GUIDE PLANE RETENTION IN REMOVABLE PARTIAL DENTURES

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A research report submitted for partial completion of Masters in Dentistry in Prosthodontics

Declaration

I, MATSHEDISO MARIA MOTHOPI declare that this research report is my own work. It is being submitted for the degree of Master of Dentistry in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

Signed ……………………………………………

06 December 2011

Dedication

I dedicate this research report to my family, especially my daughter Palesa whom at a tender age of nine continues to be an inspiration in everything I do. Also to my elderly patients who are forever grateful for our services and in this instance were the main driving forces for this research project.

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Abstract

Purpose

The purpose of this study was to measure and compare the influence of abutment teeth guide planes and partial denture guiding surfaces on the retention of removable partial dentures.

Method

An upper typodont model was modified by removing both second premolars and first molars, thus creating two bounded saddles. An impression of the model was made with irreversible hydrocolloid and a cast poured, on which an acrylic resin based removable partial denture (RPD) was made. To this denture a hooking device was added so that the model and denture could be placed on a custom-made platform and jig on a universal testing machine (Instron, UK). The RPD was then removed from the model along its path of insertion (perpendicular to the occlusal plane) as well as at 2° and 5° and the maximum load recorded. The typodont model was then modified by making guide planes on the abutment teeth, and a second RPD made and the procedure repeated. This RPD was then modified by creating guiding surfaces directly against the guide planes using autopolymerising resin, and the procedure again repeated. Each measurement was made 10 times at each path of insertion/withdrawal, resulting in 90 measurements.

Results

There were some differences between the different paths of withdrawal in each of the three situations, explicable by the lack of ideal contact in the first two dentures, and the much improved contact in the third, which caused the teeth in the model to move on withdrawal. Overall, there were significant differences between the three models. There

was a significant increase in retentive force of 1.6 times from denture 1 to denture 2, of 7.6 times from denture 2 to denture 3, and 12.3 times from denture 1 to denture 3.

Conclusion

This study confirmed that guide planes increase the retention of an RPD, but that when guiding surfaces of the denture are adapted closely to the guide planes on the teeth, there is a considerable increase in retention.

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1 Introduction and Literature review

An increase in life expectancy in populations around the world is expected to result in an increase in partially dentate individuals as people retain their teeth for a longer period of time (Marcus et.al., 1996; Zwetchkenbaum and Shay, 1997). Removable partial denture (RPD) rehabilitation is expected to increase with this increase in partial edentulism. To be able to service these patients satisfactorily it is necessary to plan, design and construct RPDs with care.

The use of RPDs is extensive in both general dental practice as well as in a specialist setting. RPDs are important for improving partially dentate patient's aesthetics, speech, function, and load distribution. They are also used in cases where there have been drifting and tilting of teeth and also where patients have lost vertical dimension and alveolar bone due to tooth loss (Owen, 2000). Unfortunately despite all these advantages RPDs have always been associated with problems which sometimes lead to patients not wearing them. Poor fit, difficulty to manipulate the denture, and plaque accumulation are some of the problems that are often encountered (MacEntee, 2011).

Several studies (Brudvik and Reimers, 1992; Stern, Brudvik and Frank, 1985) reported that the majority of finished partial denture frameworks were found to be poorly fitting onto the abutment teeth. The components of the partial dentures were found to not be as close fitting to the abutment teeth as they should be, therefore leading to the denture dislodging quite easily. Frank et al (2000) reported that patients who were not satisfied with their RPDs (76%) reported the main cause to be lack of fit.

The aim of this study is to investigate the effect of guideplanes and modified guiding surfaces on RPD retention. The guide/guiding planes are defined as “vertically parallel surfaces on abutment teeth oriented so as to contribute to the direction of the path of placement and removal of a removable dental prosthesis” (GPT 8). The guide/guiding plate or surface is “that component of a RPD framework that is the counterpart of a guide plane” (NaBadalung, Nichols and Brudvick, 1997).

The functions of guide planes have been mentioned as “1) providing one path of placement/removal of a prosthesis thereby eliminating excessive stress upon either the restoration or the abutment teeth; 2) ensuring the intended action of various reciprocating, stabilizing and retentive components; 3) aiding with retention against dislodging forces other than those acting parallel to a given path of insertion and stabilizing against horizontal direct forces; and 4) eliminating troublesome food traps” (Canning and O’Sullivan, 2008; Niu and Tarrazzi, 2010).

The advantages of the guide planes could be improved by modifying the guiding surface of the denture (NaBadalung et al, 1997). According to clinical observations in the Department of Prosthodontics (School of Oral Health Sciences, Wits Dental Hospital), this intervention improves the fit of the denture framework to the abutment teeth therefore increasing the retention of the denture. The method used to modify the denture is also found to be easy to carry out and is also cost-effective.

Guide planes are said to occur very seldom naturally and therefore need to be prepared directly on enamel or on a restoration (Bezzon, Mattos and Ribero, 1997). A number of methods and paralleling devices have been advocated to make sure that parallel guide planes are accurately prepared in the patient's mouth and transferred to the final models (Canning and O'Sullivan, 2008; Niu andTarrazzi, 2010). Unfortunately most of these techniques and paralleling devices are either too expensive or complicated for practical use. The preparation of guide planes is therefore often dependant on the ability of a clinician (Niu and Tarrazzi, 2010). Gehl & Payne (1972) mentioned that it was often not possible to achieve parallel guide planes.

An undesirable path of insertion and withdrawal of an RPD necessitates considerable adjustments once the denture has been fabricated. This can be done by modifying either the abutment teeth guide planes or by modifying the RPD guiding surfaces or sometimes doing both.

In their study NaBadalung et al (1997) modified the abutment teeth guide planes with composite resin and fitted a chrome cobalt framework to these guide planes. Their results showed an increased frictional resistance to the dislodgement forces of the denture after this retrofitting procedure. A problem that was found to be associated with their procedures was with the handling of composite resin. Care and skill was found to be needed when using composite resin to achieve a satisfactory result.

There is a paucity of other such studies in the literature, and differences in retention with and without guide planes and/or guiding surfaces have not been published. This study therefore set out to try to quantify the retention from a given simulated clinical situation, by providing a comparative analysis of the frictional forces that exist in dislodging a denture that has been fabricated on master models with no guide planes, with guide planes, and with guide planes and modified denture guiding surfaces. The study was also to provide data for the difference in retention when measurements are taken at different paths of insertion (i.e 0, 2, and 5 degrees).

The null hypothesis was that there would be no significant differences in retention with or without guide planes and guiding surfaces, at any of the paths of insertion tested.

2 Aims and Objectives

2.1 Aim

To compare the frictional force of retention when removing a partial denture with two bounded saddles along different paths of insertion, in the presence or absence of guide planes on the teeth and guiding surfaces on the denture.

2.2 Objectives

- To adjust a typodont upper model to create bounded saddles between teeth 14 and 17 and 24 and 27.
- To construct an acrylic resin based partial denture in the normal manner without any adjustment to the interproximal surfaces of the abutment teeth.
- To measure the force of retention when removing the partial denture along a zero degree path of insertion, and then at 2^{o} and 5^{o} to that path.
- To create guide planes on the abutment teeth, make a new partial denture in the normal manner, and make the same measurements.
- To modify this second denture to create guiding surfaces against the model teeth in a clinical simulation, and to repeat the same measurements.

