Rationale for a novel attachment system for implant-supported overdentures

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Abstract

Purpose: To quantify the effect of support stiffness on the retention forces of telescopic crowns and to evaluate a prototype attachment system incorporating a nickel-titanium element. Materials and Methods: In the first part of the study, telescopic crowns were fabricated employing standard laboratory procedures. For six combinations of telescopic crowns, the separation force was determined while varying the stiffness of their supporting implants. In the second study part, an in vitro mandibular model with three interforaminal implants was equipped with strain gauges and extensometers. Two prostheses either
employing cylindrical telescopic crowns or prototype attachments were fabricated and
statically loaded on the model using either the midline or the left canine or both canine
implants for support while strain in the peri-implant area and prosthesis displacement were
recorded. Statistical analysis of both study parts was based on pairwise comparisons with
the level of significance set at $\alpha = .05$. **Results:** With one exception ($P = .161$), for each
assembly of two telescopic crowns, the separating force was always dependent on the
stiffness of the supporting implants. With 3 exceptions out of a total of 14 comparisons for
peri-implant strain and prosthesis displacement, the use of the prototype attachments always
led to significantly lower mean values compared to the use of cylindrical telescopes ($P < .00$).

**Conclusion:** The individual retention force of telescopic crowns on implants should be set at
a lower level compared to telescopic crowns on natural abutments. Incorporating a nickel-
titanium element into attachment systems for implant-supported removable prostheses
reduces peri-implant strain and may facilitate the use of telescopic crowns. *Int J Prosthodont
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**Introduction**

A wide variety of attachment systems including bars, ball anchors, magnets, locators and
telescopic crowns\(^1\) is available for retaining removable prostheses on dental implants.\(^2\)
Single attachments not directly splinting different implants seem to be advantageous with
respect to restorative flexibility and patients' hygiene measures.\(^3\) A minimum of two implants
are considered being necessary for retaining a mandibular complete denture.\(^4,5\) If those
implants are not parallely aligned with each other,\(^6,7\) increased wear of attachment matrices
and/or patrices has been observed.\(^8-11\)

Although prefabricated conical telescopic crowns are available for implant-retained
prostheses,\(^12\) these attachments are frequently individually fabricated causing substantial
labatory fees.\(^13\) When using telescopic crowns on natural teeth, a reduction in retention
force can be observed in the initial phase of service, which appears being due to the
presence of a periodontal ligament allowing for lateral flexibility. On the contrary, such a reduction in retention force seems not to occur when dental implants are used as abutments for telescopic crowns. Consequently, Krennmaier et al. reported problems in adjusting an equilibrated retention when several telescopic crowns on implants are utilized.14

Moment loading caused by mandibular deformation15 and displacement of the prosthesis during mastication16,17 is another critical factor of rigid attachment systems. The uncoupling effect of magnets as well as the use of non-rigid telescopic crowns has been described as being advantageous17 but corrosion phenomena18 and the complicated fabrication respectively limit the use of both attachment types. Three clinical studies may be seen as providing evidence for the potential risk of moment loads on implants. Krennmair et al.19 showed reduced maintenance need when non-rigid telescopic crowns were used as compared to ball anchors while Weng and coworkers found rigid telescopic crowns on two maxillary implants performing worse than identical restorations on natural teeth.20 The more compact structure of mandibular bone as compared to the maxilla tolerating moment loads has been described as a biomechanical reason for the overall good performance of mandibular prostheses supported by two implants.21

As a novel concept, mandibular single implant prostheses utilizing one implant placed in the mandibular midline have been proposed as a low-cost option aimed at increasing positional stability of complete dentures.22-24 For avoiding rocking movements of the prosthesis,22,24 the implant is placed as far anterior as possible although anatomical risk factors such as the lingual neurovascular canal25-27 would favor alternative positions such as the canine region.28 Despite these measures, prosthetic maintenance is high in these cases requiring frequent replacements of worn attachment matrices and repairing fractured prostheses.28,29 The recommended use of a reinforcing metallic framework counteracts the primary intention of a cost-effective treatment solution.30

