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In vitro retention force changes of prefabricated attachments for overdentures

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SUMMARY Changes in the retention force of six prefabricated spherical and cylindrical attachments were examined *in vitro* under continuous loading. The testing machine permitted insertion–separation cycles to be tested under reproducible conditions while a calibrated measuring device determined the insertion and retention forces. At the beginning, during the so-called run-in period, all anchoring elements showed a very unstable behaviour characterized by a varying marked increase and subsequent decrease in the retention force. During the ensuing functional period, the retention force followed a more stable course. In this phase, the frictional attachments having lamellae for activation proved more stable than did the spring-loaded retention attachments. Furthermore, in two of five cylindrical anchors by Gerber, the spring broke. This provides support to the concept that prefabricated attachments should be constructed as robust elements composed of as few individual parts as possible. This would help to ensure that service and repairs remain at a minimum. Frictional attachments with lamellae for activation are to be preferred for use in matrices and patrices over attachments having spring-loaded retention.

KEYWORDS: overdentures, prefabricated attachments, retention force changes

Introduction

For anchoring overdentures various prosthetic attachments having either custom-made or prefabricated components are used. Clinical studies have shown that biological causes are the determining factors in the long-term success of overdentures (Ettinger, Taylor & Scandrett, 1984; Ettinger & Jakobsen, 1997; Studer *et al.*, 1998). When technical complications with various attachments are compared, controversial results often arise (Kerschbaum & Muhlenbein, 1987; Geering, Bourqui & Clemcon, 1988). In order to avoid a treatment failure, one must first ensure that the patient receives consistent pre-treatment and post-reconstructive follow-up (Toolson & Smith, 1978; Davis *et al.*, 1981; Toolson, Smith & Phillips, 1982). As part of long-term maintenance, it is of paramount importance that both the practitioner and the patient realize that overdentures require regular and periodic servicing. This helps to ensure that any possible tissue injury or prosthetic damage can be caught and treated at an early stage (Igarashi & Goto, 1997).

During the reconstructive phase, technical aspects particularly affect the consideration of the validity of the abutment teeth, the individualized and correct choice of denture components and the functional and non-traumatic introduction of the overdenture into the masticatory system. Additionally, one must make certain that both custom-made and prefabricated attachments are capable of withstanding the oral loading relationships and will not require excessive service or repair during their long-term maintenance (Ettinger *et al.*, 1984).

The goal of this present study was to test, under continuous loading conditions, *in vitro* retention force changes of prefabricated spherical and cylindrical attachments for the retention of tooth-borne and implant-borne overdentures.

Methods and materials

Five samples of each of the prefabricated attachments for copings or implant abutments listed in Fig. 1 were tested. The samples were mounted onto a machine which allowed insertion–separation cycle testing under reproducible conditions (Besimo *et al.*, 1995) (Fig. 2). All samples were subjected to 10 000 insertion–separation cycles. For every 50 cycles, a calibrated measuring device electronically recorded the insertion and retention forces. However, because of software-related restrictions, the data could only be shown starting at the 50th insertion–separation cycle.

With all attachments, one differentiated between an initial run-in period, which lasted for the first 2500 insertion–separation cycles, and a subsequent functional period. During the run-in period, the maximum retention force and the number of insertion–separation cycles completed up to that point were determined for each sample. Furthermore, the absolute change between the initial force at the 50th insertion–separation cycle and the maximum force was calculated, as was that between the maximum force and the retention force of the 2500th insertion–separation cycle. For the functional period between the 2500th and the 10 000th insertion–separation cycle, the arithmetic mean $\bar{x}$, standard deviation and extreme values of the retention force were determined for each sample. During this phase the absolute and the percentage change in the retention force was calculated additionaly for each sample.

The change in the retention force of the five samples per attachment system that was observed throughout the entire duration of the continuous loading experiment was displayed as a curve showing the averages calculated at every 50th insertion–separation cycle with the corresponding standard deviation.

