WEAR BEHAVIOR OF ATTACHMENTS FOR IMPLANT RETAINED OVERDENTURE ACCORDING TO MATERIAL IN VITRO

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Statement of problem. The proper materials of attachments for implant retained overdenture are unknown, such as
the correlation between retention and abrasion, as well as the types of materials that are suitable for patrix and for matrix individually.
Purpose of this study. The aim of this study was to select a proper clinical attachment system for a successful treatment as well as patient satisfaction.
Methods. Retention and abrasion of 14 commercial attachments were measured during 15,000 removes.
Results. A retentive part (matrix) which requires elasticity has to be made of gold while the patrix part which does not require elasticity has to be made of titanium. This gold matrix / titanium patrix combination showed the most retentive force and the least retention loss.

Key Words
Abrasion, Attachment material, Attachment design, Implant-retained overdenture, Retention loss, Abrasion rate, Wear, Matrix, Patrix

The dental attachment of implant-retained overdenture which binds a denture directly to an implant is an important part of being able to command denture stability, patient satisfaction, denture retention, and even the success rate. Implants can provide the foundation for various attachments that will stabilize an oral prosthesis. Even though the implant retained overdenture therapy has some advantages such as less cost, broad indications and so on, some disadvantages include more extensive postinsertion maintenance for the overdentures than that for fixed prostheses supported by implants. It has often been reported that problems which arise include fatigue fractures of the retentive clips and loss of retention in the attachment part. In this study, abrasion of commercial attachments was measured before and after 15,000 removes (cycles). Measurement of specimens was limited only to the patrix part, due to difficulty in accurate measurement of the matrix part. The used attachments were 14 articles, 3 pairs from 5 such companies as the Brånemark, the Straumann, the Friatec/IMZ, the 3i and the CM. All 42 specimens were prepared for this investigation. A special testing machine, which was constructed using a stopper motor, measured all specimens for 15,000 cycles. The 15,000 cycles indicates removal and insertion during a period of 10 years. It is presumed that the denture is removed and inserted 4 times a day.

There are four types of materials (gold, titanium, plastic and rubber) for the matrix part and two types of materials (gold and titanium) for the patrix part on the attachments tested in this study. The metal patrix of the 3i O-Ring and the Brånemark plastic cap attachments with the rubber ring showed no significant change before and after 15,000 cycles but showed striking destruction of the rubber ring.

The gold matrix / gold patrix combination, the titanium matrix / titanium patrix combination and the titanium matrix / gold patrix combination significantly showed high abrasion rates of the patrix ($P < 0.05$). The attachment groups with the titanium matrix among these groups (the titanium matrix / titanium patrix combination and the titanium matrix / gold patrix combination) showed significant retention loss ($P < 0.01$). On the other hand, some attachments with gold Dolder matrix (the Straumann and the CM gold Dolder bars in original status) showed no significant retention loss.

The gold matrix / titanium patrix combination and the plastic matrix / gold patrix combination showed the least abrasion rate and abrasion fragments. In addition, the gold matrix / titanium patrix combination demonstrated high retention forces and showed no significant retention loss.

Therefore, this study concluded that abrasion of attachment components was one of the reasons for decreased retention with fatigue of material. The matrix part must be made from strong and flexible material like gold and the patrix part must be made from strong material like titanium. This combination showed the best results in both bar and ball attachments in this study.

INTRODUCTION AND STATEMENT OF PROBLEM

Edentulous patients wearing conventional complete dentures often complain about problems with denture stability resulting in difficulties in chewing and speaking. These patients can benefit from implant-retained prostheses, which improve stability and retention. Insufficient bone support and economic considerations are often the main reasons for excluding edentulous patients from treatment with osseointegrated implants. Two implants retaining overdenture is less expensive than a fixed implant-supported prosthesis which requires more complex prosthetic restorations. Overdenture treatment can broaden the indications for implant treatment by including patients who could be treated by implant supported fixed prostheses. Implants can provide the foundation for various attachments that can stabilize a denture.

There are many attachment systems having different materials. Selection of attachment has depended on the preference of the restoration team among several different types of attachments that can be used. Sometimes there are contrary results of clinical and laboratory tests against the same attachment system.

For example, Cohen et al[1] studied that the nylon cap showed more consistent forces when compared with the metal keeper with cap insert in an in vitro test.

Mericske-Stern[2] reported that plastic retainers wore off very quickly in an in vivo test. In the study of Michael et al[3], the plastic clip and Hader bar had to be replaced often (every 2 to 3 months) in an in vivo test. Chan et al[4] reported that the average useful life span of the Friatec / IMZ POM retainer bar was 12.8 months in an in vivo test. These contrary results between the laboratory and clinical situations suggest the importance of the attachment material. Unfortunately, studies concerning the materials of attachments for implant-retained overdentures are rare. This study was conducted to test the wearability of various attachments.

This study demonstrated the correlation between retention and abrasion as well as the types of materials that are suitable for patrix and matrix individually. Finally, the aim of this study was to select a clinically proper attachment system for a successful treatment as well as patient satisfaction.

MATERIAL AND METHOD

Material

Fourteen commercially available attachments belonging to four different internationally distributed implant systems were selected. This experiment consisted of 42 specimens with 3 samples in each system. The Brånemark round gold bar system, the Straumann pear-shaped titanium Dolder bar with titanium matrix, the Straumann pear-shaped titanium Dolder bar with gold matrix, the CM U-shape gold bar with gold matrix (micro) were not preset to a proper retention force by the manufacturers. Therefore these attachments were adjusted by the researcher before testing. Two attachment systems (the Straumann pear-shaped gold Dolder bar with gold matrix and the CM U-shaped gold Dolder bar with gold matrix) were activated again after 15,000 cycles by the researcher. They were tested again during 15,000 cycles in the same method. Thus, they were actually tested during 30,000 cycles.

Table I shows all the selected attachments.

Method

From each of the four implant systems, two

Table I. This study measured 14 kinds of commercial attachments such as 7 bar attachments and 7 ball attachments.

