Clinical Performance and Material Properties of Single-Implant Overdenture Attachment Systems

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Purpose: The aim of this study was to evaluate the mechanical properties of different attachment systems used for mandibular single-implant overdentures and to compare their wear/deformation features with clinical performance in patients after 1 year. ***Materials and Methods:*** Three attachment systems were evaluated: large 5.9-mm titanium nitride–coated ball attachments with plastic matrices, standard 2.25-mm uncoated titanium alloy ball attachments with Dalla Bona–type gold alloy matrices, and Locator attachments of titanium nitride–coated patrices and nylon matrices. The hardness and elastic modulus of the systems were determined using the nanoindentation technique. Twelve attachments from each system were used in 36 edentulous patients to support mandibular single-implant overdentures. After 1 year, 5 samples from each system were retrieved and evaluated for wear changes under a scanning electron microscope. ***Results:*** The titanium nitride–coated patrices, regardless of system, appeared unchanged and did not require any maintenance. Extensive wear was evident in the uncoated titanium alloy patrices and Dalla Bona–type gold alloy matrices, resulting in high maintenance (15 activations). Minimal wear was observed in the plastic matrices with minimal maintenance (2 replacements). The Locator nylon matrices showed extensive deformation and deterioration with a substantial need for maintenance (16 replacements). The performance of the patrices was related to hardness, while that of the matrices was related to the creep response. ***Conclusions:*** Large ball attachment systems of titanium nitride–coated patrices and plastic matrices reflect favorable wear behavior and clinical performance. These attachments are recommended for patients receiving mandibular single-implant overdentures. *Int J Prosthodont 2011;24:247–254.*

Internationally, two oral implants have been used successfully to support mandibular overdentures in edentulous patients when opposing complete maxillary dentures.[1] However, recent findings suggest that a single implant in the mandibular midline symphysis can be equally successful for mandibular overdenture support.[2–4] This is both a less invasive surgical intervention and a more cost-effective approach, and is especially suitable for older edentulous patients.

Attachment systems of varied designs (balls, bars, magnets, or telescopic copings) and materials (metallic, polymeric, or a combination) are used to provide retention and stability for implant overdentures.[5,6] Ball attachments, in particular, have wide universal application since they are simple and cost-effective.[5,7] The mode of retention between the patrices and matrices of these attachments is generally frictional.

One major concern with attachment systems for implant overdentures is that wear changes over time, reflected clinically in loss of retention.[8] Wear is a complex process involving a loss of material from one or two surfaces in relative motion against one another; the mechanisms involved could be adhesive, abrasive, surface fatigue, or corrosive.[9] In addition, deformation of the softer polymeric- and gold alloy–based attachment systems may also take place.[8]

Surface changes with subsequent loss of frictional contacts between attachment components were observed in vitro[10–13] and thought to be material-dependent.[6,13,14] Hardness and elastic modulus, in particular, may influence the wear behavior of attachment systems[6]; however, the precise wear mechanisms involved remain speculative.

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Table 1 Specifications of the Attachment Systems Investigated

Attachment system	Material
Large ball attachment	
Patrix: large 5.9-mm-diameter ball	Unalloyed grade 4 titanium with titanium nitride coating 2.0- to 3.0-μm thick
Matrix: large 7.6-mm-diameter plastic cap	Plastic resin, Hostaform (polyoxymethylene copolymer)
2.25-mm standard ball attachment	
Patrix: standard 2.25-mm-diameter ball	Grade 5 titanium alloy: Ti 90%, Al 6%, V 4%
Matrix (Dalla Bona–type): 3.0-mm-diameter gold alloy matrix	Gold alloy (Orax): Au 67%, Pt 8.5%, Ag 13.5%, Cu 10.8%
Locator attachment	
Patrix: Locator 4.0-mm-diameter abutment	Grade 5 titanium alloy (Ti 90%, Al 6%, V 4%) with titanium nitride coating 2.0- to 5.0-μm thick
Matrix: nylon 4.7-mm-diameter male insert	Nylon resin, DuPont Zytel 101L NC-10 ASTM D789

Ti = titanium; Al = aluminum; V = vanadium; Au = gold; Pt = platinum; Ag = silver; Cu = copper.

