from the 41st to 51st crown there was a tendency to mill with a larger inner surface gap and a slightly smaller outer surface. They also found tiny chip marks at the cervical contour from the 21st to 51st crowns. SEM observation showed that after 11 to 21 times of machining the diamond abrasive particles were gradually lost as the number of machining times increased. [4] Roperto et al (2019) [5] reported an increase in surface roughness when milling Vita Mark II ceramic blocks and observed, but did not quantify, bur wear, as did Raposo et al (2019). [6] An increase in surface roughness has been linked to a possible limiting of flexural strength. [7]

These studies have shown that diamond burs used for chairside milling of restorations are subject to wear in proportion to the hardness of the material being milled, and the number of times the bur was used, and will also influence the surface roughness. It is therefore imperative to know the precise relationship between the state of wear of the bur and the effect on milling accuracy and surface roughness. In general, wear has been measured by particle loss in diamond burs by observations on only one part of the bur. [3.4] There have been few reports on the wear of tungsten carbide burs, which have either been observations of dulling and rupture of the blade edges of dental handpiece burs when cutting ceramics, [8] or by observations of chipping on tungsten-carbide burs used for milling titanium crown. [9]

Although the creation of a luting space for full crowns was originally advised for creating space for the luting agent, the milling constraints in CAD/CAM systems have given rise to recommendations for the creation of a luting space of up to 100 µm. Whilst a variety of methods have been used to measure the luting space, some such as the use micro-CT requiring expensive equipment, a method which has been reliably used is that of the use of a silicone replica as described by. [10] This provides a measure of the total internal fit of the preparation relative to the preparation.

The aim of this study was to assess the wear of diamond and tungsten carbide milling bears after milling up to 30 full crowns from two different ceramic materials of different hardness, and the effect of this wear if any, on the internal fit and surface roughness.

Methods

A typodont tooth (tooth 36) was prepared to receive an all-ceramic crown restoration. The preparation had a circumferential shoulder margin, an axial reduction of 1.5 mm, a 1.5 mm occlusal reduction, rounded internal angles, and 12° total occlusal convergence angle. The crown was scanned (CEREC Omnicam, Dentsply/Sirona, Germany) and printed in Cobalt-Chromium. For the crowns, the milling parameters were set to produce an internal gap of 200 µm. The materials used were Sirona blocs C (Dentsply Sirona, Germany) and Zirconium oxide (inCoris TZI puck, Dentsply Sirona, Germany). The MC X5 milling machine (Dentsply/Sirona, Germany) was used to mill all crowns.

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Diamond burs (set of 1.2, 1.4 and 2.2 mm sizes, Dentsply/Sirona, Germany) were used to mill the Sirona blocs C. Tungsten Carbide burs (set of 0.5, 1.0 and 2.5 mm sizes, Dentsply Sirona, Germany) were used to mill the inCoris TZI puck.

Prior to milling, and after the 10th, 20th and 30th milled crowns the milling process was paused, and the burs were scanned by Scanning Electron Microscope (SEM) (Carl Zeiss Sigma Filled Admission Zeiss, Germany), to count the particles lost after a method modified from Yara *et al* (2005). They were then re-installed to continue milling the crowns. The Zirconia burs were similarly scanned in order to determine any edge wear.

For the diamond burs, the bur shank was marked into four quadrants around its circumference to ensure that measurements were made in the same quadrant each time. The burs were scanned with magnifications of 100x, 200x and 500x. The SEM images of the burs were imported into a computer graphics programme (CorelDraw, Corel, Canada). A frame of 1 mm high and 1 mm wide, was prepared in the computer with a 10 × 10 grid. The top margin was adjusted to be 0.5 mm from the top of the bur and centred from the sidewalls of the bur. This frame was used to count the diamond particles within it (Fig. 1). Figure 2 shows the tip of the bur under magnification 500 times before, and at the 10th, 20th and 30th milled crowns.

