

https://dspace.org/

The calibration of a software programme to assess ceramic crown preparations in a pre-clinical setting

Roopa, Variza Daya

2016
http://hdl.handle.net/10539/21537

Downloaded from a DSpace repository. https://dspace.org/

The Calibration of a Software Programme to Assess Ceramic Crown Preparations in a Pre-clinical Setting

VARIZA DAYA ROOPA

A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Science in Dentistry.

Supervisor:

Professor CP Owen

Co-supervisor:

Dr VJ Hoods-Moonsammy

School of Oral Health Sciences, Faculty of Health Sciences, University of the Witwatersrand, South Africa

Johannesburg, 2016

DECLARATION

I, Variza Daya Roopa, declare that this research report is my own work. It has been submitted for the degree of Master of Science in Dentistry in the Faculty of Health Sciences at the University of the Witwatersrand, Parktown, Johannesburg, South Africa. It has not been submitted before for any other degree or examination at this or any other University.

Signed …….

This 13th day of April 2016

DEDICATION

I dedicate this research report to my niece, Dhiyana, who from the day she was born has been the light of my life**.**

PRESENTATIONS

1. Poster Presentation: The 46th Scientific Meeting of the International Association for Dental Research (South African Division), 3-4 September 2015, Pretoria, South Africa
2. Poster Presentation: The 16th Biennial Meeting of the International College of Prosthodontics, 16-21 September 2015, Seoul, South Korea.

ACKNOWLEDGEMENTS

Prof CP Owen (BDS, MScDent, MDent, FICD) for his undivided supervision, continued support, invaluable guidance, encouragement and inspiration throughout this research project.

Dr VJ Hoods-Moonsammy (BSc Hons, BDS, MPH, MDent) for her supervision, guidance and support throughout this research project.

Mr Roland Felber (Goethe University, Frankfurt) for training on PrepCheck 1.1 and his continued support and advice on the use of the software.

Mr Andy Cyprianos (Sirona Dental Systems, South Africa) for donating the PrepCheck license and for sponsoring training on the software.

Dr Karen Bennie, Dr Noland Naidoo, Dr Michael Michael, Dr Meriting Thokoane and Dr Sandile Mpungose for their participation in the study.

Dr Marc Slabbert and Mr Marlo Bester for their kind assistance and advice.

My parents, Bharad and Priya Daya Roopa, for encouraging me to continue furthering my education and to pursue this degree.

My dear friend, Dane Schovell, for his assistance, continued support and motivation.

ABSTRACT

Purpose

The use of the PrepCheck (v.1.1) software (Sirona Dental Systems GmbH, Germany) is to enable assessment of student tooth preparations to be digital, objective, accurate, consistent and reliable so that students can work independently. The software has its default parameters configured to arbitrary values which are not based on clinical evidence of tooth preparations. The aim of this study was to set new parameters of the software to realistically assess the quality of clinically acceptable ceramic crown preparations.

Method

Based on evidence in the literature a new assessment rubric for the evaluation of ceramic tooth preparations was created which allowed for grading of the preparations as Acceptable, Requires Modification or Unacceptable. Sixty preparations were made on typodont teeth for tooth numbers 11, 13, 15, 16, 36 (FDI system). For each tooth four preparations were made to meet all the requirements under the Acceptable Category, four with variations in taper, incisal/ occlusal reduction and axial reduction to be categorised as Requires Modification and four had further variations made so that they fall under the Unacceptable Category. The sixty preparations were assessed by five faculty instructors (acting as raters) at baseline and again after two weeks to assess intra- and inter-rater reliability. Once sufficient agreement had been reached, the software's parameters were adjusted and the preparations were scanned and compared with the categorical assessment from the instructors. This process was repeated once to test whether the software had been successfully calibrated.

Results

The intra-rater agreement was substantial, with two raters having excellent intra-rater agreement. However, two raters had poor inter-rater agreement and were then excluded, after which the inter-rater reliability measured by Cohen's kappa was 0.71, corresponding to 'substantial' agreement on both occasions. The majority decision rating from these assessments accurately resembled the intended rating and was used to compare the ratings of the software assessment using the default and new (rubric) parameter settings. The default settings performed poorly, whereas the new settings resulted in substantial agreement with the majority decision of the instructors (raters).

Conclusions

It was found that the default parameters of the software were unrealistic and not clinically based. The parameters required considerable modification to assist in the development of clinically acceptable preparations. The software shows great promise but the parameters have to be modified to be able to assess preparations that are more realistic for the clinical situation.

TABLE OF CONTENTS

Chapter 1 1

Introduction and Literature Review 1

1.1 Background to study 1

1.2 Rationale for study 5

Chapter 2 6

Aim and Objectives 6

2.1 Aim 6

2.2 Objectives 6

2.3 Null Hypothesis 6

Chapter 3 7

Method and Materials 7

3.1 Method 7

3.1.1 Development of Assessment Rubric 7

3.1.2 Preparation of Test Teeth 7

3.1.3 Assessment of Tooth Preparations by Instructors 9

3.1.4 Assessment of Tooth Preparations by Software 10

3.2 Sample Size 12

3.3 Statistical Analysis 13

3.4 Ethical Considerations 13

Chapter 4 14

Results 14

4.1 Assessment of Tooth Preparations by Instructors 14

4.1.1 Instructor Ratings 14

4.1.2 Intra-rater Reliability 15

4.1.3 Inter-rater Reliability 15

4.2 Assessment of Tooth Preparations by Software 17

4.2.1 Inter-rater Reliability: PrepCheck before calibration vs. majority decision rating 18

4.2.2 Inter-rater Reliability: PrepCheck run after calibration vs. majority decision rating 18

4.2.3 Intra-rater Reliability: First vs. second PrepCheck run after calibration 18

Chapter 5 19

Discussion 19

5.1 Instructor Assessment 19

5.1.1 Intra-rater Reliability 19

5.1.2 Inter-rater Reliability 19
5.1.3 Majority Decision 20
5.2 Software Use 20
5.2.1 Analysis Tools 20
5.2.2 Default Settings 31
5.2.3 Issues with Default Settings 32
5.3 Parameters 33
5.3.1 Parameter Setting 33
5.3.2 Comparison of Rubric Settings to the Majority Decision 34
5.3.3 Reliability 35
5.4 Limitations/ challenges encountered 35
Chapter 6 37
Conclusions and Recommendations 37
6.1 Conclusions 37
6.2 Implications 37
6.3 Recommendations 38
References 39
Appendices 42
Appendix 1: Assessment Rubric for Posterior All-ceramic Crown Preparation 42
Appendix 2: Assessment Rubric for Anterior All-ceramic Crown Preparation 43
Appendix 3: Table showing Evidence for Posterior All-ceramic Crown Preparation Criteria .. 44
Appendix 4: Table showing Evidence for Anterior All-ceramic Crown Preparation Criteria ... 45
Appendix 5: Summary of Analysis Tools: Functions, Interpretations and Parameters 46
Appendix 6: Human Research Ethics Committee (Medical) Waiver 47
Appendix 7: Modified Assessment Rubric for Posterior All-ceramic Crown Preparation 48
Appendix 8: Modified Assessment Rubric for Anterior All-ceramic Crown Preparation 49

LIST OF FIGURES

Figure 1. Taper tool on the PrepCheck software 4

Figure 2. (a) An example of an all-ceramic preparation on tooth 36 that would be Acceptable; **(b)** An example of an all-ceramic preparation on tooth 36 that would Require Modification due to undercuts present and insufficient occlusal reduction; **(c)** An example of an all-ceramic preparation on tooth 36 that would be Unacceptable due to increased occlusal reduction 9

Figure 3. Screenshot of Taper tool indicating 87% of the preparation on tooth 15 requires modification. The cursor indicates the degrees in the selected area and a description that the walls are too parallel 11

Figure 4. Screenshot of Undercut tool indicating 45% of the preparation on tooth 15 requires modification to eliminate the undercuts present 11

Figure 5. (a) Screenshot of PrepCheck using Undercut tool for preparation on 15 after defining the axis on occasion 1 indicating 24% of undercuts present; **(b)** Screenshot of the same preparation after defining the axis on occasion 2, indicating 25% of undercuts present21

Figure 6. Screenshot of Reduction tool with superimposed Splice tool and manual Measure Distance tool. The measured distance is 4.04 mm and the measured value based on the Reduction tool is 2.38 mm. Each grid block represents 1 mm 23

Figure 7. Screenshot of Reduction tool with manual Measure Distance tool. The measured distance and the measured value based on Reduction tool are both 1.44 mm.....24

Figure 8. Screenshot of Reduction tool. The tolerance for the margin width is set from 1.0 - 1.5 mm. The inner axial line of the margin is blue indicating it falls within these parameters and is thus Acceptable. The walls of the preparation are highlighted in red indicating that more than 1.5 mm of tooth structure was removed 25

Figure 9. (a) Screenshot of Reduction tool displaying blue on the inner axial line angle indicating an Acceptable preparation; **(b)** Red on the inner axial line angle indicating an Unacceptable preparation; **(c)** Green on the inner axial line angle indicating an insufficient margin width (Requires Modification) 26

Figure 10. Screenshot of Distance to Opposite Jaw tool on tooth 11. Only the colours displayed on the preparation that opposes the 41 should be interpreted. In this case it is the green colour which will indicate insufficient occlusal clearance 27

Figure 11. Screenshot of Distance to Opposite Jaw tool and manual Measure Distance tool. A distance of approximately 1.39 mm exists between the maxillary and mandibular molars of KaVo model teeth 28

Figure 12. (a) Screenshot of Preparation Type indicating 100% blue margin; **(b)** Red areas in the margin of 13%; **(c)** 85% of the margin is green.....29

Figure 13. Screenshot of Margin Quality tool indicating 5 areas of orange that will require modification 30

Figure 14. Screenshot of Surface Quality tool displaying a grey (smooth) preparation that is Acceptable.....31

LIST OF TABLES

Table 1. Combinations of test preparations.....8

Table 2. Instructor ratings and majority decision on occasion 1 and occasion 2.....14

Table 3. Intra-rater reliability for each of the fives assessors (raters).....15

Table 4. Agreement between each pair of assessors (raters) on occasion 1; A: percentage agreement; B: kappa / weighted kappa; C: p-value for Stuart Maxwell test.....16

Table 5. Agreement between each pair of assessors (raters) on occasion 2; A: percentage agreement; B: kappa / weighted kappa; C: p-value for Stuart Maxwell test.....17

Table 6. Differences between default settings (before calibration) and rubric settings (after calibration).....17

Chapter 1

Introduction and Literature Review

1.1 Background to study

Computer Assisted Design and Computer Assisted Manufacturing (CAD/CAM) technology has improved the way in which health care professionals can provide a service to patients. The concept of digital dentistry has not only been beneficial to the dental practitioner in terms of keeping a digital workflow, saving time and reducing laboratory and other costs but more importantly to the patient who receives restorations often at reduced cost and usually at reduced clinical time.

Since its introduction in the 1980s, the popularity of CAD/CAM has increased amongst dental practitioners and their patients. This has inevitably placed a demand on universities training dentists to include education on this technology into the undergraduate curriculum. At the University of the Witwatersrand, School of Oral Health Sciences, CAD/CAM dentistry has been incorporated into the Fixed Prosthodontics undergraduate and postgraduate curriculums. Many universities around the world have done the same, equipping future dentists with the knowledge and practical skill of creating milled ceramic indirect restorations.

In most dental schools a pre-clinical fixed prosthodontics course is a pre-requisite to clinical training. Students will be trained to prepare crown (or inlay/onlay) tooth preparations on acrylic teeth in a simulated clinical environment. Evaluation and feedback of these preparations are provided by instructors (trained dentists of the faculty) which enable the

student to develop and improve in order to provide accurate tooth preparations that will receive accurate permanent restorations.

Evaluation by instructors can be a weak link in dental education, where feedback is often subjective. Traditional evaluation, adopted by many schools, is carried out visually and mostly without any assessment aid. This makes grading of students' work less accurate and variable when there is a lack of calibration between multiple evaluators. Many studies (Lilley et al, 1968; Fuller, 1972; Salvendy et al, 1973; Mackenzie et al, 1982; Feil and Gatti, 1993; Haj-Ali and Feil, 2006; Sharaf et al, 2007) have highlighted these aspects, and have pointed out the many variables in assessment of pre-clinical work. Several investigators concluded that to achieve accurate feedback, it is necessary to remove the human element from evaluation and develop objective evaluation methods (Salvendy et al, 1973; Schiff et al, 1975).

