

INTERACTION BETWEEN ENAMEL, PORCELAIN AND A GOLD ALLOY: AN IN VITRO WEAR STUDY



UYEN TRAN KIEU HA (BDS, MDS)

Thesis submitted for the degree of Doctor of Philosophy

School of Dentistry

The University of Adelaide

February 2011

TABLE OF CONTENTS

	Page no
TABLE OF CONTENTS	i
LIST OF FIGURES	vi
LIST OF TABLES	xii
PREFACE	xv
ABSTRACT	xvi
DECLARATION	xix
ACKNOWLEDGEMENTS	xx
SECTION 1 INTRODUCTION	1
CHAPTER 1: TOOTH WEAR	2
1.1 Historical background.....	2
1.2 Aetiology, mechanisms and prevalence of tooth wear.....	4
1.2.1 Aetiology and mechanisms of tooth wear.....	4
1.2.2 Prevalence of tooth wear.....	12
1.3 Methods of assessment of tooth wear.....	15
CHAPTER 2: TRIBOLOGY	20
2.1 Abrasive wear.....	22
2.2 Adhesive wear.....	24
2.3 Fatigue wear.....	25

2.4	Corrosive wear.....	26
2.5	Erosive wear.....	26
2.6	Fretting wear.....	27
CHAPTER 3:	CERAMICS.....	29
3.1	Historical background.....	29
3.2	Definitions.....	30
3.3	Structures of dental ceramics.....	31
3.4	Composition of ceramics.....	32
3.5	Properties of ceramics.....	34
3.6	Classification of dental ceramics.....	34
	3.6.1 Metal-ceramic restorations.....	35
	3.6.2 All-ceramic restorations.....	36
3.7	Wear studies of ceramics.....	39
CHAPTER 4:	AIMS AND RATIONALE OF THE STUDY.....	49
SECTION 2	ENAMEL/CERAMIC WEAR.....	51
CHAPTER 5:	INTRODUCTION.....	52
CHAPTER 6:	MATERIALS AND METHODS	53
6.1	Description of tooth wear machine.....	53
6.2	Determination of experimental conditions (Preliminary experiments).....	57
	6.2.1 Effects of cycling rates.....	57
	6.2.2 Effects of type of movement.....	59
	6.2.3 Specimen orientation.....	60

6.2.4	Effects of specimen contact.....	61
6.2.5	Duration of experiments (number of cycles).....	64
6.2.6	Load.....	66
6.2.7	Effects of water uptake and measurement errors.....	67
6.2.8	Conclusion.....	70
6.3	Preparation of teeth and test materials.....	70
6.4	Mounting specimens of Scanning Electron Microscopy (SEM) Studs.....	76
6.5	Method of lubrication.....	79
6.6	Methods of assessment.....	79
6.6.1	Three Dimensional Scanning (3-D) and quantitative results.....	79
6.6.2	Scanning Electron Microscopy (SEM) and qualitative results.....	82
6.6.2.1	Fabrication of specimen replicas.....	82
6.6.2.2	Scanning Electron Microscopy (SEM) observations.....	83
6.7	Statistical analysis.....	83
6.8	Experiment at pH 6.1 and pH 1.2.....	84
CHAPTER 7: RESULTS.....		88
7.1	Introduction.....	88
7.2	Experimental results at pH 6.1.....	89
7.2.1	Quantitative assessment at pH 6.1.....	89
7.2.2	Qualitative assessment at pH 6.1.....	98
7.3	Experimental results at pH 1.2.....	105
7.3.1	Quantitative assessment at pH 1.2.....	105
7.3.2	Qualitative assessment at pH 1.2.....	112
7.4	Summary of results.....	119