For the tungsten carbide burs, as previous studies have reported only chipping of the burs after milling, this study set out to quantify the wear. The burs were scanned before use, and the diameter (Y) and width (X) of the blades were measured (Fig. 3). It was found that the SEM scan of the burs after milling did not provide accurate quantification measurements, due to the different scales and angles when scanned, and therefore a statistical proportional method was adopted to calculate any differences due to wear. With X^1 being the width after milling, the blade wear is $X - X^1$. With Y^1 being the bur diameter after milling, proportionally, $X^1 = X(Y^1/Y)$ as X/Y is proportional to X^1/Y^1 .

The 1st, 10th, 20th and 30th crowns of both materials were filled with light-body polyvinyl siloxane impression material (3M ESPE Express. 3M, United States) and placed on the metal tooth die under a constant load of 3 kg weight, placed on the flat occlusal surface of the crown for 10 minutes. After the silicone impression material had polymerised, the excess material was removed with a scalpel blade. The material from the internal gap was taken out as one piece and weighed to calculate the overall internal fit according to the formula, (Nakamura et al., 2003): -

Thickness (internal gap) = $\text{weight} / (\text{surface area} \times \text{density})$

Where the surface area was 183.8 mm^2 (calculated using FEA software) and the density was 1.29 g/ml (obtained from the manufacturer).

The 1st, 10th, 20th and 30th crowns of both materials were scanned with a 3D Measuring Laser Microscope (Olympus LEXT OLS5000, Olympus Corporation, Japan) to measure the surface roughness.
Loading [MathJax]/jax/output/CommonHTML/jax.js ...poration, Japan) a frame size 12 μm x 12 μm was placed on

the occlusal surface of the crown to give the average surface roughness (Fig. 4). The analysis parameter used was the arithmetic mean height (Sa). It is equivalent to the arithmetic mean of the measured region on the three-dimensional display diagram when valleys have been changed to peaks by conversion to absolute values (as per Olympus resource at https://www.olympus-ims.com/en/knowledge/metrology/roughness/3d_parameter/).

Data Analysis

Continuous variables were summarised by the mean, standard deviation, median and interquartile range. The effect of material and number of crowns milled on the internal fit (IF) and surface roughness (SR) outcomes was determined by a two-way Analysis of Variance (ANOVA) with the outcome as the dependent variable, and material and number of crowns milled as the independent variables. The interaction between material and number of crowns milled could not be assessed, as there were insufficient degrees of freedom for such an analysis. The relationship between wear and number of crowns milled for each material was explored descriptively, as were the relationships between IF, SR and wear for each material. Data analysis was carried out using SAS version 9.4 for Windows. The 5% significance level was used.

Results

Table 1 shows the wear of diamond particles. This table gives the measurement values of three bur sizes making use of the four sides of the bur. It can be seen that the total particle loss after the 10th milling time was an average of 369 particles, while after 30th milling time the particle loss was an average of 677 particles, an average loss of 26%.

Table 2 shows the results of the milling of the Zirconium Oxide using different bur sizes. It shows the average wear of the burs of different sizes in mm. The minimum value of wear occurred with the 2.5 mm bur size (0.03 mm) and the higher value occurred with the 1.00 mm bur size (0.12 mm).

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Table 1
Wear of Diamond Particles in the area measured

Milling time	Bur size	Side 1	Side 2	Side 3	Side 4	Average	% Loss
Before 1	1.2	280	284	300	288	1152	
	1.4	251	249	223	249	972	
	2.2	126	122	131	145	524	
Total average particle wear						**2648**	
After 10	1.2	246	229	253	236	964	16
	1.4	229	234	230	230	923	5
	2.2	86	102	103	101	392	25
Total average particle wear/% loss						**2279**	**14**
After 20	1.2	262	195	236	198	891	23
	1.4	213	217	210	209	849	13
	2.2	75	98	109	97	379	28
Total average particle wear/% loss						**2119**	**20**
After 30	1.2	218	190	251	221	880	24
	1.4	226	190	156	195	767	21
	2.2	66	105	110	43	324	38
Total average particle wear/% loss						**1971**	**26**

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Table 2
Wear of tungsten carbide burs.