3 Methodology

3.1 Study Design

The study is a laboratory-based comparative study based on measurements taken of three acrylic resin based partial dentures during their removal from a typodont model. The three different simulated clinical situations will be compared with each other at each of three different paths of insertion/withdrawal. The clinical experience is that there should be increasing retention with guide planes, and then with guide planes and guiding surfaces made to those guide planes in a simulation of the clinical method of creating such surfaces.

3.2 Sample Size

For each of the three partial denture situations, ten measurements at each of the three paths of insertion/withdrawal will be made. As the expected differences between the three simulated clinical situations are thought to be large, the 90 observations will give sufficient statistical power.

3.3 Materials and Methods

A maxillary typodont model (KaVo GmbH, Germany) was used in this study as a simulation of the patient’s mouth. Second premolars (15 & 25) and first molars (16, 26) were removed from the models to create bilateral bounded saddles (figure 1).

Figure 1 The typodont model simulating the clinical situation of two bounded saddles.

First, this model was not changed in any way, and an impression was made of it with an irreversible hydrocolloid (alginate) material (Blueprint Cremix, Densply, USA), mixed according to the manufacturer's recommendations in the normal way. A cast was poured using Type IV dental stone, and this was sent to the laboratory with an instruction to construct an acrylic based removable partial denture with no additional components. The laboratory was instructed to do this in the normal way as for a clinical case. This involved blocking out undercuts on the cast, waxing up suitably sized denture teeth in the normal manner, and flasking and polishing.

This denture was then modified by first cutting away any flanges, so they could have no influence on the retention, and then by adding a device to provide a hook (figure 2) for a universal testing machine. The horizontal bar was placed exactly mid-way between the abutment teeth on each side and level with the occlusal plane, and the hook device placed mid-way between the two arches. This bar was attached to the denture teeth by using autopolymerising acrylic resin (Unifast Trad, GC, USA).

Figure 2 Acrylic partial denture with hooking device to enable placement in a universal testing machine.

A custom built platform and jig was constructed for the tensile testing machine used (Instron, UK). This platform enabled the placement of the jig so that the hook could be directly under the upper jig of the machine, and could also be varied at an angle to the initial path of insertion, which was made perpendicular to the occlusal plane (figures 3-5).

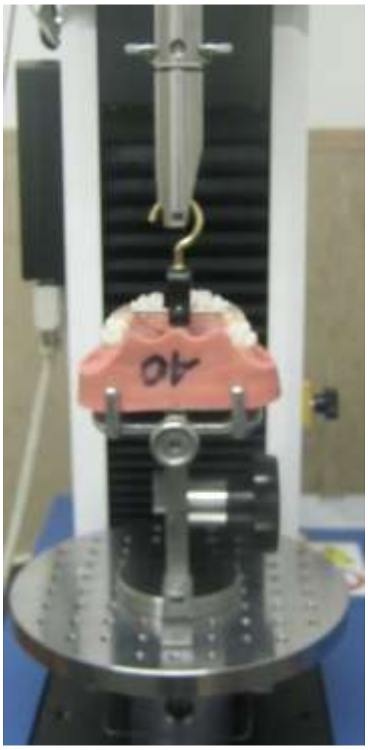


Figure 5 Typodont model on custom-made platform on universal testing machine with hook in place on upper jig.

Figure 3 Side view of lower jig made to take a model platform from a model surveyor.

Figure 4 Calibrated mechanism to provide tilt to vary the path of insertion/withdrawal.

Measurements (of forces for pulling the dentures away from their models) were then taken at 0, 2, and 5 degrees (10 measurements per angulation) by raising the upper jig at a cross-head speed of 2 mm per minute, which was considered an appropriate speed to record the frictional force effects.

This typodont model was then modified by preparing guide planes on the surfaces of the abutment teeth adjacent to the edentulous space (i.e. distal of 14 and 24 and mesial of 17, 27) using a diamond bur. This was done in the same manner as would be done clinically, without any paralleling device (figures 6 and 7).

Figure 6 Preparation of guide planes on the typodont model.

Figure 7 Occlusal view of the prepared guide planes.

An impression of this model was then made in the same as the first, and again the model sent to the laboratory for the construction of a second removable partial denture. Both these dentures were thus made in exactly the same way by the same laboratory, with no particular instructions given, in order to simulate the clinical situation.

This second partial denture was subjected to exactly the same procedures as the first, by removing the buccal flanges and placing the hooking device in the same manner. Another set of measurements were made, again at the three different paths of insertion/withdrawal.

This second denture was then modified to add guiding surfaces that would match the guide planes of the typodont teeth. Retention grooves were ground on the guiding surfaces and autopolymerising acrylic resin (Unifast Trad, GC, USA) was mixed and placed on these surfaces. The guide planes on the abutment teeth were lubricated with Vaseline, and when the autopolymerising resin had reached the dough stage, the denture was placed carefully along the path of insertion and taken in and out of the model until the exothermic heat of reaction commenced. This procedure simulated the procedure followed clinically. The denture was placed in hot water (at <70°C) until the acrylic was set, and excess acrylic was trimmed away.

Measurements were again taken in the universal testing machine as for the previous two situations.

3.4 Analysis

The results were analysed using appropriate analyses of variance using the Statistical Package and Service Solutions (SPSS Inc, Chicago, USA).

3.5 Study validity and reliability

The model, denture, guide plane and guiding surface placement are imperfect simulations of the clinical situation. In addition, only variations to the path of insertion in an antero-posterior direction were measured. Thus there may be weak external validity. However, if significant *differences* are observed between the three clinical situations, the results are valid for the clinical situation as the chewing and displacing forces in the mouth vary considerably in direction and so the retentive force from guide plane retention would be expected to be greater.

Reliability was improved by taking each set of measurements ten times and using the mean for interpreting the results. The laboratory work was performed by the same person (a senior laboratory technician), in the same dental laboratory (Wits Dental Hospital laboratory). Also one operator (i.e. the researcher) took all the measurements.

All materials that were used in this study were used according to the recommendation of the manufacturer. The measuring instrument was calibrated every time a new test was done.

4 Results

The maximum loads (measured in Newtons) were recorded for the 3 sets of dentures at 0, 2 and 5 degrees. The results were recorded as graphs and tables directly from the software (Bluehill Lite, Instron, UK). An example is given below for the first denture, and subsequent plots and tables are shown in Appendix 1. The data were then analysed for statistical comparisons and summarised as below. Full analyses also appear in Appendix 2. For each denture situation appropriate analyses of variance tests were carried out, the results of which are given below.

4.1 Model 1, Denture 1: no guide planes or surfaces

4.1.1 Denture at 0°

Figure 8 Load vs extension graph at 0^o for denture 1. The graphs were modified by offsetting each subsequent test in order to make the graph more readable.