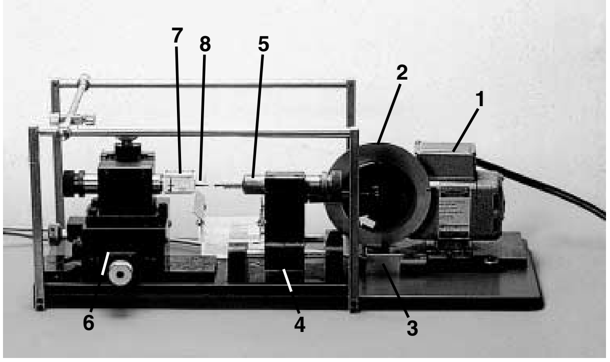

Fig. 2. Testing machine. 1, electric motor; 2, disk with connecting piston rod; 3, impulse generating device; 4, mobile carriage; 5, chuck of the carriage with mounting for the matrix; 6, fixed block; 7, chuck of the fixed block with measuring device; 8, mounting for the patrix.

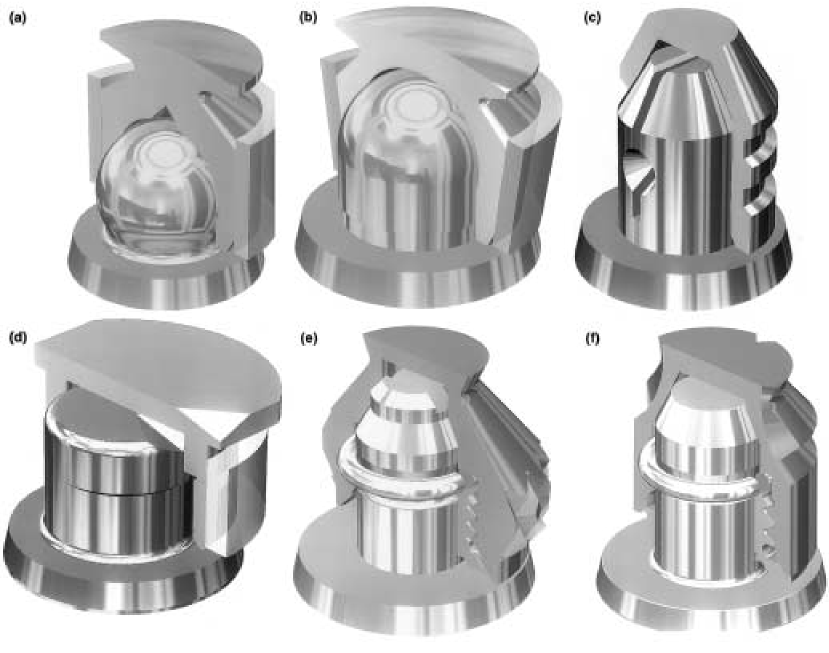

Fig. 1. Tested prefabricated attachments. Frictional attachments: a, spherical anchor by Dalla Bona®; b, cylindrical anchor by Dalla Bona®; c, Conod® attachment. Spring-loaded retention: d, stepped anchor by Fäh®; e, Gerber® attachment; f, Mini-Gerber® attachment.

Results

Retention force in the run-in period

During the first retention force measurement, which occurred at the 50th insertion–separation movement, values between 4·4 and 9·1 N were measured for all samples. The retention force varied widely during the run-in period. An initial increase in the retention force was followed by a subsequent decrease. Even within a particular series of samples, significant differences were sometimes recorded in the maximum levels. The retention forces measured for the samples of Gerber's* cylindrical anchor showed the most uniform course, while the Conod* attachments showed, with a maximum of 4·5% of the starting value, the smallest initial force increase. For all samples of the Conod attachment, the spherical and cylindrical anchors by Dalla Bona* and the Mini-Gerber* attachment, the maximum retention force in the run-in period was reached relatively early, at the latest, after 650 insertion–separation cycles. No generalizations can be made for the other attachment systems because some individual samples reached their maximum levels early, while in others, it was achieved only late in the course. After achieving the maximum, the decrease in the retention force was more dramatic in the Conod attachments and in the spherical anchors by Dalla Bona than in the other attachments. Table 1 and Fig. 3 show for each sample the maximum retention forces, the number of insertion–separation cycles when these forces were reached, and the absolute changes in the retention force before and after the maximum achieved during the run-in period.

