Reliable coupling of orthodontic elements to mini-implants: An in-vitro study

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ABSTRACT

Objectives: To investigate the reliability of mechanical and adhesive methods of fixing rectangular wires in the cross-slot of a mini-implant.

Materials and Methods: A twin-hooked wire element was placed and fixed in the slot of a mini-implant via a NiTi spring under tension, or by means of an adhesive. For the purpose of mechanical anchorage, the wire was crimped with a special crimping tool to increase its thickness and prevent it from slipping through the slot. Before applying the adhesive, there were four possible methods of preparation: Untreated Wire (Adh. 1); ROCATEC-Pre (Adh. 2); ROCATEC-PRE + Espe Sil (Adh. 3); ROCATEC-PRE + ROCATEC-PLUS + Espe Sil (Adh. 4). The mechanical fixing and two adhesive fixings were aged by means of temperature change (500 cycles). A Zwick universal testing machine was used to measure the maximum strength of the coupling.

Results: In all tests, the untreated wire + adhesive withstood the lowest maximum load (Ø 3 N and 10.8 N respectively) and failed the aging test after a maximum of eight cycles. The wires in test group Adh. 4 withstood the highest maximum load (Ø 43.3 N; 41.5 N; 45.9 N after aging) in all tests. The average load withstood by the crimped ligature was 38.7 N.

Conclusion: The adhesive method of fixation performs best when the rectangular wire is sand blasted and silanized before application. The mechanical coupling using the crimped ligature is reliable.

Key words: Adhesive, coupling elements, cross-slot, in-vitro experiment, NiTi spring, orthodontic mini-implants, orthodontic wire, rectangular wire

INTRODUCTION

Mini-implants for skeletal anchorage consist of three components: the threaded shaft, the cervical area, and the head used for attaching to, or coupling with, an orthodontic appliance. With regard to the design of the head, there are two different concepts.[1] On one hand, there are screw heads to which only tension springs or round wires can be attached. This can be by means of hooks, spherical heads, eyelets, and bore holes. Mini-implants of this type cover a wide range of indications,[2] but they are not suitable for anchoring rectangular wires. The second design concept consists of mini-implants with a slot or a cross-slot. In practice, the latter have been found to be more universal in application and can be used for all types of skeletal anchorage tasks. In addition to tension springs and round wires, mini-implants with a slot or cross-slot enable the use of rectangular wires. Among other things, they facilitate three-dimensional control of tooth movement and provide excellent anchorage for the dentition.

In order to benefit from the advantages of rectangular wires, they must be securely fixed in place in the slot. First and foremost, this means that the wire must not be allowed to slip inside the slot. If this requirement is not fulfilled, the result can be loss of anchorage, which in turn, can cause unwanted tooth movement.[3] For the purpose of attaching rectangular wires, both mechanical and adhesive methods have been described. A mechanical attachment can be achieved by bending the wire, crimping it,
or applying rubber rings. The second possibility is the use of an adhesive.\textsuperscript{18} Whilst this is the fastest method, the question of stability remains.

The aim of this in-vitro experiment was to investigate rectangular wires fixed in the cross-slot of a mini-implant by mechanical and adhesive methods. The load placed on the fixation was provided by means of a NiTi spring and aging was tested by means of temperature change loads.