There are currently four systems which have been reported on that assess tooth preparations using software. E4D Compare (D4D Technologies, Texas, USA) was evaluated by Renne et al (2013), who concluded "This study demonstrated a reliable method of scanning and comparing student tooth preparations to a known ideal preparation. Using this method makes it feasible to accurately and consistently assess student work without dependence on subjective evaluation criteria." Another system is PrepAssistant (Kavo Dental GmbH, Biberach, Germany). Cardoso et al. (2006) used this software by combining it with visual assessment in a 70:30 percentage ratio. PrepAssistant was reported to be a labour intensive system and did not show a statistically significant difference in results when compared with the visual evaluation method. However, the study showed that when used in conjunction with visual assessment, the software did provide a more objective assessment and reduced

problems in calibration amongst different evaluators. Esser et al (2006) used Scan 3D and Match 3D Software (from Gloger W, Ludwig-Maximilians-University, Munich, Germany) to evaluate the extent to which the software's analysis of prepared teeth could replace visual assessment from a dental educator. The results of their study showed that it was possible to digitally measure quality criteria for a ceramo-metal crown preparation, but the measuring method applied required improvement as did the calibration of the evaluators.

PrepCheck 1.1 is the current version available of a computer aided training system developed by Sirona Dental Systems GmbH (Bensheim, Germany) in 2014. The software works with Cerec 4.2 + and provides fully automated 3D analysis of tooth preparations and applied restorative material. The software works using Bluecam or Omnicam scanners and can assess all types of crowns and inlays. The programme is aimed at universities to aid in training students as well as to aid instructors in evaluating students' work.

There are several analysis functions that assist both the student and the instructor to assess tooth preparations digitally. The analysis functions include tools that can automatically detect the presence of undercuts, measure the taper of any aspect of the tooth preparation, measure the amount of axial reduction (and margin width), measure the amount of restorative space available occlusally, compare the preparation margin type to a pre-defined margin type (shoulder or chamfer) and can assess the margin and surface quality for smoothness or sharp edges. The analysis functions also include manual tools that enable the user to measure the distance between any two points on the preparation or measure an angle between any three points on the preparation.

Other features of the software include a 3D comparison of the preparation to a pre-selected, gold standard "Master Preparation", a 3D comparison of the preparation to the pre-operative

tooth to identify the amount of reduction that has taken place, a 3D comparison of the preparation to the proposed restoration to measure the thickness of the restoration and a 3D comparison of one preparation to another so that the user can follow their progress.

A colour scale provides the user with feedback about the quality of the preparation. Areas that are highlighted in blue indicate those within the specified tolerance range. Areas of the preparation highlighted in green are those that are below the minimum tolerance value and would require some modifications to achieve an acceptable result. Areas highlighted in red are those which are beyond the maximum tolerated values and are not acceptable.
An example of the colour scale feedback can be seen using the analysis tool that measures taper in Figure 1.

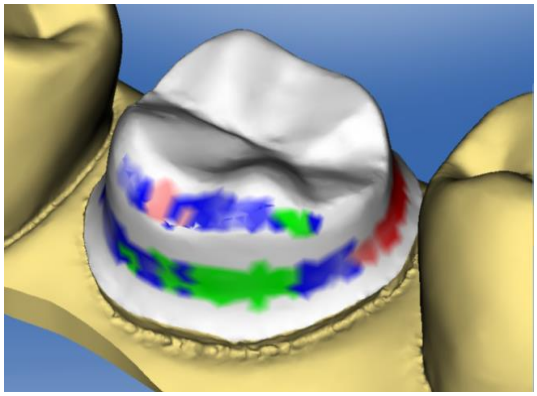


Figure 1. Taper tool on the PrepCheck software

Current studies on the use of PrepCheck are of low level evidence and include pilot studies at Goethe University in Frankfurt showing that 80% of students find PrepCheck easy to use. Another study from the same institution showed that PrepCheck was useful to objectively assess reduction, taper and height of preparations and that the results were reproducible (Felber R. Personal communication, 05 May 2014).

A pilot study carried out at Harvard University indicated that the software was reliable to measure undercut, taper and reduction, but the authors concluded that a comparison between assessors and the software needed to be made (Hou and Kristiansen, 2014).

The School of Oral Health Science at the University of the Witwatersrand has standardised the use of Sirona's Cerec CAD/CAM software, and Sirona has donated a license to use the PrepCheck software as well. Our experience has been that the software is complicated to use, but with modification might be more user-friendly and ultimately its benefit ought to include use in general practice, to improve the quality of the preparations being made. Initially, though, it requires calibration against clinically acceptable preparations, and against experienced instructors, and this is the purpose of the study.

1.2 Rationale for study

The rationale for the use of PrepCheck is to ensure that assessment of student tooth preparations can be digital, objective, accurate, consistent and reliable. Students can work independently and be motivated to improve. PrepCheck software has its parameters (tolerance values) configured at default settings. The problem this poses is that the analysis of tooth preparations is set according to arbitrary values and not that which is evidence-based. The solution and hence rationale for this research project is thus to calibrate the parameters of the various PrepCheck analysis tools according to the criteria required for assessment of all-ceramic tooth preparations at the Department of Oral Rehabilitation, University of the Witwatersrand. These criteria are not only based on evidence and widely recognised, but can be applied in the laboratory for techniques training and utilised clinically during patient treatment. By calibrating the software to these criteria student tooth preparations can be assessed digitally during the techniques course and then subsequently clinically (which would be the topic of a further study).

Chapter 2

Aim and Objectives

2.1 Aim

To set new parameters of the PrepCheck software to realistically assess the quality of all-ceramic crown preparations.

2.2 Objectives

1. To develop an assessment rubric to assess all-ceramic crown tooth preparations
2. To make standardised preparations for all-ceramic crowns for anterior and posterior teeth
3. To vary the standardised preparations in height, taper, and axial reduction
4. To determine the inter-rater and intra-rater reliability between calibrated laboratory instructors when assessing these preparations
5. To assess the preparations according to the default settings and compare these ratings to that of the majority decision rating of the instructors
6. To set new parameters for the analysis tools of the PrepCheck software to conform to the agreed assessment criteria

2.3 Null Hypothesis

The PrepCheck software cannot be successfully calibrated to the requirement criteria for assessing all-ceramic crown tooth preparations.

Chapter 3

Method and Materials

3.1 Method

3.1.1 Development of Assessment Rubric

A new assessment rubric for evaluation of anterior and posterior all-ceramic tooth preparations was created for this study (see Appendices 1 and 2). Currently the students' tooth preparations are assessed visually by instructors using a set of criteria but without any measurement or grading aids. The criteria required for preparations have been defined by evidence in the literature (see Appendices 3 and 4) (Smith, 1986; Goodacre et al, 2001; Rosenstiel et al, 2006; Beuer et al, 2009; Coehlo, 2009; Giannetopoulos et al, 2010; Ender, 2011).

The assessment will allow for grading of tooth preparations as either Acceptable (preparation conforms to all of the required criteria), Requires Adjustment (preparation conforms to some criteria, but adjustments can be made without making the preparation unacceptable) or Unacceptable where a preparation has failed to meet at least one criterion and no adjustment is possible without causing further damage to the tooth.

3.1.2 Preparation of Test Teeth

A full set of Typodont model teeth (KaVo Dental GmbH, Biberach, Germany) inserted into a KaVo basic study model placed into a simulated patient (Frasaco, North Carolina, USA) was used. The principal investigator produced sixty all-ceramic crown preparations on the

following teeth: 11; 13; 15; 16; 36, under 2,5x loupe binocular magnification (HEINE Optotechnik, Herrsching, Germany).

For each tooth four preparations were made such that they met all the requirements under the *Acceptable* category of the assessment rubric, and four preparations were made with variations in taper, incisal/ occlusal reduction and axial reduction such that they should be categorised as *Requires Modification* and a further four preparations with further variations have been made so that they should fall under the *Unacceptable* category of the assessment rubric (See Table 1).

Table 1. Combinations of test preparations

Tooth	**Category**												
	Acceptable				**Requires Modification**				**Unacceptable/ Rejected**				**Total**
11	P	P	P	P	↓ T	↓ IR	↓ AR	↓ IR ↓ T	↑ T	↑ IR	↑ AR	↑ AR ↓ T	**12**
13	P	P	P	P	↓ T	↓ IR	↓ AR	↓ IR ↓ T	↑ T	↑ IR	↑ AR	↑ AR ↓ T	**12**
15	P	P	P	P	↓ T	↓ OR	↓ AR	↓ OR ↓ T	↑ T	↑ OR	↑ AR	↑ AR ↓ T	**12**
16	P	P	P	P	↓ T	↓ OR	↓ AR	↓ OR ↓ T	↑ T	↑ OR	↑ AR	↑ AR ↓ T	**12**
36	P	P	P	P	↓ T	↓ OR	↓ AR	↓ OR ↓ T	↑ T	↑ OR	↑ AR	↑ AR ↓ T	**12**
Total	**20**				**20**				**20**				**60**

P, Perfect; T, Taper; IR, Incisal Reduction; AR, Axial Reduction; OR, Occlusal Reduction;
↓ Decrease; ↑ Increase.

Examples of how the preparations on tooth 36 have been varied to show changes in occlusal reduction are shown in Figure 2. .

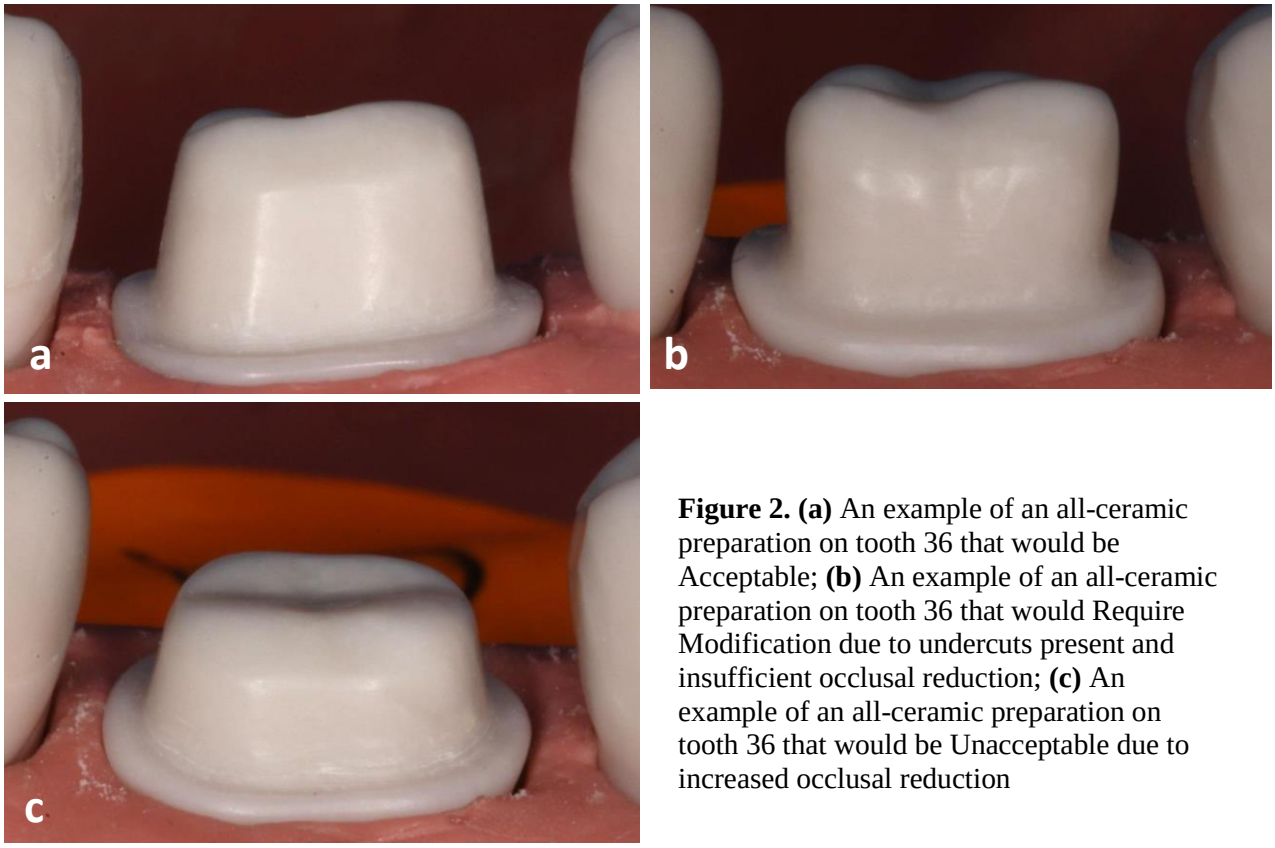


Figure 2. (a) An example of an all-ceramic preparation on tooth 36 that would be Acceptable; **(b)** An example of an all-ceramic preparation on tooth 36 that would Require Modification due to undercuts present and insufficient occlusal reduction; **(c)** An example of an all-ceramic preparation on tooth 36 that would be Unacceptable due to increased occlusal reduction

3.1.3 Assessment of Tooth Preparations by Instructors

There were five faculty supervisors / laboratory instructors who had been calibrated to achieve inter- and intra-rater reliability when visually analysing randomised tooth crown preparations by examining twenty-one crown preparations prior to the study. These preparations were from an undergraduate student course and varied in quality to reflect each of the three categories of the assessment rubric. The principal investigator had made any necessary changes to these preparations so that in the investigator's opinion they reflected the three categories of Acceptable, Requires Modification or Unacceptable.