Table 1. Run-in period. Maximum retention force (F_{max}), number of insertion–separation cycles n until achieving the maximum and absolute change of force before (ΔF_1) and after (ΔF_2) reaching the maximum for each of the five samples of the attachments tested

	Run-in period				
Attachments	Samples	F_{max} (n)	n	ΔF_1 (n)	ΔF_2 (n)
Spherical anchor by Dalla Bona®	1	11·0	300	+5·7	−0·9
	2	7·7	100	+0·5	−0·6
	3	10·0	500	+3·3	−3·7
	4	5·1	100	+0·4	−2·0
	5	11·2	200	+3·8	−5·1
Conod® anchor	1	6·1	250	+0·2	−1·9
	2	7·3	50	0	−2·5
	3	7·5	50	0	−1·1
	4	4·6	150	+0·2	−1·9
	5	5·6	50	0	−2·7
Cylindrical anchor by Dalla Bona®	1	7·9	100	+0·2	−0·5
	2	10·3	200	+2·8	−3·0
	3	9·5	350	+3·9	−1·9
	4	8·3	500	+2·5	−0·4
	5	5·9	650	+0·1	−0·7
Stepped anchor by Fäh®	1	6·5	1100	+0·2	−0·3
	2	6·8	1400	+1·0	−1·0
	3	9·9	2250	+2·5	−0·1
	4	7·9	100	+0·3	−1·5
	5	7·4	450	+1·3	−2·5
Gerber® attachment	1	6·6	1700	+1·1	−0·4
	2	8·5	400	+1·6	−1·2
	3	10·1	150	+2·0	−2·5
	4	10·2	100	+1·1	−0·8
	5	7·2	2400	+0·6	−0·5
Mini-Gerber® attachment	1	6·6	50	+0	−0·5
	2	5·7	600	+0·3	−0·3
	3	6·3	500	+1·5	−0·7
	4	7·2	50	0	−0·9
	5	6·5	50	0	−1·4

Retention force in the functional period

During the functional period, as well, there was a relatively wide variability in the average retention force among the different series. Only with the Mini-Gerber attachment could a comparable retention force course be measured among the individual samples. As per sample tested, the frictional attachments with lamellae for activation showed smaller standard deviations in the average retention forces and smaller differences among the extreme values than did the spring-loaded Gerber and Mini-Gerber attachments. The smallest change in the retention force was noted in the Conod attachments and in the cylindrical anchors by Dalla Bona. During the functional period, the cylindrical anchors by Dalla Bona tended to show an increase in the retention force while the Conod attachments had a tendency to decrease. When compared with the cylindrical anchors by Dalla Bona, a slightly stronger increase in the retention force was observed in the sister spherical anchors. The stepped anchors by Fäh* and the two types of Gerber attachments showed a more marked decrease in the retention force than did the Conod attachments. Table 2 and

