GUIDELINES FOR THE USE OF WROUGHT WIRE CLASPS FOR REMOVABLE PARTIAL DENTURES

Lushen Manickum Naidoo

A research report submitted to the School of Oral Health Science, University of the Witwatersrand, in partial fulfilment for the degree of Master of Dentistry in the branch of Prosthodontics.

Johannesburg, 2009

DECLARATION

I, Lushen Manickum Naidoo declare that this research report is my own work. It is being submitted in partial fulfilment of the degree of Master of Dentistry in the branch of Prosthodontics at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

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Lushen Manickum Naidoo

___ day of   , 2010

DEDICATION

To my family for their unconditional support throughout this journey.

ABSTRACT

Purpose: The purpose of this study was to evaluate the effects of diameter, alloy and clasp length on the behaviour of different wrought wires in order to produce clinical guidelines for their selection in removable partial dentures (RPDs).

Method: Three stainless steel round wrought wires were tested: Remanium®; Noninium® (nickel free) (Dentaurum, Pforzheim, Germany); Leowire® (Leone, Fiorentino, Italy); as well as two Type IV round wrought gold wires: Degulor® (Degudent, Hanau, Germany) and Argen (Argen Corp., San Diego, USA). Three diameters (0.8mm, 0.9mm, 1.0mm) of Remanium and Leowire were used; two diameters (0.8mm, 0.9mm) of Noninium and two diameters (0.9mm, 1.0mm) of the gold alloy wires were used based on their availability commercially. Ten samples of each diameter for the different stainless steel wires were bent to two lengths (12mm and 20mm) to represent the average buccal curvature of premolars and molars respectively. The gold wires were bent to 12mm, as gold wires are infrequently used in clinical practice on molar teeth. Each clasp was bent beyond its proportional limit in a tensile testing machine, and the force exerted was recorded at deflections which represented the clinically encountered undercuts of 0.25mm, 0.5mm, and 0.75mm.

Results: All the wires in each of the batches behaved consistently. Statistically significant differences were noted on comparison of the stainless steel wires, the gold wires and gold versus stainless steel wires. Wide variations in forces exerted by the different clasp combinations were observed.

Conclusion: The selection of wrought wires for acrylic RPDs is influenced by alloy type and diameter, length, curvature, and depth of undercut. The data from this study allowed for the provision of clinical guidelines for the appropriate selection of wrought wire clasps.

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1. INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Whilst there are many options available for the replacement of missing teeth, the most cost-effective is by means of acrylic-based removable partial dentures (RPDs). There is general consensus in the literature that RPDs will cause biological harm if constructed inappropriately (Warr 1961; Frank and Nicholls 1981; Owen 2000).

The responsibility for the optimal construction of RPDs should be shared by both the clinician and the dental technician. However, clinicians should provide the dental technician with a detailed diagrammatic prescription of the design and components of RPDs (Owen 2000).

Round wrought wires are commonly used for the fabrication of acrylic RPDs in order to provide direct retention. Details regarding the optimal prescription of wrought wire clasps could improve the retentive quality of acrylic RPDs whilst potentially reducing initial costs.

1.2 Literature Review

Retentive clasp arms exert forces on the teeth they engage, and these forces should not exceed either the properties of the material, or the ability of the tooth to withstand them (Frank and Nicholls 1981; Owen 2000).

Round wrought wires flex in all directions and have been recommended for use as retentive clasp arms in all types of RPDs, especially where periodontal support has been compromised, or the use of a cast clasp has been deemed unsuitable. However, wrought wires have several potential disadvantages related to failure as a result of poor adaptation, loss of adaptation after a period of use and susceptibility to fracture (Morris et al. 1983; Frank and Nicholls 1986; VandenBrink, Wolfaardt and Faulkner 1993).

Contemporary dental literature addresses the behaviour of wrought wire clasps only superficially. Warr (1959) used mathematical analyses to calculate the influence of alloy type, diameter, length, taper, cross-sectional shape, and undercut depth on the behaviour of the retentive arms of clasps. However, the lack of *in vitro* and *in vivo* evidence related to the performance of clasps prior to the 1970s, resulted in the assumption of several behavioural characteristics related to their performance which have continued to this day. These assumptions were based mainly on research carried out on cast circumferential clasps (Warr 1961, Bates 1968).

In vitro studies since the 1970s have shown that the behaviour of round wrought wire clasps is affected by alloy type, diameter, length, curvature, and deflection (Clayton and Jaslow 1971; Frank and Nicholls 1981; Morris et al. 1983). However, these observations were not translated into simple, effective clinical guidelines for the selection of wrought wire clasps.