CHAPTER 8: DISCUSSION.....	124
SECTION 3	
EFFECT OF ACID ON MACHINABLE CERAMIC.....	139
CHAPTER 9: INTRODUCTION.....	140
CHAPTER 10: MATERIALS AND METHODS.....	141
10.1 Erosion testing.....	141
10.1.1 Preparation of acidic solutions.....	141
10.1.2 Sample preparation and erosion testing.....	141
10.2 Porosity assessment.....	142
10.2.1 Scanning Electron Microscopy observations.....	142
10.2.2 Validation of the method for porosity assessment.....	143
10.2.3 Porosity assessment.....	148
10.3 Statistical analysis.....	151
CHAPTER 11: RESULTS.....	152
11.1 Introduction.....	152
11.2 Quantitative results.....	153
11.3 Qualitative results.....	156
CHAPTER 12: DISCUSSION.....	160

SECTION 4	PRELIMINARY STUDY OF ZIRCONIA WEAR.....	165
	CHAPTER 13: INTRODUCTION.....	166
	CHAPTER 14: MATERIALS AND METHODS.....	169
	CHAPTER 15: RESULTS.....	171
	15.1 Quantitative results.....	171
	15.1.1 Wear results.....	171
	15.1.2 X-ray Diffraction results.....	171
	15.2 Qualitative results.....	172
	CHAPTER 16: DISCUSSION.....	176
SECTION 5	CONCLUSIONS.....	178
SECTION 6	REFERENCES.....	183
SECTION 7	APPENDICES.....	202
	APPENDIX 1:Mathematical modelling of wear.....	203
	APPENDIX 2:Product information.....	207
	APPENDIX 3:Other activities during PhD candidacy.....	213

LIST OF FIGURES

Figure 1. 1:	Microwear detail of a facet showing parallel striations. The dentine (d) is not scooped out and is at the same level as the enamel (e) (adapted from Kaidonis 2008).....	5
Figure 1. 2:	An example showing the effect of an abrasive diet on the teeth of a pre-contemporary Australian Aboriginal. Note the gouged and pitted enamel and the scooping of the dentine (adapted from Kaidonis 2008).....	8
Figure 1. 3:	Microwear detail of an abrasion area showing haphazard scratch marks (adapted from Kaidonis 2008).....	8
Figure 1. 4:	Variation in the appearance of NCCLs (adapted from Nguyen et al. 2008).....	9
Figure 1. 5:	A micrograph showing the evidence of abrasion and erosion occurring concurrently in an NCCL (x4000 magnification). The wavy line at the centre of the micrograph represents the upper margin of the NCCL. Faint horizontal scratch marks below the line are indicative of abrasion over an erosive background (adapted from Nguyen et al. 2008).....	10
Figure 1. 6:	Micrograph of erosion lesion (courtesy of Dr S. Ranjitkar). Note the lack of mechanical wear.	10
Figure 2. 1:	Abrasive wear (adapted from Mair et al. 1996).....	22
Figure 2. 2:	Two-body abrasive wear (adapted from Mair 1999).....	23
Figure 2. 3:	Three-body abrasive wear (adapted from Mair 1999).....	24
Figure 2. 4:	Adhesive wear (adapted from Mair et al. 1996).....	25

Figure 2. 5:	Fatigue wear (adapted from Mair et al. 1996).	26
Figure 2. 6:	Corrosive wear (adapted from Mair et al. 1996).	27
Figure 3. 1:	Diagram of a silicate unit with each SiO tetrahedra sharing an oxygen atom (adapted from McLean 1979).	31
Figure 3. 2:	Three dimensional drawing of a silicate unit in which the silicon atom Si is surrounded by four oxygen atoms (adapted from McLean 1979).....	32
Figure 3. 3:	Three dimensional drawing of linked silicate units which form the continuous network in glass (adapted from McLean 1979).	32
Figure 6. 1:	Tooth wear machine.....	55
Figure 6. 2:	A closer view of tooth wear machine.	56
Figure 6. 3:	Trends of increasing facet area over two consecutive periods for each of four specimens.	62
Figure 6. 4:	The relationship between the facet area and mean wear rates ($\mu\text{m}/10^3$) of enamel.....	64
Figure 6. 5:	The two phases of enamel wear (with standard error bars) for upper specimens at a fixed load of 32N.....	66
Figure 6. 6:	Tooth-sectioning machine.....	71
Figure 6. 7:	Flow chart showing sequence of tooth sectioning.	72
Figure 6. 8:	Diagram showing tooth grouping for experiments.	72
Figure 6. 9:	LR-pressable ceramic- crowns attached to the button after casting.	75
Figure 6. 10:	Enamel specimen on SEM stud with three reference metal balls.....	78

