

The Effect of Denture Design and Fixatives on the Retention of Mandibular Complete Dentures Tested on a Novel *In-vitro* Edentulous Model

A. Johnson*, N.Al-Kaisy†, C.A. Miller‡ and N. Martin§

Abstract - The aim of this study was to evaluate the effect of the design (extension and adaptation) of a mandibular complete acrylic denture and the use of denture adhesives using a novel *in-vitro* edentulous model. The model is a highly anatomically accurate replica based on a moderately resorbed human mandibular edentulous arch. The model has been designed and fabricated by means of an elaborate clinical and technical process that employs synthetic elastomeric materials with properties that attempts to reproduce *in-vitro* characteristics of the soft tissues overlying the ridges and immediate reflected tissues. This model was used to measure and compare the retention of mandibular dentures of varying designs (well-fitting, over- and under-extended) with and without the aid of denture fixatives. Retention tests were conducted with different volumes of artificial saliva at a cross head speed of 50 mm/min with 4 equidistant holding points on the denture occlusal surface, using a universal tensile testing machine in an axial pull direction. The effect of three denture adhesives on denture retention was also tested on the same denture types at different times over a period of 5 hours and beyond. The *in-vitro* model presented can be effectively used to test the retention of mandibular complete dentures. The speed of dislodgement force and amount of saliva are important variables in mandibular denture retention. The retention of well-fitting dentures was statistically higher than that of ill-fitting dentures. A significantly higher retention force was needed to dislodge mandibular dentures (well and ill-fitting dentures) when using a denture adhesive.

KEYWORDS: *In-vitro* testing, artificial edentulous mandibular model, denture adhesive, denture retention, saliva volume

CLINICAL IMPLICATIONS

Effective *in-vitro* testing of denture retention systems is a logical and essential step prior to undertaking costly clinical trials. Moreover, *in-vitro* testing would complement results obtained from subsequent clinical studies.

Mandibular denture retention, compared with maxillary dentures, for patients with resorbed ridges is usually the main problem for both the patient and clinician; hence the real need to improve mandibular denture retention. Investigations of new denture designs, materials and ideas should be tested in an *in-vitro* model first to reduce the time, effort and cost of clinical trials. Such laboratory studies give an understanding of the mechanical factors that affect the retention of denture prostheses. In addition, they could investigate denture retention using forces of different loads; speeds and occlusal schemes while easily controlling environmental conditions.

Effective *in-vitro* testing of denture retention systems should ideally be undertaken using a laboratory model that closely resembles the *in-vivo* situation. This model should seek to replicate the relevant anatomy, the properties of the tissues and determine the test parameters to ensure that the model is fit for purpose to be used as a test jig.

INTRODUCTION

The problem of complete denture retention generally concerns the mandibular prosthesis rather than the maxillary one, and it is considered a major oral disease entity and characterized by individual variability in volume and rate^{1, 2}. Poor retention is often associated with loss of bone support; where the continued resorption of the mandibular alveolar ridge leads to greater difficulty with mandibular denture construction and patient satisfaction. Indeed, denture retention of the mandibular arch, compared to the maxillary arch, is of great concern to denture wearers, especially with resorbed ridges. The lower denture is often the most difficult to manage by the dentist^{1, 3-5}.

A recent service evaluation survey conducted by the University of Sheffield/CCDH for complete denture patients revealed that 64% of patients attending for treatment were dissatisfied with the retention of their mandibular complete denture, which agreed with Fenlon and Sherriff^{6, 7}. A number of recent clinical studies have attempted to investigate and improve the retention of complete dentures^{8, 9-14}. Some of these trials have focused on the refinement of endosseous methods for implant-supported dentures⁸. Others concentrated on the investigation of other non-surgical procedures such as the application of denture adhesives for resilient lining materials, which provide primary retention for prostheses that may be difficult or impossible to obtain by other means⁹⁻¹⁴. It is interesting to note that many of these *in-vivo* clinical investigations tested the retention of maxillary dentures rather than the mandibular¹⁵⁻¹⁸. This is mainly because the clinical tests regarding mandibular

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dentures, especially for highly resorbed ridges, are very difficult to conduct and the results unpredictable as it tends to be intimately associated with oral muscles control, movement of the tongue and movement of the mandible, in addition to the minimum support area.

The high prevalence of problems with the mandibular complete denture warrants an attempt to improve the effectiveness of this prosthesis. Such investigations would benefit from being performed in an *in-vitro* environment, analogous to the oral environment prior to clinical trials. This would make such clinical investigations more cost-effective and useful. *In-vitro* testing will give a better understanding of the mechanical factors that affect the retention of mandibular denture prostheses. In addition, such testing would help investigate denture retention using forces of different loads and speeds and could control the environmental conditions.

To obtain the optimum benefits from such laboratory tests, they should be conducted in a manner resembling the real situation. The primary requirement for such simulation is the simulation of the anatomy of the ridge and the physiology of the covering mucosa and reflecting tissues. Although there has been some work which looked at the physical properties of the oral mucosa¹⁹⁻²², the precise physical properties of the human oral mucosa are not fully known. Therefore the reproduction of the physical characteristics of the oral tissues cannot be completely accurate. Nevertheless the model constructed and reported in this investigation has broadly attempted the reproduction of the known physical properties of human soft tissues. Care has been taken in the clinical and technical fabrication process. The physical properties of the model were extensively tested and measured. The new model is radically different to models previously used for *in vitro* testing. It uses new materials and has known physical properties, which have been selected to resemble (as far as possible) oral conditions. Details of the model construction are given briefly below. The authors believe that as a result of this careful production technique, any new materials that could aid denture retention could be tested and compared effectively using this laboratory model.