A literature search yielded the results of six studies which investigated the behaviour of round wrought wires. Stobie (1969, cited in Frank and Nicholls 1981) found that the differences in the curvature of wrought wires of the same diameter resulted in variations in flexibility. Brudvik and Wormley (1973) suggested the selection of a small diameter wire when clasp length was minimal, but presented no data to justify this. Brudvick and Morris (1981) studied the influence of the diameter, length and alloy type on the behaviour of wrought clasps and concluded that the relationship of clasp length to retention and permanent deformation was fundamental to the performance of these clasps. This would imply that the *in vitro* testing of the flexibility of wrought wires should include the standardisation of active clasp length.

Frank and Nicholls (1981) investigated the effects of diameter, alloy and clasp length on the flexibility of round wires composed of base-plate and gold alloys. One of the objectives of that study was to determine the minimum and maximum forces required to maintain the position of a distal extension RPD. The authors calculated that 300g to 750g (150g to 375g per clasp) represented an acceptable amount of retention for a bilateral distal extension base. The presence of passive (guide plane) retention in a tooth-supported base was thought to require less active retention to keep the RPD in place. These calculations were compared with load-deflection data of wires of different alloys, diameters and lengths.

Clinical conditions were simulated by soldering the wires onto chromium-cobalt plates which were then covered by acrylic. Each clasp was bent to its proportional limit in a tensile testing machine. This study concluded that all the wires tested would provide sufficient retention when placed in a suitable depth of undercut. However, they did not specify the ‘suitable’ depth of undercut, and did not standardise the lengths or the curvature of the wires.

In a later publication, Frank (1986) published guidelines for the selection of wrought wire clasps for RPDs based on periodontal support, reciprocation, clasp length, undercut depth and retention desired. However, these were based largely on anecdotal evidence.

A MedLine search found studies which provided insight into the relationships of the factors influencing wrought wire clasp behaviour, but none were able to provide guidelines related to the selection of these clasps for commonly encountered clinical situations (Morris et al. 1983; Matheson, Brudvik and Nicholls 1986; VandenBrink et al. 1993; Shirasu et al. 2008).

A search using the Union Catalogue of Theses and Dissertations yielded one study which provided such clinical guidelines (Goolam 1992). This was a laboratory-based study which tested the suitability of stainless steel, chromium-cobalt and gold alloy wrought wire clasps for the construction of removable partial dentures. Load-deflection data of different combinations of wires based on diameter, length, alloy type, and depth of undercut were used in order to produce clinical guidelines for the selection of wire clasps in two commonly encountered clinical situations, a bounded denture saddle (tooth supported) with sound or periodontally compromised teeth, and a distal extension base (dento-gingivally supported) with sound or periodontally compromised teeth. One type of gold alloy (Platinum-Gold-Palladium; Argon, Johannesburg, South Africa) and one type of stainless steel wire (Remanium wire, Dentaurum, Pforzheim, Germany) was used.

Waldmeier et al. (1996) studied the differences in flexibility of different gold alloy and stainless steel wrought wire clasps. These authors found statistically significant differences in the flexibility of different wires in each of these groups, for a particular undercut. The study concluded that the selection of wrought wire clasps should include differences in variations of alloy manufacturing and composition. However, only straight wires were tested, without standardisation of the length of the wires.

A variety of stainless steel and gold alloy wires is currently available for wrought clasps. These are differentiated based on differences in the manufacturing process, and variations in alloy composition (Brudvick and Morris 1981). The American Dental Association classification of dental alloys comprises 3 categories (Craig and Ward 1997):

- High noble (noble metal content > 60% wt and a gold content of > 40% wt)
- Noble (noble metal content > 25% wt, with no stipulation for gold)
- Base metals (noble content < 25% wt)

Many of the base metals are generally referred to as stainless steels (Craig and Ward 1997) and the most commonly used alloys in clinical practice appear to be gold and stainless steel (Frank and Nicholls 1981; Brudvick and Morris 1981; Goolam 1992; Waldmeier et al. 1996).

It has been shown that one of the corrosion products of stainless steel wires was nickel (Shih et al. 2001). *In vitro* studies have shown that stainless steel corrosion products were cytotoxic in simulated physiological conditions (Morais et al. 1998; Shih et al. 2001; David and Lobner 2004). Nickel-induced allergic dermatitis has been reported to be responsible for more allergic reactions than a combination of all the other commonly used metals in dentistry (Pourbaix 1984). Up to 21.5 % of the population may show signs of a nickel related allergic reaction on patch testing (Schubert and Prater 1987 cited in Platt et al. 1997). Therefore the use of nickel-free stainless steel wires has been advocated in orthodontic patients with nickel allergies (Montanaro et al. 2005). Waldmeier et al. (1996) reported that a decrease in the nickel content of straight stainless steel wires resulted in a decrease in flexibility, but a MedLine literature search revealed no studies testing these wires for suitability as clasp arms in RPDs.