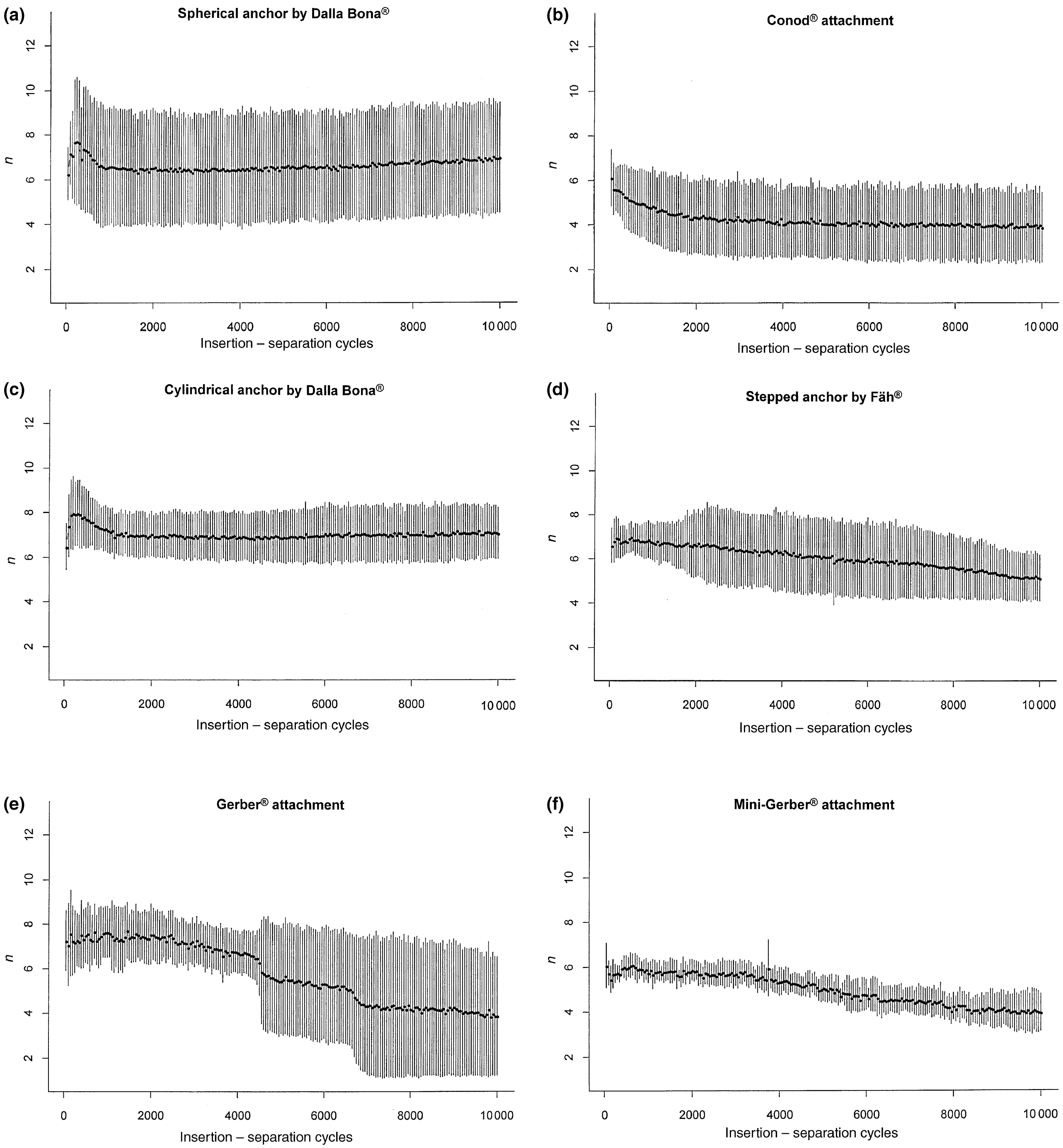

Fig. 3. (a)–(f) Diagram showing the average retention force values with standard deviation of the five samples of each type of attachment tested, as evaluated after each 50th insertion-separation cycle: a, spherical anchor by Dalla Bona®; b, Conod® attachment; c, cylindrical anchor by Dalla Bona®; d, stepped anchor by Fäh®; e, Gerber® attachment; f, Mini-Gerber® attachment.

the graphs of Fig. 3 summarize the average retention forces with standard deviation, the extreme values as well as the absolute and percentage changes in the retention force achieved with the individual samples during the functional period. The sudden and sharp decrease in the retention force seen in samples 2 and 3 of the Gerber cylindrical anchor were caused by spring breakage (Fig. 4).