This article describes the experimental process used on the *in-vitro* edentulous mandibular analogue model constructed for testing the retention of complete dentures.

The process consists of four complimentary studies designed to: (1) Determine the optimum saliva flow; (2) determine the optimum cross-head speed for testing the retention of mandibular complete dentures; (3) measure and compare the retention of different mandibular denture designs; and (4) measure and compare the retention of different mandibular denture designs with the use of different denture adhesives.

MATERIALS AND METHODS

In-vitro model construction

A definitive working impression, using addition cured silicone (Aquasil™) putty and wash was obtained of the denture bearing surfaces and immediate reflected soft tissues of a moderate-severe resorbed mandibular ridge. The combined use of chair-side border moulding and sequentially extended custom trays produced an accurate working impression of the ridges and reflected soft tissues.

A working cast was obtained by pouring the working impression with dental stone. A stone negative of the original cast was constructed. An impression was taken of the original cast using putty and light body addition cured silicone (Aquasil™). A negative of the resultant impression was poured using a laboratory duplicating silicone material (Dublisil™). The resultant negative stone cast of the original was obtained by pouring the Dublisil silicone negative with die stone.

A layer of wax with varying thicknesses approximating to the thickness of ridge oral mucosa according to Uchida, *et al*²³ was applied on the resultant stone negative cast and was measured using a thickness measuring gauge. A negative for this wax pattern was then poured with die stone and the resultant cast formed the base of the model.

A polyester mesh was fixed on the periphery and tongue space of the (mucosa wax pattern) negative cast to aid the retention of the soft tissue analogue materials (ProGel neutral skin™ for the basement layer, Elite soft lining™ for the intermediate layer, and ProGel outer skin™ for the superficial layer. A thin layer of transparent ProGel outer skin™ was applied to the surface of the negative cast. Another thin layer of Elite soft lining™ material was then laid on the ProGel outer skin™ layer on the ridge area. An appropriate amount of ProGel neutral skin™ filled the tongue and ridge area of the negative cast.

The two halves were then closed together, clamped and left to completely set for about 2-3 hours. The choice of materials was based on the data from an extensive series of experiments that tested a range of materials in various combinations²⁴.

The resultant *in-vitro* model consisted of a stone cast with a synthetic compound elastomeric tissue covering designed to artificially match the dimensions of a patient's ridge parameters and soft tissue properties (Figure 2)

Denture fabrication

Three mandibular complete dentures were fabricated for the edentulous model: well fitting, under-extended (ill-fitting) and over-extended (ill-fitting). The well fitting denture was made in a conventional manner, from impressions of the model. Using a special tray, an alginate impression was taken, which was poured to form the final cast. The teeth were arranged on the middle of the ridge using a Candulor Static-Laser®. This device is used to check the autonomous multi-local stability of a single posterior tooth in the maxilla and in the mandible.

Flasking, packing and curing followed using Aesthetic Basis™ material heat cure acrylic resin at curing cycle (5 hours at 70°C and 2 hours at 95°C). The denture was then finished using conventional techniques (Figures 1 and 2).

The ill-fitting dentures (over- and under-extended dentures) were fabricated by using a duplicating technique of the well-fitting prosthesis. Two copy dentures were created and modified to create the ill-fitting surfaces. The under-extended denture was created by trimming to 2 mm from the peripheral border and 5 mm from the retro-molar pad area. The over-extended denture was made to fit the model loosely by removing about 2 mm from the fitting surface of the denture (Figure 3).



Figure 1. Denture teeth arranged on the middle of the ridge using a Candulor Static-Laser (Candulor AG, Wangen, Switzerland)



Figure 2. Mandibular complete denture fabricated for the in-vitro simulation model

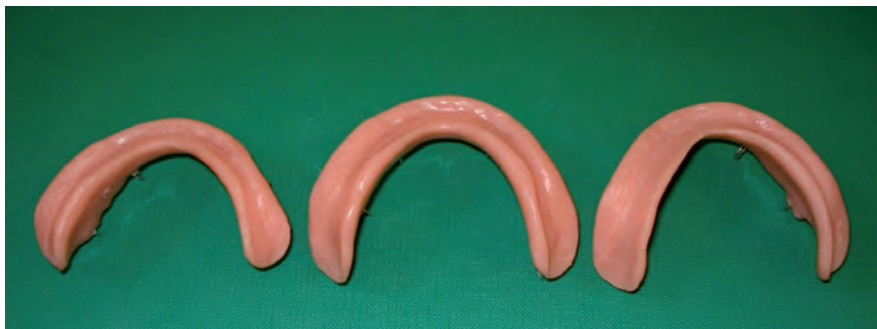


Figure 3. From left to right: under extended denture, well-fitting denture and overextended denture.