Milling time	Bur size	Average wear (mm)	% change
After 10	0.5	0.0093	1.86
	1.0	0.0017	0.17
	2.5	0.00324	0.13
Total average wear/% change		**0.01424**	**0.72**
After 20	0.5	0.0173	3.46
	1.0	0.0034	0.34
	2.5	0.00972	0.39
Total average wear/% change		**0.03042**	**1.4**
After 30	0.5	0.02	4.00
	1.0	0.0068	0.68
	2.5	0.02916	1.17
Total average wear/% change		**0.05596**	**1.95**

Table 3 and Fig. 5 show the milling times for Sirona blocs C together with the average wear (loss) of bur particles, the internal fit and the surface roughness, and Table 4 and Fig. 6 shows the similar parameters for the Zirconia. There were no statistically significant differences between the materials (*p = 0.32*) in terms of the surface roughness or for the internal fit (*p = 0.12*).

Table 3
Sirona Blocs C average wear, internal fit, and surface roughness.

Crown milling number	Average Number of Diamond bur particles in 1 mm^2 frame	Internal fit Silicone	Crown average surface roughness Sa (μm)
1	2648	0.192	3.270
10	2279	0.189	3.033
20	2119	0.186	3.061
30	1971	0.181	2.591

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Table 4
Zirconium Oxide average percentage change of the burs, the internal fit and the surface roughness.

Crown milling number	Average % change	Internal Fit Silicone	Crown average Surface Roughness Sa (µm)
1	-	0.209	2.479
10	0.72	0.192	2.928
20	1.40	0.190	2.220
30	1.95	0.181	2.953

For the Sirona blocs and diamond burs, there was an overall 6% reduction in the internal fit and a 6% reduction in surface roughness. For the Zirconia, there was an overall 13% reduction in the internal fit and a 16% increase in surface roughness.

Discussion

As was to be expected, there was a clear relationship between the wear of the burs and the number of crowns milled. Wear was assessed in the diamond burs by the loss of particles, and this was similar to the findings of other studies. [3, 4]

Studies on the wear of non-diamond burs have been limited to counts of chips off the cutting blades, and a more reliable method of assessing wear was devised for this study, whereby SEM photomicrographs could be directly measured and a factor derived to represent the wear. As with the diamond burs, there was clearly an increase in wear with the number of crowns milled.

There were no statistically significant differences between the two materials, and this was not surprising, as both materials in the form used for milling, had relatively low Vickers Hardness, which has been related to bur wear in previous studies. [3]

Interestingly, there was no clear trend in the percentage of particles lost relative to the diamond bur sizes, with the 1.4 mm diameter bur displaying the least percentage loss of particles (21%) followed by the 1.2 mm bur (24%) and the 2.2 mm bur (38%).

For the diamond burs, with the increased numbers of crowns, there was a concomitant increase in bur wear, a decrease in internal fit (6% after 30 crowns), and a decrease in surface roughness. These are logical trends, and point to the fact that when milling with diamond burs, to maintain the internal luting space, the parameters for milling must be adjusted to compensate for bur wear. If this is not done, then the internal milled luting space may be inadequate and may result in incomplete seating of the crown. This may explain any change in occlusion post-cementation, which should not occur if the luting space is adequate.

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For the tungsten-carbide burs, similar trends were observed for bur wear and internal fit (13% after 30 crowns), but there was an overall increase in surface roughness. This is logical given the nature of the burs, as increase chipping of the cutting edge would be expected to increase the roughness.

Conclusions

This would appear to be the first study to measure the wear of diamond burs in four quadrants and compare this with the internal fit and surface roughness, using two different materials. It is also the first study to measure the cutting blades of tungsten carbide burs, and so it was difficult to compare them with other sources from the literature.

The results, though, showed trends that were mostly to be expected and confirmed that with increasing bur wear, either as particle loss in diamond burs, or reduction in cutting blade size in tungsten-carbide burs, there was a concomitant decrease in the internal fit of 6% and 13% respectively after 30 crowns. It is important, therefore, to compensate for this by adjusting the milling parameters.