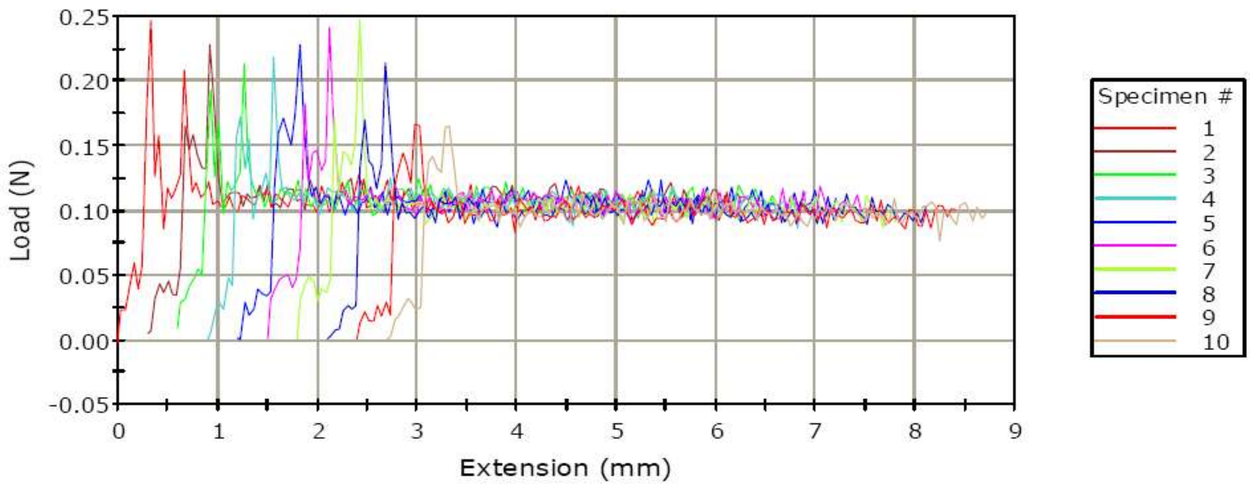


Table 1. Loads at 0^0 for denture 1

	Maximum Load (N)
1	0.24643
2	0.22793
3	0.21310
4	0.21851
5	0.22782
6	0.24114
7	0.24738
8	0.21380
9	0.16692
10	0.16540
Maximum	0.24738
Mean	0.21684
Median	0.22316
Range	0.08198
Coefficient of Variation	13.58250
Standard Deviation	0.02945
Minimum	0.16540

4.1.2 All degrees for Model 1

The means and standard deviations for all the degrees for Model 1 shown in Table 2, together with the statistical differences derived from the data in Appendix 2.

Table 2. Results for Model 1, denture 1. Figures in red are statistically significant at $p<0.05$

Denture 1	Mean Max Load (N)	Standard Deviation	ANOVA test result on mean differences	
			2^o	5^o
0^o	0.217	0.029	0.047	0.999
2^o	0.181	0.031		0.014
5^o	0.205	0.014		

The retentive force dropped significantly when the model was tilted at 2^o but was regained at 5^o.

4.2 Model 2, Denture 2: guide planes on the teeth, no guiding surfaces on the denture

The results for these tests are again summarised from the data in Table 3.

Table 3. Results for Model 2, denture 2. Figures in red are statistically significant at p<0.05

Denture 1	Mean Max Load (N)	Standard Deviation	ANOVA test result on mean differences	
			2^0	5^0
0^0	0.352	0.045	0.072	0.007
2^0	0.315	0.032		0.554
5^0	0..308	0.030		

There was a decreasing retentive force with increasing angle of deviation from the path of insertion/withdrawal.

4.3 Model 2, Denture 3: guide planes on the teeth, and guiding surfaces on the denture

The results for these tests are again summarised from the data in Table 4.

Table 4. Results for Model 2, denture 3. Figures in red are statistically significant at p<0.05

Denture 1	Mean Max Load (N)	Standard Deviation	ANOVA test result on mean differences	
			2^0	5^0
0^0	2.681	0.162	0.000	0.015
2^0	1.983	0.282		0.001
5^0	2.463	0.199		

There was a significant drop in retentive force at 2^0, regained to some extent at 5^0 but this remained significantly different from 0^0.

4.4 Comparisons between all the dentures

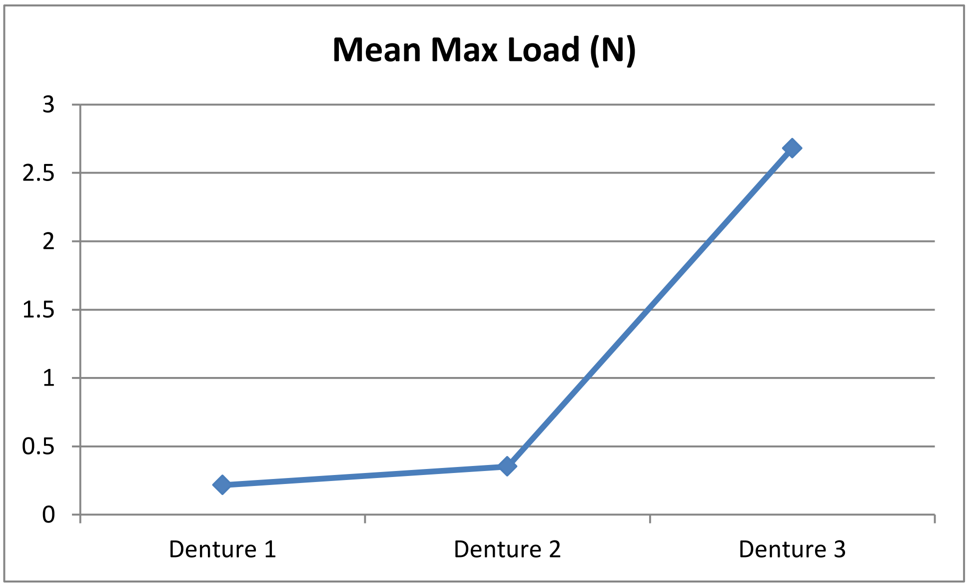
The results for comparisons of the means for all dentures using the path of insertion (i.e. at 0°) are summarised in Table 5. Denture 1 had no guiding surfaces and the teeth had no guide planes. Denture 2 had no guiding surfaces but the teeth had guide planes. Denture 3 had guiding surfaces and the teeth had guide planes.

Table 5. Results for all dentures at 0°. Figures in red are statistically significant at $p<0.05$

	Mean Max Load (N)	Standard Deviation	ANOVA test result on mean differences	
			Denture 2	Denture 3
Denture 1	0.217	0.030	0.000	0.000
Denture 2	0.352	0.045		0.000
Denture 3	2.681	0.162		

There was a statistically significant difference between all dentures, thus rejecting the null hypothesis. There was a significant increase in retentive force of 1.6 times from denture 1 to denture 2, of 7.6 times from denture 2 to denture 3, and 12.3 times from denture 1 to denture 5, as depicted in figure 9.

Fig. 9 Mean maximum loads of dentures at 0°



5 Discussion

Despite new and sophisticated methods of constructing RPDs such as the use of three-dimensional computer aided design or computer assisted manufacturing (Han and Wang, 2010), conventional acrylic RPDs are still the most widely used RPDs (MacEntee, 2011). Acrylic RPDs can be strong, are easily repaired and adjusted and comparatively easy to fabricate, certainly when compared with metal based RPDs. They are also relatively cost-effective and are prescribed for those patients who cannot afford other treatment options: in other words the majority of patients.