	COMPANY	TYPE	NAME	MATRIX	PATRIX	CATALOG Number
1	BRÄNEMARK	BAR	ROUND GOLD BAR SYSTEM	GOLD	GOLD	DCB110
2		BALL	TITANIUM CAP BALL ATTACHMENT	TITANIUM	GOLD	DCA535, SDCB526
3		BALL	GOLD CAP BALL ATTACHMENT	GOLD	GOLD	DCA 532, SDCB526
4		BALL	PLASTIC CAP BALL ATTACHMENT	RUBBER	GOLD	DCC114, SDCB115
5	STRAUMANN	BAR	PEAR-SHAPED DOLDER BAR	GOLD	GOLD	048.412, 048.414, 048.204
6		BAR	PEAR-SHAPED DOLDER BAR	TITANIUM	TITANIUM	048.465, 048.470, 048.214
7		BAR	PEAR-SHAPED DOLDER BAR	GOLD	TITANIUM	048.465, 048.214, 048.414
8		BALL	GOLD CAP RETENTIVE BALL ANCHOR	GOLD	TITANIUM	048.439, 048.410, 046.069
9	Friatec/IMZ	BAR	POM RETAINER BAR (ROUND BAR)	POM	GOLD	51-1204, 51-1225
10		BALL	BALL AND SOCKET ATTACHMENT	GOLD	TITANIUM	51-1462, 51-1470
11	3i	BALL	O-RING	RUBBER	TITANIUM	OSO40
12		BALL	DAL-RO	GOLD	TITANIUM	DRA40
13	CM	BAR	U-SHAPED DOLDER BAR (MACRO)	GOLD	GOLD	51.01.5
14		BAR	U-SHAPED DOLDER BAR (MICRO)	GOLD	GOLD	51.01.2

original implants (15 mm length) were embedded parallel in the lower metal form at a distance of 22 mm apart using self curing resin (Epoplast, JEAN WIRZ, Düsseldorf, Germany). A distance of 22 mm is similar to the distance between two natural canines.[5]

The patrix parts of the attachments were fixed on the implants as described by the manufacturer's manual using each manufacturer's original abutments or transmucosal elements respectively. Bar attachments were fixed on the original implant model using Pattern resin (GC, Fuji, Tokyo, Japan). They were invested, soldered, (or welded), reseated and screwed on the implants. To weld the titanium bar and the titanium coping abutments, the laser welding machine (LASER HAAS 44P, Heraeus Kulzer Gmbh, Wehrheim, Germany) was used. 42 overdenture analogs were made for each sample with a denture self-curing acrylic resin (Palapress, Heraeus Kulzer Gmbh, Wehrheim, Germany). For the purpose of minimizing the risk of handling error and polymerization shrinkage of the autopolymerizing acrylic resin, these analogs were already made several days before the testing. They were firmly fixed in the upper metal form by 4 screws. Before attachments were secured on the implants, the width of the lateral bar and ball head were measured by a hand digital measuring machine (Electronic digital caliper, Conrad Electronic Gmbh Hirschau, Germany). The lower metal form with implants attached to the patrix parts of the attachments was placed in the water bath. The water bath and the lower metal form were simultaneously fixed to the testing machine by three screws. Thereafter, the upper metal form with the overdenture resin analog was fixed to the upper parts of the testing machine by a screw. The matrix parts which were first placed on the bar or ball of the lower metal form, were directly attached to the overdenture analog of the upper metal form by modeling resin (Palavit G, Heraeus Kulzer Gmbh, Wehrheim, Germany). To maintain a definite position of attachments, immediately before testing, the matrix part was attached to the overdenture analog by modeling resin. After fixation of the matrix, we waited for at least 2 hours to allow perfect setting of the resin. The bath was flooded with demineralized water at about 22°C to ensure that the entire attachment was covered with water.

Fig. 1-2 illustrate the testing machine and a specimen.

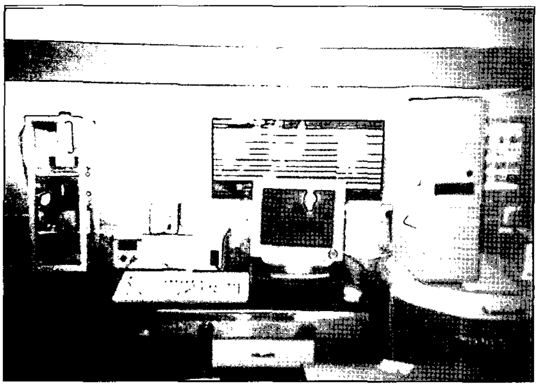

Fig. 1. The measuring instrument set

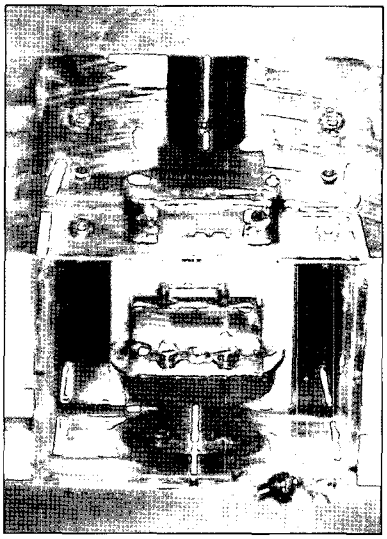

Fig. 2. The view of prepared specimen and machine completely

FORCE MEASUREMENTS AND MONITORING POINTS

The testing machine was constructed using a stepper motor (ISEL, Eiterfeld, Germany) which allows reproducible movements in steps of 10μm, moving the matrix part up 3 mm and replacing it to its initial position. Each cycle took 6.5 seconds including a one second pause, removing and insertion of an attachment was repeated 15,000 times for 27 hours. The cross head speed was 80 mm/min. 15,000 cycles indicate the use of overdenture in patients for 10 years (assuming removal and insertion 4 times a day).