**MATERIALS AND METHODS**

**Preparing the Test Blocks**

All the miniscrews were screwed into plastic blocks specially prepared for this study. A plastic block (OBO-Werke GmbH and Co. KG, Obomodulan\textsuperscript{\textregistered} 302) in expanded Polyurethane with a density of 650 kg/m\textsuperscript{2} is shown in Figure 1. 20 rectangular blocks were cut from the plastic blocks (49.5 mm long, 10 mm wide, and 15 mm high). Each block received three vertical holes on the mid-line of the widest side. The holes were placed at a distance from the edge of 5 mm (hole 1), 25 mm (hole 2), and 45 mm (hole 3) and aligned perpendicular to the upper and lower surfaces of the test block. The dried and degreased mini-implants were screwed into the blocks until the floor of the slot reached a distance of 3 mm from the surface of the test block (mesially and distally). Before the mini-implants were screwed (LuZi-Screw; Denvenio, Bad König, Germany; www.denvenio.com) into the test block, they were placed in a solution of 70\% ethanol for 5 min. One of the two slots was aligned with the longitudinal axis of the test block [Figure 1]. The M3 (ISO metric thread) anchorage screw served as a fixed point for the 12 mm NiTi spring (150 g, FORESATDENT, Germany). The coupling between the screw and the spring was made using a rectangular wire (0.406 × 0.559 mm; 0.016" × 0.022", FORESATDENT). The tension spring was stretched between the S-loop and the twin-hooked wire element, the latter being treated or untreated depending on the method of fixation (as described below). This was then placed in the slot of the mini-implant. The test rig was inserted into a Zwick universal testing machine [Figure 1]. The springs were then tensioned to a force of 1.4 N. The force was then reduced to 1.0 N and was fixed at the tension spring and the position for the mechanical [Figure 2\texttextsuperscript{a}] or adhesive coupling [Figure 2\texttextsuperscript{b}].

**Mechanical Coupling/Attachment (Crimped Ligature)**

The twin-hooked wire element was marked at the level of the horizontal slot [Figure 3]. After removal from the test machine, the wire was crimped at the mark with a pair of rectangular wire crimping pliers, (Denvenio, Bad König, Germany; www.denvenio.com) as shown in Figure 4. The part of the rectangular wire compressed with the pliers [Figure 5] served to prevent the wire from slipping out of the slot. The slot entrances were sealed off with a rubber ring. This mechanical coupling is referred to as the crimped ligature [Figure 6].

**Adhesive Fixation**

For the adhesive attachment of the twin-hooked wire element, four variants or test groups were selected [Table 1]. In group (Adh. 1), the wire received no treatment before the adhesive was applied. In the other three groups (Adh. 2 to Adh. 4), the twin-hooked wire element was sandblasted with ROCATEC-PRE (3M ESPE, Seefeld, Germany) in accordance with the manufacturer’s instructions [Figure 7], in order to obtain a stronger bond. In group Adh. 3 and Adh. 4, further measures were taken to increase the bond strength [Table 1]. Immediately after this pre-treatment, the slightly viscous light-cured adhesive was applied, AdhesivFlowTain\textsuperscript{\textregistered} (Reliance Orthodontics Products, Inc.), in such a way that only the slots were covered [Figure 2\texttextsuperscript{b}]. The adhesive was cured with a polymerization light (SmartLiteTMPS / Dentsply) for 3 × 10 s.

**Measuring the Bond Strength**

The adhesive and mechanical fixations were subject to several tests in order to establish the maximum load capacity of the fixation. The twin-hooked wire element was pulled [Figure 1] until the fixation gave way. This was evident in the marked reduction in force shown in the force/distance graph [Figure 8].

The first two series of measurements were only carried out on the adhesive coupling. Twenty minutes after the adhesive had cured, the maximum load capacity for all four variants were determined (Adh. 1 to Adh. 4). The second series of tests were carried out 24 h later. During this period, the test blocks were stored in distilled water at a temperature of 37°C. In the third series of tests, an aging test was carried out on the mechanical and adhesive fixations. All ten test blocks of a series (fixation type) were screwed onto a support [Figure 9]. The artificial aging test was performed in a thermocycler (Willytec Type V2.8; Willytec, Munich).

The test comprised of 500 cycles. For each cycle, the ten test blocks were immersed for 20 s in a water bath at 55°C. After a drip time of 3 s and a transfer time of 6 s [Figure 10], the test blocks were immersed in cold water (5°C) for 20 s. The maximum load capacity of the mechanical and adhesive fixation was then measured.