After achieving the required calibration, the sixty test preparations were coded, and the order in which they were to be assessed was randomised using Excel Rand function (Microsoft Excel 2010, Microsoft, Washington, USA) throughout the study. The instructors then assessed the sixty tooth preparations under 2.5 x loupe magnification. After 2 weeks all sixty

test preparations were randomised again and re-assessed by the same instructors. From each of the five instructors each preparation had been categorized as Acceptable, Requires Modification or Unacceptable. The data from the two occasions of assessments were collected and analysed to determine the inter-rater reliability, intra-rater reliability and the majority decision of the five instructors.

3.1.4 Assessment of Tooth Preparations by Software

The sixty test preparations were again randomised and each one captured in the PrepCheck software using a Cerec AC and Omnicam scanner (Sirona Dental Systems GmbH, Bensheim, Germany). The preparations were assessed digitally using the following tools: Undercut, Taper, Reduction, Distance to Opposite Jaw, Preparation Type, Margin Quality, and Surface Quality. See Appendix 5 for more details on the analysis tools.

The interpretation of the analysis is based on different colours displayed:

- Blue indicates the preparation falls within the tolerance range and is thus acceptable
- Green indicates areas that require further modification
- Red indicates areas that are over-prepared and thus unacceptable
- Yellow indicates the presence of an undercut and will require modification
- Orange indicates an area of an indentation or sharp edge, and will require modification
- Grey indicates a smooth surface which is acceptable
- White indicates areas that are acceptable, such as a smooth margin or areas free of undercuts

The outcome or category of the preparation took into consideration all of the above mentioned tools used and was based on the colours displayed. For example if a preparation was highlighted green for taper (Figure. 3) and yellow for undercuts (Figure. 4) and all other features fell in the acceptable range, it was categorised as Requires Modification based on the insufficient taper and presence of undercuts. If, however, the same preparation was

highlighted red on reduction or distance to opposite jaw it would be automatically categorised as Unacceptable.

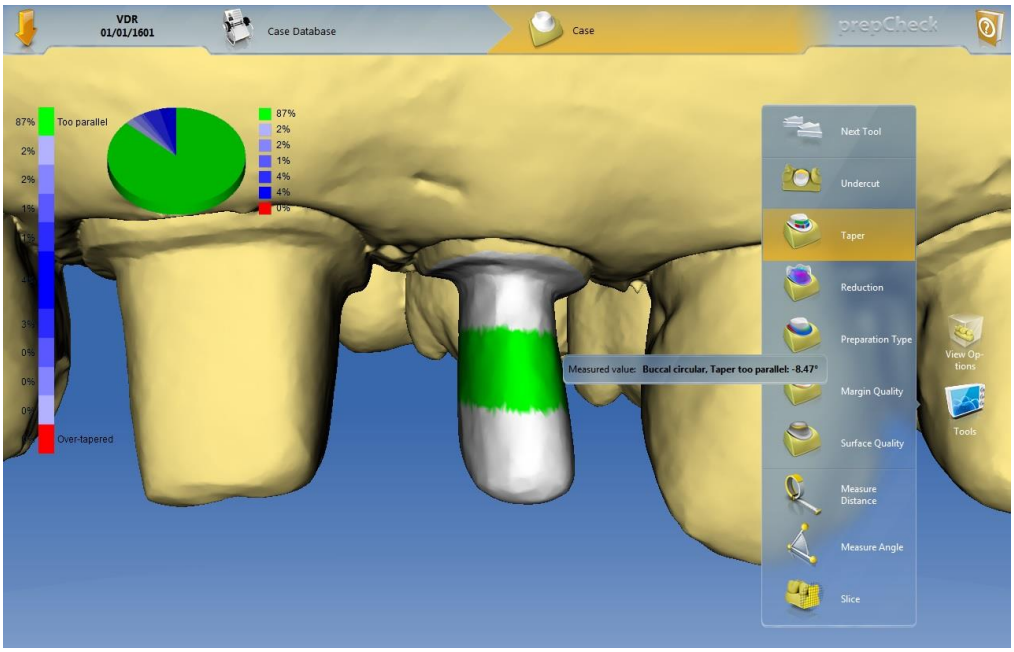


Figure 3. Screenshot of Taper tool indicating 87% of the preparation on tooth 15 requires modification. The cursor indicates the degrees in the selected area and a description that the walls are too parallel.

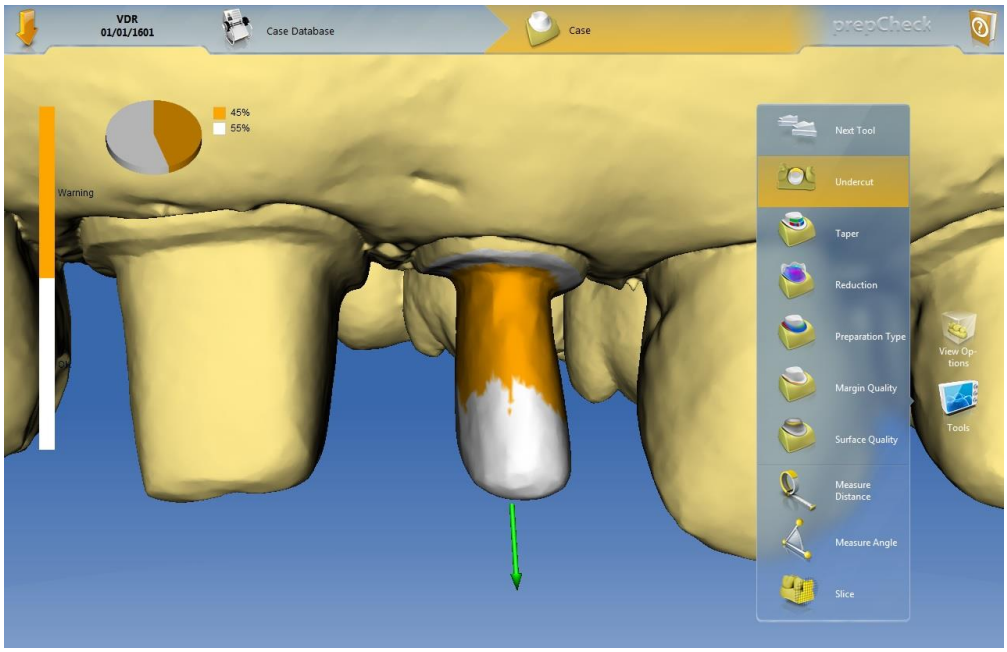


Figure 4. Screenshot of Undercut tool indicating 45% of the preparation on tooth 15 requires modification to eliminate the undercuts present.

The test preparations were randomised and first assessed and recorded using the default settings of the software parameters. The software's parameters were then manually re-set to the criteria according to the rubric and other additional changes were made (See Appendix 5).

The test preparations were again randomised and re-scanned into the software and analysed using the new rubric settings. The final outcome/ selected category for each tooth preparation using the new settings was recorded and compared against that of the default settings.
Each difference found was recorded and tabulated and compared with the categorical assessment from the assessors.

The parameters of the software did not require further adjustment based on the results. The tooth preparations were then randomised again and re-scanned and assessed by the PrepCheck software with the new parameters to test whether the software had been successfully calibrated.

3.2 Sample Size

An estimation of the sample size was based on the determination of the inter-rater reliability for the five instructors, and the inter-rater reliability of the software versus the instructor majority decision. The sample size depended on the relative error, the number of subjects and the difference between the overall agreement probability and chance.

Assuming a relative error of 20%, a large number of subjects, and that the chance-agreement probability is 0, for an overall agreement probability of at least 0.6 (0.7), the required sample size is 69 (51). The chosen sample size of 60 was thus adequate for the purposes of this study.

3.3 Statistical Analysis

Descriptive statistics were presented as frequencies and percentages. The inter-rater and intra-rater reliability for the instructors were assessed using Cohen's kappa for ordinal data. Cohen's kappa for ordinal data was also used for the comparison between the majority instructor rating and each of the derived software ratings. For two raters and ordinal responses, Fleiss' quadratically weighted kappa was used to allow each category combination to be weighted according to the degree of agreement between the categories (Shoukri, 2010). The magnitude of kappa was interpreted according to the classification by Landis and Koch (1977). Inter-rater and intra-rater bias was assessed by the Stuart-Maxwell test. Data analysis was carried out using SAS Software Version 9.3 for Windows (SAS Institute Inc., North Carolina, USA). The 5% significance level was used throughout.

3.4 Ethical Considerations

This was a laboratory based study. A waiver for ethical clearance has been granted by the Human Research Ethics Committee (Reference: W-JC-150205-2). See Appendix 6.

The donation of PrepCheck 1.1 from Sirona Dental Systems to the School of Oral Health Science has not resulted in any bias in favour of the software.

Chapter 4

Results

4.1 Assessment of Tooth Preparations by Instructors

4.1.1 Instructor Ratings

The descriptive statistics of the data for the intended rating, the 10 instructor ratings (5 raters on each of 2 occasions), and the majority decision of both occasions, are presented in Table 2.

Table 2. Instructor ratings and majority decision on occasion 1 and occasion 2

Rater		1		2		3		4		5		Majority Decision	
Occasion		1	2	1	2	1	2	1	2	1	2	1	2
% of samples rated as:	Intended rating												
Acceptable	33.3	31.7	33.3	33.3	36.7	28.3	25.0	23.3	26.7	8.3	11.7	26.7	28.3
Requires Modification	33.3	28.3	30.0	45.0	43.3	30.0	38.3	40.0	35.0	35.0	38.3	31.7	35.0
Unacceptable	33.3	40.0	36.7	21.7	20.0	41.7	36.7	36.7	38.3	56.7	50.0	41.7	36.7
% correct with respect to intended rating:		81.7	83.3	81.7	83.3	80.0	78.3	85.0	90.0	65.0	73.3	90.0	91.7

The figures highlighted in red show that rater 5 stands out from the other raters as this rater has a lower percentage of preparations rated as Acceptable and a higher percentage rated as Unacceptable on both occasions. This rater also has a lower percentage correct with respect to the intended rating on both occasions. These results show that rater 5 was far stricter than the other raters.

4.1.2 Intra-rater Reliability

The raw percentage agreement, Cohen's kappa, Fleiss' weighted kappa and interpretation of the Fleiss' weighted Kappa and the results of the Stuart-Maxwell test are shown in Table 3.

Table 3. Intra-rater reliability for each of the fives assessors (raters)

Rater	% agreement	kappa	weighted kappa	interpretation of weighted kappa	p-value for Stuart-Maxwell test
1	80.0	0.70	0.68	substantial agreement	0.77
2	90.0	0.84	0.86	almost perfect agreement	0.55
3	83.3	0.75	0.75	substantial agreement	0.14
4	88.3	0.82	0.90	almost perfect agreement	0.51
5	76.7	0.59	0.63	substantial agreement	0.35

The Stuart-Maxwell test results indicate that there was no evidence of intra-rater bias between the two occasions.

4.1.3 Inter-rater Reliability

On the first occasion of ratings, the raw agreement for all raters was 45%, with a Cohen's Kappa of 0.59, which corresponds to a 'moderate' agreement. Therefore the agreements between pairs of raters were calculated, and are shown in Table 4.

Table 4. Agreement between each pair of assessors (raters) on occasion 1; A: percentage agreement; B: kappa / weighted kappa; C: p-value for Stuart Maxwell test

Rater	1	2	3	4	5
1					
2	A: 78.3% B: 0.68 / 0.71 C: 0.0003				
3	A: 80.0% B: 0.70 / 0.61 C: 0.74	A: 71.7% B: 0.58 / 0.62 C: 0.011			
4	A: 80.0% B: 0.70 / 0.73 C: 0.047	A: 76.7% B: 0.65 / 0.67 C: 0.007	A: 81.7% B: 0.72 / 0.74 C: 0.08		
5	A: 66.7% B: 0.49 / 0.43 C: 0.0007	A: 53.3% B: 0.33 / 0.34 C: <0.0001	A: 70.0% B: 0.53 / 0.47 C: 0.002	A: 71.7% B: 0.55 / 0.57 C: 0.0004	

There are significant inter-rater biases (values in red), but also some low Kappa values (values in blue) in the pairwise comparisons. In particular, rater 5 had significant biases with all other raters (was stricter and had the lowest pairwise inter-rater agreement with the other four raters). Rater 2 had similar inter-rater biases although the kappa values were reasonable.