Our clinical experience has been that acrylic-based RPDs with tooth support can be regarded as permanent prostheses and are ideal not only because they are cost-effective but also because if they can be made retentive enough through the use of guide plane retention there may be no need for clasp arms. This would make them also ideal for the elderly, and institutionalised patients who find it difficult to manipulate a denture with clasps and who may rely on care-givers who may not take sufficient care with clasps. Consequently many of these are lost or bent and the denture becomes unserviceable.

This study therefore set out to ascertain whether our experience of trying to improve guide plane retention by refining guiding surfaces in the mouth, had any validity. The results clearly show this to be the case, but there are some interesting observations to be made. From clinical observation the denture is considered to be more retentive when the path of insertion is at a slight angle. The expectation in this case was therefore to observe significant differences between the 0º and the 2º and 5º with 0º being the least retentive. But in this case the 2^{o} seemed to have a decreased frictional force and the 5^{o} almost the same as the 0^{o}.

There are two possible explanations for this. First, considering the denture 1 (without guiding surfaces or guide planes), it is logical that the 'fit' of the denture against the teeth would be best when in its position at rest. However, there could only be points of contact between the resin and the teeth, most of which will be recruited when the denture is moved along its path of withdrawal. However, when tilted at 2^{0}, many of these points will initially be lost, and so the retentive force will be less. At 5^{0} on the other hand, there will be greater 'binding' of the denture against the teeth, and the retentive force is likely to increase. These were precisely the observations in this study (Table 2).

With respect to the second denture (without guiding surfaces but with guide planes), the same situation is likely to occur, but this time the retentive force should be greater as more of the denture is likely to contact the now prepared guide planes on the teeth. However, the quality of the contact may still not be that improved, because of the inherent inaccuracies in the processing of an acrylic base and the need for the technician to block out undercuts. Hence it was not surprising that once again there was a decrease in retentive force at 2^{0}, but there was a further slight but not significant decrease at 5^{0} (Table 3).

Logically, therefore, with denture 3 there should be no such drop in retention at 2^{0} because now there is intimate contact between the guide planes on the teeth, and the guiding surfaces on the denture. However, once again, a drop in retentive force was observed at 2^0 (Table 4). There is a possible explanation for this, which lies in the nature of the model used. This is a typodont model, where the teeth are held in the model by means of retentive elements and undercuts: they 'click' into place. But they are also not rigid, and are capable of movement. The superior contact of the denture guiding surfaces with the tooth guide planes is evidenced by the greatly increased retentive force at 0^0. But it is possible that this improved contact will cause binding against the teeth when at an angle to the path of withdrawal. This should produce a higher retentive force, but it may also be great enough to move the teeth slightly first during withdrawal at an angle, and this could explain the drop in retentive force at 2^0. At 5^0 the force exerted on the teeth will be greater and exceed their movement and therefore it is logical that the retentive force would again increase.

Observations have been made that most of the time RPDs still fit poorly despite the care that is taken to fabricate them (Stern et al, 1985; Brudvik & Reimers, 1992). Both laboratory and clinical procedures have an impact on this outcome. The preparation of guide planes on the abutment teeth of RPDs is one of the important principles of constructing RPDs. RPD retention has been reported to increase when guide planes are prepared on abutment teeth. Steward, Rudd and Kuebker (1993) recommended that as many guide planes as possible must be prepared on the abutment teeth.

The results obtained from this study show an increase in retention when guide planes are prepared on the teeth; but more than that, when the guiding surfaces were specifically shaped to those guide planes after processing of the denture, retention was almost doubled. The outcome of this study is very encouraging. It highlights how a quick and easy procedure such as modifying the guiding surfaces can make a large difference to the fit of an RPD. It allows for more applications of claspless dentures (but which should always have tooth support) for dentures in the aesthetic zone; for patients with less dexterity such as those with rheumatoid arthritis and the elderly; for improved ease of maintenance; and for reducing the financial burden on patients and the health sector.

Problems associated with the use of removable partial dentures include development of caries on abutment teeth, mobility of abutment teeth, and continuation of periodontal breakdown. All of these are linked to poor oral hygiene and so regular maintenance and oral hygiene care must be carried out (Akaltan and Kaynak, 2005). It may be somewhat cynical to mention that the advantage of modifying guiding surfaces with autopolymerising acrylic is that the acrylic will deteriorate over a certain period of time and may result in a slight loss of retention. This will call for another modification of the guiding surfaces and may hopefully encourage the patient to return for this, at which stage the abutment teeth and oral hygiene may be assessed and managed accordingly.

The preparation of guide planes might also pose a challenge/problems to both the clinician and the patient. After tooth loss, teeth adjacent to edentulous spaces tend to tilt, drift or over-erupt into the edentulous space (Owen, 2000). Guide plane preparation to these teeth might be difficult if not impossible without mutilating the teeth. Sometimes preparation of the guide plane might cause sensitivity to the teeth especially if the preparation was not confined to the enamel only (i.e. dentine exposure). Krikos (1975) advised that the guide plane preparation be polished and protected by an application of fluoride.

This study has given insight into how oral rehabilitation with acrylic RPDs can be improved without any complicated procedures at comparatively little cost. This improvement will lead to more predictable results with RPDs and the possibility of more individuals being able to wear their RPDs. In some earlier studies cited in van der Bilt et al (1994), improved masticatory performance was observed after treatment with removable partial dentures. Van der Bilt et al (1994) found the objective masticatory function and average masticatory performance to increase in partially dentate patients who were given RPDs. This outcome of RPDs is very important especially for frail elderly patients.

Limitations and opportunities

The limitations of this study are that it is an *in vitro* simulation of clinical situations and that the 'teeth' were typodont resin-based teeth and are softer than enamel. Furthermore, they are not firm in their sockets. The study could be repeated with a better simulation of the clinical situation, perhaps with extracted teeth embedded in an artificial periodontium. It would also be useful to know just where the contacts between the denture and the teeth occur.

Despite the limitations, the stark differences between the three clinical situations are considered sufficient to confirm the clinical anecdotal evidence of much improved retention when guiding surfaces are adapted clinically to guide planes.

This study has also highlighted a number of opportunities for other studies. The study was done using a bounded saddle and therefore other types of RPD Kennedy classification such as class I and II could be investigated in the future. The influence of guide plane and guiding surfaces when used in combination with clasp should also be investigated.

6 Conclusions

The main objective of this study was to measure the influence of abutment teeth guide planes and partial denture guiding surfaces on removable partial denture retention, one of the important elements of RPD success. The outcome of the study showed that guide planes increase the retention of the RPD, but that when guiding surfaces are adapted closely to the guide planes, retention was observed to increase even more. Guide plane retention has been reported in the past but the effect of guiding surface modification has not been reported at all in the literature, especially using a simplified and cost-effective method that was used in this study.