Table 2. Functional period. Arithmetic mean ($\bar{x}$) and standard deviation (s.d.), extreme values and absolute and percentage change in the retention force (ΔF) for the five samples of the attachment types tested

	Functional period						
Attachments	Samples	x (n)	s.d. (n)	Minimum	Maximum	ΔF (n)	ΔF (%)
Spherical anchor by Dalla Bona®	1	10·0	0·2	9·4	10·5	+0·2	+1·5
	2	6·9	0·1	6·5	7·2	−0·2	−2·0
	3	7·4	0·7	6·2	8·8	+2·5	+41·0
	4	3·2	0·1	2·7	3·5	+0·3	+9·4
	5	6·0	0·1	5·8	6·3	+0·1	+1·6
Conod® attachment	1	4·0	0·2	3·6	4·6	−0·5	−12·8
	2	4·3	0·2	4·0	4·9	−0·9	−18·8
	3	6·7	0·2	6·0	7·6	−0·2	−2·9
	4	2·4	0·1	2·2	2·6	−0·2	−5·9
	5	3·0	0·1	2·8	3·2	−0·1	−3·2
Cylindrical anchor by Dalla Bona®	1	6·6	0·2	6·3	7·5	−0·8	−11·2
	2	7·5	0·1	7·2	7·7	+0·2	+2·0
	3	7·7	0·2	7·3	8·2	+0·2	+2·0
	4	8·2	0·3	7·6	8·8	+0·5	+6·9
	5	5·2	0·1	4·9	5·5	+0·3	+6·8
Stepped anchor by F50	1	6·2	0·1	5·9	6·6	+0·1	+0·8
	2	5·7	0·3	5·1	6·6	−0·5	−9·0
	3	7·9	1·2	5·2	9·6	−4·2	−44·8
	4	6·0	0·3	5·5	6·5	−0·9	−13·7
	5	3·8	0·4	2·9	4·7	−1·2	−26·0
Gerberl® attachment	1	5·5	0·4	4·8	6·3	−1·3	−21·1
	2	2·7	2·1	1·4	6·9	−5·3	−78·8
	3	3·6	2·7	0·5	7·9	−6·4	−89·8
	4	7·8	0·6	6·3	9·1	−2·5	−28·1
	5	6·7	0·4	6·0	7·4	−1·2	−16·4
Mini-Gerber® attachment	1	5·5	0·5	4·3	6·5	−1·0	−16·7
	2	4·8	0·4	4·0	5·7	−1·0	−18·9
	3	4·0	0·9	2·6	5·8	−2·6	−48·2
	4	5·0	0·9	3·8	8·2	−2·3	−38·4
	5	4·5	0·4	3·7	5·4	−1·3	−24·3

Retention force throughout the entire duration of the experiment

Throughout the entire duration of the experiment, the two types of Gerber attachments and the Conod anchors showed the most significant decrease in the retention force. For the Gerber cylindrical anchors, the percentage change ranged between 10·9 and 85·2%, for the Mini-Gerber attachments between 18·5 and 44·4%, and for the Conod anchors between 17·3 and 50·0%. For the majority of samples from the stepped anchors by Fäh, there was also a significant change in the retention force noted. This reached a maximum of 39·3%. In three of the five samples from both the spherical and cylindrical anchors by Dalla Bona, an increase in the force ranging between 1·4 and 94·3% was observed. If a decrease in the retention force did occur, it was <15%, with one exception, when it reached 31·9%.