While until now resilient plastic inserts have been utilized as secondary attachment components31 to overcome the problems described, shape memory Nickel-Titanium (NiTi)
alloys have so far not been applied for introducing a cushioning function. However, different authors have already implemented NiTi in implant dentistry for constructing gap-free abutments\(^32\) and for retaining suprastructures.\(^33-35\)

The first goal of this in vitro study was to compare the separating forces of telescopic crowns on implants while varying the stiffness of their support. The null hypothesis tested was that the stiffness of the support structure has no effect on the separating force of telescopic crowns. The second goal was to compare a prototype attachment system with an intermediate NiTi element and traditional telescopic crowns as retainers for mandibular complete dentures. The null hypothesis tested was that the type of attachment had no effect on peri-implant strain and prosthesis displacement during static loading.

**Materials and Methods**

**Measurements of separating force**

Two bone level implants with a diameter of 4.2mm and a length of 10mm (SCIP1042, AlfaGate, KfarQara, Israel) were placed in aluminum holders using polyurethane resin (Biresin G27, SIKA Deutschland GmbH, Bad Urach, Germany) as embedding media (Fig. 1a). The left implant was positioned perpendicularly while the right implant was tilted with its long axis 5° towards the left implant. Using custom dental implant abutments (AGM-UCLA, AlfaGate), three telescopic crowns were fabricated for the left implant and named L1, L2 and L3 while two telescopic crowns were fabricated for the right implant and named R1 and R2. The surfaces of the telescopic crowns were adjusted so that a common path of insertion was achieved. All telescopic crowns were fabricated by standard casting and milling procedures using high-noble alloy (Wegold Norm, Wegold Edelmetalle GmbH, Wendelstein). The maximum separating forces of the secondary telescopic crowns were individually measured three times by mounting them on their respective implant and positioning them in a universal testing machine equipped with a 100N load cell (Z020, Zwick/Roell, Ulm, Germany).

Subsequently, the separating forces of a total of six combinations of left and right telescopic crowns connected using pattern resin (Pattern Resin LS, GC Europe, Leuven, Belgium) were measured.
tested. These assemblies were again positioned in the universal testing machine (Z020, Zwick/Roell) and the maximum separating forces were recorded three times. Afterwards, a trephine drill (Trephine drill 5.2/6.2, Nobel Biocare Deutschland, Köln, Germany) was used for creating a 0.5mm circumferential relieve around both implants to their full length in order to reduce the stiffness of their anchorage (Fig. 1b) and the separating forces were measured again (Fig. 2). Implant stability measurements based on resonance frequency analysis (SmartPeg, Osstell ISQ, Osstell AB, Gothenburg, Sweden) were conducted both in the status as embedded in resin and following trephining. The process of trephining could be reversed by applying low viscosity polyurethane resin.

In vitro strain and displacement measurements

Three bone level implants with a diameter of 4.2mm and a length of 10mm (SCIP1042, AlfaGate) were positioned in the midline and canine regions of an acrylic resin model (ProBase Cold, Ivoclar Vivadent, Schaan, Liechtenstein) reflecting a human mandible (Fig. 3a). Strain gauges (LY11-0.6/120, 120Ω reference resistance, Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germany) were attached to the model material mesially and distally adjacent to the implants.\textsuperscript{17, 36-38} In the posterior area of the model, the alveolar process was split horizontally and metal rods were incorporated in the upper and lower sections allowing for extensometers (Extensometer, Sandner Messtechnik GmbH, Biebesheim, Germany) to be attached.\textsuperscript{39} Finally, a soft tissue mask with an approximate thickness of 2mm was created using polyether material (Vestogum, 3M Espe).\textsuperscript{40} In this status the model could be used for supporting mandibular prostheses during simulated static loading in the premolar/molar area (Fig. 3b).