The nature of the wear in the tungsten carbide bur wears was such that the cutting blades became rough, and this resulted in an increase in surface roughness (16%) of the milled crown. In contrast, the nature of the wear in diamond burs is a reduction of particle numbers, such that the bur becomes smoother, and this was reflected in the decrease in surface roughness (6%) with the number of crowns milled.

It is hoped that this study will provide a base-line for further studies using different burs and different materials, so that recommendations can be made as to when to not only change the burs, but also to adjust the milling parameters to adjust for the wear. It would also be useful to mill sufficient crowns to discover for each bur and material combination, the number of crowns at which clinically unacceptable results would be obtained.

Abbreviations

CAD/CAM
Computer-Aided Design/Computer-Aided Manufacturing.
SEM
Scanning Electron Microscope.
IF
Internal Fit.
SR
Surface Roughness.

Declarations

Availability of data and materials:

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The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate:

not applicable to an in vitro study

Consent for publication:

not applicable

Competing interests:

None

Funding:

None

Authors' contributions:

Single author

Acknowledgments:

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Unsectioned Paragraphs

Research paper

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A base-line study of the wear of burs used for chairside milling of ceramic crowns of different hardness: effect on internal fit and surface roughness

Declarations

Figures

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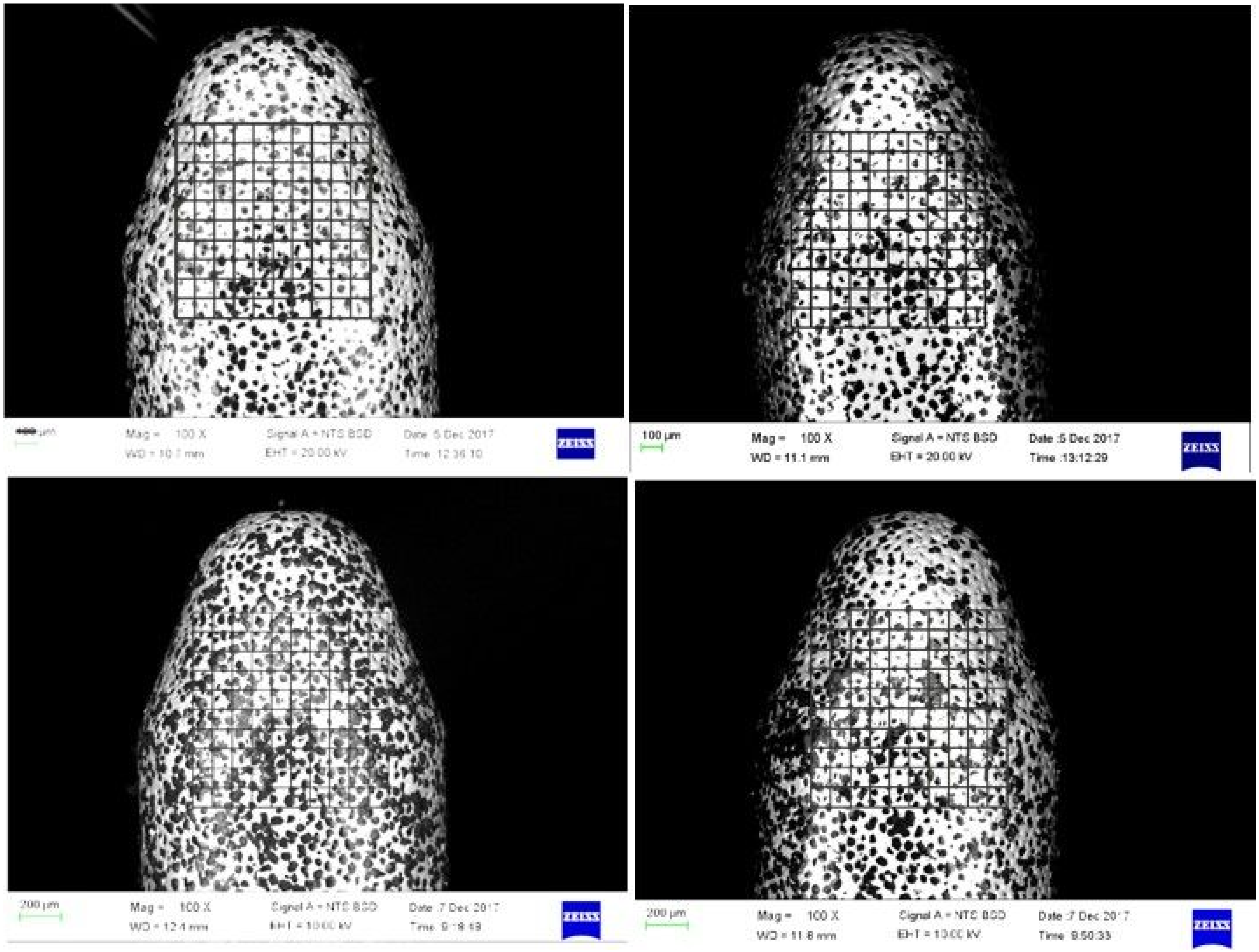