Wear of attachment systems has been mainly determined by observing the retentive force changes under in vitro loading conditions[10–13,15–17] and quantified roughly by measuring the dimensional changes of the attachment systems.[12] Other studies have evaluated wear of attachment systems under higher magnification using scanning electron microscopes.[11,13] The findings described structural and dimensional changes, the extent of which differed between metallic and polymeric attachments.

Findings from in vitro–induced wear are known to be of limited clinical relevance.[16,18,19] This arises because the complex oral environment and the multidirectional forces applied to the attachment systems are difficult to replicate in vitro. Hence, only under actual clinical conditions can wear of attachment systems be evaluated precisely.

The purpose of this research was to evaluate the mechanical properties of three attachment systems for mandibular single-implant overdentures and to relate the wear and deformation features with their clinical performance in patients after 1 year.

Materials and Methods

Three types of attachment systems for mandibular single-implant overdentures were investigated: *(1)* large 5.9-mm ball attachment system of titanium nitride–coated ball patrices and plastic matrices (Southern Implants), *(2)* standard 2.25-mm ball attachment system of uncoated titanium alloy ball patrices and Dalla Bona–type gold alloy matrices (Southern Implants and Alphadent), and *(3)* Locator attachment system of titanium nitride–coated patrices and nylon matrices (Zest Anchors and Neoss International). Material composition specifications of the attachment systems are detailed in Table 1.

Mechanical Testing

The hardness and elastic modulus of the attachment systems, as supplied by their respective manufacturers, were determined using the nanoindentation technique (IBIS, Fischer-Cripps Laboratories). Three patrices and three matrices from each attachment system were used (18 samples in total). The samples were embedded in acrylic resin cylinders with a diameter of 20 mm and a thickness of 10 mm. The nanoindenter tip was calibrated using fused silica of known properties, and thermal drift prior to testing was controlled at less than 1 nm/min. Test parameters included the use of a three-sided Berkovich indenter with a maximum load of 250 mN for metallic attachments (50 mN for polymeric attachments) and a 20-second hold time at maximum load. Three indentations were made 20-μm apart across the surface of each sample. The hardness and elastic modulus were measured automatically from load versus displacement curves based on the analysis of Oliver and Pharr.[20]

Clinical Performance

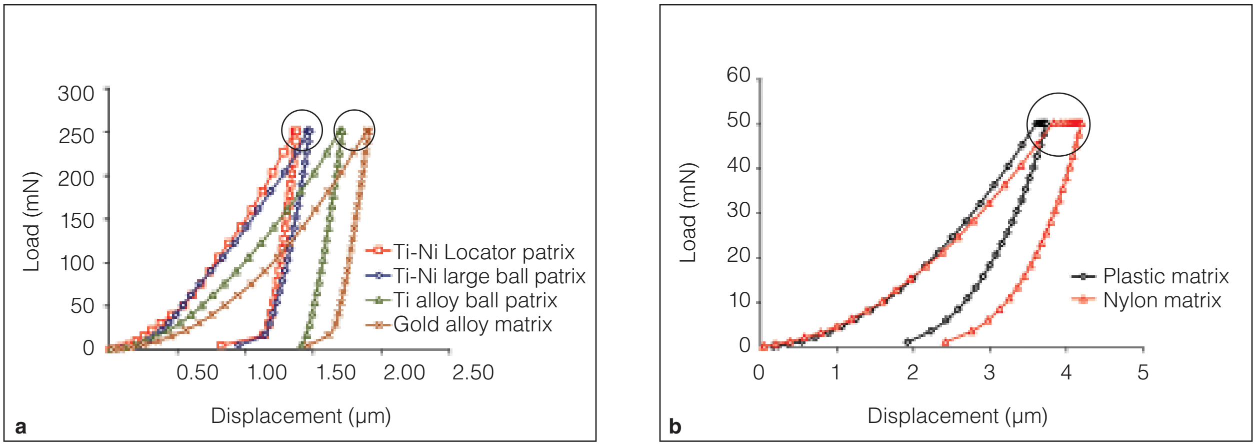
Twelve attachments from each system (36 in total) were used in 36 edentulous patients to support mandibular single-implant overdentures opposing complete maxillary dentures in a randomized clinical trial.[21] Over a 1-year period, the number and types of prosthodontic maintenance events required by each attachment system were recorded systematically.[22]