Figure 6. 11:	Porcelain specimen on SEM stud with three reference metal balls.....	78
Figure 6. 12:	Gold specimen on SEM stud with three reference metal balls.....	78
Figure 6. 13:	PIX-4 3D scanner.....	80
Figure 6. 14:	The graphic data in 3D.....	81
Figure 6. 15:	Reference plane defined for volume calculation with Matlab.....	81
Figure 6. 16:	Experimental design at pH 6.1.....	86
Figure 6. 17:	Experimental design at pH 1.2.....	86
Figure 6. 18:	Specimens covered with nail varnish.....	87
Figure 7. 1:	Mean wear rates of enamel (with standard error bars) wearing against different indirect restorative materials under a load of 100N at pH 6.1. .	91
Figure 7. 2:	Mean wear rates of different indirect materials (with standard error bars) opposing enamel under a load of 100N at pH 6.1.	94
Figure 7. 3:	Mean wear rates of enamel and different indirect restorative materials under a load of 100N at pH 6.1.....	97
Figure 7. 4:	Buccal enamel surface. The control group (x 200).....	99
Figure 7. 5:	Lingual enamel surface. The control group (x 200).	99
Figure 7. 6:	Surface of enamel wearing against PBM-veneering (x 200).....	100
Figure 7. 7:	Surface of PBM-veneering (x 200).....	100
Figure 7. 8:	Surface of enamel wearing against LR-veneering (x 200).	101
Figure 7. 9:	Surface of LR-veneering (x 200).....	101
Figure 7. 10:	Surface of enamel wearing against LR-pressable (x 200).	102

Figure 7. 11: Surface of LR-pressable (x 200).....	102
Figure 7. 12: Surface of enamel wearing against machinable ceramic (x 200).	103
Figure 7. 13: Surface of machinable ceramic (x 200).	103
Figure 7. 14: Surface of enamel wearing against gold (x 200).	104
Figure 7. 15: Surface of gold (x 200).	104
Figure 7. 16: Mean wear rates of enamel (with standard error bars) wearing against different indirect restorative materials under a load of 100N at pH 1.2.	106
Figure 7. 17: Mean wear rates of different indirect materials (with standard error bars) opposing enamel under a load of 100N at pH 1.2.	109
Figure 7. 18: The mean wear rates of enamel and different indirect restorative materials under a load of 100N at pH 1.2.....	111
Figure 7. 19: Buccal enamel surface. The control group (x 200).....	113
Figure 7. 20: Lingual enamel surface. The control group (x 200).	113
Figure 7. 21: Surface of enamel wearing against PBM-veneering (x 200).....	114
Figure 7. 22: Surface of PBM-veneering (x 200).....	114
Figure 7. 23: Surface of enamel wearing against LR-veneering (x 200).	115
Figure 7. 24: Surface of LR-veneering (x 200).	115
Figure 7. 25: Surface of enamel wearing against LR-pressable (x 200).	116
Figure 7. 26: Surface of LR-pressable (x 200).....	116
Figure 7. 27: Surface of enamel wearing against machinable ceramic (x 200).	117
Figure 7. 28: Surface of machinable ceramic (x 200).	117
Figure 7. 29: Surface of enamel wearing against gold (x 200).	118