Figure 1

The four quadrants of the Diamond bur, size 1.2 mm before milling.

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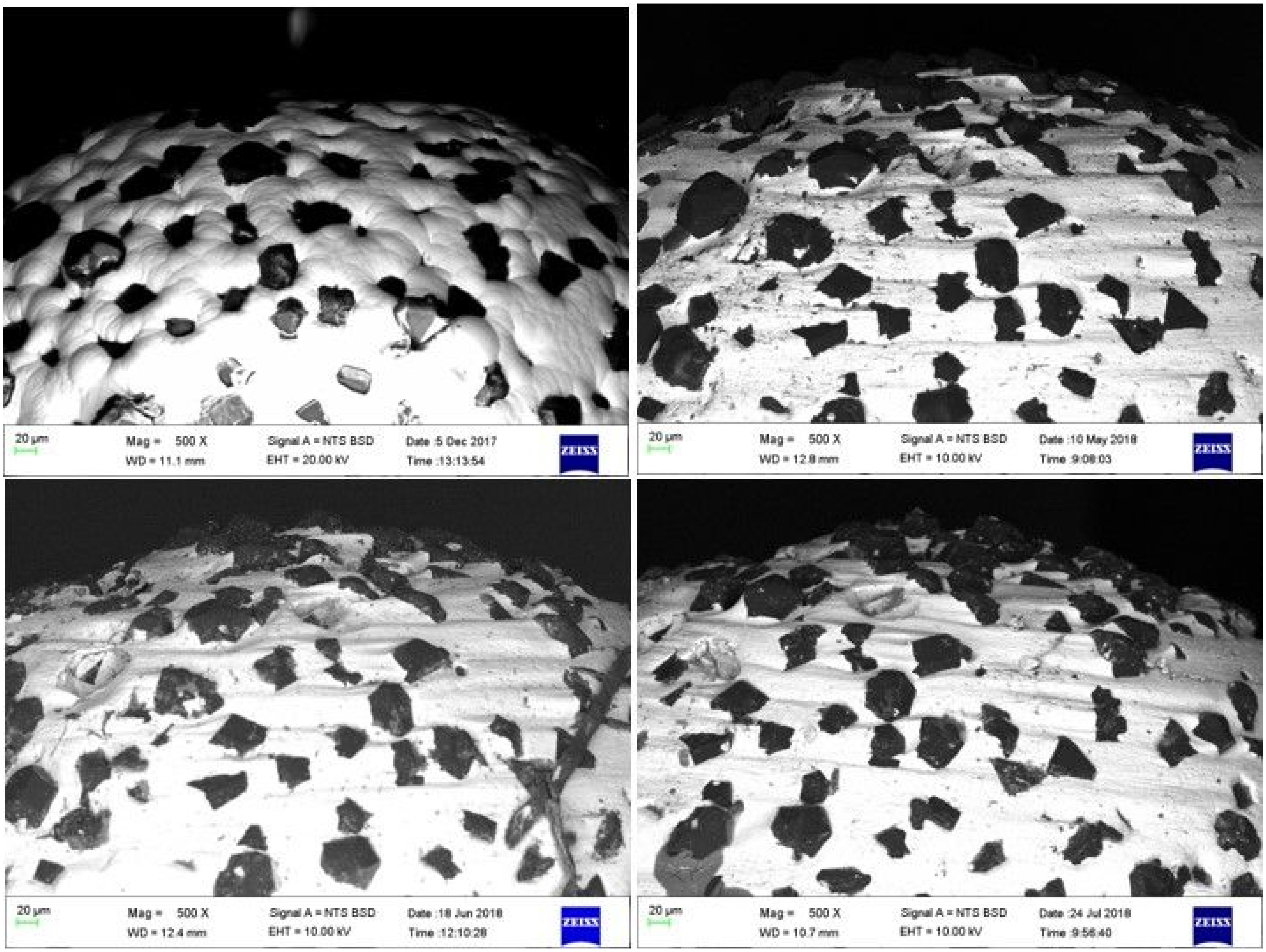
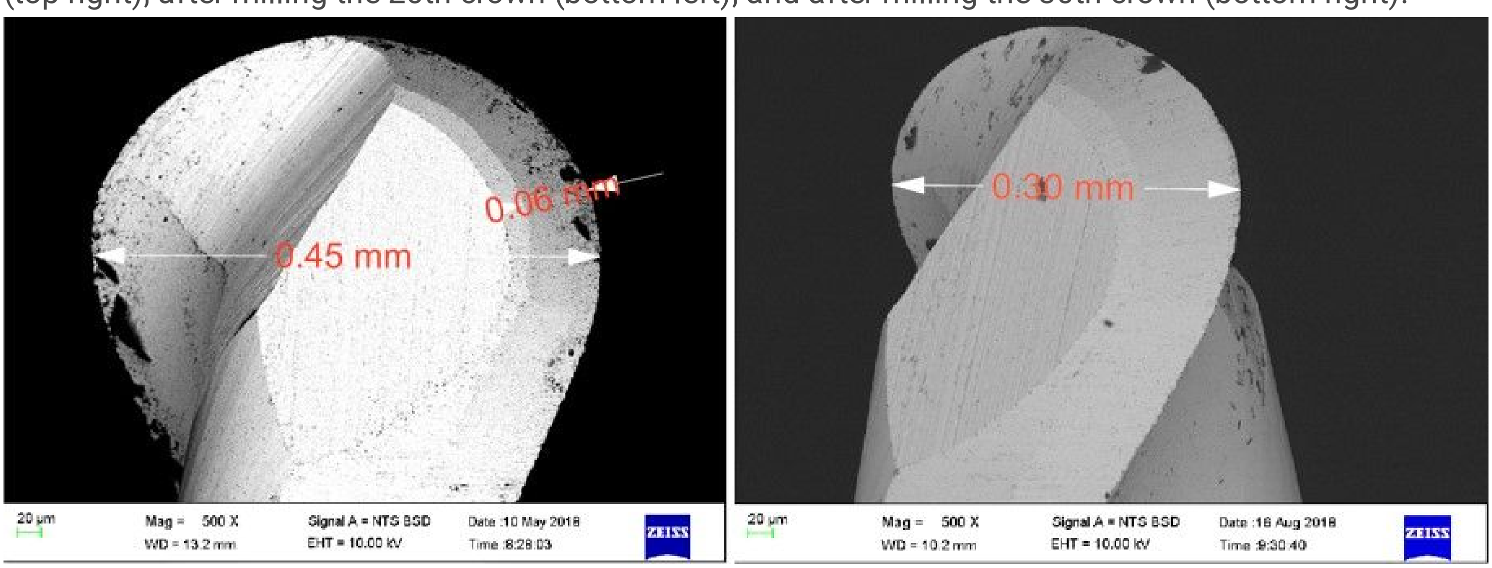


Figure 2

The Diamond bur, size 1.2 mm magnification X500 before milling (top left), after milling the 10th crown (top right), after milling the 20th crown (bottom left), and after milling the 30th crown (bottom right).