No clear guidelines have emerged in the literature. The closest attempt was an unpublished thesis by Goolam (1992), and as that study used standardised curvatures of round wrought wires, it was decided to use a similar methodology and to include different types of stainless steel and gold alloy wrought wires.

1.3 Aim

To evaluate the effects of alloy, diameter and clasp length on the behaviour of different round wrought wire clasps, in order to produce clinical guidelines for the selection of these clasps for RPDs.

2. MATERIALS AND METHOD

2.1 Materials used

Wrought wires are available in round and half round forms. However, round wire is more easily contoured compared with half-round wire. Therefore only round wrought wires have been selected for this study. The various types of alloys and their corresponding diameters were chosen based on commercial availability in South Africa, previous studies (Frank and Nicholls 1981; Waldmeier et al. 1996) and load-deflection data from Goolam (1992). The lengths of the wires used were based on premolars and molars, which serve as ideal abutments for clasping due to their form. It has been shown (Goolam 1992) that the length of the average curvature of the buccal surface of a premolar is 12 mm and that of a molar, 20 mm. The wires which have been chosen were grouped according to alloy type, diameter and length (Table 1).

Table 1. Stainless steel and gold alloys tested

		Number of specimens according to length	
Wire	**Diameter (mm)**	**12mm**	**20mm**
Stainless steel			
Remanium[a]	0.8; 0.9; 1.0	30[f]	30[f]
Remanium (hard)[a]	1.0		10
Leowire[b]	0.8; 0.9; 1.0	30[f]	30[f]
Noninium[a] (Nickel-free)	0.8; 0.9	20[f]	20[f]
Gold alloy			
Argen[c]	0.9; 1.0	20[f]	-[e]
Degulor[d]	0.9; 1.0	20[f]	-[e]

Key:

[a] Dentaurum, Pforzheim, Germany

[b] Leone, Fiorentino, Italy

[c] Argen is a type IV gold alloy (Argen Corporation, San Diego,USA)

[d] Degulor is a type IV gold alloy (Degudent, Hanau, Germany)

[e] Gold wire is used predominantly for aesthetics and therefore is rarely if ever used on a molar

[f] 10 specimens of each diameter

2.2 Method

2.2.1 Determination of sample size

A statistical calculation of sample size could not be achieved using standard methods, due to the fact that load-deflection data was being analysed up to the proportional limits of the wires. A pilot study was not carried out on the basis that none of the previous studies which were reviewed contained samples in excess of 10 per diameter of wire. It was expected that the results obtained for each batch of samples in this study would follow a normal distribution.

2.2.2 Determination of clasp shape

The use of curved wires in this study was in accordance with evidence related to the differences in flexibility of straight versus curved wrought wires (Brudvick and Morris 1981; Frank and Nicholls 1981). The curvature of wrought wires was standardised using a specially manufactured device, employing rollers of different diameters to produce an even curvature for the two different lengths of wires (Figure 1).

Figure 1. Bending of a stainless steel wire

2.2.3 Construction of the samples

In order to simulate the clinical situation, the construction of the specimens was identical to the methods described by Goolam (1992). All clasps were embedded in identical auto-polymerising resin blocks, measuring 38mm x 25mm x 6mm. This was achieved by using a brass mould for standardised placement of the clasps into the acrylic (Figure 2). The specimens containing the 12mm clasps were bevelled to allow for repetitive placement in the tensile testing machine (Instron Corporation, High Wycombe, United Kingdom).