For each of the retention experiments, the dentures were linked to a universal tensile testing machine with the aid of 4 holding points attached to the denture's occlusal surface and connected to the machine by an adjustable wiring system connected to the holding points by S-shape hooks. The wires were adjusted so that they all produced an equal axial pull in a simultaneous manner. The occlusal surface of the denture teeth was made parallel with the base of the tensile tester by holding the model on a surveyor table to allow adjustment to ensure parallelism to the base of the machine (Figures 4 and 5).

1. Optimum saliva volume

The aim of this experiment was to determine the optimum amount of artificial saliva and the ideal tensile speed to be used for subsequent, reproducible experiments. A series of retention experiments were conducted with different amounts of artificial saliva at different tensile speeds with

the well-fitting denture. The retention force of the mandibular denture was tested on the tensile testing machine by applying an axial upward pulling force.

To determine the optimum amount of saliva, two series of experiments were conducted with different volumes of saliva (0, 0.3, 0.5, 0.7, 0.9, 1.1 and 1.5 ml) at a speed of 50 mm/min, as this speed was suggested in previous literature²⁵⁻²⁷.

2. Optimum cross-head tensile test speed

To determine the ideal tensile speed, four series of experiments were conducted using the optimum amount of saliva at different speed of dislodgment.

For each experiment, ten full separation tests were measured and the means are presented in the results. 'Loss of retention' in this experiment was taken as complete separation of the denture from the underlying supporting tissues.

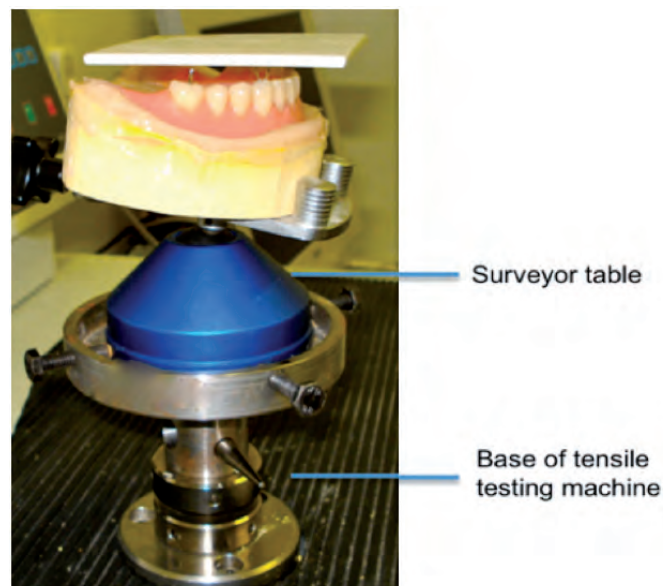


Figure 4. The occlusal surface of the denture teeth was made parallel with the base of the tensile tester

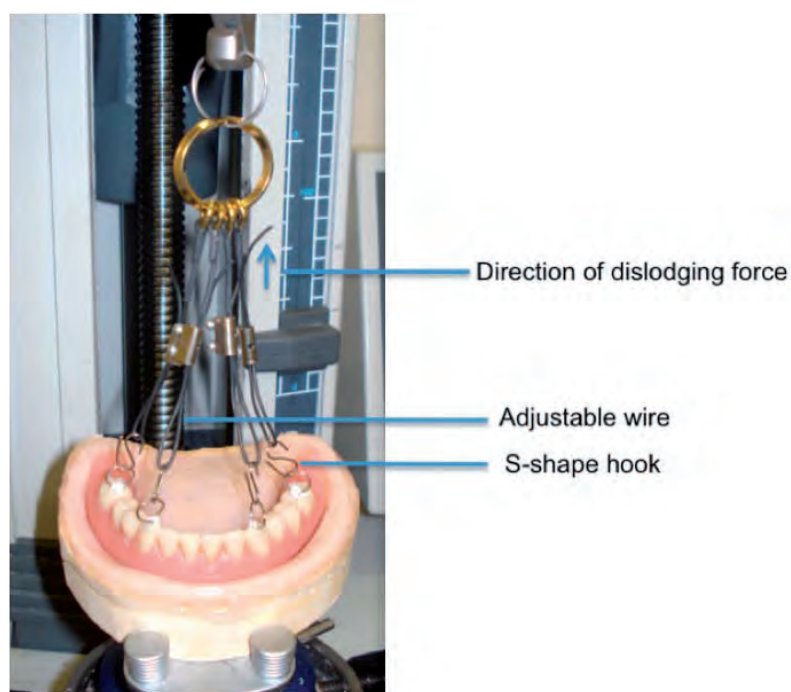


Figure 5. Dentures linked to a universal tensile testing machine (LLOYD Instruments – LRX, UK) with the aid of 4 holding points attached to the denture's occlusal surface

3. Retention of different mandibular denture designs

The retention of 3 mandibular complete dentures was tested; well fitting, under-extended (ill-fitting) and over-extended (ill-fitting), designed and fabricated as described above. Using the same retention experiment principles, the retention tests for the three types of denture were conducted on three different days with the use of 0.9 ml of saliva and at a 50 mm/min tensile speed to full denture separation from underlying tissues. Ten pulling actions were performed at each test for each denture (n=10).