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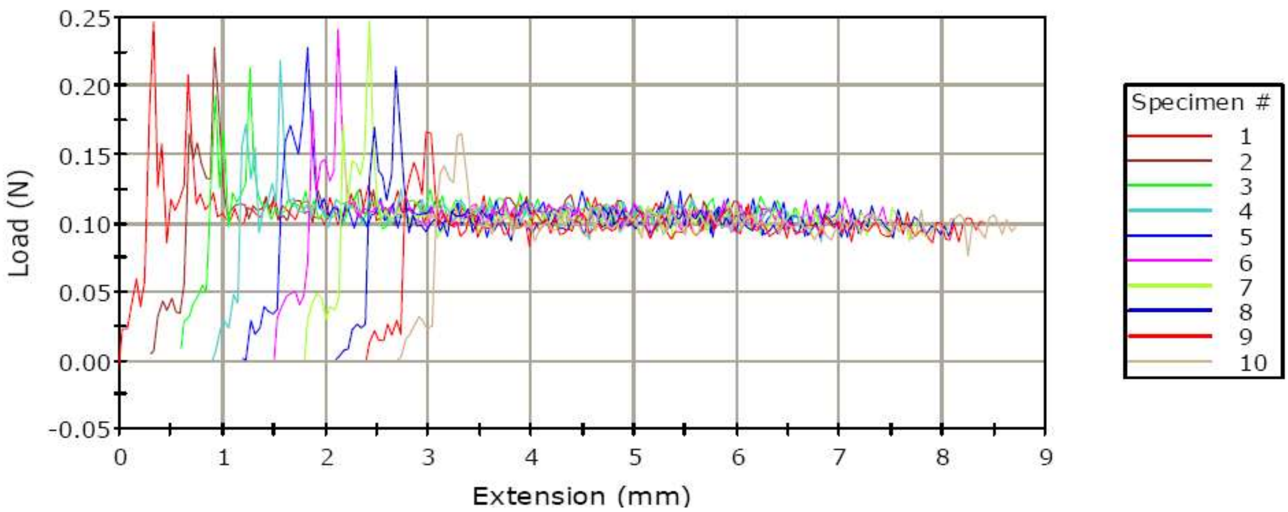
8 APPENDIX 1. Graphs and tables from the tensile testing machine

MODEL 1 DENTURE 1

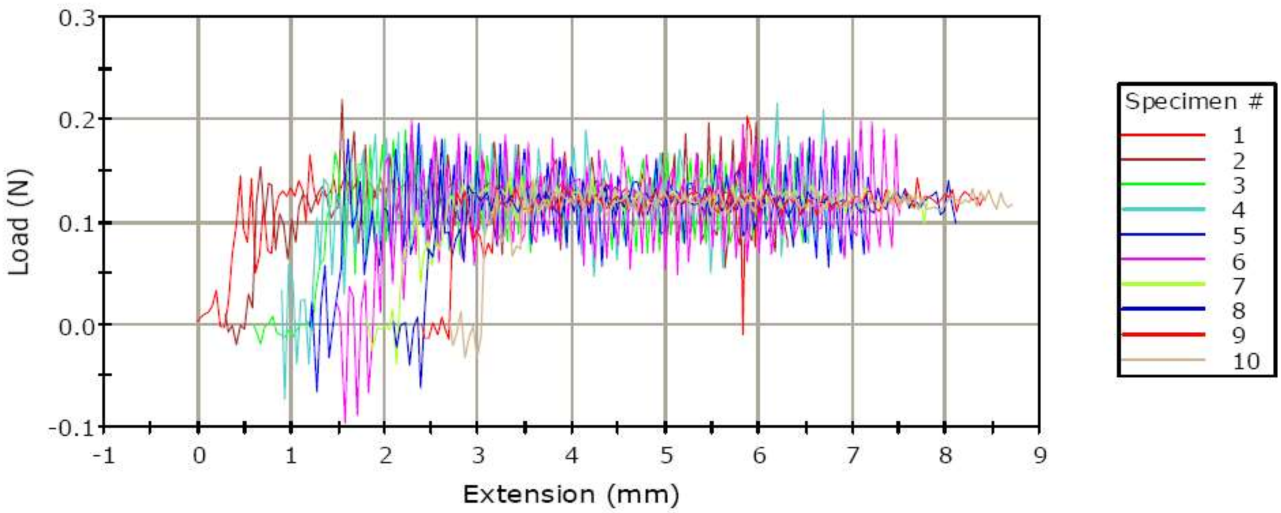
Denture at 0 degrees



	Maximum Load (N)
1	0.24643
2	0.22793
3	0.21310
4	0.21851
5	0.22782
6	0.24114
7	0.24738
8	0.21380
9	0.16692
10	0.16540
Maximum	0.24738
Mean	0.21684
Median	0.22316
Range	0.08198
Coefficient of Variation	13.58250
Standard Deviation	0.02945
Minimum	0.16540

MODEL 1 DENTURE 1

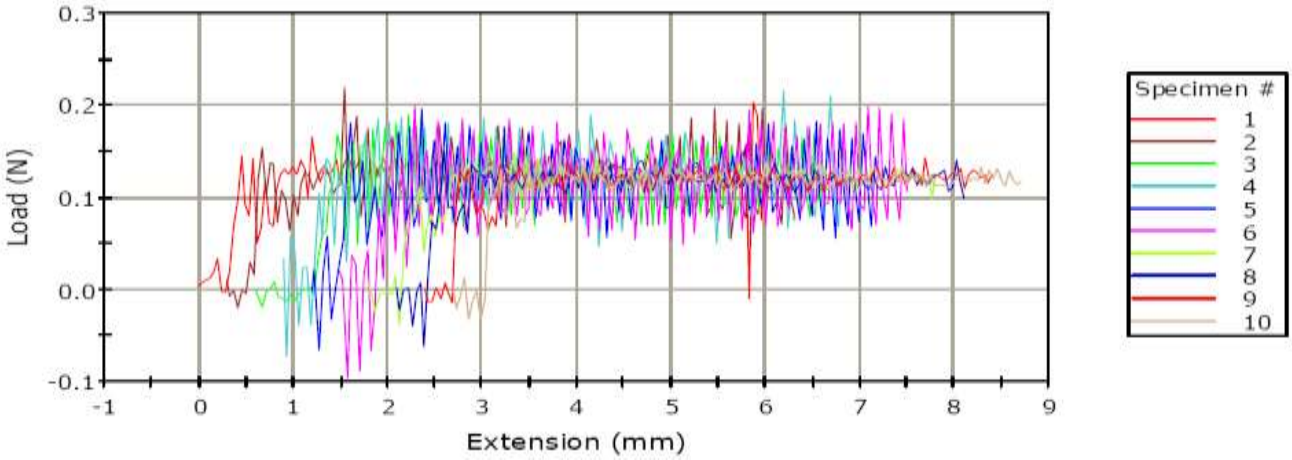
Denture at 2 degrees



	Maximum Load (N)
1	0.20358
2	0.21921
3	0.18989
4	0.21536
5	0.19591
6	0.19962
7	0.14885
8	0.15108
9	0.14279
10	0.14069
Maximum	0.21921
Mean	0.18070
Median	0.19290
Range	0.07852
Coefficient of Variation	17.31532
Standard Deviation	0.03129
Minimum	0.14069