On the second occasion of ratings with all 5 raters, the raw agreement was 48.3% and Cohen's Kappa 0.60 which corresponds to 'substantial' agreement. However, the pairwise evaluations were identical to the first round. The agreements between pairs of raters were calculated, and are shown in Table 5.

Table 5. Agreement between each pair of assessors (raters) on occasion 2; A: percentage agreement; B: kappa / weighted kappa; C: p-value for Stuart Maxwell test

Rater	1	2	3	4	5
1					
2	A: 73.3% B: 0.60 / 0.63 C: 0.005				
3	A: 75.0% B: 0.63 / 0.66 C: 0.18	A: 70.0% B: 0.55 / 0.55 C: 0.001			
4	A: 85.0% B: 0.77 / 0.74 C: 0.31	A: 73.3% B: 0.60 / 0.59 C: 0.004	A: 83.3% B: 0.75 / 0.78 C: 0.077		
5	A: 66.7% B: 0.50 / 0.55 C: 0.001	A: 56.7% B: 0.37 / 0.33 C: <0.0001	A: 78.3% B: 0.66 / 0.68 C: 0.003	A: 76.7% B: 0.64 / 0.72 C: 0.002	

4.2 Assessment of Tooth Preparations by Software

The descriptive statistics (percentage correct) for the ratings of the PrepCheck software using the default settings (before calibration) and using the rubric settings (after calibration on occasion 1 and 2) are presented in Table 6. Included in this table are the intended rating and the majority decision data.

Table 6. Differences between default settings (before calibration) and rubric settings (after calibration)

Rater		**Majority decision**	**PrepCheck before calibration**	**PrepCheck after calibration**	
Occasion				**1**	**2**
% of samples rated as:	Intended rating				
Acceptable	33.3	26.7	6.7	33.3	33.3
Requires Modification	33.3	31.7	85.0	33.3	33.3
Unacceptable	33.3	41.7	8.3	33.3	33.3
% correct with respect to intended rating:		90.0	45.0	96.7	96.7
% correct with respect to majority decision:	90.0		40.0	86.7	86.7

4.2.1 Inter-rater Reliability: PrepCheck before calibration vs. majority decision rating

The raw agreement with the majority decision was 40.0% and Cohen's kappa and Fleiss' weighted kappa were 0.12 and 0.15 respectively. The latter corresponds to 'slight agreement'. The Stuart-Maxwell test was significant ($p<0.001$), indicating significant bias between the two sets of data.

4.2.2 Inter-rater Reliability: PrepCheck run after calibration vs. majority decision rating

The raw agreement with the majority decision was 86.7% and Cohen's kappa and Fleiss' weighted kappa were 0.80 and 0.72 respectively. The latter corresponds to 'substantial agreement'. The Stuart-Maxwell test was not significant ($p=0.19$), indicating no significant bias between the two sets of data.

4.2.3 Intra-rater Reliability: First vs. second PrepCheck run after calibration

The raw agreement was 100% and Cohen's kappa and Fleiss' weighted kappa were both 1.00, i.e. there was perfect agreement.

Chapter 5

Discussion

5.1 Instructor Assessment

5.1.1 Intra-rater Reliability

There was no evidence of intra-rater bias and the results in Table 3 show that all five instructors (raters) had been consistent in their ratings between occasion 1 and 2. Raters 2 and 4 had almost perfect intra-rater agreement and raters 1, 3 and 5 each had substantial agreement between the 2 occasions.

5.1.2 Inter-rater Reliability

Occasion 1

In Table 4 the p-values for the Stuart Maxwell test show many significant inter-rater biases. Rater 5 was more strict than the other four raters (significant inter-rater bias in all four cases) with low kappa values and rater 2 was less strict than the other four raters (significant inter-rater bias in all four cases), although the kappa values were reasonable.

Given the low overall kappa (0.59), it was then decided to exclude rater 5 and rater 2, to keep an uneven number of raters and to simplify the majority decision derivation. By making this exclusion and only using data for raters 1, 3 and 4, the data were validated as the raw agreement was 71.7% and Cohen's kappa was 0.71, corresponding to 'substantial' agreement. The majority decision data remained unchanged from the 5-rater version, but the basis for the majority decision outcome was much improved.

Occasion 2

The conclusions from the pairwise evaluation in occasion 2 were identical to those from occasion 1, though perhaps not as extreme (Table 5).

Using the ratings from occasion 2 (with all five raters) the Cohen's kappa was a low of 0.60, corresponding to 'substantial' agreement.

By using only data for raters 1, 3 and 4, the raw agreement was 73.3% and Cohen's kappa was 0.71, corresponding to 'substantial' agreement.

5.1.3 Majority Decision

The majority decision data from raters 1, 3 and 4 from occasion 1 were used in the subsequent phase of the data analysis. Cohen's kappa was identical for this scenario for both occasions; thus the results from the first occasion were used by default. Table 2 shows the accuracy (% correctly classified preparations) of the majority decision rating vs. the intended rating on occasion 1 was 90.0%. This indicated the intended accuracy of the assessment when categorising the tooth preparations.

5.2 Software Use

5.2.1 Analysis Tools

The use of the analysis tools of the PrepCheck software came with inherent difficulties. These were overcome by creating a method or protocol to interpret the digital data and percentages displayed in a way that made the assessment realistic. The difficulties in using the tools and the method of analysing the interpretations to reach categorisation of the tooth preparations are explained for each analysis tool below. A summary can also be found in Appendix 5.

Undercut

This tool detects undercuts present on the preparation and displays the areas which will require modification in yellow.

Difficulties: The extent of the undercuts measured was affected by defining the tooth axis which is a preceding step before analysis, i.e. if the tooth axis was defined in a different way on two occasions the percentage of undercuts present would change as the tooth axis changed (Figure 5.) This, however, was a change in 1-2%.

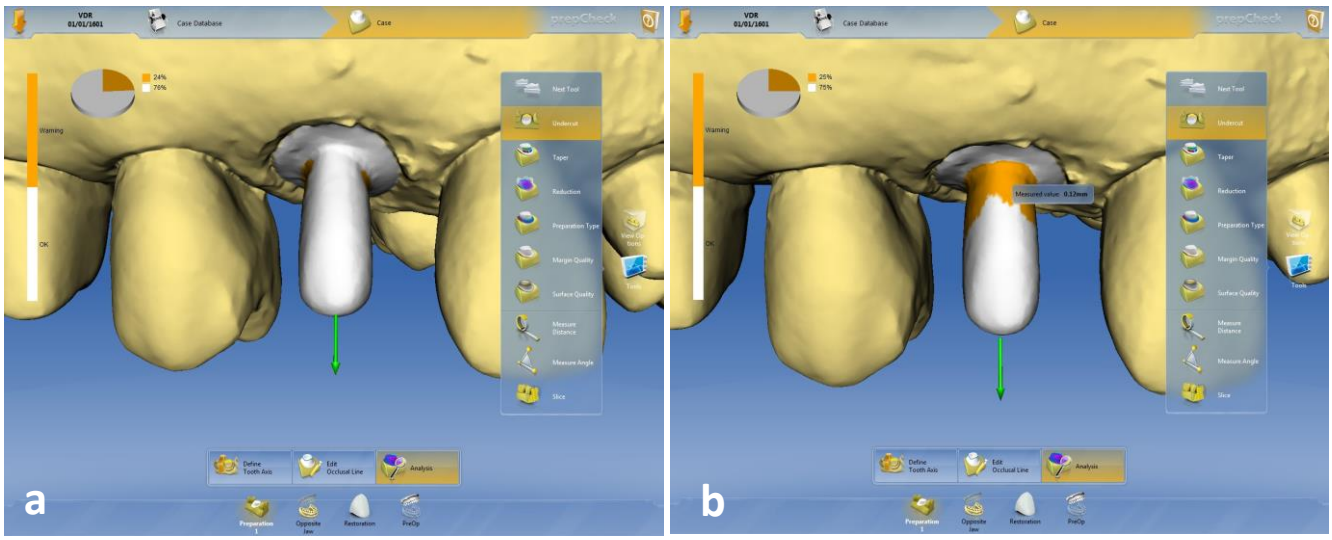


Figure 5. (a) Screenshot of PrepCheck using Undercut tool for preparation on 15 after defining the axis on occasion 1 indicating 24% of undercuts present; (**b)** Screenshot of the same preparation after defining the axis on occasion 2, indicating 25% of undercuts present

Interpretation: Acceptable preparations have 0-4% undercut. The rest of the preparation is white indicating no undercuts present. The presence of "undercuts" on an Acceptable preparation was mostly due to inaccuracies in the scan quality. Under-tapered preparations, which will require modification, show undercuts in yellow equal to and greater than 5%.

Taper

This tool measures the taper of the preparation walls at any given point. The degree of functional cusp bevel on posterior teeth is also assessed.

Difficulties: As with the undercuts, the analysis of taper changed by a small degree by changing the tooth axis. Editing the occlusal line is a preceding step to this analysis. The occlusal line selected affects the amount of cuspal taper (functional cusp bevel) that is highlighted. Again the change in units is minimal.

The Taper tool on this version of the software measures the taper of individual line sections of the preparation instead of measuring the total convergence angle. It is recommended that subsequent versions of the software should display the total convergence angle instead of taper.

Interpretation: Based on average ranges from Acceptable preparations, if the amount of blue displayed was 60% and more, the taper was deemed Acceptable. If the percentage of blue displayed was less than 60% then the colour displayed with the next highest percentage, determines the category i.e. if red, the preparation is over-tapered (Unacceptable) and if green, the preparation is under-tapered (Requires Modification) (see Figure 3).

Reduction (Distance to pre-operative)

Difficulties: The manual for PrepCheck 1.1 (Sirona Dental Systems GmbH. Operator's Manual PrepCheck 1.1. 2014; 24-43) describes the Reduction tool as: "Measures amount of material removed compared to original tooth" but does not describe in which plane this is measured. However, it was found that the Reduction tool does not measure occlusal reduction. Figure 6 indicates the measured value from the Reduction tool does not match that

of the manual measured distance. This image and many other similar images, verified that this tool does not measure the occlusal reduction.

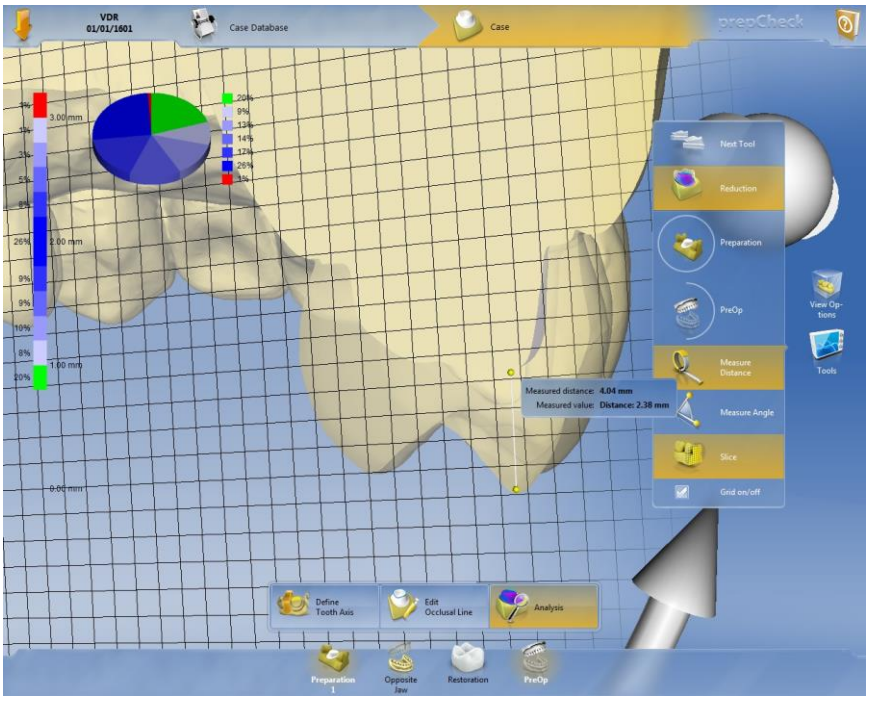


Figure 6. Screenshot of Reduction tool with superimposed Splice tool and manual Measure Distance tool. The measured distance is 4.04 mm and the measured value based on the Reduction tool is 2.38 mm. Each grid block represents 1 mm.

The Reduction tool does, however, measure axial reduction and margin width accurately. Figure 7 shows the measured value using the Reduction tool accurately matched that of the manual measured distance when applied to the axial walls. It is for this reason that the occlusal aspect of the tooth was ignored during the analysis and the focus was placed on the axial reduction and margin width.

