Stability of connected mini-implants and miniplates for skeletal anchorage in orthodontics

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SUMMARY The aim of this study was to examine the primary stability of connected mini-implants and miniplates. Three different skeletal anchorage systems were investigated: (1) two 1.5 mm diameter cylindrical mini-implants connected with a 0.021×0.025 inch stainless steel (SS) wire, (2) two 1.6 mm diameter tapered mini-implants connected with a 0.021×0.025 inch SS wire, and (3) two 2.0 mm diameter cylindrical mini-implants connected by a titanium locking miniplate. Fifteen standardized bovine bone specimens were prepared, five specimens for each experimental group. The connected mini-implants were fixed on the bone specimens. The systems underwent uniaxial pull-out tests at the midpoint of the connecting wire or miniplate using a mechanical testing machine. One-way analysis of variance was used to determine the difference of the pull-out test results between the groups.

Both the titanium miniplate and SS wire connection systems showed severe deformation at the screw head, which broke before the mini-implants failed. The 2.0 mm miniplate system showed the highest pullout force (529 N) compared with the other two wire connection systems (P<0.001). The 2.0 mm system was also stiffer than the 1.6 and 1.5 mm systems (P<0.001). The yield force of the 2.0 mm miniplate (153 N) was significantly higher than the 1.5 mm (88 N) and 1.6 mm (76 N) systems (P<0.001).

This *in vitro* study demonstrated that the connection of two mini-implants with a miniplate resulted in higher pull-out force, stiffness, and yield force to resist pulling force and deformation. Such a set-up could thus provide a stable system for orthodontic skeletal anchorage.

Introduction

Anchorage is fundamental to the success of orthodontic treatment. Use of skeletal anchorage in orthodontics has gained increasing popularity in both clinical applications and research since its introduction (Creekmore and Eklund, 1983). The indications for skeletal anchorage can range from intrusion of an individual tooth to the retraction of the whole dentition or even orthopaedic movement (Henry and Singer, 1999; Chang et al., 2004; Lee et al., 2004; Park et al., 2004a,b; Kircelli et al., 2006). Mini-implants have been used to manage upper molar intrusion to increase the vertical space before the placement of implants in the opposing arch (Chang et al., 2004; Lee et al., 2004). Furthermore, they have been used to retract the whole dentition in Class II, Class III, or non-extraction cases (Park et al., 2004a,b). Maxillary protraction can also be accomplished with skeletal anchorage (Henry and Singer, 1999; Kircelli et al., 2006).

Different types of skeletal anchorage have been adopted for a wide range of applications. The main modalties commonly used are (1) conventional endosseous implants of normal size, (2) mini-implants that are usually less than 2 mm in diameter, and (3) miniplates fixed with miniscrews (Higuchi and Slack, 1991; Kanomi, 1997; Sugawara *et al.*, 2002). The success rate of mini-implants and miniplates is reported to be more than 80 per cent (Miyawaki *et al.*, 2003; Cheng *et al.*, 2004; Park *et al.*, 2006). Primary stability is an important factor in the success of implants. Using two or more connected implants might increase stability (Balshi and Wolfinger, 1997a, b) and the connection of two miniimplants has indeed been shown to improve the stability of the skeletal anchorage system (Sugawara *et al.*, 2002; Chang *et al.*, 2004; Lee *et al.*, 2004).

A new miniplate system that has a 'locking' feature could also increase implant stability (Alpert *et al.*, 2003; Gutwald *et al.*, 2003). The locking screw has a special double-thread design that allows the threaded screw head to engage the corresponding threaded plate holes on the miniplate during insertion. To date, no published study has sought to biomechanically evaluate the stability of connected miniimplants and miniplates. The objective of this study was to examine the primary stability of connected mini-implants and miniplates.

Materials and methods

Bone harvesting and preparation

Fifteen bone plates were harvested from 15 mandibles of recently killed domestic oxen. The soft tissues were stripped off the angle of the mandible. Bone specimens of 30×40 mm were cut from one side of the mandible with a bone saw. These were then ground under coolant until 2 mm of cortical bone was left with 6 mm of cancellous bone

attached. After preparation, the bone specimens were stored in a solution of equal amounts of normal saline and 70 per cent ethanol at 4°C before mechanical testing was carried out within 1 week (Mittra *et al.*, 2005).

Pull-out tests were performed on the 15 bone specimens using three types of skeletal anchorage systems (Figure 1): (1) 1.5×7 mm (diameter 1.5 mm and length 7 mm) cylindrical mini-implants (Bracket head type, AbsoAnchor, Dentos Inc., Seoul, Korea); (2) 1.6×7 mm tapered mini-implants (Regular type, Orlus, Ortholution Co., Seoul, Korea); and (3) 2.0×8 mm cylindrical miniplate locking screws (Lock screw; Synthes GmbH, Oberdorf, Switzerland). Each of the three test groups consisted of five bone specimens.