Discussion

The experimental design, as described in this paper, was constructed to evaluate the retention force of a total of six spherical and cylindrical attachments for tooth-borne and implant-borne overdentures under continuous *in vitro* loading. Constant measurement of the retention forces was carried out under standardized and reproducible conditions (Sener, 1991). The high sensitivity of the measuring device and the electronic data transfer achieved a high degree of measurement accuracy of ±0·05 N. The 10 000 insertion–separation cycles to which each sample was subjected corresponded to a

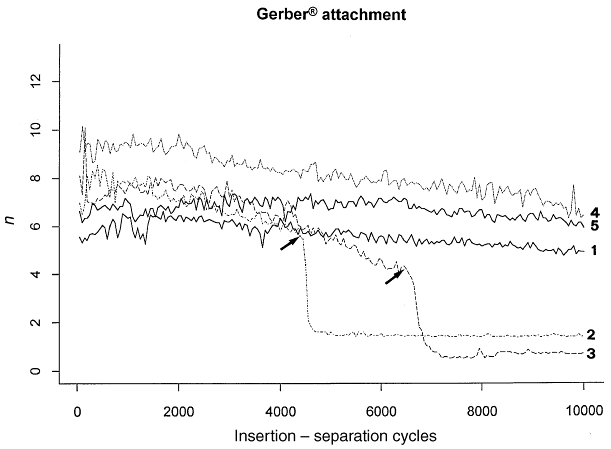

Fig. 4. Curve showing the retention force of samples 1–5 of the Gerber® attachment, as recorded at each 50th insertion-separation cycle. Sample numbers 2 and 3 experienced a dramatic decrease in the retention force after spring breakage (arrows).

thrice-daily overdenture removal for oral hygiene, with a time in use of about 9 years. Contra-axial force impacts on the attachment components were not considered in this experimental design.

An analysis of the retention force behaviour raised the question of whether two experimental periods could be distinguished for the attachments which clearly differed in the retention force change. To answer this question, a comparison of the values from these two phases had to be undertaken. Here, when performing the statistical analysis, one had to consider that the values of one sample were autocorrelated. Furthermore, because of the large differences among the individual series, no evaluation could be undertaken of the five series per attachment type as a combination. The definition of the end of the so-called run-in period depended on the individual sample. If this time were chosen prematurely, then the influence of those values – which actually belonged to the run-in period and thus subject to greater fluctuations – would be too high on the more stable, so-called functional period. Conversely, if the end were chosen at too late a time in the run-in period, a possible difference between the two test periods would be blurred.

In order to counteract the problem of autocorrelation, only every 10th value of a series was included in the statistical analysis. Furthermore, the end of the run-in period was conservatively chosen to be at the 2500th insertion–separation cycle. This gave a high ranking for any significant difference between the run-in and functional periods. Additionally, when poor results were achieved with one anchoring element, the cause could not be attributed to a premature end of the run-in period. For ensuring the correct choice of the end of the run-in period with each sample, a *t*-test was carried out to test for uniformity of the averages of the two periods. Results from the *t*-test are summarized in Table 3. Two-thirds of all samples showed a *P*-value < 0·05 and thus a significant difference in retention force characteristics between the run-in and functional periods. Only with three of the five spherical anchors by Dalla Bona was this difference not significant.

The large variability in the starting values at the 50th insertion–separation cycle confirmed the clinical experience that it is almost impossible to adjust the retention forces of prefabricated attachments in a targeted manner (Besimo *et al.*, 1995). Also clearly noted was the fact that the spherical and cylindrical anchors demonstrated very unstable behaviour at the beginning of the continuous loading experiments. This was characterized by an increase and then subsequent decrease in the retention force (Lehmann, 1971; Lehmann & Arnim, 1976; Jung & Borchers, 1983; Owall, 1991, 1995; Stark, 1996). There was a high degree of variability both among and within the sample groups. Only the Mini-Gerber cylindrical anchors exhibited a similar behavior for all five samples. Comparable characteristics of the run-in period were also demonstrated

Table 3. P values of the *t*-tests for conformity of the arithmetic means of the run-in and functional periods