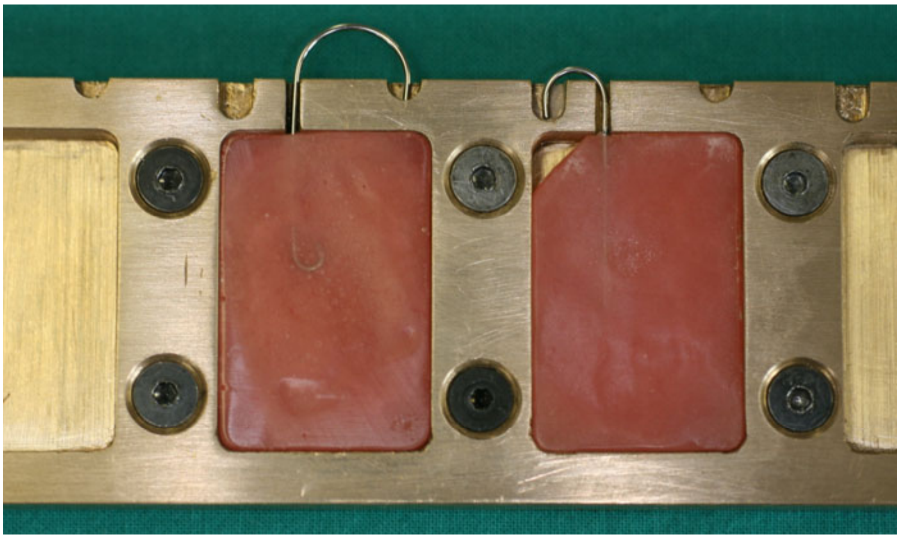

Figure 2. 20mm clasp on left and 12mm clasp on right in brass mould

This device was used to prepare six specimens simultaneously. All the samples were carefully checked by a single operator, to ensure no mobility of the wires in the resin blocks.

2.2.4 Testing

A specialised jig was constructed for the tensile testing machine, so that each clasp tip could be positioned on the upper holding device (Figure 3). The specimens containing the

12mm clasps were bevelled on the side of the clasp tips in order for these to allow sufficient space for placement of all clasps tips along the long axis of the load cell.

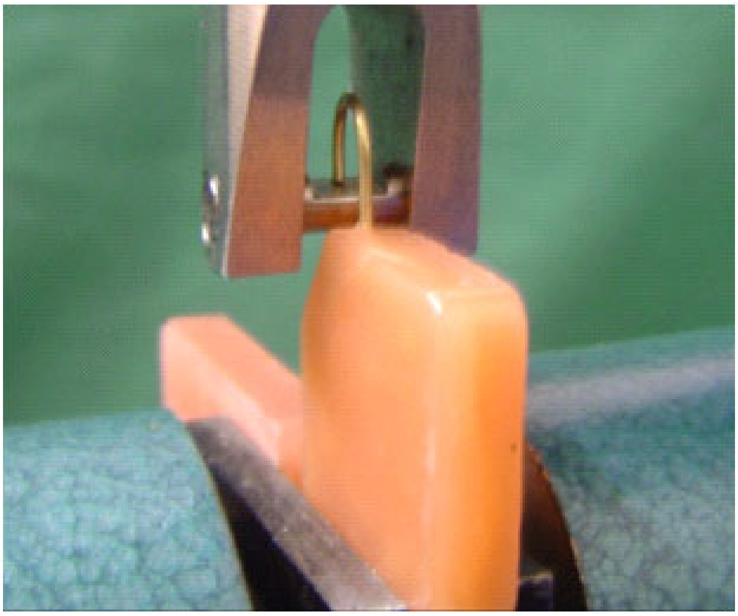

Figure 3. Position of clasp and block on jigs of tensile testing machine

The upper holding device was connected directly to the load cell of the machine and any contact with it would record a load. A magnifying glass was used to ensure that the clasp tip did not rest on the upper holding device. The software was programmed so that the load-deflection data was obtained only on contact of the clasp tip with the upper holding device. A second acrylic block without a clasp was placed on the lower jig to prevent movement of the test specimen on commencement of the test. All testing was conducted by the researcher in order to standardise the recording of data.

Each specimen was bent beyond its proportional limit using a cross-head speed of 0.33mm/sec and load cell of 2kN (Figure 4). The room testing temperature ranged between 19°-22°C.

Figure 4. 12mm clasp on right bent beyond its proportional limit

As the clasp tip was the point of application of the force it was found that some slippage of the tip on the platform of the jig occurred, resulting in a non-linear deflection which could cause a slight inaccuracy in the calculation of the proportional limit. Therefore in order to compensate for this, an offset of 0.02mm was created in the software (Bluehill® Lite, Instron, USA) so that any deviation from this would represent the true proportional limit of the specimen (Figure 5).