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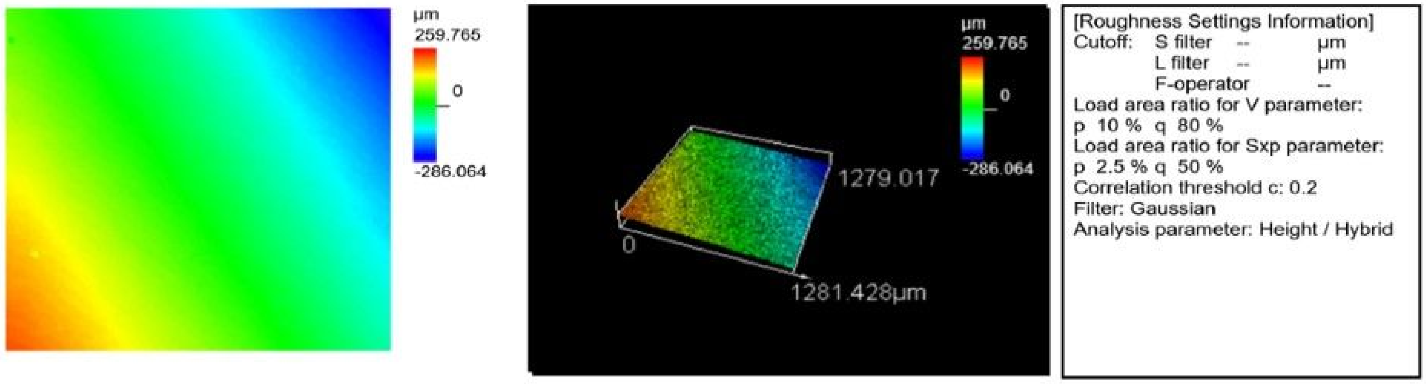
Bur size 0.5 for Zirconia. (left) before milling (right) after milling of the 30th crown, magnification 500x



No.	Result	Sq[µm]	Ssk	Sku	Sp[µm]	Sv[µm]	Sz[µm]	Sa[µm]	Sdq	Sdr[%]	FOperator	S-filter[µn	L-filter[µn
1		3.999	-0.833	8.586	33.092	56.433	89.525	3.033	2.211	117.753	--	-	-

Figure 4

Sirona blocs C surface roughness for Crown number 1.