4. Retention of different mandibular denture designs with the use of different denture adhesives

The *in-vitro* model was used to compare the retention of well and ill-fitting dentures when combined with 3 different types of denture adhesives. The experiment was conducted using the same tensile testing rig as described. For each of the three types of mandibular complete denture designs, three types of popular, commercially used, denture fixatives were assessed in this study, in accordance with the manufacturer's instructions (Table 1).

Table 1. The types of denture adhesives tested.

Adhesive name	Consistency	Composition	Company
PoliGrip® Ultra	Paste	Poly (methylvinylether/ maleic acid) Sodium- magnesium-zinc mixed partial salt. Petrolatum cellulose gum, Paraffinum liquidum, Silica, Aroma, CI 45430.	GlaxoSmithKline, Stafford Miller Ltd, Dungarvan Co. Waterford, Ireland).
Fixodent® Neutral Taste	Paste	Calcium/Zinc PVM/MA Copolymer, Paraffinum liquidum. Cellulose gum. Petrolatum. Silica.	Procter & Gamble, Technical Centres Ltd., Egham, Surrey, UK).
Super Wernets®	Powder	Cellulose Gum, Dicalcium phosphate. PEG-90M. Sodium phosphate. Aroma.	GlaxoSmithKline, Stafford Miller Ltd, Dungarvan Co. Waterford, Ireland).

In these *in vitro* experiments, undertaken with denture fixatives, retention has been expressed as the force required to dislodge the mandibular denture to a separation distance of 2.5 mm from the underlying ridge tissue using a tensile testing machine. This separation distance was determined by identifying the break in the curve produced on the tensile tester that occurred when the separation distance exceeded 2.5 mm. The separation distance of the denture from underlying tissue was measured. As a fair representation of the *in-vivo* situation, where small lateral displacements, rocking and tipping movements are very difficult to measure accurately or reproducibly, the decision was made to consider this minimum separation (2.5 mm) as the basic separation distance that would occur in the patient's mouth before full detachment would occur. This displacement will usually be transitory and may not reach a point of complete detachment.

The retention force for one well-fitting denture, one over-extended, and one under extended denture for each of the denture fixative type tested was carried out. Prior to the application of the adhesive, the denture was thoroughly cleaned with water and liquid soap and dried. Adhesive was applied onto the fitting surfaces of the mandibular dentures. The paste type was applied in five strips of 8

mm at the frontal, right and left canine and 2nd molar areas as recommended by the manufacturer. Strips were measured with dividers and excess removed with a wax knife (Figure 6). The powder adhesive type was applied onto the moist fitting surfaces of the mandibular denture, 0.2 ml was found sufficient to make a uniform layer on the fitting surfaces of the mandibular dentures as recommended by manufacturers (Figure 7).

The dentures were then placed on the model after applying a new sample of artificial saliva (0.9 ml) on the ridge mucosa for each test and then pressed into position using moderate finger pressure for 2-3 seconds. The seating force could not be measured, but was carried out by the same operator each time. A study by Norman *et al*²⁸ found that the seating force of a thumb to the plate of maxillary dentures was equal to 17.1 Newton.

The retention forces of the three types of dentures used with the adhesives were measured in two different experiment series to determine (a) the best testing procedure to reflect the true onset and duration of activity of the denture adhesives, and (b) to investigate if the deterioration of adhesive retention is due to natural degradation of the constituents or due to repeated denture dislodgment.



Figure 6. Five strips of past adhesive applied on the tissue surface of mandibular denture, 8 mm length measured using dividers.



Figure 7. 0.2 ml of powder adhesive applied on the moistened tissue surface of mandibular denture.

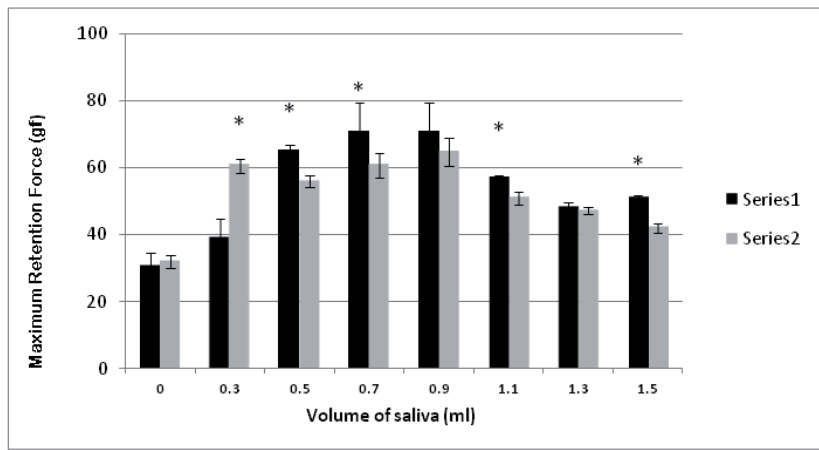


Figure 8. The effect of saliva amount on the retention of mandibular complete denture on the model with 50 mm/min tensile speed. Series 1 experiments (5mins to 5hrs) and Series 2 experiments (after 5 hrs) were conducted with n=10 at each amount of saliva. * Represent a statistical difference between the two experiments with the use of the same amount of saliva.