Transfer copings for open-tray impressions (AGM-302-C, AlfaGate) were then attached to the implants and the implant positions were recorded using a custom tray (PalatrayXL, Kulzer GmbH, Hanau, Germany) and polyether impression material (Impregum, 3MEspe, Seefeld, Germany). Following standard definitive cast fabrication (Fujirock EP, GC Europe); two prostheses incorporating attachments for all three implants were fabricated following
standard laboratory procedures. Besides cylindrical telescopic crowns, prototype NiTi attachments were used (Fig. 4). The cylindrical telescopic crowns were fabricated on the basis of screw-retained abutments (AGM-207-2H, AlfaGate) using dental training alloy (Phantom-Metall NF, Dentsply Sirona Deutschland GmbH, Bensheim, Germany) employing standard casting and milling procedures. The prototype NiTi attachments were fabricated on the basis of stock conical double crowns (Ankylos SynCone, Ankylos Taper Cap for Syncone, DENTSPY Implants Manufacturing GmbH, Mannheim, Germany). These components were modified such way that they could be mounted on modified healing abutments (Standard healing cap, AGM-203-3, AlfaGate) incorporating an intermediate NiTi element derived from rotary endodontic files (FlexMaster, VDW GmbH, Munich, Germany).

Both prostheses were positioned on the acrylic resin model either employing only the midline implant (Fig. 5) or the left canine implant (position 33 FDI) or both canine implants (positions 33 and 43 FDI) while the remaining implants were left without an abutment. Following positioning in the universal testing machine (Z020, Zwick/Roell), a force of 100N was applied in the second premolar / first molar area using the universal testing machine equipped with a 100N load cell (Z020, Zwick/Roell, Ulm, Germany). A measurement amplifier (Quantum X, Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germany) and analyzing software (jBEAM, AMS GmbH, Chemnitz, Germany) were used for recording strains at the supporting implants and displacement at the extensometers during loading.

Statistical analysis (R, The R Foundation for Statistical Computing, Vienna, Austria; www.R-project.org) of separation force measurements was based on pairwise comparisons. Strain and displacement data were also analysed using pairwise comparisons based on one sided t-tests with Bonferroni adjustment according to the Holm method for multiple comparisons. Shapiro-Wilks tests were performed for verifying normal distribution of measurement values. The level of significance was set at α=0.05 for all comparisons.

Results

Measurements of separating force
The two implants used for this experiment showed mean stability (ISQ) values of 85 (left implant) and 83 (right implant) when fully embedded in resin. Following trephining, the stability had decreased to means of 46 (left implant) and 50 (right implant). The mean separating forces for the individual telescopic crowns (Tab. 1a) ranged from 0.0N (+/- 0.0) to 19.2N (+/- 1.53). The mean separating forces of two combined telescopic crowns measured on embedded implants ranged from 13.7N (+/- 1.36) to 58.6N (+/- 4.45) while the mean separating forces of two combined telescopic crowns measured after trephining ranged from 12.0N (+/- 0.36) to 44.1N (+/- 3.78). For each assembly of two telescopic crowns, the separating force was always higher in embedded implants as compared to the situation after trephining (Tab. 1b). With the exception of combination telescopic crown L3 / telescopic crown R2 (p=0.161) this difference was always statistically significant.

In vitro strain and displacement measurements

The mean values and standard deviations for both, strain and displacement measurements are given in tables 2a-c. Overall, the lowest measurement values were recorded when only the midline implant had been used for retaining the prosthesis. While prosthesis displacement did not change considerably, strains particularly at the distal aspect of the supporting implant were much greater when the prosthesis was retained by the implant in position 33 as compared to using the midline implant for support. As expected, using both implants in the canine positions for retention reduced mean maximum strains recorded at the implants as compared to using only the left canine implant.

Only in four out of 28 measurement series, the data obtained could not be assumed normally distributed. With three exceptions (implant midline & extensometer 3, p=1.00; implants 33 and 43 & mesial strain gauge at implant 43, p=1.00; implants 33 and 43 & extensometer 3, p=0.68), the use of the prototype NiTi attachments always led to significantly lower mean values in strain development and displacement as compared to the use of cylindrical telescopic crowns.