MODEL 1 DENTURE 1

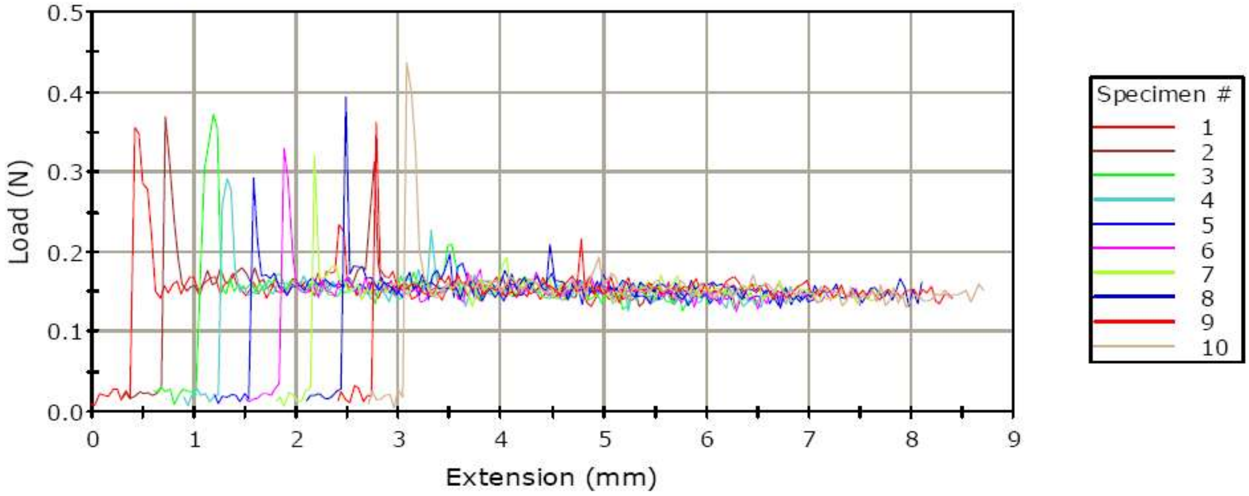
Denture at 5 degrees



	Maximum Load (N)
1	0.23183
2	0.20359
3	0.21071
4	0.22975
5	0.21705
6	0.23938
7	0.21300
8	0.19348
9	0.22799
10	0.21377
Maximum	0.23938
Mean	0.21805
Median	0.21541
Range	0.04589
Coefficient of Variation	6.47038
Standard Deviation	0.01411
Minimum	0.19348

MODEL 2 DENTURE 2

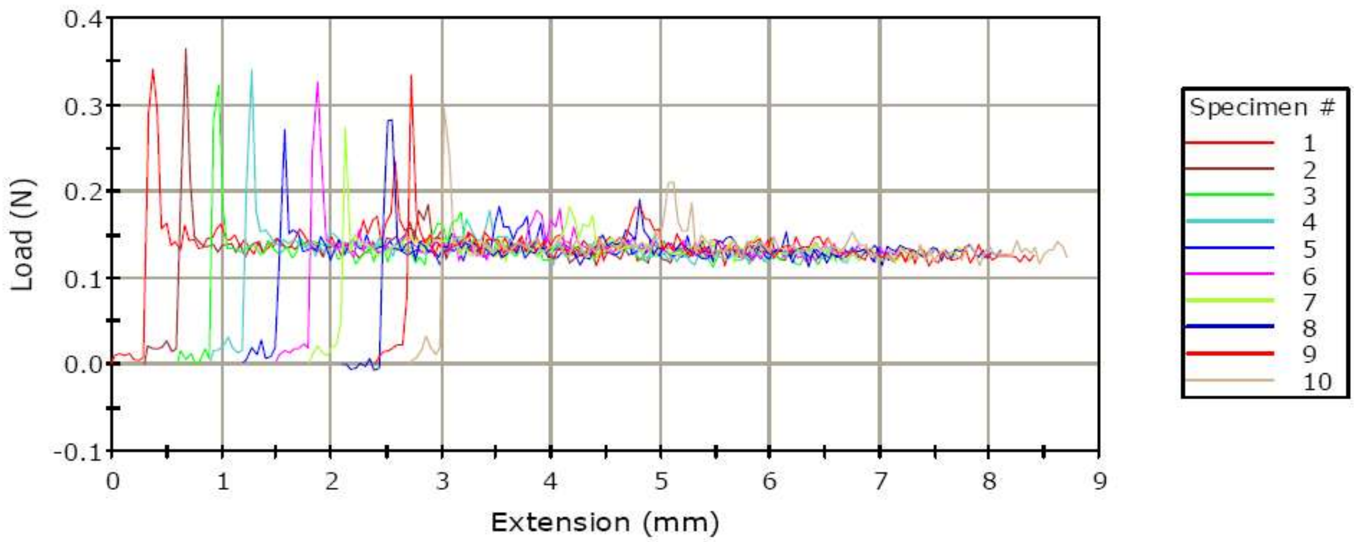
Denture at 0 degrees



	Maximum Load (N)
1	0.35496
2	0.36837
3	0.37220
4	0.29109
5	0.29276
6	0.32945
7	0.32070
8	0.39318
9	0.36259
10	0.43607
Maximum	0.43607
Mean	0.35214
Median	0.35877
Range	0.14498
Coefficient of Variation	12.79412
Standard Deviation	0.04505
Minimum	0.29109

MODEL 2 DENTURE 2

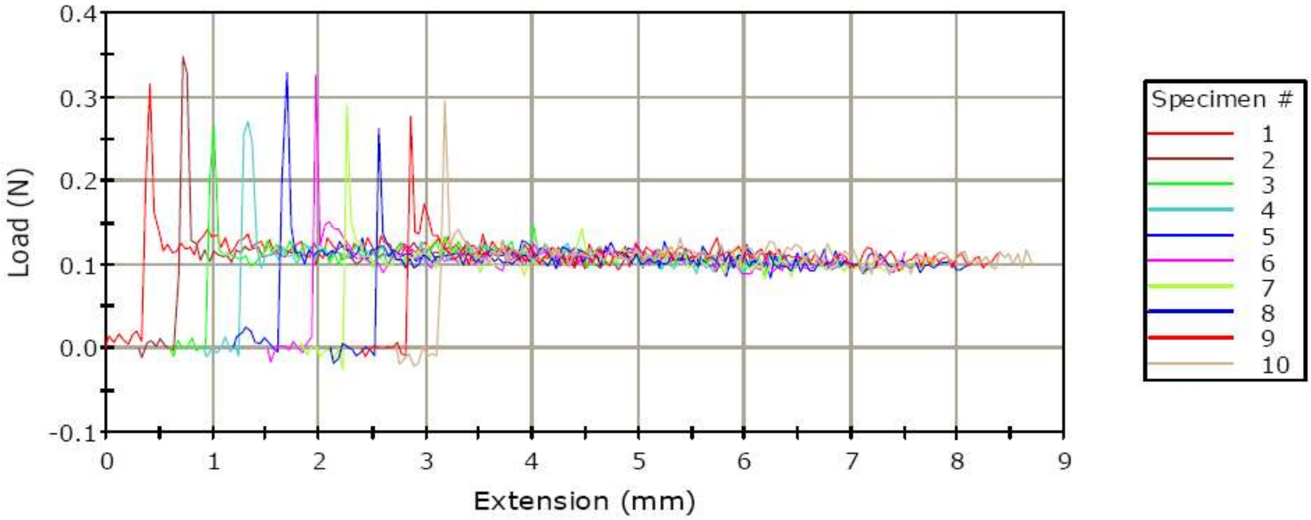
Denture at 2 degrees



	Maximum Load (N)
1	0.34040
2	0.36416
3	0.32299
4	0.33911
5	0.27095
6	0.32546
7	0.27287
8	0.28186
9	0.33342
10	0.29558
Maximum	0.36416
Mean	0.31468
Median	0.32423
Range	0.09320
Coefficient of Variation	10.23994
Standard Deviation	0.03222
Minimum	0.27095