Scanning Electron Microscopic Evaluation

After 1 year of clinical use, representative samples (five from each attachment system) were carefully retrieved at random from patients and overdentures. All

Table 2 Mean (SD) Hardness and Elastic Modulus of the Attachment Systems

Attachment system	Hardness (GPa)	Elastic modulus (GPa)
Large ball attachment		
Patrix: titanium nitride–coated ball	6.49 (0.67)	164.72 (17.35)
Matrix: plastic resin	0.22 (0.06)	3.29 (0.39)
Standard 2.25-mm ball attachment		
Patrix: uncoated titanium alloy ball	4.95 (0.90)	142.65 (17.45)
Matrix (Dalla Bona–type): gold alloy	3.92 (0.65)	144.76 (25.87)
Locator attachment		
Patrix: titanium nitride–coated abutment	6.85 (0.52)	222.30 (22.52)
Matrix: nylon resin	0.14 (0.01)	3.00 (0.15)



Figs 1a and 1b Load versus displacement curves for **(a)** the metallic attachments and **(b)** polymeric attachments. Note the negligible creep in Fig 1a and the remarkable creep in Fig 1b *(circles)*.

metallic and polymeric attachment samples were examined using a scanning electron microscope (SEM; STEREOSCAN 360, Cambridge Instrument). Areas of surface wear were imaged using backscattered electron radiation, and when particles of different imaging intensity were detected, the sample was further examined under a field emission scanning electron microscope (FESEM; JEOL 6700F). The FESEM was equipped with an accessory energy dispersive spectrometer (JED 2300F, JEOL) for elemental analysis and a computer interface capable of real-time image acquisition and data processing.

Results

The nanoindentation test results are listed in Table 2. The hardness and elastic modulus of the attachment systems are expressed as means and standard deviations of nine measurements recorded for each attachment system. Typical load versus displacement curves for metallic and polymeric attachments are illustrated in Figs 1a and 1b, respectively.

At the maximum load of 250 mN, the hardness of the titanium nitride–coated Locator patrices was slightly higher with a shallower depth of indentation (approximately 1.33 µm) than that of the titanium nitride–coated large ball patrices (approximately 1.47 µm). The creep response of the titanium nitride–coated patrices was negligible. The uncoated titanium alloy ball patrices and gold alloy matrices demonstrated lower hardness values than the coated patrices. The depth of indentation of the much softer gold alloy reached approximately 1.88 µm at a maximum load of 250 mN, compared with approximately 1.55 µm for the stiffer titanium alloy. Both materials did not display any notable creep response (Fig 1a).

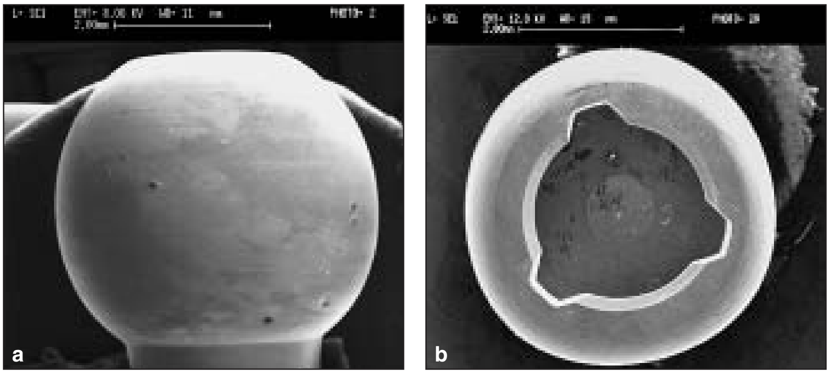
The polymeric matrices of plastic (Hostaform polyoxymethylene copolymer) and nylon (DuPont Zytel 101L) composition were the softest, as expected, with remarkable creep. The creep response of nylon was almost twofold that of the plastic at a 50-mN maximum load (Fig 1b).