The head size of ball attachments and the width of the bar attachments were measured two times before testing and after 15,000 cycles, each 5 times by hand digital measuring machine (Fig. 3-6). Pictures were taken of all attachments before and after testing to compare the before and after changes (Fig. 8).

The forces that occurred while removing the matrix part from the patrix part were detected by recording 100 measurements per second using a computer-supported system. This system consisted of a platform load cell (PW2-2, HOTTINGER BALDWIN, Marlboro MA, USA), a DC amplifier (ME10, HOTTINGER BALDWIN, Marlboro,

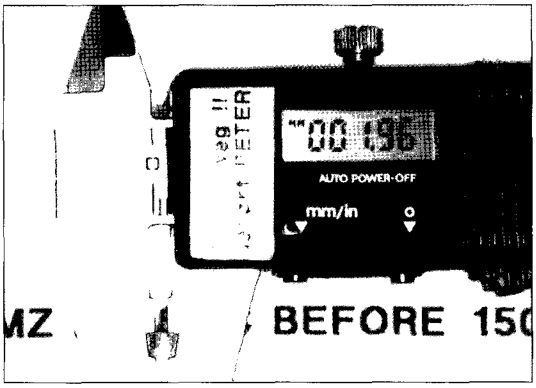

Fig. 3. Measuring width of the Friatec/IMZ round gold bar before 15,000 cycles

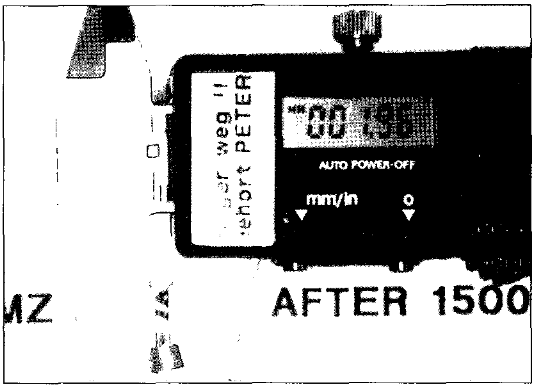

Fig. 4. Measuring width of the Friatec/IMZ round gold bar after 15,000 cycles

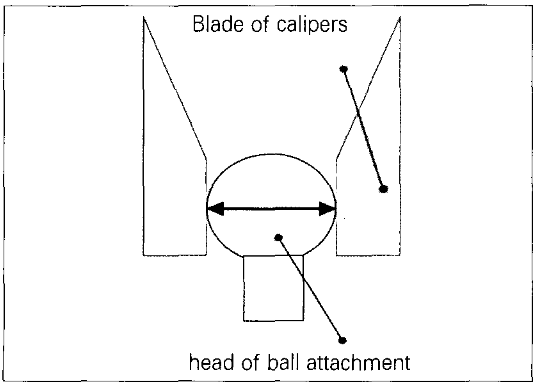

Fig. 5. Measuring width of the ball head with calipers

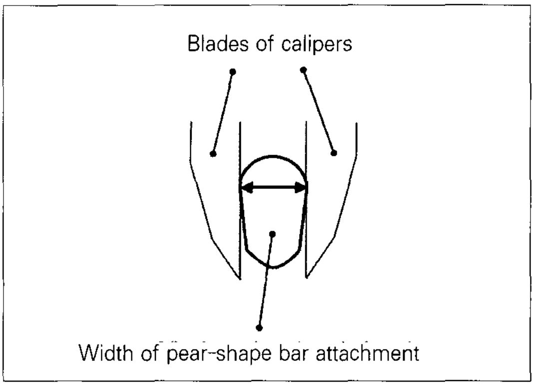

Fig. 6. measuring width of the pear-shape Dolder bar with calipers

MA, USA), an AD converter (PC-LPM-16, NATIONAL INSTRUMENTS, Austin, TX, USA) and the software LabView 4.0 (NATIONAL INSTRUMENTS, Austin, TX, USA). The measurement equipment was calibrated at the amplifier using a set of precision weights prior to each experiment.

The patrix part and the matrix part of the attachments were compared through pictures which were taken as a same zoom before testing and after testing. In addition, some changes were observed in the abrasive fragments and distilled water in the bath during 15000 cycles. This study carefully considered the affecting factors of attachment retention such as material, design, components of attachment and so on.

RESULT

This study monitored surface changes and recorded dimensional changes of bar and ball attachments before and after 15,000 cycles.

The results were analyzed by SPSS statistical analysis package (7.5 version, SPSS Inc., Chicago, Ill). For primary statistical analysis, one way analysis of variance (One way ANOVA) was used to compare the between-attachment abrasion amount and the within-attachment abrasion amount, followed by Tukey studentized range statistics to make pairwise multiple comparisons between the attachments. Attachments were divided into seven homogenous groups in Fig. 7. Attachment 5a shows the most dimensional