MODEL 2 DENTURE 2

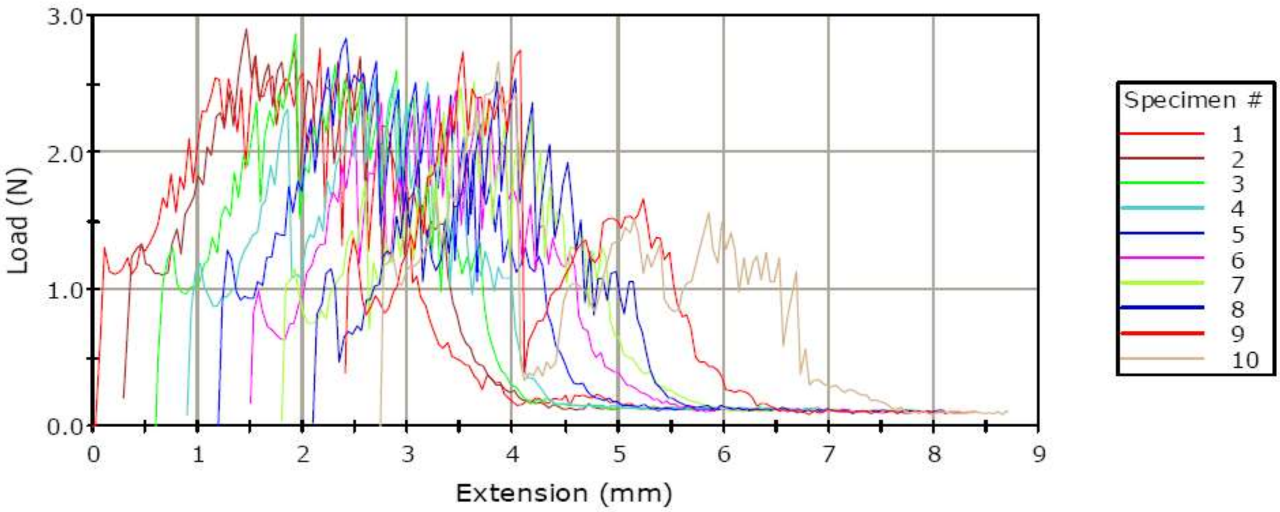
Denture at 5 degrees



	Maximum Load (N)
1	0.31532
2	0.34772
3	0.26596
4	0.27004
5	0.32854
6	0.32530
7	0.29054
8	0.26223
9	0.27627
10	0.29462
Maximum	0.34772
Mean	0.29766
Median	0.29258
Range	0.08548
Coefficient of Variation	10.06334
Standard Deviation	0.02995
Minimum	0.26223

MODEL 2 DENTURE 3

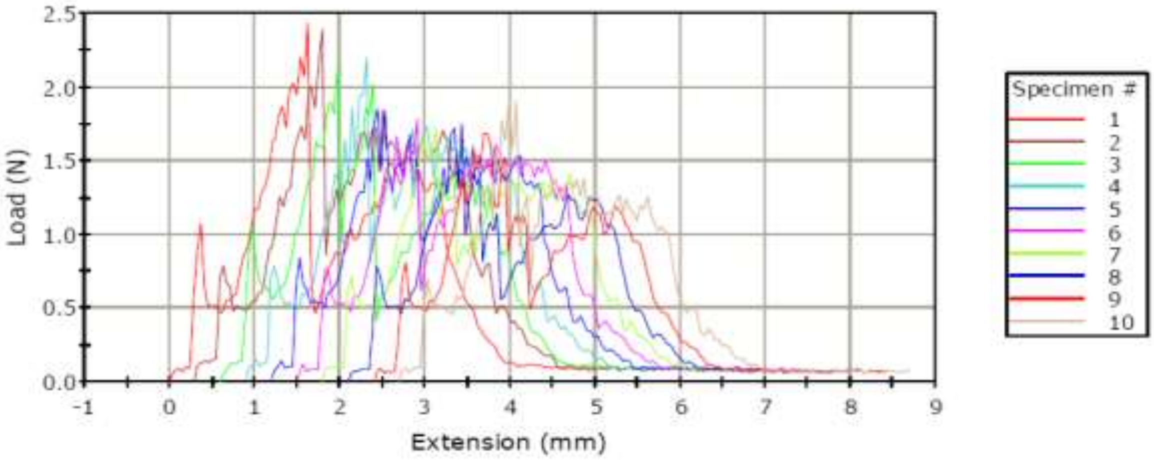
Denture at 0 degrees



	Maximum Load (N)
1	2.76033
2	2.90040
3	2.86568
4	2.54575
5	2.83228
6	2.44923
7	2.51699
8	2.53768
9	2.74719
10	2.65872
Maximum	2.90040
Mean	2.68143
Median	2.70295
Range	0.45117
Coefficient of Variation	6.03583
Standard Deviation	0.16185
Minimum	2.44923

MODEL 2 DENTURE 3

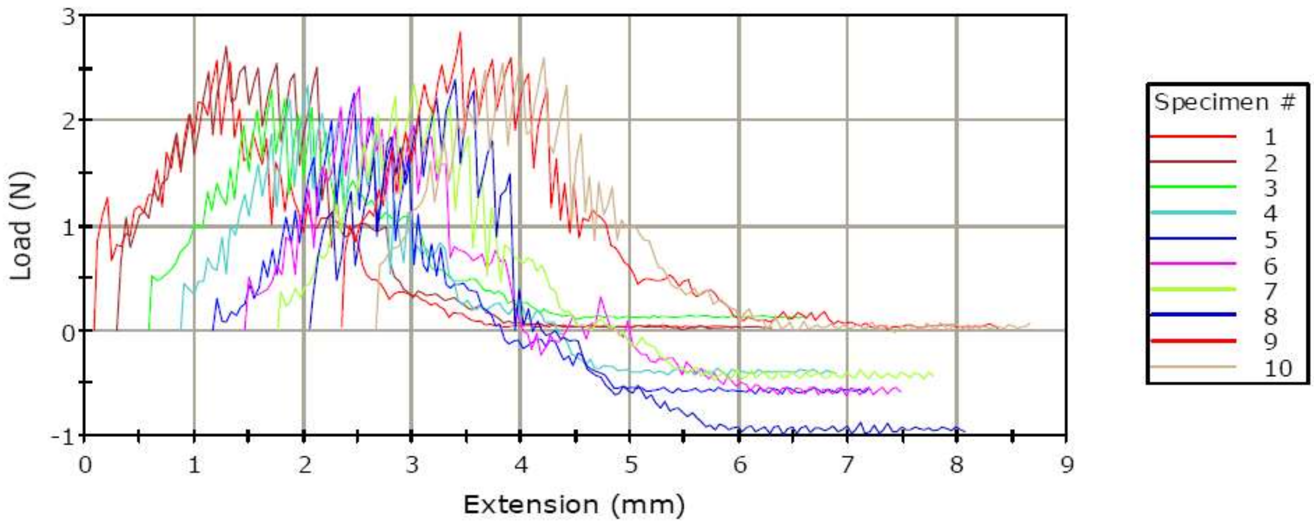
Denture at 2 degrees



	Maximum Load (N)
1	2.43273
2	2.38743
3	2.13279
4	2.19640
5	1.84974
6	1.78102
7	1.71537
8	1.74891
9	1.68574
10	1.89828
Maximum	2.43273
Mean	1.98284
Median	1.87401
Range	0.74699
Coefficient of Variation	14.20805
Standard Deviation	0.28172
Minimum	1.68574