Discussion
This combination of in vitro studies evaluated the use of telescopic crowns on implants with respect to retention force and loading situation. Based on the results obtained in the first part of this study, the null hypothesis that the stiffness of the support structure has no effect on the separating force of telescopic crowns had to be rejected. Similarly, the observations made in the second part led to rejection of the null hypothesis that the type of attachment had no effect on implant loading and prosthesis displacement.

Despite high fabrication costs, telescopic crowns can successfully be applied for retaining removable dentures on natural teeth. When employed as attachment system on dental implants, the separating force required for removing the prosthesis has been reported to be difficult to adjust.\textsuperscript{14} In addition, considerable moment loading of the supporting implants can occur potentially causing biologic or technical problems.\textsuperscript{17,43} The basic problem seems to be that proper alignment of implants is not achieved during surgery\textsuperscript{6,7} as well as the stiffness of osseointegrated implants as compared to natural teeth. This in turn results in increased wear of attachment systems at the matrice/patrice interface\textsuperscript{8,9} despite using more or less resilient plastic inserts. Industry tries to respond to these problems by introducing angulated attachment systems and by using different types of plastic inserts forming the patrice/matrice interface of prefabricated attachments. Two recent in vitro studies in this field have shown that despite these measures retention forces still change over time indicating that a proper solution to the problem described does not yet exist.\textsuperscript{31,44}

The study at hand showed that the separation force of pairs of telescopic crowns in fact depends on the stiffness of the supporting structure with lower retention recorded when resiliency was simulated. This difference results from inaccuracies caused by positional deviations in implant positions when transferring a specific patient situation onto a definitive cast.\textsuperscript{45} While positional changes of osseointegrated implants in bone have been shown to occur when fixed restorations lacking passivity of fit are delivered\textsuperscript{46} or when orthodontic loads are exerted,\textsuperscript{47} this seems not to occur when removable prostheses are employed. As a
consequence, the separation forces for telescopic crowns on implants remain at a higher level as compared to those placed on natural teeth.\textsuperscript{14}

While considerable experience is available with the use of two interforaminal implants supporting complete dentures, the use of only one implant is comparably new.\textsuperscript{22-24} With the implant aimed at stabilizing a prosthesis, rocking movements during excentric masticatory loading has to be avoided. Using conventional attachment systems, this can only be achieved by placing the single implant as far anteriorly as possible despite the risk of harming the lingual neurovascular canal.\textsuperscript{25-27} The use of an attachment system with a cushioning function as realized here with the NiTi attachments could help reducing moment loading on implants and also might help avoiding potential rocking movements of the prosthesis.

Prior to recommending a novel attachment system, substantial development is required. It has to be kept in mind that the two experiments performed here are only indicative of the potential advantages a NiTi based attachment system might have. Several limitations have to be taken into consideration when interpreting the findings of this study. Fabricating telescopic crowns can not be standardized in particular with respect to the separating force required, which led to considerable variation in the first part of this experiment. Consistently showing that regardless of the combination of telescopic crowns used, the separating force was lower when circumferential relief was created around the supporting implants, this variation had no effect on study outcome but was the reason for fabricating several telescopic crowns and for repeatedly testing separating force. Due to the high laboratory cost associated with the fabrication of telescopic crowns, the sample size used in the first part of the study was very small and cautious statistical analysis was applied. It is well recognized by the authors that repeated trephining of the implants in the first study part is of concern as it lacks a clinical counterpart. It was neither intended to simulate a periodontal ligament nor a dental implant showing mobility. Instead, this approach seemed to be the only feasible option for creating identical models with varying levels of support stiffness as shown with resonance frequency
analysis. Also, due to that approach, it has not been possible to use only one model for both experimental parts.

Acknowledgements

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The authors wish to thank Dr. Friedrich Graef, Professor emeritus, Department of Mathematics, University of Erlangen-Nuremberg for statistical data analysis.

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T. Grobecker-Karl discloses a conflict of interest as she has filed a patent describing the novel attachment system used in this study.