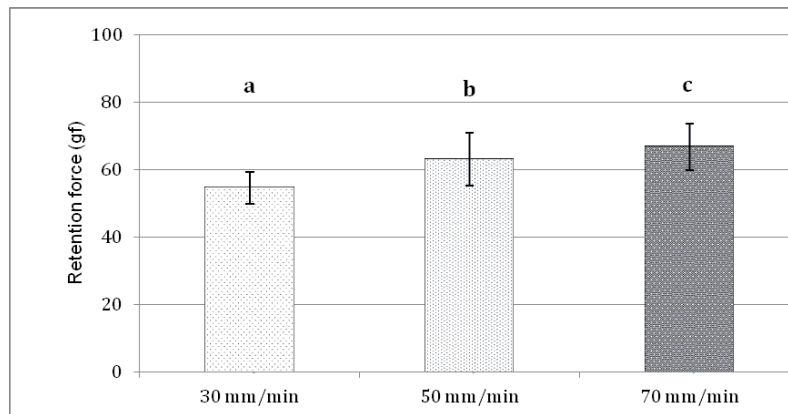


Figure 9. The mean retention force of a well-fitting mandibular complete denture at different tensile speeds (n=40). The letters represent the statistical differences between different tensile speeds.

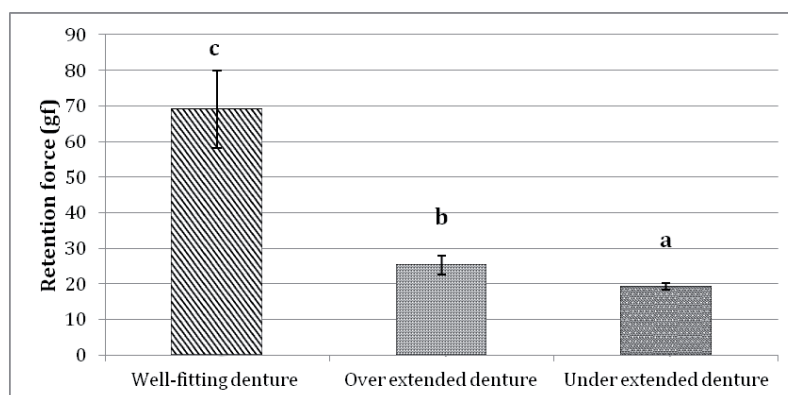


Figure 10. The mean retention forces (gf) of the three types of denture with artificial saliva at full separation of the denture from the underlying artificial mucosa. The letters represent the statistical differences of the 3 types of dentures (different letters indicate significant differences (P<0.05)).

4.1 Series 1 experiments: Denture retention with adhesive from 5 minutes to 5 hours

The retention was measured at different intervals up to a 5 hour period, the intervals were: 5 minutes, 1 hour, 3 hour and 5 hour intervals. These intervals were chosen according to Chew *et al.* and Chew, who used this timing to test the *in-vitro* and *in-vivo* retention forces of adhesives^{29, 30}. This period is considered as the maximum period that the denture wearer could leave a denture with adhesive in the mouth. 10 axial pulls were measured at each time interval, and the mean of these 10 pulls presented in the results. Initial testing was started after the initial five minutes post-insertion to allow moistening of the adhesive by the saliva³¹.

4.2 Series 2 experiments: Denture retention with adhesive after 5hrs

To provide ample time for the adhesive to exert whatever effect it might have on denture retention, an uninterrupted period of 5 hours was allowed to elapse between the application of the adhesive and the measurement of retention. The denture was not removed from the model after the application of the adhesive and before the retention measurement after 5 hours. Forty vertical pulls were conducted at the end of this period.

In both series of experiment, an addition of 0.1 ml of artificial saliva was added around the periphery of the denture after one hour of denture adhesive application and 0.2 ml at the 3 and 5 hours testing period to compensate for any evaporation from the original amount of saliva during this period.

The data from well fitting, under and overextended dentures with and without the use of the three types of adhesives in both experiment series were analysed by one-way ANOVA at the 95% confidence intervals ($P \leq 0.05$). A Newman-Kuel multiple comparison summary was used to indicate significant differences.

RESULTS

1. Determination of the optimum volume of saliva

The retention of the well fitting mandibular denture without the use of fixative, improved with the use of saliva with a force of 50 gf (Figure 8). For both experimental series, retention continued to increase up to a volume of 0.9 ml of saliva for both experiments (70, 65 gf) ($P > 0.05$). The maximum retention force showed a reduction as the amount of saliva increased beyond 0.9 ml.

2. Determination of the optimum tensile speed

The mean retention force of the well-fitting mandibular complete denture at each speed for the four experiments is shown in Figure 9. The maximum retention force was observed with a speed of 70 mm/min with a range from 60-74 gf in the four series of experiments, while with a speed of 50 mm/min the range was 52-71 gf. The minimum retention forces were seen at a speed of 30 mm/min with a range from 52-62 gf.

3. Retention of different mandibular denture designs

Figure 10 shows the mean retention forces of the three different designs of denture at three different occasions using of 0.9 ml of saliva at a 50 mm/min tensile speed. Statistical differences were seen between the retention denture forces at different occasions for the same denture in the case of the well-fitting and overextended dentures. The retention forces of the well-fitting denture were significantly higher than the retention seen for the ill-fitting denture (70 gf for well-fitting denture versus approximately 20 gf for ill-fitting dentures). The overextended denture showed significantly higher values than the under extended denture ($P < 0.05$) (Figure 11).