Documentation of the clinical performance accumulated a total of 33 maintenance events related to the

Table 3 Maintenance Record by Type and Number for the Attachment Systems over 1 Year

	Maintenance event	
Attachment system	Activation	Replacement
Large ball attachment		
Patrix: titanium nitride–coated ball	0	0
Matrix: plastic resin	0	2*
Standard 2.25-mm ball attachment		
Patrix: uncoated titanium alloy ball	2†	0
Matrix (Dalla Bona–type): gold alloy	13†	0
Locator attachment		
Patrix: titanium nitride–coated abutment	0	0
Matrix: nylon resin	0	16*
Total events	15	18

*Not amenable to activation to maintain retentiveness, need to be totally replaced.
†Can be activated by tightening the four-finned retentive lamellae to maintain friction with the opposing ball.



Figs 2a and 2b SEM micrographs of the titanium nitride–coated patrices after 1 year with absence of detectable wear. **(a)** Large ball patrix (Southern). **(b)** Locator patrix.

matrices and patrices of the attachment systems in 1 year (Table 3). The large ball attachment system required 2 replacements of its plastic matrices because of inadequate retention. The standard 2.25-mm ball attachment system required 15 activations (2 patrix, 13 matrix) to maintain adequate retention. Sixteen nylon matrices of the Locator attachment system were replaced as a result of loss of retention or damage.

Results of the SEM observations showed that after 1 year of service, the titanium nitride–coated large ball patrices in contact with the plastic matrices appeared unaffected by the wear process (Fig 2a). The area of maximum convexity of the patrices, which forms the principal area of frictional contact, remained intact with no discernible signs of surface abrasion, erosion, or deterioration. The titanium nitride–coated Locator patrices in contact with the nylon matrices also appeared unaffected (Fig 2b). Their inner and outer ring peripheries, the main areas of frictional contact, remained free of abrasive wear or surface deterioration. On the other hand, the uncoated titanium alloy ball patrices in contact with the gold alloy matrices demonstrated extensive material loss, abrasion, and gouging (Figs 3a and 3b). Wear tracks along the path of insertion and removal and across the circumference were distinct, extending to the subsurface layers (Fig 3b). The surface loss in some patrices rendered them cylindric in shape, with loss of areas of maximum convexity. Observation under FESEM and results of elemental analysis confirmed the presence of gold alloy wear debris within the area of surface loss of the titanium alloy balls (Figs 3c and 3d). The gold alloy debris was concentrated across and below the area of maximum convexity of the titanium alloy balls (main area of frictional contact, Fig 3b). The counterparts, the gold alloy matrices, demonstrated considerable deformation and adhesive failure (Figs 4a to 4d). The retentive lamellae of the gold alloy matrices, forming the initial points of contact with the opposing titanium alloy balls, demonstrated adhesive wear with apparent material flaking and sloughing (Fig 4c). The inner surfaces of the retentive lamellae appeared deformed plastically (Fig 4d).

Figs 3a and 3b SEM micrographs of the titanium alloy patrix (Southern). **(a)** New titanium alloy patrix. **(b)** Appearance after 1 year showing extensive material loss *(circle)*. Note the scattering of gold alloy wear debris *(insert)*.

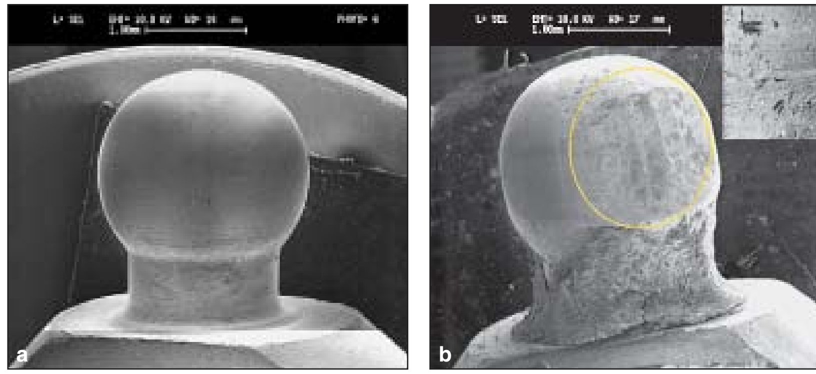
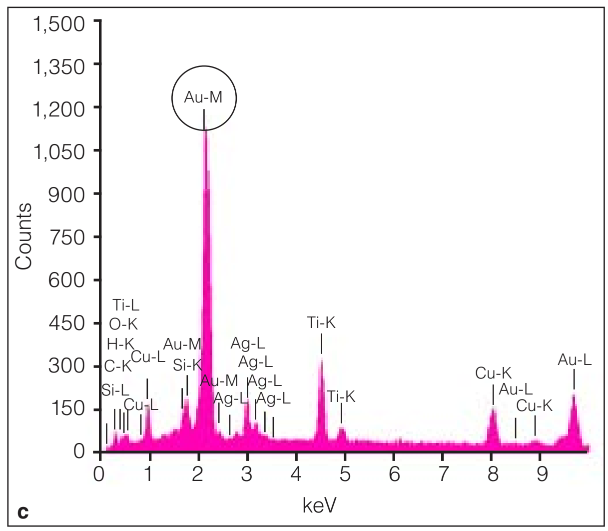
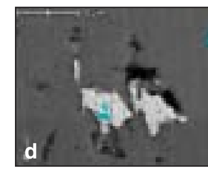