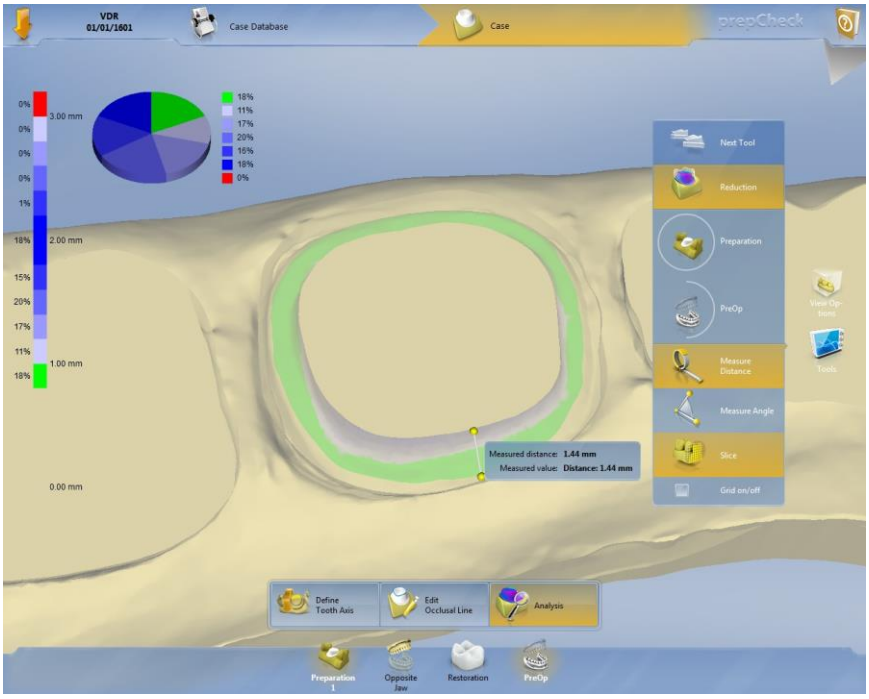


Figure 7. Screenshot of Reduction tool with manual Measure Distance tool. The measured distance and the measured value based on Reduction tool are both 1.44 mm.

However, since axial reduction is always greater for bulbous teeth such as the KaVo Typodont teeth used in this study, the amount of axial reduction will always be greater than the margin width. If the tolerance values are set according to the margin width, the axial walls will always be beyond this tolerance and be displayed in red as if they were over-prepared and the inner axial line angle of the margin will show up blue if correct (see Figure 8). For this reason one cannot set the parameters to assess axial reduction and margin width simultaneously.

Therefore, it was decided that the interpretation will only involve observing the inner axial line angle to determine the margin width as this coincides with what was assessed visually and what would be assessed clinically.

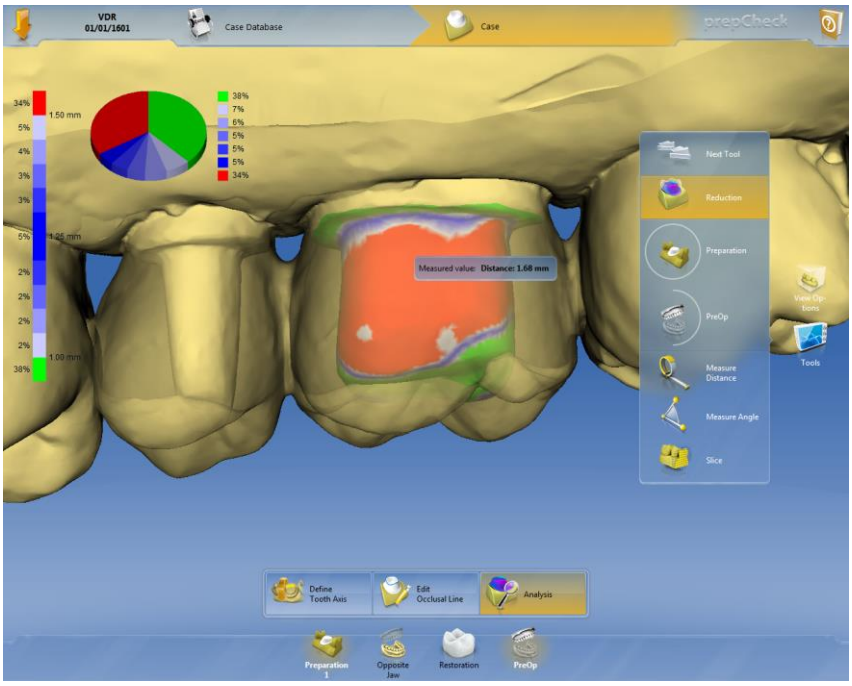


Figure 8. Screenshot of Reduction tool. The tolerance for the margin width is set from 1.0 -1.5 mm. The inner axial line of the margin is blue indicating it falls within these parameters and is thus Acceptable. The walls of the preparation are highlighted in red indicating that more than 1.5 mm of tooth structure was removed.

Interpretation: For the purpose of this study it was decided to ignore colours displayed on the axial and occlusal surfaces as this was not what the parameter was measuring. The Reduction tool was in fact assessing the margin width, displayed as the colour seen on the inner axial line angle of the margin. If the colour displayed was blue the margin was within the limits and was Acceptable; if red the margin width was greater than the maximum tolerance value (and therefore categorised as Unacceptable); and if green, the margin width was less than the minimum tolerance value (and therefore categorised as Requires Modification) (See Figure 9 for examples).

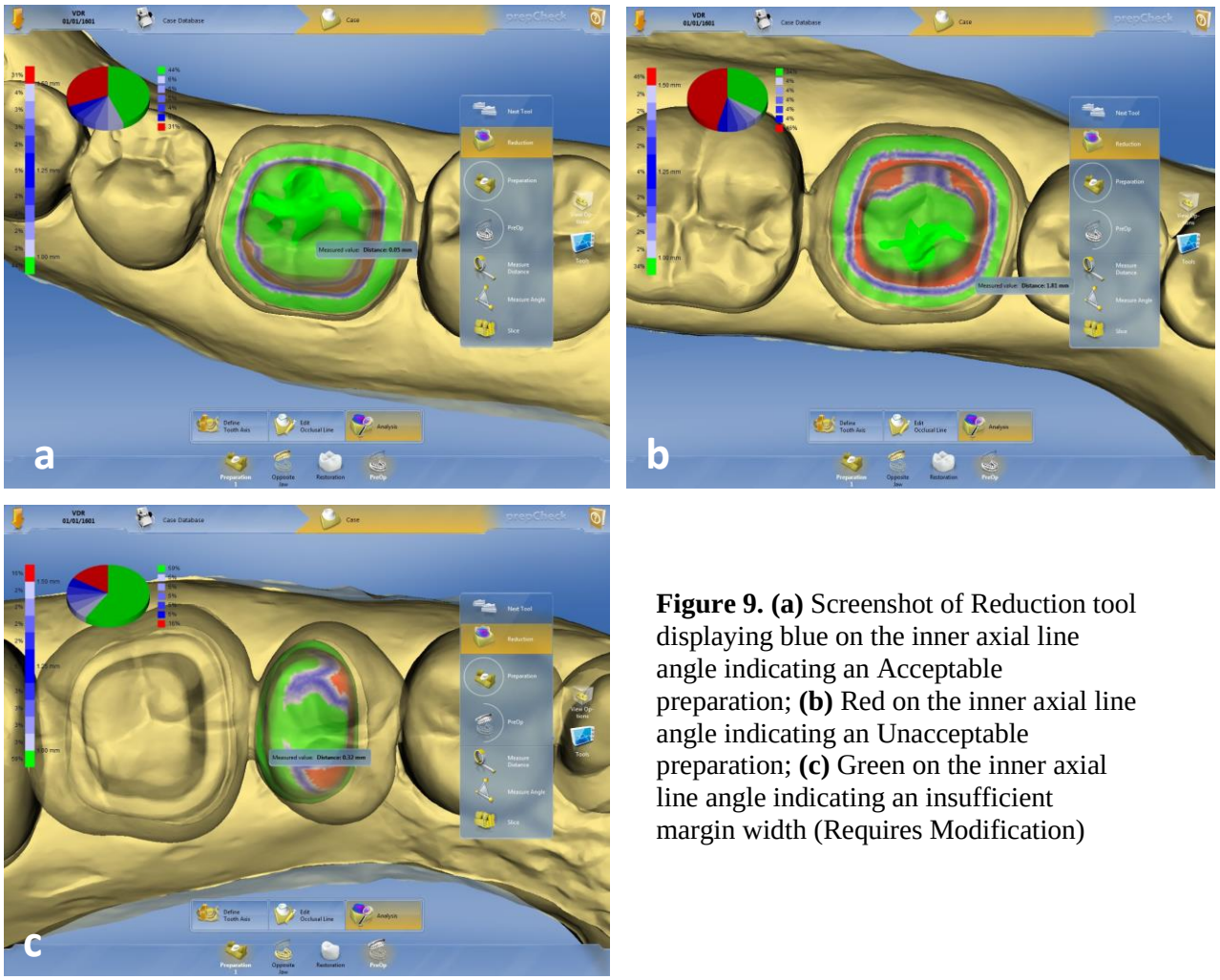


Figure 9. (a) Screenshot of Reduction tool displaying blue on the inner axial line angle indicating an Acceptable preparation; **(b)** Red on the inner axial line angle indicating an Unacceptable preparation; **(c)** Green on the inner axial line angle indicating an insufficient margin width (Requires Modification)

Distance to Opposite Jaw

Difficulties: As with taper the areas selected by editing the occlusal line affects the percentages highlighted in the analysis of the distance to the opposite jaw; however, this was minimal.

The manual states that the Distance to Opposite Jaw tool "measures the distance between the occlusal surface of the prepared tooth and the antagonist. The distance represents the maximum possible height and width of the restoration". This can also be interpreted as the amount of occlusal clearance between the preparation and the opposing dentition.

For anterior teeth the tool measures the distance of the entire preparation towards the opposing tooth and not just the incisal/ palatal aspect (Figure 10). Therefore it was decided to read the palatal aspect of the anterior tooth where it occludes only and to ignore the other colours as they were not a representation of occlusal clearance. In addition, it was noted that incisal reduction was also not indicated.

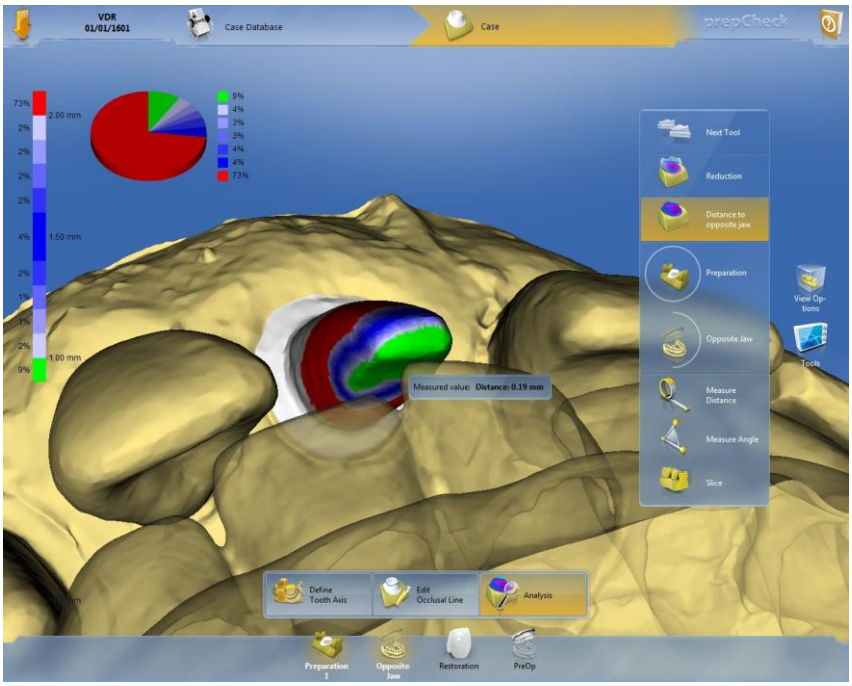


Figure 10. Screenshot of Distance to Opposite Jaw tool on tooth 11. Only the colours displayed on the preparation that opposes the 41 should be interpreted. In this case it is the green colour which will indicate insufficient occlusal clearance.

For posterior teeth the tool displays colour on the occlusal surface only, and shows the measurement of the distance from the occlusal surface to the opposing teeth. This tool is not a representative of occlusal reduction either. It was also found that there is a space that exists between lower molars and upper molars of KaVo models (inter occlusal 16 and 46) as shown in Figure 11. This space is created by the deep fissures. Hence a more accurate tool for measuring occlusal reduction is required.