**Statistical Analysis**

The statistical analyses was performed using SPSS for Windows, version 19.0 (SPSS Inc., USA). The description of continuous variables was shown as averages and medians, and the deviations were specified as standard deviations. The

**Table 1: Preparation of the twin-hooked wire element for adhesive fixation**

| Code  | Pre-treatment                  | Adhesive         |
|-------|--------------------------------|------------------|
| Adh-1 | No pre-treatment               | Flow Tain        |
| Adh-2 | Sandblasted with ROCATEC-PRE   | Flow Tain        |
| Adh-3 | Sandblasted with ROCATEC-PRE   | Flow Tain        |
|       | Coated with Espe Sil           | Flow Tain        |
| Adh-4 | Sandblasted with ROCATEC-PRE   | Flow Tain        |
|       | and ROCATEC-PLUS               |                  |
|       | Coated with Espe Sil           |                  |

ROCATEC-PRE, ROCATEC-PLUS and Espe Sil are products obtained from 3M Espe (Seefeld, Germany)
individual trials were checked by means of the Shapiro-Wilk test with regard to their normal distribution. When comparing two independent, not normally distributed samples, the Mann-Whitney U test was applied and for more than two independent variables, not normally distributed samples, the H-test to Kruskal and Wallis. When all tests were carried out, a two-sided significance check took place. For all statistical tests, a $P$ value $<0.05$ was adopted as statistically significant.
RESULTS

Twenty minutes after the adhesive had cured, the untreated twin-hooked wire element (Adh. 1) exhibited the weakest bond (3.079 N, ±3.77). The twin-hooked wire element (Adh. 4) sandblasted with ROCATEC-PRE, ROCATEC-PLUS, and coated with Espe Sil proved to be the most stable adhesive bond (43.394 N, ±10.91). The details of this series of tests are given in Table 2. There are significant differences among the bonding values of these four test groups.

After being immersed in water for 24 h, the values for the bonding strength of the untreated twin-hooked wire elements (Adh. 1) were found to have increased. Nevertheless, this type of fixation again exhibited the lowest bond strength (10.857 N, ±6.2). The details of this series of tests are given in Table 3. The bond strengths of these three test groups varied significantly.

None of the untreated twin-hooked wire elements (Adh. 1) withstood the aging test. The bond broke after a maximum of eight cycles (Ø 3.2±2.39). Like the mechanical coupling, the adhesive bonding of untreated wires (Adh. 3) withstood the planned 500 cycles of the aging test. The maximum load capacity was measured [Table 4]. At 38.797 N (±4.43), the mechanical coupling exhibited the lowest values of the two test groups. They differed significantly. In Figure 8, the Kaplan-Meier-survival distribution of the aging test simulating the oral situation is shown. The detailed results with P-values, so as standard deviation, are presented in Tables 2-7 and Figure 8.

DISCUSSION

Mechanical Coupling (Crimped Ligature)

Using rectangular wire crimping pliers to compress the wire creates a bulge in the wire over an area of a few tenths of a millimeter. If the wire fills the slot completely, this bulge is adequate to prevent the wire from slipping out of the head of the mini-implant during orthodontic treatment. In our tension test, the maximum load capacity was tested. The lowest value for the crimped ligature was 28.65 N. This means that this mechanical coupling withstood forces beyond that which would normally be exerted during orthodontic treatment. Such strong tensile forces result in the wire sliding out of the slot, since the bulge in the wire wears off and/or the relatively thin walls of the implant head bend. The alternative to crimping the wire would be an angled wire [Figure 11]. This cannot slide out of the slot.
Hence, by rounding the edges of the slot, space is created for the round contours of the right angle bend in the wire.

### Adhesive Attachment

When attaching a rectangular wire to the slot of a mini-implant, the wire must be fixed as securely as possible in order to avoid loss of anchorage during orthodontic treatment. After each series of tests, the group of treated wires with the poorest bond was excluded from the next series of tests. The untreated wire was tested during all series of tests, since this method of fixing is the most common in clinical practice and therefore acts as a reference group.

The partly uneven distribution of bond strengths probably resulted from the differing volumes and localization of the adhesive. It was difficult to obtain an even coating of adhesive and this would in any case not be representative of clinical practice. The more times the measurements were taken to increase the strength of the bond [Table 1], the lower the deviations/variation in the maximum bond strengths [Tables 2-4].

In group 1 (Adh. 1), the twin-hooked wire elements only held because the gaps between the wire and the slot walls of the implant head were filled with adhesive. The strength of this bond was entirely dependent on macroretention. In the cases of the other three series of tests (Adh. 2 to Adh. 4), the strength was due to both macro and microretention and a chemical bond. This gave a considerable improvement in retention [Tables 2-4].