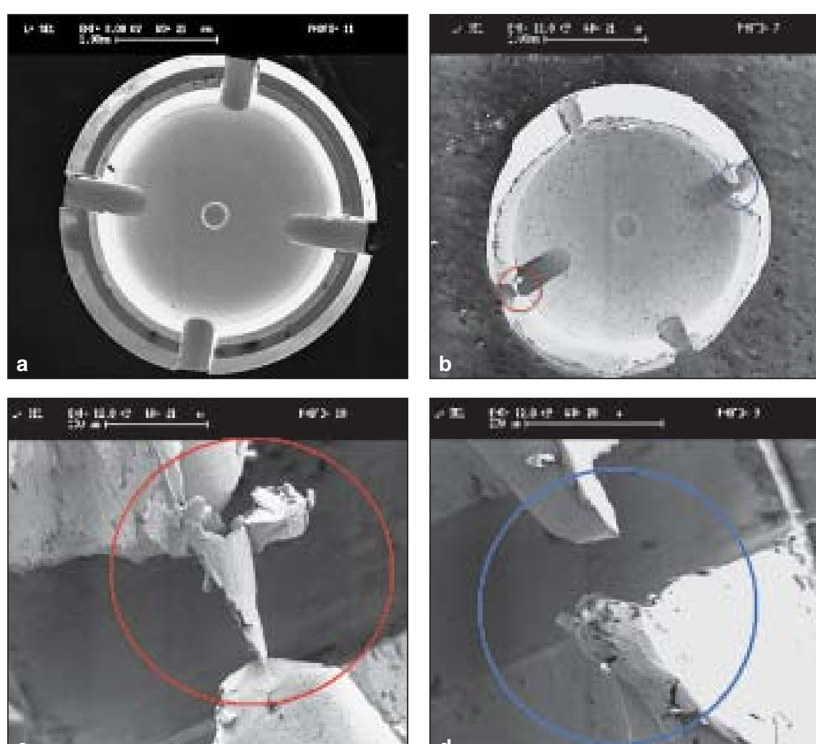
Fig 3c Elemental analysis identifying adhesive failure with evidence of gold alloy transport to the titanium alloy patrix *(circle).*

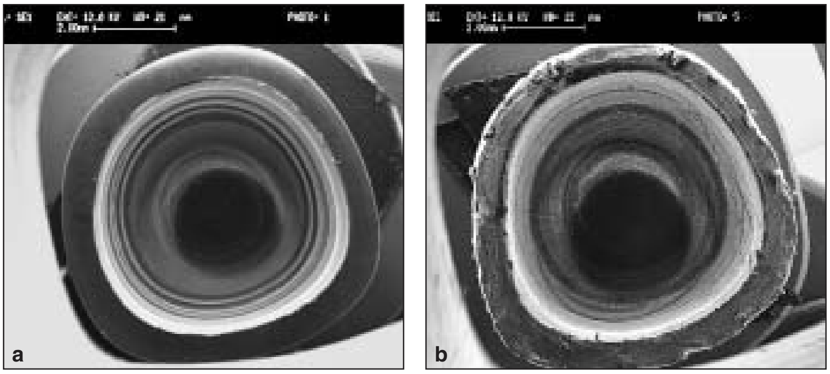
Fig 3d FESEM micrograph identifying gold alloy particles within the worn surface of the titanium alloy patrix.