Attachments	Samples 1	2	3	4	5
Spherical anchor by Dalla Bona®	0·0859	0*	0·2356	0·0963	0·0068*
Conod® attachment	0*	0·0001*	0·0982	0·0099*	0·0006*
Cylindrical anchor by Dalla Bona®	0*	0·1270	0·2581	0·0023*	0·0003*
Stepped anchor by Fäh®	0·2222	0·0006*	0·9262	0*	0*
Gerber® attachment	0·0160*	0·0003*	0·0046*	0·0001*	0·9411
Mini-Gerber® attachment	0·0312*	0·0009*	0·0034*	0·0004*	0*

* Values < 0·05 indicate a significant difference between the periods.

in vitro for extra coronal and paracoronal attachments (Besimo *et al*., 1995; Wichmann & Kuntze, 1999). The hardening of the contact surfaces of the attachments by cold working (Jung & Borchers, 1983) and an initially appearing surface release and wear down of metal particles have been discussed as possible explanations for this observation (Owall, 1991).

As prefabricated attachments apparently require a certain run-in period before they achieve their best possible functioning, it would seem advisable to optimize the function of the anchors during laboratory procedures with multiple insertion–separation movements. Furthermore, it might also be advantageous to make the retention force of the attachment during the first denture placement initially at a minimum, and then gradually, but continually, increase it to the desired level. This would facilitate the patients in learning how to handle their overdentures without having to exert an excessive degree of force or effort (Besimo *et al*., 1995).

In the functional period, the retention forces of the frictional attachments followed a more stable course than did the spring-loaded retention attachments. Practice has shown that spring attachments undergo an increased wear of the patrix and thus experience a more rapid decrease in the retention force which, when a certain level of wear has been reached, can no longer be compensated for by attachment activation (Besimo & Rohner, 1999). The increased wear of the patrix may be related to the loose fit of the spring. With each insertion–separation cycle, the spring must be newly centered as it leads to an increased wearing down of the patrix and possibly even to spring breakage. Spring breakage in two of the five Gerber cylindrical anchors well corresponded to the clinical experience observed with this type of attachment. More than the usual amount of wear and tear and increased repairs in the attachment components have led the manufacturer of these retainers to replace the springs with plastic inserts, as are currently used in the Mini-Gerber Plus® attachment* (Cendres & Métaux, 1999). In one *in vitro* investigation, a possibly smaller decrease in the retention force was demonstrated when plastic inserts were used instead of purely metallic components (Wichmann & Kuntze, 1999).

Throughout the entire duration of the experiment, Conod attachments showed a significantly higher decrease in force than that observed for the spherical and cylindrical anchors by Dalla Bona. This could be a result of the significantly longer lamellae for activation found in the Conod attachments, which are possibly responsible for this larger loss in the retention force observed during the run-in period. Based on this assumption, frictional attachments with shorter lamellae should be preferably employed in clinical practice.

In comparable investigations with more than 10 000 insertion–separation cycles, custom-made tapered (Besimo, Graber & Fluhler, 1996) and parallel-sided telescope crowns (Stark & Stiefenhofer, 1994; Stark, 1996) made out of precious metal alloys or pure titanium showed different retention force characteristics than those seen with prefabricated attachments. A comparable run-in period was not recognizable. Until the end of the experiment, a continuous increase in the retention force was observed more often. This could be an indication of a not-yet completed and, when compared with prefabricated attachments, significantly longer, run-in period. As possible causes, one could postulate various processing steps and different dimensions of the contact surfaces of the attachment components.

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Conclusions

Prefabricated attachments should be robustly constructed and consist of as few individual parts as possible. This will help keep service and repair at a minimum. Lamellae for activation in matrices and patrices should be preferred over spring-loaded retention.

The function of the retainers should be optimized in laboratory procedures with multiple insertion–separation cycles and the retention force of the attachments after denture placement should only be increased in a stepwise fashion until the desired level is attained.

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