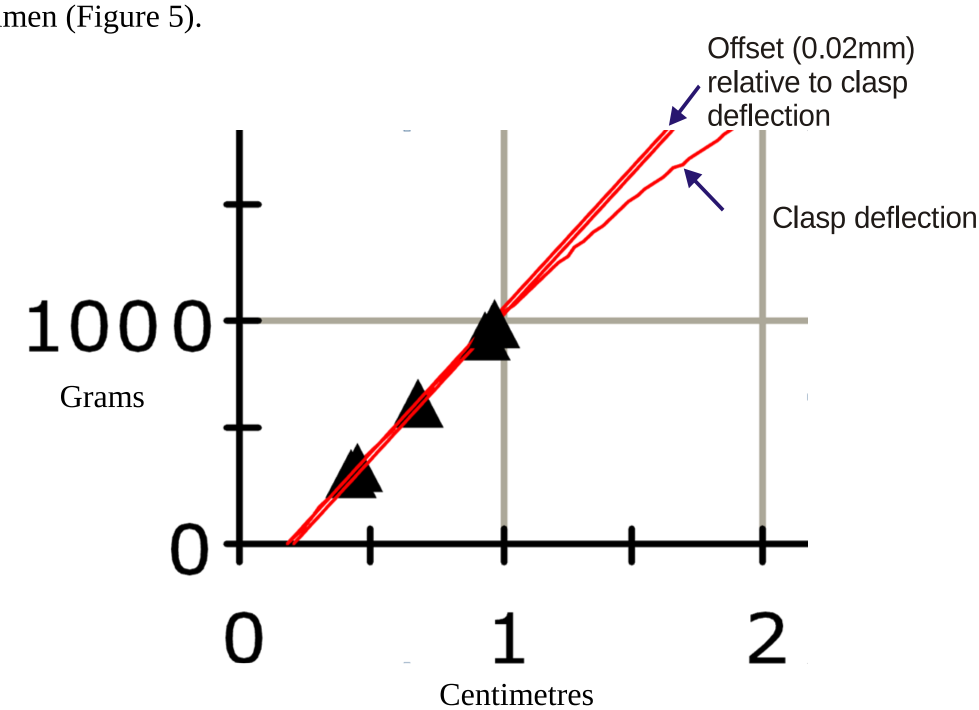

Figure 5: Compensation for slippage of clasp tip

The offset was calculated by producing virtual graphs for each of the 210 specimens. A single point per graph was selected by the researcher to represent the onset of non-linear deflection. The amount of straight line deviation up to the point selected was calculated using the Bluehill Lite software for each of the 210 graphs.

The software was also programmed to generate the loads exerted by each specimen at deflections of 0.25mm, 0.5mm and 0.75mm. These deflections represent the common clinically encountered undercuts of abutment teeth.

3. RESULTS

None of the samples fractured during testing, nor did any of the wires become loose from the acrylic blocks.

The forces for each of the 210 samples were analysed statistically using the Statistical Package and Service Solutions (SPSS Inc, Chicago, USA). This was done in order to reduce each batch to a representative value for ease of analysis. Both parametric (Kolmogorov-Smirnov Z) and non-parametric tests (Exact Method) confirmed that the data were normally distributed and consistent. Therefore the mean values were used to analyse each batch of samples. The standard deviations of the batches were similar and therefore the data were considered to be consistent.

A retentive clasp is required to behave elastically in clinical situations, i.e. within its proportional limit (Bates 1965, Frank and Nicholls 1986). Bates (1965) suggested that a reason for the failure of clasps clinically was that they may have functioned too close to their proportional limits. He suggested that retentive clasps should function within two standard deviations from their proportional limit, which he termed the "realistic limit". Therefore the realistic limit of each wire was calculated (Table 2). From these data, a table was then derived to show whether the wires functioned within their realistic limits at 0.25mm, 0.5mm and 0.75mm deflections respectively for the different lengths representing premolars and molars (Table 3).

Table 2. Calculation of realistic limit (grams force) for each specimen

Type of alloy and corresponding diameter	Proportional Limit	Standard Deviation (SD)			Realistic limit		
		0.25mm	0.5mm	0.75mm	0.25mm	0.5mm	0.75mm
1. Argen 0.9 12mm	227.1	12.6	24.5	36.3	201.9	178.1	154.5
2. Argen 1.0 12mm	358.9	15.6	26.4	37.3	327.7	306.1	284.3
3. Degulor 0.9 12mm	475.3	13.6	25.7	35.7	448.1	423.9	403.9
4. Degulor 1.0 12mm	599.1	19.3	33.9	44.9	560.5	531.3	509.3
5. Remanium 0.8 12 mm	366.6	11.1	17.1	24.6	344.4	332.4	317.4
6. Remanium 0.8 20mm	200.3	8.3	8.4	9.3	183.7	183.5	181.7
7. Remanium 0.9 12mm	590.1	14.8	25.7	33.9	560.5	538.7	522.3
8. Remanium 0.9 20mm	181.2	3.7	8.2	11.5	173.8	164.8	158.2
9. Remanium 1.0 12mm	676.2	20.3	35.5	49.9	635.6	605.2	576.4
10. Remanium 1.0 20mm	386.8	17.3	22.5	29.7	352.2	341.8	327.4
11. Remanium Hard 1.0 20mm	240.7	7.5	12.5	15.8	225.7	215.7	209.1
12. Noninium 0.8 12mm	483.6	9.5	18.2	26.2	464.6	447.2	431.2
13. Noninium 0.8 20mm	136.6	4.2	4.0	4.9	128.2	128.6	126.8
14. Noninium 0.9 12mm	528.7	27.1	45.6	57.3	474.5	437.5	414.1
15. Noninium 0.9 20mm	230.4	6.2	9.2	11.7	218.0	212.0	207.0
16. Leowire 0.8 12mm	442.1	10.6	14.5	20.4	420.9	413.1	401.3
17. Leowire 0.8 20mm	1166.0	8.2	7.2	6.6	1149.6	1151.6	1152.8
18. Leowire 0.9 12mm	708.1	10.3	20.2	33.2	687.5	667.7	641.7
19. Leowire 0.9 20mm	202.5	4.9	7.3	10.5	192.7	187.9	181.5
20. Leowire 1.0 12mm	716.7	26.3	50.9	72.4	664.1	614.9	571.9
21. Leowire 1.0 20mm	268.0	3.3	5.2	7.6	261.4	257.6	252.8