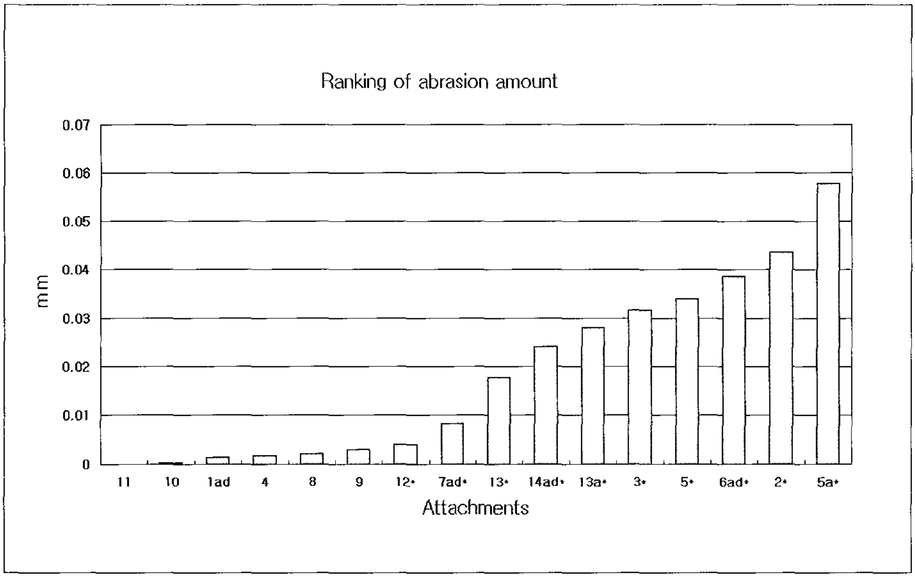

Fig. 7. The abrasion amounts of patrix parts
* : (P < 0.01)
1ad. Brånemark bar and clip set adjustment, 2. Brånemark titanium cap ball attachment, 3. Brånemark gold cap, 4. Brånemark plastic cap ball attachment, 5. Straumann pear-shaped gold Dolder bar, 5a. Straumann pear-shaped gold Dolder bar activation, 6ad. Straumann pear-shaped titanium Dolder bar adjustment, 7ad. Straumann pear-shaped gold matrix + titanium bar adjustment, 8.Straumann gold cap, 9. Friatec/IMZ round bar and plastic clip, 10. Friatec/IMZ ball and socket (gold cap), 11. 3i O-RING ball attachment, 12. 3i gold cap ball attachment (DALRO), 13. CM U-shaped Dolder bar (Macro), 13a. CM U-shaped Dolder bar activation (Macro), 14ad. CM U-shaped Dolder bar (Micro) adjustment.

change for abrasion of patrix and attachment 11 shows the least dimensional change.

Paired samples T-test was used to compare the abrasion amount between and after cycling and to determine the significance of retention loss during 15,000 cycles.

The attachments tested in this study were divided into five groups according to the material combination. Group1 comprised soft (rubber/plastic) matrix and metal (gold/titanium) patrix combination. Group 2 comprised gold matrix and gold patrix combination. Group 3 included gold matrix and titanium patrix combination. Group 4 included titanium matrix and titanium patrix combination. Group 5 included titanium and gold patrix combination. Table Ⅱ shows the tested results and statistical significance of abrasion rate and retention loss. Six (1ad, 4, 8, 9, 10, 11) among sixteen tested attachments showed no significant abrasion of patrix before and after

Table II. The abrasion rate and the retention loss of attachments according to material combinations.

Materials		Attachments	Appearance of matrix	Abrasion rates of patrix	Mean width of patrix		Significance of retention loss	Mean retention forces
Matrix	Patrix				before	After		
Rubber / plastic	Gold / titanium	4	Abraded	0.05%	3.501mm	3.500mm	*	18 N
		9	No detectable	0.15%	1.990mm	1.987mm	-	15 N
		11	Destroyed	0.00%	2.327mm	2.327mm	**	9 N
Gold	Gold	1ad	Scratched	0.07%	1.992mm	1.990mm	*	20 N
		3	Scratched	1.41 %**	2.249mm	2.217mm	**	33 N
		5	Scratched	1.55 %**	2.191mm	2.157mm	-	30 N
		5a	Abraded	2.69 %**	2.157mm	2.099mm	**	88 N
		13	Scratched	0.80 %**	2.199mm	2.182mm	-	31 N
		13a	Abraded	1.28 %**	2.182mm	2.154mm	*	80 N
		14ad	Scratched	1.52 %**	1.578mm	1.554mm	-	51 N
Gold	Titanium	7ad	Scratched	0.39 %**	2.154mm	2.145mm	-	79 N
		8	Scratched	0,09 %"	2.256mm	2.254mm	**	85 N
		10	Scratched	0.01%	2.995mm	2.995mm	-	90 N
		12	Scratched	0.18 %**	2.250mm	2.246mm	-	86 N
Titanium	Titanium	6ad	Abraded	1.80 %**	2.155mm	2.116mm	**	24 N
Titanium	Gold	2	Destroyed	1.94 %**	2.250mm	2.206mm	**	20 N

* : ($P < 0.05$), ** : ($P < 0.01$) - : not significantly different during 15,000 cycles.

1ad. Brånemark bar and clip set adjustment, 2. Brånemark titanium cap ball attachment, 3. Brånemark gold cap, 4. Brånemark plastic cap ball attachment, 5. Straumann pear-shaped gold Dolder bar, 5a. Straumann pear-shaped gold Dolder bar activation, 6ad. Straumann pear-shaped titanium Dolder bar adjustment, 7ad. Straumann pear-shaped gold matrix + titanium bar adjustment, 8.Straumann gold cap, 9. Friatec/IMZ round bar and plastic clip, 10. Friatec/IMZ ball and socket (gold cap), 11. 3i O-RING ball attachment, 12. 3i gold cap ball attachment (DAL-RO), 13. CM U-shaped Dolder bar (Macro), 13a. CM U-shaped Dolder bar activation (Macro), 14ad. CM U-shaped Dolder bar (Micro) adjustment.

cycling. Seven (5, 7ad, 9, 10, 12, 13, 14ad) among sixteen attachments showed no significant retention loss during 15,000 cycles.

Soft (rubber/plastic) matrix and metal (gold/titanium) patrix combination

Group 1 showed no significant abrasion of the patrix during 15,000 cycles. However, the rubber rings of the matrix in attachment 11 were almost destroyed (Fig. 8a ,8b) and turned white in the water bath after 15,000 cycles (Fig. 8d, 8e). The rubber ring of attachment 4 was severely abraded during 15,000 cycles (Fig. 8c). These two attachments showed significant retention loss during 15,000 cycles ($P < 0.05$). Attachment 9 significantly showed no detectable change and no significant retention loss.