4.1. Series 1 experiments: Denture retention with adhesive from 5 minutes to 5 hours

The use of denture adhesives improves the retention of all 3 types of dentures, when compared to the results with no adhesive (Figures 11-13). There was greater variation in the retention force of the well-fitting denture with all types of adhesives. The max and min retention results for both well-fitting and ill-fitting dentures are detailed below, together with the max and min retention forces achieved for each of the adhesives.

For the well-fitting denture, the maximum retention force was achieved with PoliGrip® at the 5 minute interval (799 gf) and the minimum retention force was with Wernets® at the 5 minute interval (174 gf). For the ill-fitting dentures, the maximum retention force for the overextended denture was with Wernets® at the 5 hour interval (322 gf); and for the under extended denture it was with PoliGrip® at the 5 minute interval. The minimum retentive force for both ill-fitting dentures was reached with Fixodent® at the 5 hour interval (113 gf for overextended denture, and 64 gf for the under extended denture).

The maximum retention ability for the well-fitting denture with each of the adhesives was: For PoliGrip® and Fixodent® from the 5 minute until the 3 hour intervals, but this activity statistically reduced at the 5 hour period (Figures 11 and 12). For Wernets® fixative, the retention started at the 5 minute point at a low level, peaking at the 3 hour period and ended at the 5 hour interval with the same retention level as at the 1 hour interval (Figure 13).

The maximum retention ability for the ill-fitting dentures with each of the adhesives was: For PoliGrip®, this was achieved at the beginning of the experiment (5 minute interval), and kept this maximum retention fairly constantly through the 5 hour intervals (Figure 11). While with Fixodent® adhesive, the ill-fitting dentures showed the highest level of retention at the 5 minute and 1 hour intervals, then the retention began to drop off with a minimum retention seen at the 5 hour interval (Figure 12). In contrast, the retention with Wernets®, steadily rose to peak at the middle of the experimental period (1-3 hours) and then dropped off after this with the under extended denture, but kept its highest level of retention with the overextended denture at the end of 5 hour (Figure 13).

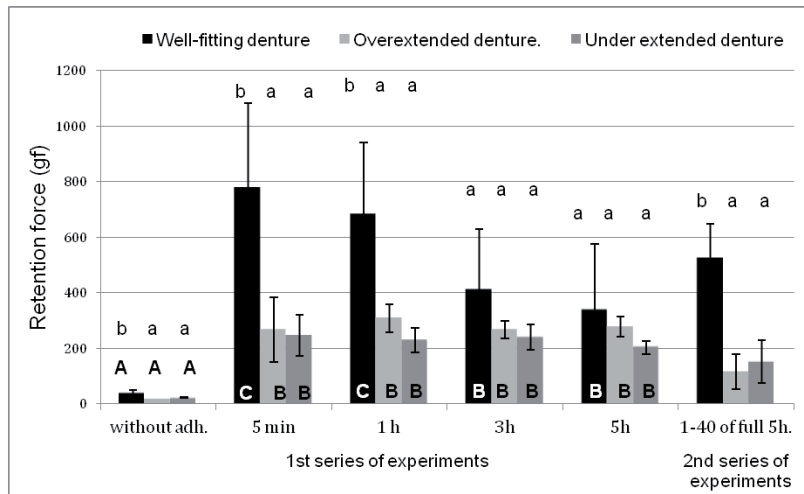


Figure 11. The retention force of 3 types of dentures with PoliGrip® adhesive over a period of 5 hours (series 1 & series 2 experiments). The small letters represent the statistical analysis of the 3 types of dentures at the same time interval; while the capital letters are for the same denture at each time interval (different letters indicate significant differences).

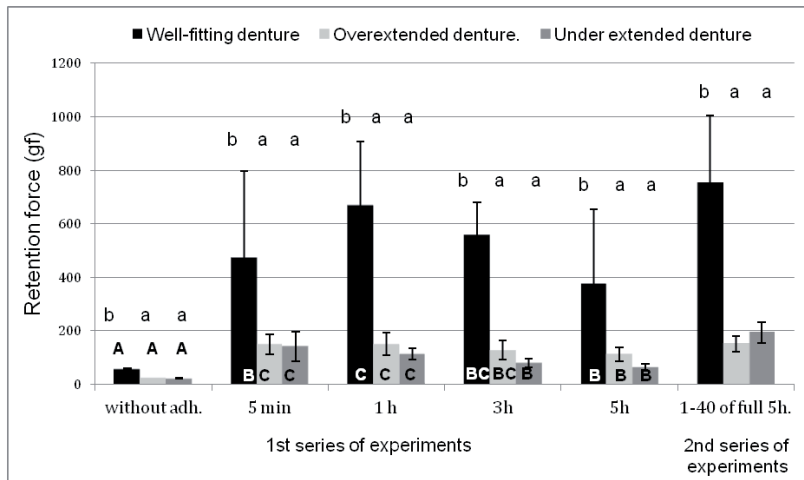


Figure 12. The retention force of 3 types of dentures with Fixodent® adhesive over a period of 5 hours (series 1 & series 2 experiments). The small letters represent the statistical analysis of the 3 types of dentures at the same time interval; while the capital letters are for the same denture at each time interval (different letters indicate significant differences).