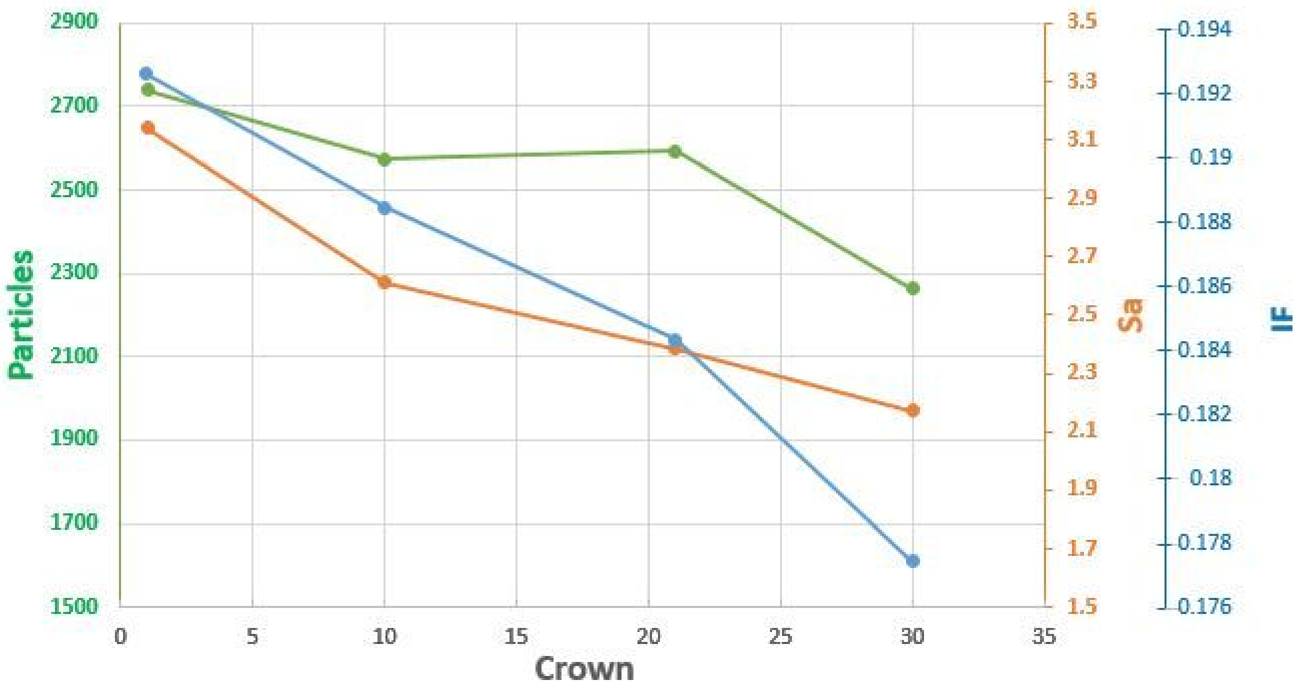


Figure 5

Sirona Blocs C average wear (Particles, green), internal fit (IF, blue), and surface roughness (Sa, orange).

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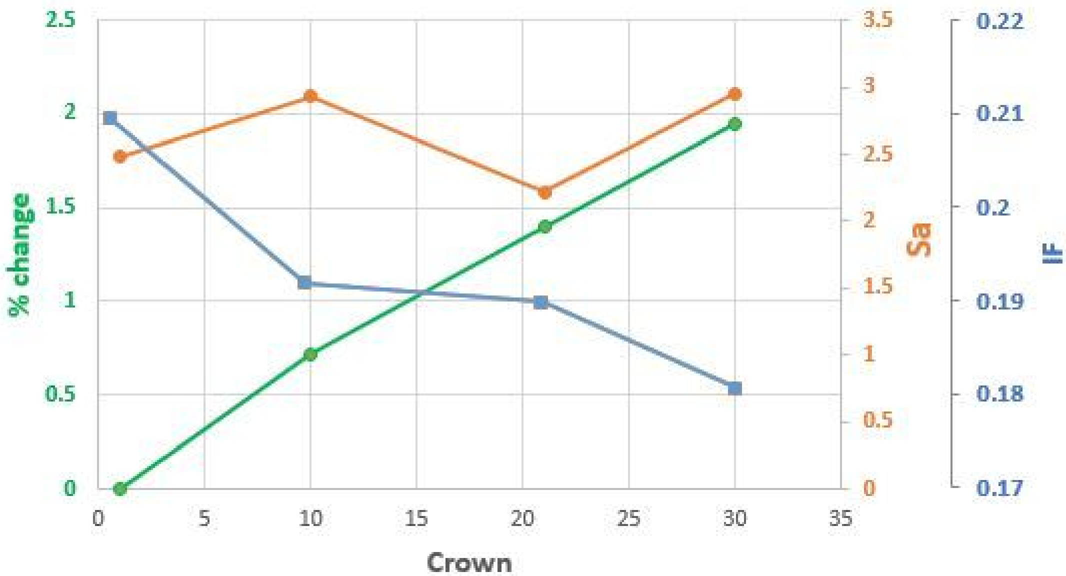

Figure 6

Zirconia burs average percentage change (green), internal fit (IF, blue), and surface roughness (Sa, orange).

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