Table 3. Mean loads and realistic limits (in parentheses) for premolar and molar clasps. Mean loads highlighted in bold (red) represent values which have exceeded the realistic limit for that deflection.

Type of Alloy and Diameter	Premolars (12mm)			Molars (20mm)		
	Deflection			Deflection		
	0.25mm	0.5mm	0.75mm	0.25mm	0.5mm	0.75mm
Argen 0.9mm	120.5 (201.9)	**235.7** (178.1)	**346.8** (154.5)	-	-	-
Argen 1.0mm	155.6 (327.7)	303.4 (306.1)	**446.0** (284.3)	-	-	-
Degulor 0.9mm	176.1 (448.1)	343.8 (423.9)	**500.8** (403.9)	-	-	-
Degulor 1.0mm	239.9 (560.5)	467.8 (531.3)	**681.9** (509.3)	-	-	-
Remanium 0.8mm	120.4 (344.4)	234.9 (332.4)	**341.9** (317.4)	19.3 (183.7)	41.6 (183.5)	63.7 (181.7)
Remanium 0.9mm	211.8 (560.5)	414.7 (538.7)	**612.2** (522.3)	37.4 (173.8)	77.4 (164.8)	117.1 (158.2)
Remanium 1.0 mm	285.0 (635.6)	552.3 (605.2)	**804.3** (576.4)	67.5 (352.2)	126.1 (341.8)	184.3 (327.4)
Remanium Hard 1.0mm	-	-	-	68.3 (225.7)	136.7 (215.7)	202.7 (209.1)
Noninium 0.8mm	135.4 (464.6)	265.4 (447.2)	391.6 (431.2)	21.3 (128.2)	51.9 (128.6)	81.2 (126.8)
Noninium 0.9mm	245.0 (474.5)	**468.0** (437.5)	**676.2** (414.1)	50.7 (218.0)	102.8 (212.0)	153.3 (207.0)
Leowire 0.8mm	119.1 (420.9)	229.8 (413.1)	338.4 (401.3)	23.1 (1149.6)	47.1(1151.6)	70.5 (1152.8)
Leowire 0.9mm	180.6 (687.5)	354.1 (667.7)	530.3 (641.7)	39.6 (192.7)	82.3 (187.9)	124.7 (181.5)
Leowire 1.0mm	314.6 (664.1)	605.8 (614.9)	**882.1** (571.9)	55.7 (261.4)	111.3 (257.6)	165.5 (252.8)

Analyses of the results in Table 3 were as follows:

1. All the 12mm (premolar) clasps were within their respective realistic limits at 0.25mm deflections. Argen 0.9mm and Noninium 0.9mm exceeded their respective realistic limits at 0.5mm deflections.
2. Noninium clasps (0.8mm) together with Leowire (0.8mm and 0.9mm) were the only premolar clasps to record mean loads within their respective realistic limits at a deflection of 0.75mm.
3. All the 20mm (molar) clasps were within their respective realistic limits for all three deflections.
4. Increases in diameter and undercut resulted in higher loads being recorded for each of the respective wires.
5. Remanium Hard 1.0mm wire produced higher loads at similar deflections compared with Remanium 1.0mm wire.

A one-way Analysis of Variance (ANOVA) test was used to identify significant differences in the distribution of data related to the following:

1. Comparison of 0.8mm and 0.9mm diameters of Noninium, Leowire and Remanium wires for lengths 12mm and 20mm respectively.
2. The behaviour of the stainless steel versus gold alloys

The one-way ANOVA was chosen on the basis that the following assumptions were upheld (Norusis 1993):

1. Each of the groups was an independent random sample.
2. The data indicated a normal distribution.
3. The variances of the groups were equal.

The ANOVA tests revealed statistically significant differences on comparison of the stainless steel clasps ($p<0.05$) as well as the gold versus the stainless steel clasps ($p<0.05$).