Figure 7. 30:	Surface of gold (x 200).	118
Figure 7. 31:	Mean wear rates of enamel worn by different indirect materials in two acidic environments.	120
Figure 7. 32:	Mean wear rates of different indirect materials opposing enamel in two acidic environments.	121
Figure 8. 1:	Mean wear rates of enamel and opposing materials at pH 6.1 (previously presented in Fig. 7.3).	126
Figure 8. 2:	Mean wear rates of enamel and opposing materials at pH 1.2 (previously presented in Fig. 7.18).	128
Figure 8. 3:	Gold surface after wearing against enamel (×200).	130
Figure 8. 4:	The rough surface of porcelain after wear (in the middle) compared to the smooth surface after polishing (×20).	134
Figure 10. 1:	Diagram showing the assignment of specimens for erosion test.	142
Figure 10. 2:	Test image created with known surface area percentage of dark areas.	144
Figure 10. 3:	Test image after modification.	145
Figure 10. 4:	SEM image under 1000 times of magnification.	149
Figure 10. 5:	SEM image after being adjusted with Adobe®Photoshop®.	150
Figure 10. 6:	SEM image analyzed with “Image J”.	150
Figure 11. 1:	The relative percentages of surface porosities of Vita Mark II treated at various pHs (with standard error bars)	153

Figure 11. 2: Machinable ceramic. Surface treated with HCl pH 1.2 for 2 hours (×500).....	157
Figure 11. 3: Machinable ceramic. Surface treated with HCl pH 2 for 2 hours (×500).	157
Figure 11. 4: Machinable ceramic. Surface treated with HCl pH 3 for 2 hours (×500).	158
Figure 11. 5: Machinable ceramic. Surface treated with HCl pH 4 for 2 hours (×500).	158
Figure 11. 6: Machinable ceramic. Surface treated with HCl pH 5 for 2 hours (×500).	159
Figure 11. 7: Machinable ceramic. Surface treated with deionised water pH 6.1 for 2 hours (×500).....	159
Figure 15. 1: XRD traces of specimen	173
Figure 15. 2: Enamel surface after 120,000 cycles of wear in deionised water (pH 6.1) (x200).....	174
Figure 15. 3: Zirconia surface after 120,000 cycles of wear in deionised water (pH 6.1) (x200).....	174
Figure 15. 4: Enamel surface after 10,000 cycles of wear in HCl (pH 1.2) (x 200). ..	175
Figure 15. 5: Zirconia surface after 10,000 cycles of wear in HCl (pH 1.2) (x 200).	175
Figure A1.1: Abrasive wear by a conical indenter (adapted from Halling 1975).....	203

LIST OF TABLES

Table 3. 1:	Selected physical properties of dental porcelain and enamel.	34
Table 3. 2:	Some of the wear machines used in previous porcelain wear studies.	42
Table 3. 3:	Some of the loads (in increasing order) used in previous porcelain wear studies.	43
Table 3. 4:	Some of the cycles (in increasing order) used in previous porcelain wear studies.	44
Table 6. 1:	Comparison of average loss of enamel (mg) at 80 cycles/min and 160 cycles/min of machine speed.	58
Table 6. 2:	Comparison of mean rate of tooth wear for uni-directional and bi-directional movements for various loads (N).	59
Table 6. 3:	Mean wear rate ($\mu\text{m}/10^3$) of composite resin for uni-directional and bi-directional movements at pH=7.0 and under three different loads (N) after 80,000 cycles.	60
Table 6. 4:	Loss of enamel (mg) for both upper and lower specimens over a total of 89,000 cycles.	60
Table 6. 5:	Mean wear rates ($\mu\text{m}/10^3$) of enamel for upper and lower specimens under different loads and after 80,000 cycles.	61

Table 6. 6:	Change in facet height and facet areas after 5000 cycles (S1) and 40,000 cycles (S2) of wear.	63
Table 6. 7:	Cumulative loss of enamel (mg) for upper (n=8) specimens over a total of 89,000 cycles.	65
Table 6. 8:	Two different calculations of volume of enamel and different restorative materials specimens.	69
Table 6. 9:	Firing temperatures of porcelain systems.	73
Table 6. 10:	Composition of type III gold.....	74
Table 6. 11:	Set up temperature and time for porcelain firing.	74
Table 7. 1:	Types of materials and their abbreviations.	88
Table 7. 2:	Mean wear rates of enamel opposed by different restorative materials under a load of 100N and at pH 6.1.....	90
Table 7. 3:	Pair-wise comparison of enamel wear rates between groups by Bonferroni test (load 100N, pH 6.1).....	92
Table 7. 4:	Mean wear rates of different indirect restorative materials under a load of 100N at pH 6.1.....	93
Table 7. 5:	Pair-wise comparison of material wear rates between groups by Bonferroni test (load 100N, pH 6.1).....	95
Table 7. 6:	Comparison of mean wear rates of enamel and opposing materials within groups (load 100N, pH 6.1).	96