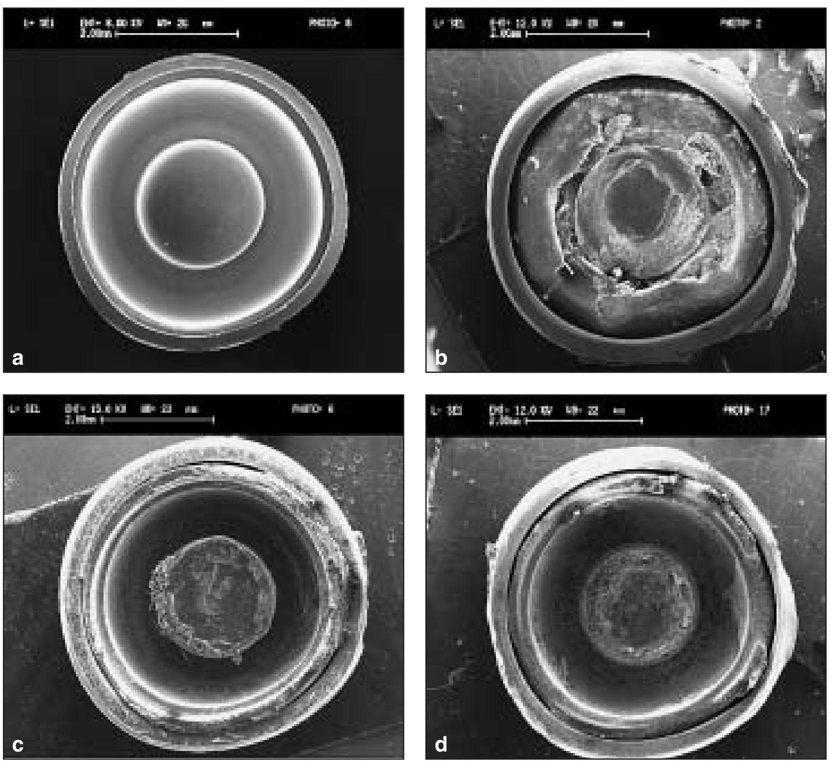


Figs 4a to 4d SEM micrographs of the Dalla Bona–type gold alloy matrix (Alphadent). **(a)** New gold alloy matrix. **(b)** Appearance after 1 year with evidence of extensive wear process *(circles)*. **(c)** Adhesive failure with material sloughing and flaking of the retentive lamellae. **(d)** Plastic deformation of the inner surface of the retentive lamellae.





Figs 5a and 5b SEM micrographs of the plastic matrix (Southern). **(a)** New plastic matrix. **(b)** Appearance after 1 year showing minimal scoring of the internal surfaces.



Figs 6a to 6d SEM micrographs of the Locator nylon matrix. **(a)** New nylon matrix. **(b)** Plastic deformation and detachment of the nylon patrix from its metal housing. Note the debris accumulation underneath the deformed areas. **(c)** Surface deterioration of the central portion of the nylon patrix and detachment from its metal housing. **(d)** Deterioration of the outer margins of the nylon matrix and detachment of the edges from the metal housing.

The plastic matrices appeared only slightly affected, with minimal scoring of the internal surfaces in contact with the opposing large titanium nitride–coated ball patrices (Figs 5a and 5b). The nylon matrices, on the other hand, demonstrated extensive deterioration and plastic deformation (Figs 6a to 6d). Detachment of the nylon matrices from the metal housings (Figs 6b to 6d) with plaque and debris accumulation underneath the deformed areas (Fig 6b) was evident. Surface rupture and material loss from the central portion of the nylon matrices, in frictional contact with the inner ring of the titanium nitride–coated patrix, was also apparent (Fig 6c). No sign of metal transport between the titanium nitride–coated patrices and their plastic or nylon counterparts was found.