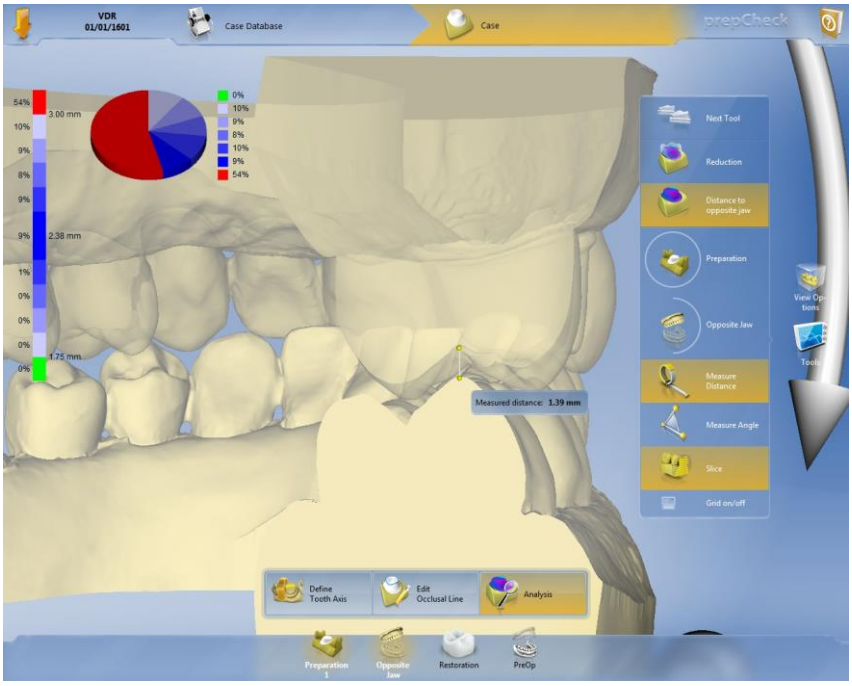


Figure 11. Screenshot of Distance to Opposite Jaw tool and manual Measure Distance tool. A distance of approximately 1.39 mm exists between the maxillary and mandibular molars of KaVo model teeth.

Interpretation: For anterior teeth, for the purpose of this study, the palatal area showing the distance to the opposing tooth was regarded as the only significant area to interpret. This area represents no more than 12% of the tooth. It was concluded that the percentages were not important, but rather the colour in that area: blue representing an Acceptable category, green indicating insufficient clearance and therefore Requires Modification, and red indicating a preparation that was over-prepared and therefore Unacceptable.

When assessing the posterior teeth the parameter had to be increased in order to compensate for the occlusal space between the fissural areas of opposing teeth.

For posterior teeth to be Acceptable more than 60% of the occlusal surface had to be displayed as blue. If less than 60%, the colour displaying the greatest percentage determined the category. Green would be insufficient occlusal clearance (Requires Modification) and red over-reduced occlusally and therefore catergorised as Unacceptable.

Preparation Type

This tool compares the margin type created to a pre-defined curve which can be a shoulder or a chamfer or any curve set in the parameters. For this study a shoulder preparation type was selected.

Difficulties: Preparation type is also affected by defining the tooth axis by a small percentage.

Interpretation: A margin displaying 90-100 % blue would conform to a shoulder configuration and be categorised as Acceptable. If more than 10% is shown as red the margin is over-prepared (too much material removed, thus Unacceptable). If more than 10% is shown as green the margin is under-prepared (conforms to a chamfer i.e. Requires Modification). See Figure 12 for examples of different preparation types.

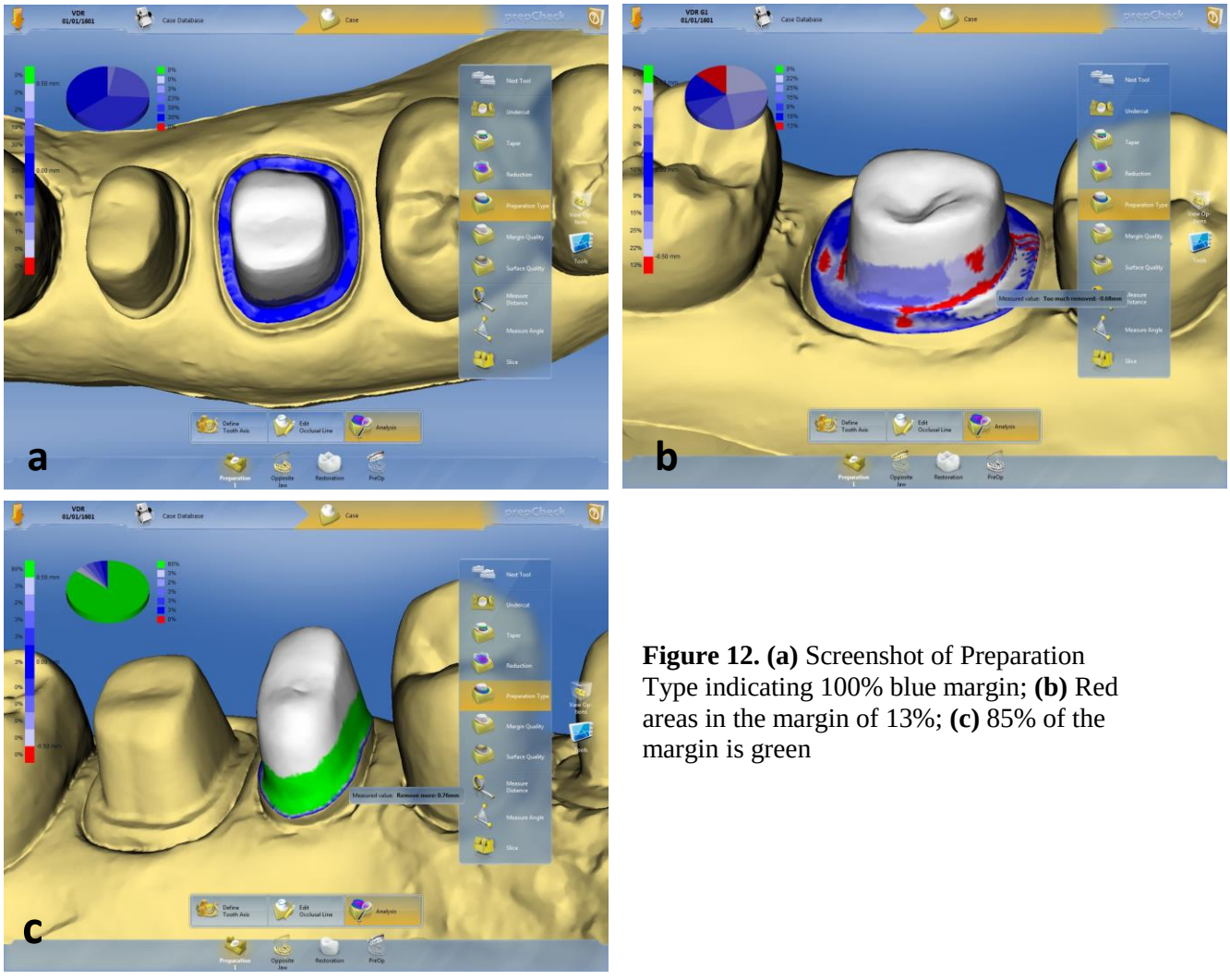


Figure 12. (a) Screenshot of Preparation Type indicating 100% blue margin; **(b)** Red areas in the margin of 13%; **(c)** 85% of the margin is green

Margin Quality

This tool assesses the quality of the margin for indentations or sharp edges by displaying these areas in orange.

Difficulties: the amount of orange displayed changes with differences in scan quality. Often, the areas that are displayed as orange (indentations/ sharp edges) are not detectable on the actual preparation visually or on probing. This would suggest that the tool is unnecessarily sensitive.

Interpretation: It was decided that Acceptable preparations should display as completely white or up to 2 areas of orange. More than 2 areas of orange and those which are detectible on the actual preparation would require modification. Figure 13 is an example of a preparation that will require smoothing of the margin.

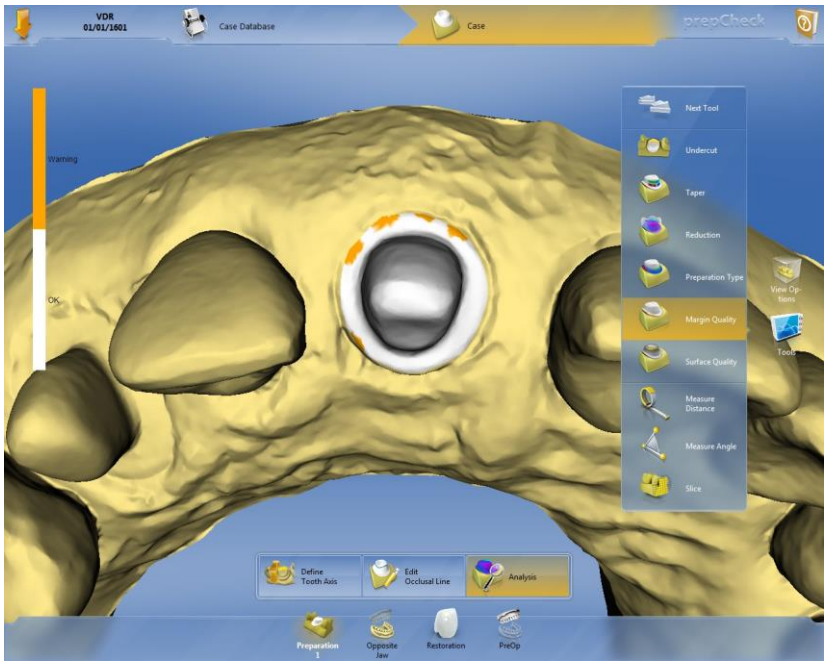


Figure 13. Screenshot of Margin Quality tool indicating 5 areas of orange that will require modification

Surface Quality

This tool measures the surface of the preparation for sharp edges. Any angle greater than 50 degrees is considered a sharp angle and is highlighted orange.

Interpretation: Should a preparation have grey displayed it is Acceptable (smooth) as shown in Figure 14. Should a preparation have orange displayed, these sharp edges will require modification.



Figure 14. Screenshot of Surface Quality tool displaying a grey (smooth) preparation that is Acceptable

5.2.2 Default Settings

As seen in Table 6, the software assessment using the default settings before calibration performed very poorly. When comparing the default ratings against the intended rating the accuracy (percentage correct) was only 45.0%. When comparing the default ratings with the majority decision the raw agreement was 40.0%. There was a significant bias towards the Requires Modification category where 85% of the preparations were classified.

5.2.3 Issues with Default Settings

When using the default settings the interpretations of the preparations were unrealistic, due to the parameters having been set with unrealistic tolerance values. This resulted in the majority of the preparations being assessed as Requiring Modification. Several issues were noted with these default settings that resulted in the poor performance of the software when compared with the rubric settings. Some of the important issues are discussed here, and Appendix 5 provides a summary.

Firstly, the parameters have the same settings for all teeth, when criteria for anterior, maxillary posterior and mandibular posterior teeth should all be different.

In terms of measuring taper the minimum (4 degrees) and maximum (12 degrees) tolerance values are too high and apply to all teeth irrespective of position in the mouth. This results in many over-tapered and under-tapered preparations being classified as Acceptable. In addition, the cusp taper (functional cusp bevel) is set on the incorrect side of maxillary posterior teeth, hence preparations on these teeth were classified as requiring modification.

For the Reduction tool, the tolerance band is too wide with the minimum tolerance value set too high at 1.75 mm and the maximum set too high at 3.0 mm. These values would not only result in possible exposure of the pulp clinically, but would also result in preparations with margins below 1.75 mm being classified as Requires Modification.

For the Distance to Opposite Jaw tool, as with the Reduction tool, the tolerance band is too wide and the minimum value (1.75 mm) and maximum value (3.0 mm) are set too high. These values would result in the incorrect interpretation of preparations as Requiring Modification.

In terms of preparation type the tolerance value is set at 0.4 mm. This appears to be too strict and results in Acceptable preparation types being classified as Requires Modification or Unacceptable.

For margin quality, many preparations displayed many orange areas on the digital margin, resulting in the preparation being classified as Requiring Modification. However these preparations did not display any indentations or sharp edges visually.

Therefore the parameters were adjusted as set out in the following section.

5.3 Parameters

5.3.1 Parameter Setting

All of the analysis tools required adjustments except two, the surface quality and undercut tools. Fortunately, it was possible to re-set the parameters and to interpret the colours displayed in such a way that the preparations could be placed in the three different categories. The parameter changes were based on evidence in the literature as outlined in Appendices 3 and 4 for measurable tools as well as trial and error investigation to re-set tools such as Margin Quality and Preparation Type.
The description of the parameter changes are outlined below and summarised in Appendix 5.