Table 7. 7:	Mean wear rates of enamel opposed by different restorative materials under a load of 100N at pH 1.2.....	105
Table 7. 8:	Pair-wise comparison of mean wear rates of enamel worn by different indirect materials by Bonferroni test (load 100N, pH 1.2).	107
Table 7. 9:	Mean wear rates of different indirect restorative materials under a load of 100N at pH 1.2.....	108
Table 7. 10:	Comparison of the mean wear rates of enamel and the opposing material within groups (load 100N, pH 1.2).	110
Table 7. 11:	Summary of both experiments including materials, sample sizes (n), mean wear rates (x) and standard deviation (SD).....	119
Table 7. 12:	A t-test comparing the wear rates of enamel and different indirect restorative materials at pH 6.1 and 1.2.	122
Table 10. 1:	Mean surface area proportion of digital images	146
Table 10. 2:	Double determination of 12 random samples.	148
Table 11. 1:	The relative percentage of surface porosities of control specimens and specimens exposed to HCl solutions of pH 1.2, 2, 3, 4, 5 and deionised water at pH 6.1.....	154
Table 11. 2:	Pair-wise comparison of the prevalence of surface porosites by Bonferroni.....	155
Table 15. 1:	Summary of quantitative XDF analysis.....	172

PREFACE

This thesis reports on research work that was carried out during my PhD candidature at the School of Dentistry, The University of Adelaide, from August 2006 to 2010. The work initially aimed to investigate wear between enamel and different indirect materials including four porcelain systems (a porcelain bonded to metal veneering system, a leucite-reinforced glass ceramic used for veneering, a leucite-reinforced pressable ceramic, a machinable ceramic) and a type III gold alloy under various pH conditions. However, an interesting finding from qualitative analysis of the machinable ceramic has led to a more detailed examination of this system. In addition, over the years for the project to be accomplished, zirconia has become more popular, therefore a preliminary study on the wear behaviour of this relatively new material has been conducted to make the thesis more complete.

This thesis consists of seven sections, starting with a review of the literature, leading to the aims and rationale of the study (Section 1). The next three sections (Section 2, 3 and 4) present on the studies of enamel/ceramic wear, effect of acid on machinable ceramic and preliminary study of zirconia wear, respectively, that have been carried out. Each of this section composes of four chapters including an introduction, materials and methods, results and discussion for that specific study. These were followed by a section of general conclusions (Section 5), references (Section 6) and appendices (Section 7).

ABSTRACT

In dental practice, wear of the natural dentition is commonly seen in patients of all ages. It can have a mild effect on teeth, or be severe enough to affect patients' quality of life. Although different indirect restorative materials such as gold alloy or porcelain have been used for many years to restore excessively worn teeth, the procedures are generally complex and challenging to the dentists as well as costly and time-consuming for the patients.

A good restorative material should be aesthetic, durable and not be abrasive to the opposing dentition. Gold has been reported to be "enamel-friendly", but the colour makes it un-aesthetic. On the contrary, porcelain is aesthetic, biocompatible, durable and has become a popular choice for both clinicians and patients. However, previous studies have shown that some of the porcelain systems can be abrasive to the opposing natural enamel. The use of such abrasive porcelain systems would therefore be harmful to a patient's dentition in the long term.

Four porcelain systems and a gold alloy have been selected for this study:

- a veneering porcelain normally used in porcelain bonded to metal restorations (PBM-veneering porcelain)
- a leucite-reinforced glass ceramic used for veneering (LR-veneering ceramic)

- a leucite-reinforced pressable ceramic (LR-pressable ceramic)
- a machinable ceramic
- a type III gold alloy (gold).