Discussion

This research compares the mechanical properties and describes the wear features and clinical performance of three different types of attachment systems for mandibular single-implant overdentures. The fact that the attachment systems were subjected to actual masticatory function in patients for 1 year is distinctive. While this short period of prosthesis use may be considered a limitation, there is evidence that failure of attachment systems for implant overdentures is greatest during the first year of service.[23,24]

Mechanical testing identified the titanium nitride–coated Locator and the large ball patrices as the hardest, with a slightly higher value for the former.

According to the manufacturers, the thickness of the titanium nitride coating is between 2 and 3 and 2 and 5 µm for the large ball and Locator patrices, respectively. The depth of indentation at full load, therefore, was well within the domain of the titanium nitride coating. The difference in hardness between the two coated patrices could only be attributed to the differences in their titanium nitride layer thickness.

The extensive creep response observed with the plastic and nylon matrices was expected and in accordance with their material composition, in contrast to the metallic attachments. The creep response, however, was greater and concurrent with a deeper penetration depth with the nylon matrices compared to the plastic matrices. This could be related to specific composition differences between the two materials.

Different mechanisms of wear were also demonstrated. The titanium nitride–coated patrices did not reflect detectable wear behavior, which could be related to the increased surface hardness imparted by the titanium nitride coating. These patrices also did not require any clinical maintenance, a finding that further validates the SEM observations. The opposing polymeric matrices, on the other hand, differed in their wear behavior clinically and structurally. This correlates with the minimal wear observed under SEM with the plastic matrices compared with the more extensive deformation and deterioration of the nylon matrices. The mechanism involved in the nylon surface loss seems to be gross surface deformation and cohesive failure, resulting in significant deterioration. The differences in the clinical and wear performance observed between the plastic and nylon matrices could be related to specific differences in their physical and mechanical properties. The extent of creep deformation of the nylon at maximum load is almost double that of the plastic material (see Fig 1b). Nylon also has a lower glass transition temperature (Tg) and a stronger affinity to uptake water, resulting in a further lowering of the Tg.[25] In the moist oral environment of 37°C, more creep would be expected in nylon, contributing to the observed deformation and wear process. The in vitro findings presented are in agreement with those reported by other investigators[11,12] on attachment systems of similar materials, although the specific wear mechanisms involved were not fully described.

The extensive material loss in the uncoated 2.25-mm titanium alloy ball patrices and their gold alloy matrices was notable. The mechanism of wear involved seems to be adhesive failure leading to plastic deformation of the softer gold alloy matrices, as well as abrasive/adhesive wear of the titanium alloy balls. The presence of gold alloy wear debris between the contacting surfaces further indicates that a high coefficient of friction was present, resulting in an adhesive material transport that exacerbated the material loss. The frequent clinical need for activation of the gold alloy matrices to compensate for the material loss and to maintain retentiveness correlates with the wear response. These findings are in contrast to a recent in vitro study[13] on a similar attachment system (titanium alloy patrices opposing gold alloy matrices). In that study, only minimal wear was observed under SEM with no significant loss of the retentive force after 50,000 wear simulation cycles in a wet environment. It could only be speculated that differences in the specific alloy composition may have resulted in the different wear behaviors between the two attachment systems. This is also accepting the limitations of findings based solely on in vitro–induced wear.

Material selection for attachment systems for single-implant overdentures must be made with the objective of reducing wear to ensure service longevity and reduce maintenance cost. The large 5.9-mm ball attachment system of titanium nitride–coated patrices and plastic matrices presented favorable wear resistance and clinical performance. It has also demonstrated a significantly higher retentive force than the other two attachment systems.[26] This attachment system seems to be the preferred option for use with mandibular single-implant overdentures. Caution is recommended with regard to using Locator nylon matrices or combinations of titanium alloy patrices with gold alloy matrices in attachment systems for mandibular single-implant overdentures.

Conclusions

For patients receiving mandibular single-implant overdentures to oppose complete maxillary dentures, titanium nitride–coated patrices, regardless of system, have favorable wear behavior and clinical performance compared with uncoated patrices. The performance of the plastic (Hostaform polyoxymethylene copolymer) and nylon (DuPont Zytel 101L) matrices appears to be related to their creep response. Titanium alloy patrices with gold alloy matrices are associated with adhesive failure and extensive material loss. Therefore, large ball attachment systems of titanium nitride–coated patrices and plastic matrices are recommended for patients receiving mandibular single-implant overdentures.

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