Gummelt[4] tested the resistance of the adhesive attachment of a smooth rectangular wire (0.55 mm × 0.64 mm) in the cross-slot of a mini-implant. The wire was not pre-treated and was fixed with three different adhesives. The maximum strength in this trial was between 8.4 and 47.7 N. These values are considerably higher than in this study ([Table 2], Adh. 1). The results obtained by Gummelt show that the adhesive itself has a considerable influence on the strength of the fixation. In those tests, different adhesives were used than in this study. This could be a reason for the discrepancy in the values. A
further possible cause is the different mini-implants used and the somewhat different method.

After 24 h storage, the values for the strength of the bond were higher, except for one case (test series Adh. 4). This was presumably because the adhesive was not fully polymerized until quite some time after light curing. Adhesives with a low viscosity have a relatively high organic component. This is responsible for the shrinkage during polymerization. This contraction gives rise to stresses in the adhesive, which also affects the neighboring material (the wire and the slot of the mini-implant). It can therefore be surmised that the shrinkage due to polymerization also contributed to the increase in the strength of the bond.

Aging test

On average, mini-implants remain in the mouth for 6 to 12 weeks. During this time, it is essential for the orthodontic elements to be reliably fixed in the slot of the mini-implant. Depending on the type of coupling element used and the method of attachment itself (direct or indirect[5]), the coupling is subjected to a greater or lesser load. This was simulated in our study by coupling the twin-hooked wire element with a NiTi spring. Additional stresses, which could cause the materials to age, result from changes in temperature in the mouth. These effects were simulated in a thermocycler by means of water baths of different temperatures. In view of the limited clinical lifetime of mini-implants, the aging test was defined as 500 cycles. In the study carried out by Gummelt,[4] the adhesive bond on rectangular wire in the slot of a mini-implant was tested, but the measurements taken only reflected the situation immediately after the orthodontic appliance was fitted. According to our research, the present in-vitro test is the first to include a study of the effects of aging on the adhesive bond.

As was to be expected, aging has no effect on a mechanical coupling, but it does on an adhesive bond. As already indicated, the bond strength in the case of an untreated rectangular wire coupling, but it does on an adhesive bond. As already indicated, the bond strength in the case of an untreated rectangular wire is the result of these three types of bonding or retention. All values obtained during the aging test are considerably higher than the forces expected from a clinical point of view.

Orthodontic mini-implants with a cross-slot facilitate the use of rectangular wires and thereby provide better movement control or anchorage for the teeth. However, these benefits only come into play if the wire is firmly and reliably fixed in the slot during the entire functional life of the mini-implant. In this in-vitro study, only the mechanical method of fixing with the crimped ligature and adhesive attachment, by means of sandblasting, silanization and adhesive, passed the aging test. The untreated twin-hooked wire elements exhibited the weakest bond and failed the aging test.

The rectangular wire crimping plier is a special tool [Figure 5] designed for compressing a rectangular wire [Figure 6] in order to prevent it from slipping out of the slot. Although, this instrument can be used for other purposes than those shown here, its range of uses is very limited. It is therefore a relatively expensive acquisition. The alternative to the crimped wire is an angled wire [Figure 7]. This method of attachment is completely free of slippage and easy to achieve without special tools. Adhesive-bonded straight and untreated wires are at risk of slipping through the slot.[5] Apart from the time-consuming task of pre-treating the wire, expensive equipment is required which has no other use in an orthodontic practice. The easiest way to achieve the goal of securely fixing a rectangular wire without risk of it slipping out of the slot is to use a rectangular wire bent at a 90° angle. To prevent the wire from slipping out of the head, in the direction of the axis of the mini-implant, a rubber ligature or a drop of adhesive can be used. The advantage of the adhesive is that it can cover sharp edges. The disadvantage is that it may under certain circumstances be difficult to remove, for example, in order to replace the rectangular wire.

CONCLUSIONS

The results of the present study provide guidance for the secure and permanent coupling of a rectangular wire in the slot of a mini-implant. For mechanical anchorage, crimped or bent wires are suitable. When an adhesive is used for fixing, the wires should first be sandblasted and silanized.

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