The aims of the study were to determine the wear rates of the selected porcelains and opposing enamel under controlled conditions which simulated two clinical conditions:

- heavy attrition at near neutral pH (pH 6.1)
- heavy attrition with gastric regurgitation (pH 1.2)

In addition, preliminary studies on the wear of zirconia and enamel were conducted.

In this study, electro-mechanical tooth wear machines were used to simulate wear. Wear volume loss was measured by scanning specimens with 3D profilometers and evaluating the data using a purpose-written software. The surface micromorphology of wear facets was also observed by scanning electron microscopy (SEM). As a result of this analysis a more detailed investigation of the machinable ceramic was undertaken.

The results revealed that at pH 6.1, while enamel wear caused by the PBM-veneering porcelain, LR-veneering ceramic, machinable ceramic and gold alloy were not significantly different to the control group in which enamel specimens were worn against each other, significantly increased enamel wear was associated with the LR-pressable. Although enamel wear rates increased dramatically in conditions simulating attrition combined with gastric regurgitation, the gold alloy did not wear the opposing

enamel more than the enamel controls. In addition, in this study the machinable ceramic became porous under acidic conditions.

The findings presented in this thesis have implications for selection of porcelain for specific clinical cases. Although the findings should be cautiously extrapolated to in vivo conditions, they contribute to the understanding of new porcelain materials in terms of wear and erosion. In addition, results from preliminary experiments with zirconia will provide data to inform the development of protocols for future research.

DECLARATION

This work contains no material which has been accepted for the award of any other degree or diploma in any other university or other tertiary institution to Uyen Tran Kieu Ha and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis when deposited in the University library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968.

I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library catalogue, the Australasian Digital Theses Program (ADTP) and also through the web search engines, unless permission has been granted by the University to restrict access for a period of time.

UYEN TRAN KIEU HA

Dated this.....day of2011

ACKNOWLEDGEMENTS

I take this opportunity to express my thanks to many people who have provided their assistance in the production of this report and throughout my time at the School of Dentistry, the University of Adelaide.

I would like to sincerely thank my supervisors Professor Lindsay Richards and Associate Professor John Kaidonis for their wise and thoughtful advice and support. I greatly appreciate their precious time they offered to give me a hand whenever I was in need.

My thanks also extend to staff of the O.F. Makinson Laboratory (Victor Marino), the East Laboratory (Chanthan Kha, Kathryn Pudney) and the Technician Laboratory (Greg Natt, Greg Hamlyn, Kien Nguy) at the Adelaide Dental Hospital for their great advice, material and technical support with sample preparation. My sincere thanks are to Dr Massimiliano Guazzato (The University of Sydney) for the advised idea and the provision of zirconia material. I also thank 3M ESPE Australia for support through the supply of impression materials.

I wish to acknowledge the help given to me by the staff of CEMMSA (Center of Electron Microscopy and Microstructure Analysis) at the University of Adelaide. My

thanks also go to Andrew Robinson (Ian Wark Research Institute, the University of South Australia) for X-ray diffraction analysis. Thanks to Dr Chinh Dang for the help with statistical analysis and Dr Hai Tran for proofreading of this thesis.

In addition, I extend my gratitude to Associate Professor John Abbott for his advice and guidance in the implant clinic. My benefit from his broad experience and knowledge is greatly appreciated.

The financial support from the government of Vietnam gave me the opportunity to complete this course, and is greatly appreciated. This project was also supported by a grant from the Australian Dental Research Foundation.

Last, but not least, I would like to thank my friends, Dr Sarbin Ranjitkar, Dr Nattira Suksudaj, Ms Jactty Chew, Ms Syatirah Abdullah and Dr Jimin Xiong for their wonderful friendship. It has been a great pleasure to know you all.

*I wish to dedicate this thesis to my parents, Manh-Thu Ha and Trung-Moc Tran, for
continued support and encouragement of their three daughters*