Taper

The minimum taper was set according to ideal Total Occlusal Convergence angle required as 6 degrees, but the evidence shows that most crowns are prepared with larger convergence angles: anteriorly from 12-17 degrees and posteriorly from 12-20 degrees. By taking 6 degrees as a minimum and 17 and 20 degrees as a maximum for anterior teeth and posterior teeth respectively and if these values are halved the minimum and maximum taper becomes 3-8.5 degrees for anterior teeth and 3-10 for posterior teeth (0.1 unit added for leniency).

Therefore the taper was set as 2.9 – 8.6 degrees for anterior teeth and 2.9 - 10.1 for posterior teeth.

Cusp taper (functional cusp bevel) for posterior maxillary teeth was adjusted to analyse the palatal surface and not the buccal surface as it had in the default settings.

Reduction (Distance to pre-operative)

This was set to achieve an acceptable margin width of 1.0 -1.5mm for all teeth. The minimum tolerance value was set at 1.0 mm and the maximum at 1.5 mm.

Distance to Opposite Jaw

This was adjusted to for anterior teeth to achieve an acceptable occlusal clearance of 1.0-1.5 mm. For posterior teeth the setting had to take into consideration the extra inter-occlusal space inherent in KaVo models, and was changed to 1.5 -2.5 mm to assess both functional and non-functional cusps.

Preparation Type

The tolerance value was increased to 0.5 mm for leniency and to eliminate the unnecessary green and red areas showing up with the default settings. Anything beyond this tolerance was classified as Requiring Modification or Unacceptable.

Margin Quality

These settings were adjusted so that Acceptable preparations would have up to 2 areas of orange highlighted.

5.3.2 Comparison of Rubric Settings to the Majority Decision

As seen in Table 6 the software assessment using the new parameters performed well. When compared with the majority decision the raw agreement was 86.7%.

Only one “Acceptable” preparation was classified as “Unacceptable” and one “Unacceptable” preparation was classified as “Acceptable”. Since there were only a few changes in the categories, it suggests that certain features are highlighted and measured more accurately digitally.

The accuracy when using the rubric settings compared to the intended rating was 96.7%. This is similar yet higher than the accuracy / percentage correct of the instructors’ majority decision which was 90%. This result suggests that the software with the same criteria can be more accurate at categorising the preparations than the assessment done by the instructors.

5.3.3 Reliability

Again in Table 6 one can see that the PrepCheck software performed well using the rubric settings (after calibration) on both occasions, with 100% agreement. This result shows that the software is reliable at categorising preparations on two different occasions and was successfully calibrated, thus rejecting the null hypothesis.

5.4 Limitations/ challenges encountered

Below are some of the challenges encountered and how these can be compensated for and avoided in the future.

1. It was found during the first calibration exercise that the initial assessment rubrics created were cumbersome and had to be refined to allow assessment to take place more efficiently. The modified assessment rubrics (See Appendices 7 and 8) were used for the second calibration exercise and throughout the duration of the study.

2. The models required re-scanning to include the pre-operative models for some of the software analysis tools to function. Creating a protocol for use of the software was necessary to avoid missing any steps.
3. Undercut, Preparation type, Margin Quality and Surface Quality tools were affected by the quality of the scanned model. Different scans of the same preparations may appear different, however the change was minimal and did not affect the categorisation.
4. Preceding steps such as the 'Edit Occlusal Line', 'Define Tooth Axis' and edit 'Copy line' affected the interpretation of the tooth preparations to a small degree.
   They did not change the ultimate category, however care must be taken when carrying out these steps
5. With KaVo basic study models there is no definite occlusal relation hence it is difficult to assess the exact distance to the opposing jaw visually and digitally. The buccal bite registration can also be captured differently on different scans since the two opposing models are not stable in occlusion. This can affect the reading of the Distance to Opposite Jaw tool.
6. The software required considerable manipulation and interpretation in order for the analysis tools to provide useful feedback. This will require modification from the developers to make the software easier to use.

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

Under the conditions of this study the following conclusions can be drawn:

- The default parameters of the software are not adequately related to tooth morphology, nor are they based on appropriate clinical evidence for the features of crown preparation.
- It is possible to re-set and manipulate the parameters of the software so that tooth preparations can be realistically assessed. However, some aspects of the software have to be ignored to correctly categorise the preparations.
- It is possible to calibrate instructors to an evidence-based rubric for ceramic preparation features, and by aligning the instructors and re-calibrated software, a high degree of correlation can be obtained.
- The calibrated software achieved a greater correlation with the rubric than the instructors. This confirms that the use of PrepCheck software for the assessment of student tooth preparations can be digital, objective, accurate, and reliable.

6.2 Implications

In a pre-clinical setting, dental students will be able to have their all-ceramic tooth preparations assessed independent of a supervisor/ laboratory instructor and can then carry out the modifications required, if necessary, by visualising what changes are required digitally.

6.3 Recommendations

1. The PrepCheck software should be appropriately updated using the proposed parameters to conform to evidence-based guidelines for tooth preparations.
2. Its benefit as a teaching and learning tool for assessing crown preparations in both the pre-clinical and clinical settings needs to be assessed for ease of use by the students and time taken to use it.

References

Beuer F, Aggstaller H, Richter J, Edelhoff D, Gernet W. Influence of preparation angle on marginal and internal fit of CAD/CAM- fabricated zirconia crown copings. Quintessence Int. 2009; 40: 243-250

Cardoso JA, Barbosa C, Fernandes S, Silva CL, Pinho A. Reducing subjectivity in the evaluation of pre-clinical dental preparations for fixed prosthodontics using the Kavo PrepAssistant. Eur. J. Dent. Ed. 2006; 10: 149-156

Coelho PG, Silva NR, Thompson VP, Rekow D, Zhang G. Effect of proximal wall height on all-ceramic crown core stress distribution: A finite element analysis study. Int. J. Prosthodont. 2009; 22: 78-86

Ender A. Cerec Basic Information 4.0: A Clinical Guide. Manual, Sirona Dental Systems GmbH, Germany. 2011; 14

Esser C, Kerschbaum T, Winkelmann V, Krage T & Faber FJ. A comparison of the visual and technical assessment of preparations made by dental students. Eur. J. Dent. Ed. 2006; 10: 157-161

Feil PH, Gatti JJ. Validation of a motor skills performance theory with applications for dental education. J. Dent. Ed. 1993; 57: 628-633

Fuller JL. The effects of training and criterion models on inter-judge reliability. J. Dent. Ed. 1972; 36: 19-22

Giannetopoulos S, van Noort R, Tsitrou E. Evaluation of the marginal integrity of ceramic copings with different marginal angles using two different CAD/CAM systems. J. Dent. 2010; 38: 980-986

Goodacre CJ, Campagni WV, Aquilino SA. Tooth preparations for complete crowns: An art form based on scientific principles. J. Prosthet. Dent. 2001; 85: 364-376

Haj-Ali R, Feil P. Rater reliability: short and long-term effects of calibration training. J. Dent. Ed. 2006; 70: 428-433

Hou D, Kristiansen J. Evaluating CAD/CAM as an Objective Grading Tool. Poster presented at: Annual session and exhibition of the American Dental Education Association. 2014; San Antonio, USA.

Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977; 33: 159-174

Lilley J, Bruggen Cate HJ, Holloway P, Holt JK, Start KB. Reliability of practical tests in operative dentistry. Br. Dent. J. 1968; 125: 194-197

Mackenzie RS, Antonson DE, Weldy PL, Welsch BB, Simpson WJ. Analysis of disagreement in the evaluation of clinical products. J. Dent. Ed. 1982; 46: 284-289

Renne WG, McGill ST, Mennito AS, Wolf BJ, Marlow NM, Shaftman S, Holmes JR. E4D Compare Software: An Alternative to Faculty Grading in Dental Education. J. Dent. Ed. 2013; 77: 168-175

Rosenstiel SF, Land MF, Fujimoto J. Contemporary Fixed Prosthodontics: Fourth Edition. Mosby Elsevier, St. Louis, Missouri. 2006; 323-327

Salvendy G, Hinton WM, Ferguson GW, Cunningham PR. Pilot study on criteria in cavity preparation. J. Dent. Ed. 1973; 37: 27-31

Schiff AJ, Salvendy G, Root CM, Ferguson GW, Cunningham PR. Objective evaluation of quality in cavity preparation. J. Dent. Ed. 1975; 39: 92-96

Sharaf AA, Abdel Aziz AM, El Meligy OAS. Intra- and inter-examiner variability in evaluating preclinical pediatric dentistry operative procedures. J. Dent. Ed. 2007; 71: 540-544

Shoukri MM. Measures of Interobserver Agreement and Reliability: Second Edition. Chapman & Hall/CRC Press, Boca Raton, FL. 2010

Smith BGN. Planning and making crowns and bridges: Third Edition. Martin Dunitz Ltd, London. 1986; 40-49

Appendices

Appendix 1: Assessment Rubric for Posterior All-ceramic Crown Preparation

Grading	Reduction	Margin Configuration	Additional
Acceptable (only if all of the following criteria are met)	**Occlusal:** o 1.5 mm up to 2 mm over functional cusps o Occlusal configuration with a convex surface according to pulpal morphology o Length of preparation should not exceed 9mm **Axial:** o 1.0 – 1.3 mm all around	o 1.0 -1.3 mm internally rounded shoulder o Inner axial line angle of shoulder smooth and rounded o Finish lines should be equi/ supra-gingival and on sound tooth tissue (may extend up to the level of the depressed crest if needed for aesthetics and retention) o All shoulders should be at a 90° cavo-surface angle	o Smooth transitional line angles o No unsupported tooth structure left at edge of finish lines o No damage to adjacent teeth o Clearance in centric occlusion and lateral and protrusive movements o No undercuts o Visible convergence angle of 12-20° o Contact areas between adjacent teeth clearly broken
Requires Modification (if at least one of the following is present)	**Occlusal:** o <1.5 mm o Occlusal configuration not according to pulpal morphology but can be modified o Length of preparation >9 mm **Axial:** o <1.0 mm	o <1.0 mm internally rounded shoulder o Inner axial line angle of shoulder not smooth and rounded o Finish lines too far supra-gingival resulting in short axial walls o Finish lines not on sound tooth tissue but can be modified o >/<90° cavo-surface angle	o Transitional line angles not smooth o Unsupported tooth structure left at edge of finish lines o No clearance in centric occlusion and lateral and protrusive movements o Undercuts present o Visible convergence angle <12 ° o Contact areas between adjacent teeth not clearly broken but can be modified
Unacceptable/ Rejected (if at least one of the following is present)	**Occlusal:** o >2 mm o If correction of occlusal configuration requires further damage **Axial:** o >1.5 mm	o >1.5 mm internally rounded shoulder o Inner axial line angle of shoulder cannot be smooth/rounded without causing further destruction of tooth structure o Finish lines sub-gingival o Finish lines not on sound tooth tissue and cannot be modified	o Damage to adjacent teeth o Damage to the gingival tissues o Damage to/ exposure of pulp o Over tapered preparation o Contact areas between adjacent teeth clearly not broken

Appendix 2: Assessment Rubric for Anterior All-ceramic Crown Preparation

Grading	Reduction	Margin Configuration	Additional
Acceptable (only if all of the following criteria are met)	**Incisally:** o 2 mm (up to 4 mm for long crowns such as typodont teeth) o Length of preparation should not exceed 9 mm o Labio-palatal thickness of incisal edge should not be less than 1 mm **Palatally:** o 1 mm reduction on cingulum o Sufficient height of palatal/lingual wall for retention and resistance form **Labially:** o 1 mm o Reduction in 2 planes/ follows external tooth contour **Axial:** o 1 mm (up to 1.5 mm for tapered crowns such as typodont teeth)	o 1 mm internally rounded shoulder all around o Inner axial line angle of shoulder smooth and rounded o **Labial shoulder** at the level of the depressed gingiva with a 90° cavo-surface –angle o **Palatal shoulder** equi/supra gingival o **Interproximal shoulder** follows gingival contours	o Smooth transitional line angles o No unsupported tooth structure left at edge of finish lines o No damage to adjacent teeth o Clearance in centric occlusion and excursive movements o No undercuts o Visible convergence angle of 12-17° o Contact areas between adjacent teeth clearly broken
Requires Modification (if at least one of the following is present)	**Incisally:** o <2 mm (<4 mm for long crowns such as typodont teeth) o Length of preparation >9 mm **Palatally:** o <1 mm cingulum reduction **Labially:** o <1 mm o Reduction in 1 plane/ not following external tooth contour **Axial:** o <1 mm	o Shoulder < 1 mm o Inner axial line angle of shoulder not smooth /rounded o **Labial shoulder** above the level of the depressed gingiva with a cavo-surface-angle </>90° o **Palatal shoulder** too supra gingival compromising palatal vertical wall length o **Interproximal shoulder** does not follow gingival contours	o Transitional line angles not smooth o Unsupported tooth structure left at edge of finish lines o No clearance in centric occlusion and excursive movements o Undercuts present o Visible convergence angle <12° o Contact areas between adjacent teeth not clearly broken but can be modified
Unacceptable/ Rejected (if at least one of the following is present)	**Incisally:** o >2 mm (>4 mm for long crowns such as typodont teeth) o Labio-palatal thickness of incisal edge <1mm **Palatally:** o >1.5 mm cingulum reduction o Insufficient height of palatal/lingual wall for retention and resistance form **Labially:** o >1.5 mm **Axial:** o >1.5 mm	o Internally rounded shoulder >1.5 mm o Inner axial line angle of shoulder cannot be smooth/rounded without causing further destruction of tooth structure o Any part of shoulder sub-gingival	o Damage to adjacent teeth o Damage to the gingival tissues o Damage to/ exposure of pulp o Over tapered preparation o Contact areas between adjacent teeth clearly not broken