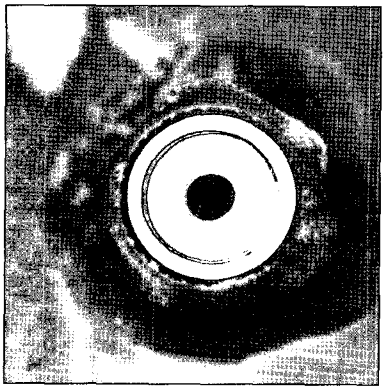

Fig. 8a. New rubber ring of the 3i O-RING

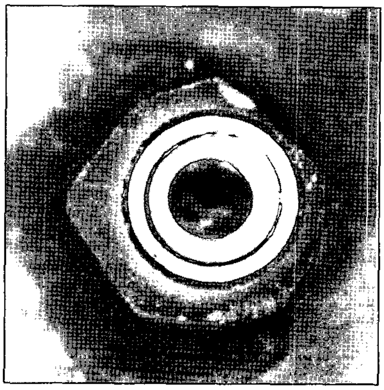

Fig. 8b. Used rubber ring of the 3i O-RING after 15,000 cycles

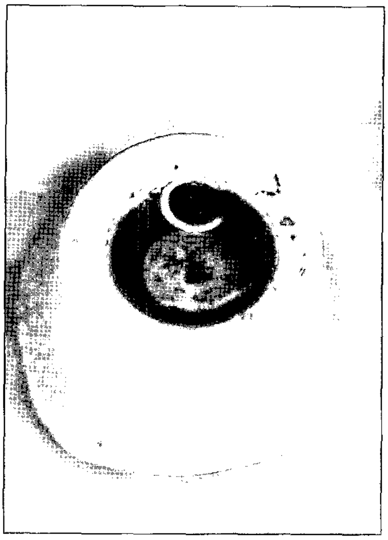

Fig. 8c. Abrasion fragments of used rubber ring in the Brånemark plastic cap ball after 15,000 cycles

Gold matrix and gold patrix combination

Group 2 has seven attachment systems (1ad, 3, 5, 5a, 13, 13a, 14ad) as shown in Table 3. Six among these seven attachments showed significant abrasion (P < 0.01). Only attachment 1ad did not significantly change for abrasion. However, attachment 1ad showed significant retention loss (P < 0.05). On the other hand, attachments 5, 13 and 14ad did not show significant retention loss. Attachments 3, 5a and 13a showed a relatively large number of abrasion fragments (Fig. 9, 10).

Gold matrix and titanium patrix combination

The gold matrix / titanium patrix combination has 4 attachment systems (7ad, 8, 10 and 12) in this study. Two (7ad and 12) among these four attachments showed significant abrasion (P < 0.01) but no significant retention loss. Abrasion rates were only 0.39 % and 0.18 %.

These four attachments barely showed abraded patrix and abrasion fragments (Fig. 11b). The attachments in this group also showed high retention forces. Only one ball attachment out of four attachments showed significant retention loss (P < 0.01) during 15,000 cycles.

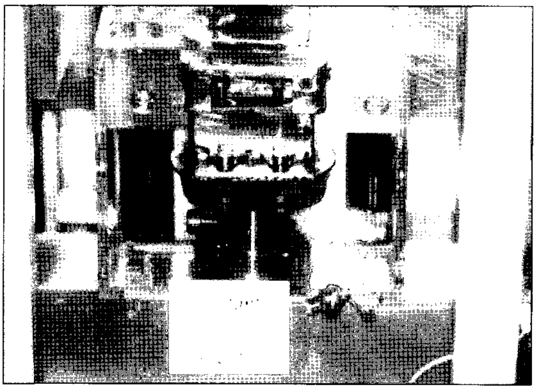

Fig. 8d. Transparent color in water bath before measuring of the 3i O-RING

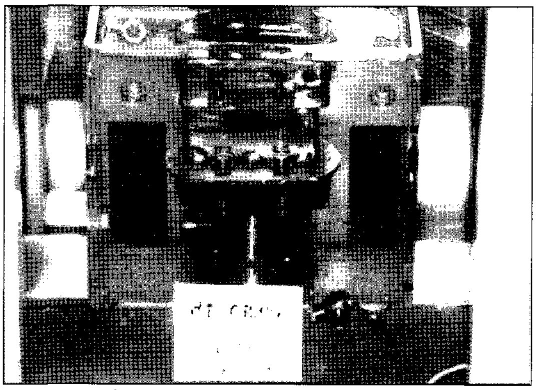

Fig. 8e. Whitely contaminated color in water bath after measuring of the 3i O-RING

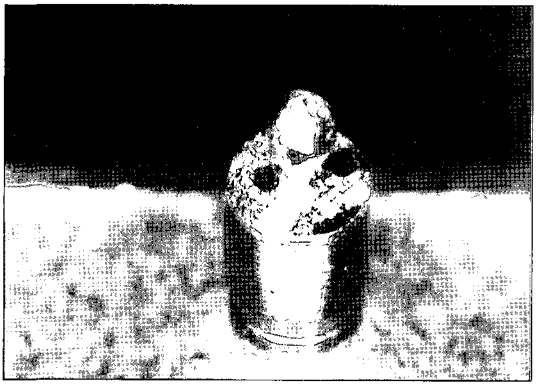

Fig. 9. Fragments from Brånemark gold ball with gold cap after 15,000 cycles.

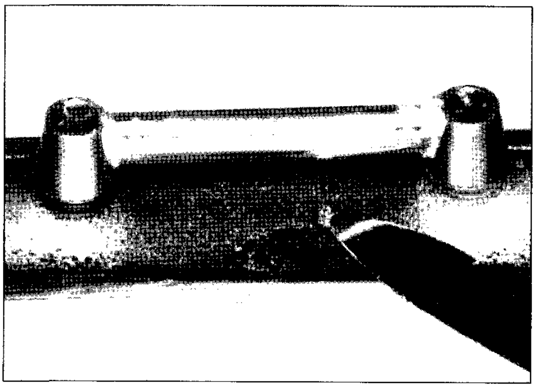

Fig. 10. Plenty of fragments of severe abraded gold Dolder bar from the attachment 5a.