Owing to the relatively small sample size in each batch ($n=10$), non-parametric tests (Kruskal-Wallis and Monte Carlo) were used to compare the results obtained from the ANOVA tests. Both tests confirmed the results obtained using the ANOVA tests.

Two-tailed T tests were used to identify differences in the distribution of data related to the following:

1. The behaviour of Leowire (Length =12mm and Diameter=1.0mm) compared with Remanium wire of the same length.
2. The behaviour of Argen wire compared with Degulor wire

The results of the T tests were as follows:

1. Statistically significant differences were found between Leowire and Remanium wires at the various deflections ($p<0.05$).
2. Statistically significant differences were found between Argen and Degulor wires when 0.9mm and 1.0mm diameter wires were compared ($p<0.05$).

4. DISCUSSION

Although the clasp behaviour was statistically consistent for each of the batches of each of the wires, variations did exist in the forces applied at different deflections, and in the proportional limits, indicating that there are inconsistencies, presumably as a result of the manufacturing process. Hence Bates' (1965, 1968) contention that a realistic limit be used still has merit.

Clayton and Jaslow (1971) reported that the length of a wrought wire clasp was not a significant factor related to its flexibility. In the present study, however, all the 20 mm (molar clasps) produced lower loads compared with the 12mm (premolar clasps) for all three depths of undercuts respectively (Table 3). An increase in the diameter of wrought wire clasps, from 0.8mm to 1.0mm, has been reported to produce higher loads at deflections of 0.25mm and 0.5mm respectively (Frank and Nicholls 1981). The findings of the present study for molar clasps are in agreement with this.

Caldwell (1962) measured the adhesiveness of various types of foods, by measuring the amount of force per area required to dislodge the food when held between two flattened enamel surfaces. Bates (1963) employed a similar method and calculated that the bond strength required to dislodge a sticky toffee held between two porcelain plates was 1kg/cm^2. In the same study Bates combined this bond strength with the total surface area of a premolar and two molars in order to calculate the force required to dislodge a unilateral distal extension RPD replacing three teeth. This was calculated to be 2600g, on the basis that the maximum displacing force on an RPD occurred when the teeth had penetrated the food followed by the jaw being opened after 0.5 seconds. Bates used the findings by Caldwell (1962) and calculated that the force required to retain a unilateral distal extension RPD replacing three teeth would range from 850g to 1500g for “normal foods” (cornflakes, mashed potato, bread and butter). A literature search revealed no similar studies to confirm the amount of time and force required to dislodge an RPD whilst eating.

Frank and Nicholls (1981) used a tensile testing machine to measure the forces required to remove five distal extension base RPDs when round wrought wire clasps were placed in both 0.01”(0.25mm) and 0.015” (0.38mm) undercuts of premolars. They reported that 300 to 750 grams (150 to 375 grams per clasp) of force represented effective retention for a mandibular bilateral distal extension RPD. The displacing force in that study was directed toward the centre of the RPD in each case and each RPD was removed along its path of insertion. However the direction, magnitude and point of application of forces on RPDs are very different clinically, especially when RPDs are subjected to forces other than those along their path of insertion or removal. Therefore it is likely that forces in excess of 750 grams, as mentioned by Bates (1963), could be required to retain distal extension base RPDs.

Passive retention produced by guideplanes in the tooth-supported RPD scenario, would assist the retention from clasps to a greater extent in the bounded saddle, with two guideplanes per saddle compared with only one in a distal extension base. Therefore the retentive force required will be greater in a distal extension base, than for a bounded saddle.

The above studies seem, therefore, to have made recommendations for the desired retention from clasps to be in a wide range of 300g to 2600g. In order to produce effective clinical guidelines for the choice of clasps for RPDs, it would seem reasonable to define a minimum force required from clasps. There appear to be no previous studies providing information on the ability of abutment teeth to withstand forces from clasps. However, *in vivo* occlusal forces have been reported to range from 200 Newtons (20 387g) to 450 Newtons (45 871g) on average during normal function (Worthington, Lang and Rubenstein 2003). It is clear from these values that teeth are able to withstand high forces as a result of the physiological behaviour of the periodontal ligament. The maximum forces recorded for all clasps in the current study, below their realistic limits, are therefore well within the capacity of the periodontium.

The guidelines presented in Tables 4 and 5 could be further simplified to provide the gold or stainless alloy which produced the maximum force at each of the deflections tested (0.25mm, 0.5mm and 0.75mm).

As an RPD would benefit from the best available retentive forces, it seems reasonable to advocate the use of clasp wire, length and undercut combinations that would provide the maximum available retentive force in any given situation.

Tables 4 and 5 show the maximum (realistic) forces exerted by each of the wires at their respective diameters and lengths at the different undercut depths.