MODEL 2 DENTURE 3

Denture at 5 degrees



	Maximum Load (N)
1	2.57061
2	2.70183
3	2.29480
4	2.33072
5	2.25402
6	2.31473
7	2.34145
8	2.39462
9	2.83462
10	2.59331
Maximum	2.83462
Mean	2.46307
Median	2.36803
Range	0.58061
Coefficient of Variation	8.05886
Standard Deviation	0.19850
Minimum	2.25402

9 APPENDIX 2. Statistical tests

Oneway ANOVA – Model 1 Denture 1

Descriptives

max_load_N

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0 degrees	10	.2168430	.02945127	.00931331	.1957748	.2379112	.16540	.24738
2 degrees	10	.1806980	.03128956	.00989463	.1583148	.2030812	.14069	.21921
5 degrees	10	.2180550	.01411077	.00446222	.2079608	.2281492	.19348	.23938
Total	30	.2051987	.03075001	.00561416	.1937164	.2166809	.14069	.24738

ANOVA

max_load_N

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.009	2	.005	6.608	.005
Within Groups	.018	27	.001		
Total	.027	29			

Test of Homogeneity of Variances

max_load_N

Levene Statistic	df1	df2	Sig.
4.026	2	27	.030

Post Hoc Tests

Multiple Comparisons

Dependent Variable: max_load_N
Tamhane

(I) Degrees	(J) Degrees	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0 degrees	2 degrees	.03614500*	.01358828	.047	.0003798	.0719102
	5 degrees	-.00121200	.01032711	.999	-.0295013	.0270773
2 degrees	0 degrees	-.03614500*	.01358828	.047	-.0719102	-.0003798
	5 degrees	-.03735700*	.01085426	.014	-.0672324	-.0074816
5 degrees	0 degrees	.00121200	.01032711	.999	-.0270773	.0295013
	2 degrees	.03735700*	.01085426	.014	.0074816	.0672324

*. The mean difference is significant at the .05 level.

Oneway ANOVA – Model 2 Denture 2

Descriptives

max_load_N

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0 degrees	10	.3521370	.04505292	.01424699	.3199081	.3843659	.29109	.43607
2 degrees	10	.3146800	.03222390	.01019009	.2916284	.3377316	.27095	.36416
5 degrees	10	.2976540	.02995539	.00947273	.2762252	.3190828	.26223	.34772
Total	30	.3214903	.04202911	.00767343	.3057964	.3371843	.26223	.43607

ANOVA

max_load_N

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.016	2	.008	5.877	.008
Within Groups	.036	27	.001		
Total	.051	29			

Test of Homogeneity of Variances

max_load_N

Levene Statistic	df1	df2	Sig.
.721	2	27	.495

Post Hoc Tests

Multiple Comparisons

Dependent Variable: max_load_N
Tukey HSD

(I) Degrees	(J) Degrees	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0 degrees	2 degrees	.03745700	.01625930	.072	-.0028566	.0777706
	5 degrees	.05448300*	.01625930	.007	.0141694	.0947966
2 degrees	0 degrees	-.03745700	.01625930	.072	-.0777706	.0028566
	5 degrees	.01702600	.01625930	.554	-.0232876	.0573396
5 degrees	0 degrees	-.05448300*	.01625930	.007	-.0947966	-.0141694
	2 degrees	-.01702600	.01625930	.554	-.0573396	.0232876

*. The mean difference is significant at the .05 level.

Oneway ANOVA – Model 2 Denture 3

Descriptives

max_load_N

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0 degrees	10	2.6814250	.16184611	.05118023	2.5656473	2.7972027	2.44923	2.90040
2 degrees	10	1.9828410	.28172408	.08908898	1.7813077	2.1843743	1.68574	2.43273
5 degrees	10	2.4630710	.19849373	.06276923	2.3210771	2.6050649	2.25402	2.83462
Total	30	2.3757790	.36478893	.06660104	2.2395646	2.5119934	1.68574	2.90040

ANOVA

max_load_N

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.554	2	1.277	26.432	.000
Within Groups	1.305	27	.048		
Total	3.859	29			

Test of Homogeneity of Variances

max_load_N

Levene Statistic	df1	df2	Sig.
3.381	2	27	.049

Post Hoc Tests

Multiple Comparisons

Dependent Variable: max_load_N
Tamhane

(I) Degrees	(J) Degrees	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0 degrees	2 degrees	.69858400*	.10274367	.000	.4211609	.9760071
	5 degrees	.21835400*	.08099008	.045	.0043858	.4323222
2 degrees	0 degrees	-.69858400*	.10274367	.000	-.9760071	-.4211609
	5 degrees	-.48023000*	.10898083	.001	-.7702845	-.1901755
5 degrees	0 degrees	-.21835400*	.08099008	.045	-.4323222	-.0043858
	2 degrees	.48023000*	.10898083	.001	.1901755	.7702845

*. The mean difference is significant at the .05 level.

Oneway ANOVA – All models/Dentures at 0 degrees

Descriptives

max_load_N

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Model 1 (no guideplanes)	10	.2168430	.02945127	.00931331	.1957748	.2379112	.16540	.24738
Model 2 (guideplanes)	10	.3521370	.04505292	.01424699	.3199081	.3843659	.29109	.43607
Model 3 (guideplanes + guiding surfaces)	10	2.6814250	.16184611	.05118023	2.5656473	2.7972027	2.44923	2.90040
Total	30	1.0834683	1.15453120	.21078759	.6523593	1.5145774	.16540	2.90040

ANOVA

max_load_N

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	38.394	2	19.197	1979.638	.000
Within Groups	.262	27	.010		
Total	38.655	29			

Test of Homogeneity of Variances

max_load_N

Levene Statistic	df1	df2	Sig.
22.767	2	27	.000

Post Hoc Tests

Multiple Comparisons

Dependent Variable: max_load_N
Tamhane

(I) model	(J) model	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Model 1 (no guideplanes)	Model 2 (guideplanes)	-.13529400*	.01702100	.000	-.1808172	-.0897708
	Model 3 (guideplanes + guiding surfaces)	-2.46458200*	.05202071	.000	-2.6145933	-2.3145707
Model 2 (guideplanes)	Model 1 (no guideplanes)	.13529400*	.01702100	.000	.0897708	.1808172
	Model 3 (guideplanes + guiding surfaces)	-2.32928800*	.05312620	.000	-2.4801484	-2.1784276
Model 3 (guideplanes + guiding surfaces)	Model 1 (no guideplanes)	2.46458200*	.05202071	.000	2.3145707	2.6145933
	Model 2 (guideplanes)	2.32928800*	.05312620	.000	2.1784276	2.4801484

*. The mean difference is significant at the .05 level.