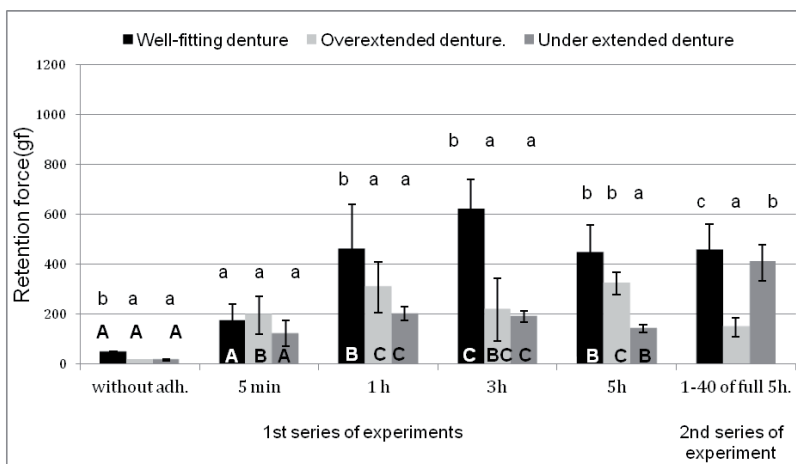


Figure 13. The retention force of 3 types of dentures with Wernets® adhesive over a period of 5 hours (series 1 & series 2 experiments). The small letters represent the statistical analysis of the 3 types of dentures at the same time interval; while the capital letters are for the same denture at each time interval (different letters indicate significant differences).

4.2. Series 2 experiments: Denture retention with adhesive after 5hrs

The well-fitting denture showed the greatest retention force values with all denture adhesives and was significantly better than the ill-fitting dentures ($P \leq 0.05$) (Figures 11-13).

There was no significant difference between the two ill-fitting dentures when PoliGrip® and Fixodent® adhesives were used (Figures 11 and 12) ($P > 0.05$), but with Wernets®, the under-extended denture showed significantly higher retention than the over-extended denture. This was the exact opposite of what was observed in case of Wernets® in the 5mins to 5hrs series of experiments (Figure 13).

DISCUSSION

The principle of the test for retention depends on the use of dislodgment forces between the denture and the tissue covering the mandibular ridge with an intervening film of saliva. The principle dislodgment force is a pulling force in the direction opposite to the direction of denture insertion when the denture is held in a static condition.

In the mouth, the compressible mucosa is of vital importance to the retention of the denture. Tyson (1967) stated that any attempt to remove the denture by a pulling action would be strongly resisted by the impaction of the mobile mucosa against the denture base because this produces an extremely thin film of saliva in this area, which slows the flow of fluid from the periphery³².

In these retention test experiments, the dislodgment force was an axial pull in an opposite direction to that of denture insertion. The variables, which need to be controlled, are the amount of saliva between the denture and mucosa and the speed of dislodgment. The variability of viscosity of the saliva is a further variable that is considered too complex to factor into the experiment. Thus a single viscosity artificial saliva replacement was used, that has been manufactured as a close and validated substitute for human saliva (As saliva orthana®, As pharma, Hampshire, UK). Teraoka *et al.*, used 1 ml of artificial saliva when testing the retention of complete palate coverage and palate less dentures *in-vitro* using a tensile tester³³. Others used artificial saliva to investigate the *in-vitro* retentive ability of denture adhesives when interposed between an acrylic disk specimen and a clean glass surface, where they found highly significant differences between the retentive ability of different types of denture adhesives with the use of artificial saliva³⁴.

The amount of saliva is considered to play an important role in the retention of the denture. With no saliva present, the minimum retention value was reached (Figure 8). The role of saliva in denture retention is important with evidence suggesting that the retention of dentures *in-vivo* is mainly related to the presence of saliva^{35,36}. Current understanding of adhesion and cohesion between substrates would support the concept for an intervening film of saliva aids denture retention. This work found that when the layer of saliva is increased in thickness a reduction or even a loss of retention could happen.

To test the effectiveness of the *in-vitro* model as an analogue of the natural *in-vivo* situation, retentive tests were performed with accurately fitting and well-designed mandibular complete denture. In these experiments, the

retention increased with the increased amount of saliva between the fitting surface of the denture and artificial mucosa layer until it formed a continuous thin layer of saliva, this was between 0.7 and 0.9 ml. When this amount was exceeded, the retention began to reduce. This agreed with Blahova and Neuman, who stated that as saliva accumulated around the denture, the physical retention factor (capillary attraction) reduces and little resistance is needed to pull them apart^{16,17}. A volume of 0.9 ml of saliva was chosen as the optimum volume as this provided the maximum retention force for the denture. It was chosen rather than 0.7 ml, which was not significantly different to 0.9 ml, as having slightly more saliva would compensate for any evaporation during testing.