It is now possible to select those wires, which are readily available in South Africa, giving the maximum retentive force for each tooth/undercut combination; and for stainless steel wires it would be advantageous to include the nickel-free wires in such a selection. Table 6 presents these selections as clinical guidelines for the use of the wires tested in this study.

Table 4. Selection of clasps for premolars based on maximum loads achieved by each alloy below the realistic limit

Premolars												
	0.25mm undercut					**0.5mm undercut**					**0.75mm undercut**	
	GOLD		**STAINLESS STEEL**			**GOLD**		**STAINLESS STEEL**			**STAINLESS STEEL**	
Alloy:	Argen	Degulor	Remanium	Noninium	Leowire	Argen	Degulor	Remanium	Noninium	Leowire	Noninium	Leowire
Max. force (g):	155.6	239.9	285.0	245.0	314.6	303.4	467.8	552.3	265.4	605.8	391.6	530.3
Diameter (mm):	1.0	1.0	1.0	0.9	1.0	1.0	1.0	1.0	0.8	1.0	0.8	0.9

Table 5. Selection of clasps for molars based on maximum loads achieved by each alloy below the realistic limit

Molars								
	0.5mm undercut				**0.75mm undercut**			
Alloy:	Remanium	Remanium Hard	Noninium	Leowire	Remanium	Remanium Hard	Noninium	Leowire
Max. force (g):	126.1	136.7	102.8	111.3	184.3	202.7	153.3	165.5
Diameter (mm):	1.0	1.0	0.9	1.0	1.0	1.0	0.9	1.0

Table 6. Clasp selection for premolars and molars based on maximum loads exerted.

	Premolars					**Molars**	
	0.25mm		**0.5mm**		**0.75mm**	**0.5mm**	**0.75mm**
	Gold	**Stainless Steel**	**Gold**	**Stainless Steel**	**Stainless Steel**	**Stainless Steel**	**Stainless Steel**
Clasp (force in grams)	Degulor 1.0mm (239.9)	Leowire 1.0mm (314.6)	Degulor 1.0mm (467.8)	Leowire 1.0mm (605.8)	Leowire 0.9mm (530.3)	Remanium Hard 1.0mm (136.7)	Remanium Hard 1.0mm (202.7)
For nickel sensitive patients		Noninium 0.9mm (245.0)		Noninium 0.8mm (265.4)	Noninium 0.8mm (391.6)	Noninium 0.9mm (102.8)	Noninium 0.9mm (153.3)

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Whilst metal-based RPDs have the benefits of providing adequate comfort and fit with limited coverage of soft tissues, previous research has shown that cast clasps with short retentive arms may not function adequately and are prone to fracture (Bates 1965).

Acrylic-based RPDs are more cost-effective than metal-based frameworks, and if designed correctly, can be regarded as permanent prostheses for those patients who cannot afford metal bases. However, poor selection and construction of wrought wires used for their fabrication could result in poor adaptation to abutment teeth, loss of adaptation over a period of time, and potential fracture (Frank 1986). Therefore, it was felt that an understanding of the behaviour of readily available round wrought wires used in the fabrication of acrylic RPDs, in South Africa, would be beneficial. Such data would also be beneficial for short retentive clasps in metal-based dentures.

Within the limitations of this study, it has been shown that round wrought wire clasp selection is influenced by alloy type, diameter, length and undercut depth. On the assumption that maximum retention from clasps is desirable for an RPD, guidelines have been produced for the use of the wrought wires available for various clinical scenarios.

5.2 Recommendations

Within the limitations of this study, the following recommendations are made:

- The guidelines produced for the wires used for this study are based on the maximum forces obtained. Generally, only one clasp per side of the arch should provide adequate active retention, except in tooth-supported bases with long spans. However, clasps were tested for premolars and molars only. Future research could employ a similar method to this study to obtain load-deflection data for canine teeth.
- Wire diameters greater than 1.0mm could be tested using a similar method to produce higher loads for molar clasps compared with those reported in this study.
- For patients with allergies to nickel, the Noninium 0.8mm diameter round wrought wire clasp could be placed in both 0.5mm and 0.75mm undercuts on premolars, and the Noninium 0.9mm wire can be placed in a 0.75mm undercut of a molar.
- The results of this study have shown that, for 0.9mm and 1.0mm diameters of wires, statistically significant differences exists between the gold and stainless steel round wrought wire clasps. However, the large cost difference between these alloys suggests that the only advantage of using gold alloy wire on premolars would be for the cosmetic value.
- Studies are required to investigate the forces required to retain both tooth-supported and distal extension RPDs and the ability of abutment teeth to withstand these forces.
- Studies are required to assess the effects of other factors such as guide plane retention and paths of withdrawal on the overall retention of an RPD.

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