Appendix 3: Table showing Evidence for Posterior All-ceramic Crown Preparation Criteria

Posterior All-ceramic Crown				
Feature	**Requirements**	**Reference**	**Check with PrepCheck**	**Analysis Tool**
Reduction	**Occlusal:** 1.5 mm up to 2 mm over functional cusps	Goodacre et al, 2001 Smith,1986 Rosenstiel et al, 2006	✓	Reduction
	Occlusal configuration with a convex surface according to pulpal morphology	Smith, 1986	✓	Reduction Surface Quality
	Length of preparation should not exceed 9 mm	Ender, 2011	✓	Distance
	Axial: 1.0 – 1.3 mm all around	Goodacre et al,2001	✓	Reduction
Margin Configuration	1.0 -1.3 mm internally rounded shoulder	Goodacre et al, 2001	✓	Preparation Type
	Inner axial line angle of shoulder smooth and rounded	Goodacre etal,2001 Smith, 1986	✓	Preparation Type Margin Quality
	Finish lines should be equi/ supra-gingival and on sound tooth tissue (may extend up to the level of the depressed crest if needed for aesthetics and retention)	Goodacre et al,2001	✓	No tool, but assess digitally when drawing margin
	All shoulders should be at a 90° cavo-surface angle	Giannetopoulos et al, 2010 Smith, 1986	✓	Angle
Additional	Smooth transitional line angle	Goodacre et al, 2001 Smith,1986	✓	Surface Quality
	No unsupported tooth structure left at edge of finish lines	Rosenstiel et al, 2006	✓	Surface Quality Margin Quality
	No damage to adjacent teeth	Smith, 1986	✓	No tool, but assess digital image
	Clearance in centric occlusion and lateral and protrusive movements	Rosenstiel et al, 2006	✓	3D Comparison to opposite jaw
	No undercuts	Smith,1986	✓	Undercuts
	Visible convergence angle of 12-20°	Beuer et al, 2009 Goodacre et al, 2001 Smith, 1986	✓	Taper
	Contact areas between adjacent teeth clearly broken	Rosenstiel et al, 2006	✓	Assess when drawing margin

Appendix 4: Table showing Evidence for Anterior All-ceramic Crown Preparation Criteria

Anterior All-ceramic Crown				
Feature	**Requirements**	**Reference**	**Check with PrepCheck**	**Analysis Tool**
Reduction	**Incisally:** 2 mm (up to 4 mm for long crowns such as typodont teeth)	Goodacre et al, 2001 Rosenstiel et al, 2006	✓	Reduction
	Length of preparation should not exceed 9 mm	Ender, 2011	✓	Distance
	Labio-palatal thickness of incisal edge should not be less than 1mm	Ender, 2011	✓	Distance
	Palatally: 1 mm reduction on cingulum	Smith, 1986 Rosenstiel et al, 2006	✓	Reduction
	Sufficient height of palatal/lingual wall for retention and resistance form	Coehlo et al, 2009	✓	Distance (Manual)
	Labially: 1 mm	Goodacre et al, 2001 Smith, 1986 Rosenstiel et al, 2006	✓	Reduction
	Reduction in 2 planes/ follows external tooth contour	Rosenstiel et al, 2006	✓	Reduction
	Axial: 1 mm	Goodacre et al, 2001	✓	Reduction
Margin Configuration	1 mm internally rounded shoulder all around	Goodacre et al, 2001	✓	Preparation Type
	Inner axial line angle of shoulder smooth and rounded	Goodacre et al, 2001 Smith, 1986	✓	Preparation Type Margin Quality
	Labial shoulder at the level of the depressed gingiva with a 90° cavo-surface –angle	Giannetopoulos et al, 2010 Smith, 1986	✓	Angle
	Palatal shoulder equi/supra gingival	Goodacre et al,2001	✓	Assess when drawing margin
	Interproximal shoulder follows gingival contours	Rosenstiel et al, 2006	✓	Assess when drawing margin
Additional	Smooth transitional line angles	Goodacre et al, 2001 Smith,1986	✓	Surface Quality
	No unsupported tooth structure left at edge of finish lines	Rosenstiel et al, 2006	✓	Surface Quality Margin Quality
	No damage to adjacent teeth	Smith, 1986	✓	No tool, but assess digital image
	Clearance in centric occlusion and excursive movements	Rosenstiel et al, 2006	✓	3D Comparison to opposite jaw
	No undercuts	Smith,1986	✓	Undercuts
	Visible convergence angle of 12-17°	Beuer et al, 2009 Goodacre et al, 2001 Smith, 1986	✓	Taper
	Contact areas between adjacent teeth clearly broken	Rosenstiel et al, 2006	✓	Assess when drawing margin

Appendix 5: Summary of Analysis Tools: Functions, Interpretations and Parameters

Analysis Tool	Function	Affected by	Issues with default settings	Parameter changes	Interpretation
Undercut	Detect undercuts	Define tooth axis	None	None No parameter to set	0-4% Yellow → Acceptable > 4% Yellow → Requires Modification
Taper	Measures outer wall angle relative to defined tooth axis	Define tooth axis Edit occlusal line	Set at 4°-12° for all teeth irrespective of anterior or posterior teeth Minimum and maximum tolerance value too high Cusp taper for maxillary posterior teeth set on buccal surface and not palatal	Set according to total occlusal angles in literature Set anterior teeth at 3.9°-8.6° Set posterior teeth at 3.9°-10.1° Changed cusp taper for maxillary posterior teeth to palatal surface	If Blue displayed > 60% → Acceptable If Blue displayed <60%: Green highest percentage→ Requires Modification Red highest percentage→ Unacceptable
Reduction	Measures axial reduction / margin width compared to pre-operative tooth	Copy line of bio-generic copy	Tolerance band too wide Minimum (1.75 mm) and maximum (3.0 mm) tolerance value too high	Set to assess margin width only Set for anterior and posterior teeth at 1.0-1.5 mm	Assessment of margin width only: Blue = 1.0-1.5 mm → Acceptable Green = <1.0 mm → Requires Modification Red = >1,5 mm → Unacceptable
Distance to Opposite Jaw	Measures occlusal clearance between preparation and opposing tooth	Edit occlusal line	Tolerance band too wide Minimum (1.75 mm) and maximum (3.0 mm) tolerance value too high	Set to assess occlusal clearance Anterior teeth: 1.0-1.5 mm Posterior teeth: 1.5-2.5 mm	If Blue displayed > 60% → Acceptable If Blue displayed <60%: Green highest percentage→ Requires Modification Red highest percentage→ Unacceptable
Preparation Type	Detects chamfer or shoulder margin preparation	Draw margin Scan quality Define tooth axis	Too strict unnecessary red areas displayed Tolerance value = 0.4 mm	Set to reduce amount of red displayed Tolerance value =0.5 mm	Blue 90-100% = Adequate reduction (Shoulder) →Acceptable Green > 10% = Too little removed (chamfer) → Requires Modification Red > 10% = Too much removed → Unacceptable
Margin Quality	Detects indentations or sharp angles	Scan quality	Too strict: unnecessary orange areas displayed Tube Window length = 0.4 mm Tube Radius = 0.055 mm	Set to reduce amount of orange displayed Tube Window length = 0.24 mm Tube Radius = 0.065 mm	White margin or up to 2 orange spots displayed→ Acceptable Greater than 2 orange spots displayed and detectable on preparation → Requires Modification
Surface Quality	Detects smooth surfaces or sharp angles	Scan quality	None 50° adequate to assess difference between smooth surfaces and sharp angles	None 50° adequate to assess difference between smooth surfaces and sharp angles	Grey areas or up to 2 orange spots displayed→ Acceptable Greater than 2 orange spots displayed and detectable on preparation → Requires Modification

Appendix 6: Human Research Ethics Committee (Medical) Waiver

Human Research Ethics Committee (Medical)

Research Office Secretariat: Senate House Room SH10005, 10th floor. Tel +27 (0)11-717-1252
Medical School Secretariat: Tobias Health Sciences Building, 2nd floor Tel +27 (0)11-717-2700
Private Bag 3, Wits 2050, www.wits.ac.za. Fax +27 (0)11-717-1265

Ref: W-CJ-150205-2 05/02/2015

TO WHOM IT MAY CONCERN:

Waiver: This certifies that the following research does not require clearance from the Human Research Ethics Committee (Medical).

Investigator: **Dr Variza Daya Roopa. (Student no 0704002E)**

Project title: **The calibration of a software programme to assist ceramic crown preparations in a pre-clinical setting.**

Reason: This is a laboratory study using dental materials. There are no human participants

UNIVERSITY OF THE WITWATERSRAND
PROF PETER CLEATON-JONES
HREC (MEDICAL)
2015 -02- 05
JOHANNESBURG

Professor Peter Cleaton-Jones

Chair: Human Research Ethics Committee (Medical)

Copy – HREC (Medical) Secretariat: Zanele Ndlovu, Langutani Masingi.

Appendix 7: Modified Assessment Rubric for Posterior All-ceramic Crown Preparation

Grading	Reduction	Margin Configuration	Taper	Additional
Acceptable (only if all of the following criteria are met) ☐	**Occlusal:** ☐ 1.5 mm up to 2 mm over functional cusps ☐ 45° functional cusp bevel ☐ Follows external contour **Axial:** ☐ 1.0 – 1.3 mm all around	☐ 1.0 -1.3 mm shoulder all around ☐ Internally rounded shoulder ☐ Shoulder with a 90° cavo-surface angle	☐ Adequate convergence angle ☐ No undercuts present	☐ Smooth line angles ☐ No unsupported tooth structure remaining
Requires Modification (if at least one of the following is present) ☐	**Occlusal:** ☐ <1.5 mm ☐ No/ insufficient functional cusp bevel ☐ Does not follow external contour **Axial:** ☐ <1.0 mm	☐ <1.0 mm shoulder ☐ Inner axial line angle of shoulder not smooth and rounded ☐ A cavo-surface angle >/<90°	☐ Inadequate convergence angle ☐ Undercuts present	☐ Line angles not smooth ☐ Unsupported tooth structure remaining
Unacceptable/ Rejected (if at least one of the following is present) ☐	**Occlusal:** ☐ >2 mm **Axial:** ☐ >1.5 mm	☐ >1.5 mm shoulder	☐ Over tapered preparation	

Appendix 8: Modified Assessment Rubric for Anterior All-ceramic Crown Preparation

Grading	Reduction	Margin Configuration	Taper	Additional
Acceptable (only if all of the following criteria are met) ☐	**Incisally:** ☐ 2 mm (up to 4 mm for long crowns) ☐ Labio-palatal thickness of incisal edge> 1 mm **Palatally:** ☐ 1 mm reduction on cingulum **Labially:** ☐ 1 mm ☐ Follows external tooth contour **Axial:** ☐ 1 mm (up to 1.5 mm for tapered crowns)	☐ 1 mm shoulder all around ☐ Internally rounded shoulder ☐ Shoulder with a 90° cavo-surface –angle	☐ Adequate convergence angle ☐ No undercuts present	☐ Smooth line angles ☐ No unsupported tooth structure remaining
Requires Modification (if at least one of the following is present) ☐	**Incisally:** ☐ <2 mm ☐ Length of preparation >9 mm **Palatally:** ☐ <1 mm cingulum reduction **Labially:** ☐ <1 mm ☐ Reduction not following external tooth contour **Axial:** ☐ <1 mm	☐ Shoulder < 1 mm ☐ Inner axial line angle of shoulder not smooth /rounded ☐ A cavo-surface-angle </>90°	☐ Inadequate convergence angle ☐ Undercuts present	☐ Line angles not smooth ☐ Unsupported tooth structure remaining
Unacceptable/ Rejected (if at least one of the following is present) ☐	**Incisally:** ☐ >2 mm ☐ Labio-palatal thickness of incisal edge <1mm **Palatally:** ☐ >1.5 mm cingulum reduction **Labially:** ☐ >1.5 mm **Axial:** ☐ >1.5 mm	☐ Shoulder >1.5 mm	☐ Over tapered preparation	