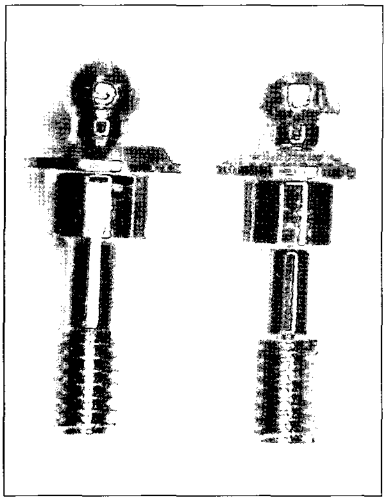

Fig. 11a. Unused gold ball (left) and abraded one after 15,000 cycles (right) in the Brånemark gold ball with titanium cap attachment.

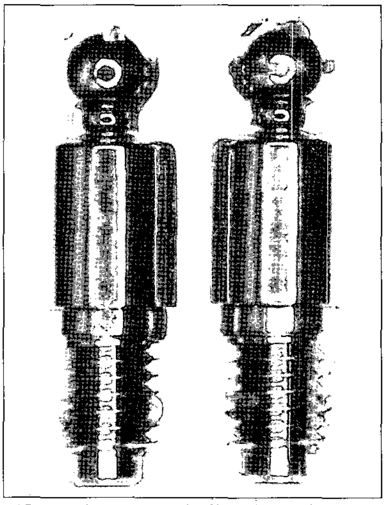

Fig. 11b. Unused titanium ball (left) and used titanium ball patrix having only minor superficial scratched surface after 15,000 cycles in the Friatec/IMZ titanium ball with gold cap.

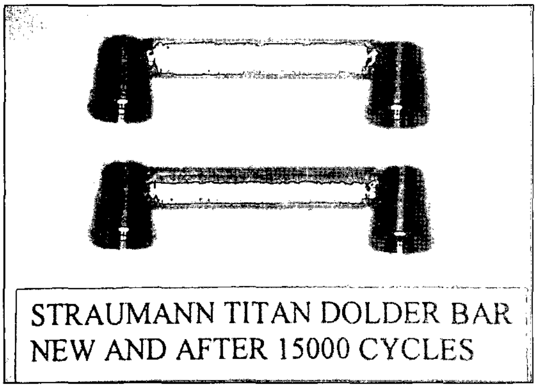

Fig. 12. The Straumann titanium Dolder bars with titanium matrix at before and after use.

Titanium matrix / titanium patrix and titanium matrix / gold patrix combinations

These two groups had one attachment each in this study. These two attachments (6ad and 2) showed significant abrasion and retention loss (P < 0.01). Severe abraded patrix could also be seen around the specimens tested (Fig. 11a). In Fig. 12, abraded titanium Dolder bar can be seen compared to the new titanium Dolder bar.

DISCUSSION

Materials for attachments

Correlation between abrasion and retention

Decreased retention of attachments may be due to fatigue and abrasion of attachment materials.

Walton J. N. and Ruse D. R.[7] reported that greater wear was observed on the gold bar when gold Dolder type retainers were used and it may have played a role in the greater loss of retention.

Ten out of sixteen attachments tested in this study showed significant abrasion (P < 0.01). Seven (2, 3, 5, 5a, 6ad, 13a and 14ad) of these ten attachments showed severe abrasion rates of up to 1.00 % on the patrix. Likewise, in two attachments (4 and 11), severe abraded rubber ring was observed after 15,000 cycles. Seven (2, 3, 4, 5a, 6ad, 11 and 13a) of these nine attachments with severe abraded patrix and matrix showed significant retention loss (P < 0.05). Two Dolder bar attachments did not show significant retention loss.

Walton' s study supports this result. Therefore, abrasion directly affected retention loss.

Attachments with the plastic matrix

Cohen et al[1] conducted an in vitro test which demonstrated that the nylon cap design required less force for removal but showed more consistency in the force required over the course of the 2000 pulls when compared with the metal keeper with cap insert.

The Friatec/IMZ POM matrix (plastic clip) with round gold bar attachment (9) did not show significant retention loss and significant abrasion in this study. Even though attachment 9 did not have high retention force, initial retention forces were maintained during 15,000 cycles. Cohen's vitro study supports this result. But, Michael et al[3] reported that a plastic clip and Hader bar were initially used for retention of the overdenture, however the plastic clips had to be replaced often (every 2 to 3 months). Also, Chan et al[4] reported that an average useful life span of the Friatec / IMZ POM matrix with round gold bar was 12.8 months in an vivo test. The contrary results of these studies demonstrate the difference between vivo and vitro tests. It is hard to compare clinical and laboratory results, because the laboratory results of this study did not include special oral situations such as contamination of plastic materials, lateral destructive force, and so on. Therefore, the durability of plastic matrix against destructive force in the mouth will be studied more in the future.

Suitable materials for the matrix and for the patrix of attachments

When the Brånemark gold ball with the gold cap or the titanium cap attachments (2 and 3) were measured, they showed significant abrasion ($P < 0.01$) and abraded fragments around the head of the patrix part (Fig. 9, 11a). The abrasion rates of these two attachments (2 and 3) were respectively 1.94 % and 1.41 ($P < 0.01$). When the 3i, the Straumann and the Friatec/IMZ titanium ball with gold cap attachments were measured, abraded fragments or abraded ball heads were not found (Fig. 11b). The abrasion rates of these three attachments (8, 10 and 12) were respectively 0.09 %, 0.01 % and 0.18 %. Although attachment 12 showed significant abrasion of patrix, the value was only 0.18 %. This value of attachment 12 is far smaller than those of attachments 2 and 3 having the gold patrix. It can be assumed that the material combination of the matrix and patrix are responsible for the difference of the tested results. The patrix parts of the Brånemark gold cap ball and the Brånemark titanium cap ball attachments are made of the Elitor (gold). The patrix parts of the 3i, the Straumann and the Friatec/IMZ are made of titanium. The gold cap ball attachments (8, 10 and 12) with the titanium patrix showed higher retention forces and less abrasion compared to the gold cap and the titanium cap ball attachments (2 and 3) with the gold patrix. When the Brånemark titanium cap was tested with the gold ball, the patrix part showed severe abraded fragments and abraded ball head (Fig. 11a). Both of the Brånemark titanium cap and gold cap attachments (2 and 3) showed significant retention loss ($P < 0.01$). Only attachment 8 among the three gold cap attachments (8, 10 and 12) with the titanium patrix showed significant retention loss ($P < 0.01$). There is an exchangeable steel wire in the Brånemark titanium cap. This steel wire in the Brånemark titanium cap was almost worn out after 15,000 cycles. If the steel wire in the Brånemark titanium cap was exchanged with a new one at the proper time, abrasion of the gold patrix might be more severe. This indicates that the titanium matrix / gold patrix combination and the gold matrix / gold patrix combination are not suitable for lifelong ball attachments.