References


Figure 1: Two bone level implants placed in an aluminum bar using polyurethane resin in the status „embedded“ mimicking an osseointegrated implant (a) and in the status „trephined“ mimicking implants with lateral resilience (b)
Figure 2: Pairs of two telescopic crowns were assembled using patern resin and the separation force of these assemblies was measured in a universal testing machine.
Figure 3: Model situation with three implants placed in the inerforaminal region and strain gauges attached to the model material mesially and distally adjacent to each implant. Extensometers positioned in the posterior area were used for recording displacement of the prosthesis (a). The two different prostheses were loaded occlusally in the area of the second premolar / first molar (indicated by white arrow) by applying a force of 100N in a universal testing machine (b).
Figure 4: Cross section of prototype NiTi attachment. The attachment consists of a bottom part derived from a healing abutment, a connector obtained from a NiTi endodontic instrument and a top part constituted by a prefabricated SynCone abutment (patrice and matrice).
Figure 5: Prototype NiTi attachment (attachment matrice not shown here for clarity) positioned on the midline implant in the in vitro model.
Tables

Tab. 1a: Mean values and standard deviations for separation force measurements conducted for single telescopic crowns.

<table>
<thead>
<tr>
<th>Telescopic crown</th>
<th>Mean separating force [N]</th>
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<tr>
<td>L1</td>
<td>19.2</td>
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<tr>
<td>L2</td>
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<tr>
<td>L3</td>
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<td>R1</td>
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<td>R2</td>
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Tab. 1b: Mean values and standard deviations for separation force measurements conducted for all possible combinations of telescopic crowns. Results of pairwise comparisons are given as p-values ($\alpha=0.05$) and significant differences are marked with *.

<table>
<thead>
<tr>
<th>Combination of telescopic crowns</th>
<th>Separating force on embedded implants</th>
<th>Separating force after trephining</th>
<th>Comparison embedded vs. trephining</th>
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<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
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<tr>
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<td>L2 R2</td>
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<td>L3 R1</td>
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<td>L3 R2</td>
<td>13.7</td>
<td>1.36</td>
<td>12.0</td>
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Tab. 2a: Mean values and standard deviations recorded for strains [µm/m] and displacement [µm] when the midline implant was used for supporting the prosthesis. Results of pairwise comparisons between the two attachment systems employed (one sided t-tests with Bonferroni adjustment according to the Holm method) are given as p-values (α=0.05) and significant differences are marked with *

<table>
<thead>
<tr>
<th></th>
<th>Extenso 4 NiTi</th>
<th>Extenso 4 Telescope</th>
<th>SG Midline 4 NiTi</th>
<th>SG Midline 4 Telescope</th>
<th>SG Midline 3 NiTi</th>
<th>SG Midline 3 Telescope</th>
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Abbreviations: Extenso: Extensometer; SG: strain gauge
Tab. 2b: Mean values and standard deviations recorded for strains [µm/m] and displacement [µm] when implant 33 was used for supporting the prosthesis. Results of pairwise comparisons between the two attachment systems employed (one sided t-tests with Bonferroni adjustment according to the Holm method) are given as p-values (α=0.05) and significant differences are marked with *

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<th>SG 33 mesial Telescope</th>
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Abbreviations: Extenso: Extensometer; SG: strain gauge
Tab. 2c: Mean values and standard deviations recorded for strains [µm/m] and displacement [µm] when implants 33 and 43 were used for supporting the prosthesis. Results of pairwise comparisons between the two attachment systems employed (one sided t-tests with Bonferroni adjustment according to the Holm method) are given as p-values (α=0.05) and significant differences are marked with *

<table>
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<th></th>
<th>Extenso 4 NiTi</th>
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<th>SG 43 distal Telescope</th>
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<th>SG 43 mesial Telescope</th>
<th>SG 33 mesial NiTi</th>
<th>SG 33 mesial Telescope</th>
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Abbreviations: Extenso: Extensometer; SG: strain gauge