As with the increased amount of saliva, an increase in tensile speed used to dislodge the denture away from the ridge, positively affects the retention and this is clearly demonstrated in Figure 9. The increase in retention force with the increase of tensile speed was explained according to Stefan's law that states 'the magnitude of separating force of two parallel circular plates that are separated by liquid is positively proportional with the velocity of the applied force'³⁷.

The dislodgment speed results show that the maximum retention of the denture was at a tensile speed of 70 mm/min, but the decision was made to consider a speed of 50 mm/min as being the optimum dislodgment speed for the denture retention tests on the *in-vitro* model. This was because many previous reports in the literature were performing at a cross-head speed of 50 mm/min²⁵⁻²⁷. This cross-head speed has also been reported by Sarnat (1983) to approximate clinically to the movement of the denture away from the edentulous ridge³⁸. Using this same speed would enable us to compare results with other studies, as the majority of them have used similar testing conditions. In addition, a speed 70 mm/min seemed very high compared to the *in-vivo* dislodgment of the denture when performing occlusal activity other than heavy mastication.

For both the saliva and tensile speed experiments, statistical differences were observed within the same sets of experiments, which were conducted at different days. This finding confirmed Floystrand and Orstavik's (1984) observation when they tested the retention ability of a complete denture against a unilateral occlusal load³⁹. They found that the resistance against dislodgment varied considerably when tested on different days.

This variability could be due to the timing variation in the volume and resiliency of the supporting soft tissue, which is affected directly by uncontrollable finger pressure magnitude and direction when trying to seat the denture each time during the experiment. In addition variations of the environmental conditions, such as laboratory temperature and humidity may have had an effect. In order to reduce the effect of these variables, the experiment was repeated on different days.

The results from the different denture designs indicate that dislodgment loads remained relatively stable and did not vary greatly during a test series of 10 pulls within the same occasion, but statistical differences were seen between different experiment periods for the same denture agreeing with work by Floystrand and Orstavik, who demonstrated that complete maxillary dentures they tested *in-vivo*

showed different retention rates on different days³⁹. This indicates that model factors governing retention did not vary greatly within a limited period, but day-to-day differences show that the retention factors cannot be expected to act equally on different days.

The retention forces of a well-fitting denture were much higher than the forces for ill-fitting dentures, and this underlines the importance of the maximum extension and good fit of the denture to its supporting tissues for optimum retention. This agreed with Ghani *et al.* (1991), who found that the *in-vivo* retention force of well-fitted palatal plates were significantly higher compared to the values for ill-fitting plates⁴⁰.

Using the same test principles, the retention of differently designed complete dentures: under and overextended dentures in addition to a well-fitting denture were measured and compared. The model showed a significant difference in retention values between these three designs and the retention forces of a well-fitting denture were much higher than the forces for ill-fitting dentures, and this agreed with Ghani *et al.*,⁴⁰. The *in-vitro* model effectively reflects differences in retention for dentures with differing degrees of ridge adaptation and compares well to the *in-vivo* findings.

Further retentive tests were conducted to determine if the model could be used to test the effectiveness of denture adhesives on denture retention and compare the results with previously reported clinical studies. In this study three different types of commercially popular denture adhesives (PoliGrip®, Fixodent® and Wernets®) were used to test the retention of different denture designs (well-fitting, over- and under-extended dentures).

The fixatives used in this study produced an instantaneous improvement in retention, which was statistically significant compared to the force shown with saliva only. At the end of the 5 hour period, retention was still greater than without the use of any adhesives. The retention with well-fitting denture was statistically higher than with ill-fitting dentures, which is in agreement with previous studies^{31, 40, 41}. The retentive activity of denture adhesives in this current study did not follow a constant trend at various time intervals with different types of denture, in agreement with Chew *et al.*²⁹.

CONCLUSIONS

In conclusion, a novel *in-vitro* model of a mandibular ridge was created to approximate the characteristics of a moderately resorbed mandibular ridge, the overlying soft tissues and immediate reflected tissues. A series of complementary experiments demonstrated the effect of denture design and use of denture fixative on the retention of a mandibular complete denture on this *in-vitro* model.

The following specific conclusions have been reached with respect of this model and its suitability as an apparatus for testing the retention of mandibular complete dentures.

The speed of the dislodging force and the amount of saliva are important variables that affected the *in-vitro* retention testing of the mandibular complete dentures.

The model was able to show significant differences between the retention of well- and ill-fitting dentures.

The model was able to show that a significantly higher retention force was obtained to dislodge complete mandibular dentures when using denture adhesives. The retention force of different types of dentures (well- and ill-fitting dentures) increased significantly with the use of denture adhesives.

The highest retention forces were recorded for well-fitting denture with adhesives.

There was no significant difference between the two ill-fitting dentures (over and under extended dentures) when adhesives were used.

Differences were noted between the performances of the adhesives, but no specific trend was observed.

The *in-vitro* model developed in this study can be used to test the retention of mandibular complete dentures. There was a good correlation between the denture retention *in-vitro* results obtained and the reported *in-vivo* data in the literature.

MANUFACTURERS' DETAILS

- Candulor static-laser Candulor AG, Wangen, Switzerland
- Aesthetic Basis Candulor AG, Wangen, Switzerland
- Universal tensile tester Lloyd Instruments – LRX, UK
- Dividers DB Orthodontics Ltd, Silsden, Keighley, UK
- Aquasil

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