When the Dolder bar attachments with different material combinations were compared, there were three kinds of material combinations. Attachments 5 (the gold matrix / gold patrix combination), 7ad (the gold matrix / titanium patrix combination) and 6ad (the titanium matrix / titanium patrix combination) were made by the manufacturer, were pear-shaped and almost similar in size. They only differed in material combinations. They all showed significant abrasion ($P < 0.01$). However, the values of abrasion differed remarkably. Attachment 7ad was only 0.09 % and attachments 5 and 6ad were respectively 1.55 % and 1.80 %. The gold matrix / titanium patrix combination among the three combinations showed the most stable abrasion rate. The matrix parts of these three Dolder attachments were also observed during 15,000 cycles. The titanium matrix of attachment 6ad among three Dolder bars was severely abraded and showed severe abrasion fragments. Also, attachment 6ad among the three Dolder bars only showed significant retention loss ($P < 0.01$). This means that titanium is not a suitable material for the matrix part. These results are similar to the results of ball attachments according to the material combination.

The gold matrix / titanium patrix combination for both bar and ball attachments showed the highest retention forces and the least retention loss during 15,000 cycles in this study.

The 3i O-RING consisted of a titanium ball and white rubber ring in the metal holder. The white rubber rings of the 3i O-RING attachment were made white by distilled water in the bath during 15,000 cycles in 27 hours. The white rubber ring was almost ruined (Fig. 8b) and this attachment showed significant retention loss ($P < 0.01$). The Brånemark plastic caps (O-Ring) with gold ball attachment also showed abraded rubber ring and significant retention loss ($P < 0.05$). Thus, extremely weak materials like rubber rings are responsible for severe abrasion, contamination of water and retention loss. This means that rubber is not a suitable material for long life span of attachments.

In conclusion, the patrix part of the ball attachments which were made of titanium were hardly abraded in this study. The test results of the titanium ball were superior to those of the gold ball. In the same way, the titanium Dolder bar with the gold matrix showed the least abrasion amount among three kinds of materials for the Dolder bar combinations (the gold / gold patrix combination, the titanium matrix / titanium patrix combination and the gold matrix / titanium patrix combination). Thus, the best combination is to make the matrix from flexible materials like gold, and the patrix which needs no flexible portion from hard materials like titanium. Also, the retentive part of the matrix does not have to be made from extremely soft materials like a rubber ring of the 3i O-RING attachment.

Design of attachments

Wirz[6] reported that the retainer must make use of the entire length of the bar, because this helps absorb horizontal forces better.

The Dolder bar attachment has been used as the main retainer of overdenture on both the natural teeth and the implants, and has been reported in many successful clinical studies. The main advantages of it include big size and the firm broad contact between the bar and the matrix.

The retention forces of the attachments were controlled by the fatigue of materials and friction between the matrix and patrix. In this study, four kinds of Dolder attachments with gold matrix (5, 7ad, 13 and 14ad) were used. Even though these four attachments showed significant abrasion ($P < 0.01$), they did not show significant retention loss. This indicates that the gold matrix maintained flexibility during 15,000 cycles. It is supposed that big size attachments can resist against the fatigue of materials more than small size attachments. For example, attachment 1ad showed no significant abrasion but significant retention loss ($P < 0.05$). It indicates increased fatigue of the matrix. Attachment 1ad consists of a round gold bar and two gold clips. The gold clip is far smaller than the Dolder matrix.

Also, attachments 8, 10 and 12 have the same design and same material combinations. The size of attachment 10 is bigger than attachments 8 and 12(Table Ⅱ). Attachment 10 showed no significant abrasion and no retention loss. Although attachment 8 showed no significant abrasion, it showed significant retention loss ($P < 0.01$). Attachment 12 showed significant abrasion ($P < 0.01$). Attachment 10 showed more stable results than attachments 8 and 12. Thus, big size attachments are profitable for overdenture therapy, and two attachments with big size matrix appears to resist against the fatigue of material well.

The gold caps of ball attachments tested in this study have 4 or 6 lamellae. The Brånemark gold cap has 6 lamellae on the flexible portion. And the 3i, the Straumann and the Friatec/IMZ have 4 lamellae on the flexible portion (Fig. 13).

The results of the 4 lamellae gold caps (attachments 8, 10 and 12) were superior to those of the gold cap (attachment 3) with 6 lamellae in this study. This suggests that increasing the number of lamellae in the gold cap is equal to decreasing the retention force and the attachment size. However, because these two kinds of gold caps used different patrix materials in this study (caps with the 4 lamellae were combined with the titanium patrix and cap with the 6 lamellae was combined with the gold patrix), we are not sure whether the number of lamellae has any relationship with retention forces and fatigue or not. This aspect needs further study in the future.

Role of spacer

In contrast to natural teeth, implants do not have an alveolar ligament. Therefore implants have no vertical resilience. It is likely that the role of the spacer is more important in tissue and implant borne overdentures than in tissue and tooth borne overdentures. Many commercial gold cap ball attachments do not have a spacer. When any attachment system of implant retained overdenture is not applied with a spacer, vertical translation do not occur. Thus, mastication force will need to be concentrated on the attachment of the implant and small area on the posterior residual ridge. The Brånemark plastic cap ball attach-

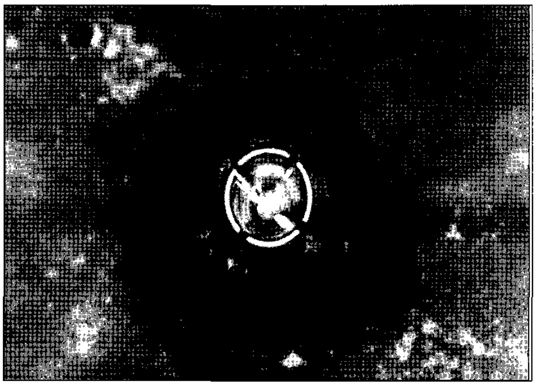

Fig. 13a. Gold cap with 4 lamellae (the 3i, the Straumann and the Friatec/IMZ system).

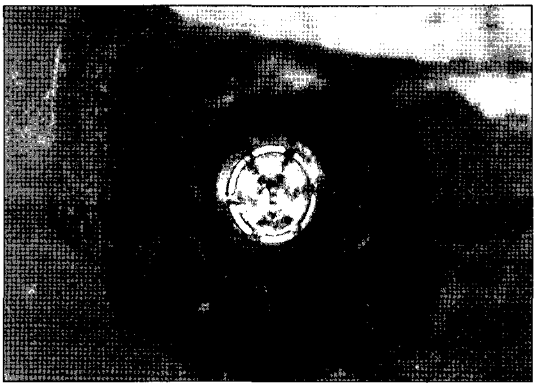

Fig. 13b. Gold cap with 6 lamellae (the Brånemark system).

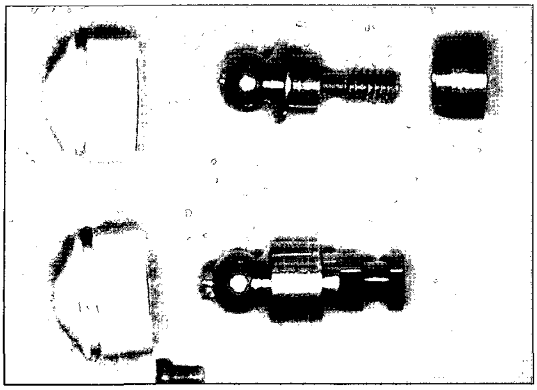

Fig. 14. The plastic cap with the rubber-ring and spacer of the Brånemark plastic cap ball attachment.

ment is a unique attachment with a spacer among the tested ball attachments. It is likely that this system has a more suitable design for ball attachments retained overdenture (Fig. 14).

Almost all attachments do not have special instruments to fix the right angle to the occlusal plane or parallel to the long axis of the implant fixture when attachments are cured to the denture in the laboratory or in the oral condition. These instruments should be developed to facilitate correct mounting of the attachments.

In a clinical situation, many factors can affect the retention of implant retained overdenture, and it is difficult to predict the clinical action of attachments from laboratory tests. This means that the results presented in this study are limited to in vitro correlation and can only be carefully transferred to the clinical situation. Further clinical studies are necessary to test the attachments clinically and to describe the behavior under clinical conditions.

CONCLUSION

On the basis of the laboratory study, some conclusions are as follows.

1. Abrasion of attachment directly affected retention loss. In this study, seven attachments (2, 3, 4, 5a, 6ad, 11 and 13a) with severe abraded patrix and matrix showed significant retention loss ($P < 0.05$).
2. The Friatec/IMZ POM matrix (plastic clip) with round gold bar attachment (9) did not show significant retention loss and significant abrasion in this study. Even though attachment 9 did not have high retention force, initial retention forces were maintained during 15,000 cycles.
3. The best combination is to have the matrix made from flexible materials like gold and the patrix which needs no flexible portion from hard materials like titanium. The patrix part of the ball attachments which were made of titanium were hardly abraded in this study. The test results of the titanium ball were superior to those of the gold ball. In the same way, the titanium Dolder bar with the gold matrix showed the least abrasion amount among three kinds of materials for the Dolder bar combinations (the gold matrix / gold patrix combination, the titanium matrix / titanium patrix combination and the gold matrix / titanium patrix combination). Also, the retentive part of the matrix does not have to be made from extremely soft materials like rubber ring of the 3i O-RING attachment.
4. The big size attachments can resist against the fatigue of materials more than small size attachments. Attachments 8, 10 and 12 have the same design and same material combinations, attachment 10 which is bigger in size than attachments 8 and 12 showed no significant abrasion and no significant retention loss during 15,000 cycles. On the other hand, attachment 8 showed significant retention loss ($P < 0.01$) and attachment 12 showed significant abrasion ($P < 0.01$) during 15,000 cycles. Also, the Dolder bar attachments showed no significant retention loss, but the Brånemark gold clip attachment showed significant retention loss ($P < 0.05$). Thus, the big size attachments are profitable for

overdenture therapy retained by two attachments. The retention loss of gold caps with the 4 lamellae (attachments 8, 10 and 12) showed more stable and higher retention forces than that of the gold cap (attachment 3) with 6 lamellae in this study. It may be suggested that increasing the number of lamellae in the gold cap is equal to decreasing the retention force and treatment size. Thus, the gold cap with 4 lamellae can resist against the fatigue of material more than the gold cap with 6 lamellae.

5. The Brånemark plastic cap ball attachment is a unique attachment with a spacer among the tested ball attachments. It is likely that this system has a more suitable design for ball attachments retained overdenture (Fig. 14).

This study did not consider clinical situations such as destructive lateral force, contamination of attachment, and long time soaking in an oral situation. Moreover, the retention characteristics of an attachment system cannot be defined by the vertical breakaway force alone. Therefore, caution must be taken against the direct extrapolation of the results to clinical situations. Nevertheless, this study does provide good information concerning the choices of the proper attachment.

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