Pilot holes were drilled perpendicularly in the bone specimens which were then fixed onto a drilling machine. A 1.2 mm pilot drill with a depth of 4 mm was used for the 1.5 mm mini-implant and the 1.6 mm tapered mini-implant and a 1.5 mm pilot drill with a depth of 5 mm for the 2.0 mm mini-implants. The bone specimens were then secured onto the crosshead platform of a mechanical testing machine (Model 1185; Instron, Norwood, Massachusetts, USA) by a steel plate with a 20×30 mm window.

Mechanical testing of connected mini-implants

For the 2.0 mm miniplate system, two mini-implants, 15 mm apart, were connected with a titanium locking plate (Lock Plate, 1 mm thick, straight, four holes, Synthes GmbH) that





Figure 2 The 2.0 mm mini-implant with screw threads on the screw head and the inside surface of the holes in the miniplate.

was offset by 1 mm from the surface of the bone specimen. Threads on both the head of the screw and the inside of the plate holes allowed the locking screws to be secured to the locking plate as they were screwed in (Figure 2). For the 1.5 mm cylindrical mini-implant and 1.6 mm tapered mini-implant, two mini-implants 15 mm apart were inserted into the bone with 1 mm offset after pre-drilling. Subsequently, a section of a 0.021×0.025 inch stainless steel (SS) archwire (Kleen PakTM System, Ormco Corporation, Orange, California, USA) was inserted and wrapped around the slot at the screw head with the thicker side in the slot. A 0.010 inch steel ligature wire was tied to fix the archwire at the screw head. The ligature wire, archwire, and screw head were then embedded in composite resin using the TransbondTM XT system (3M Unitek Orthodontic Products, Monrovia, California, USA; Figure 3).

Uniaxial pull-out force was applied by the testing machine through a rectangular SS blade at the midpoint of the archwire or miniplate (Figures 4 and 5). The crosshead platform speed was 1 mm per minute and testing was terminated when a component in the systems broke and the loading force dropped to zero. From the force–displacement graph plotted by the testing machine, the maximum pull-out force, displacement at the maximum pull-out force, stiffness (gradient of load to displacement), yield load, and yield displacement were evaluated. Yield load and yield displacement were the load and the displacement, respectively, at which permanent deformation began (Haug *et al.*, 2002).

Statistical analysis

One-way analysis of variance was applied to assess the difference of pull-out test results between mini-implants of different groups using the Statistical Package for Social Sciences (Version 13, SPSS Inc., Chicago, Illinois, USA). The level of statistical significance was set at P < 0.05. Multiple comparisons were undertaken using a Bonferroni test at $\alpha = 0.05$.

Results



For the 1.5 mm mini-implant system, which was connected by SS wire, the first response to the pull-out test was a

Figure 3 Connection of two mini-implants with a stainless steel (SS) connecting wire, ligated using SS ligature wire and composite resin.



Figure 4 Schematic drawing of the pull-out test. A $30 \times 40 \times 8$ mm bovine bone specimen was secured on a crosshead platform by a stainless steel (SS) plate with a 20×30 mm window. Two mini-implants connected by a SS wire or miniplate underwent mechanical testing. A uniaxial pull-out force was applied through a rectangular steel blade at the midpoint of the wire or miniplate.



Figure 5 Uniaxial pull-out test on the miniplate (a) and archwire (b) systems.

V-shaped deformation of the archwire at the point of force application. Following this, the composite resin and ligature wire fractured on one or both of the mini-implants. The screw heads then broke at the slot in three cases and at the neck in two cases (Figure 6a,b). The remaining parts of the screws remained in the bone and showed only slight deformation or tilting.

The response to the pull-out test for the 1.6 mm mini-implant system was initially also deformation at the midpoint of the archwire. Again, the composite resin and ligature wire broke off. The archwire then slipped from the slot of the screw head and the force dropped to zero. The two mini-implants stayed in the bone and were intact with only slight deformation or tilting (Figure 6c).

Deformation with the 2.0 mm miniplate system started at the middle of the miniplate which became more deformed and elongated. Screw threads at the screw head and the inside of the holes of the miniplate stripped off. As a result, the miniplate slipped off the screws and testing was terminated (Figure 6d). The damaged mini-implants were left in the bone and showed more distortion and tilting than the other two systems (Figure 6e).

The force–displacement graphs (Figure 7a–d) show the loading behaviour of the three systems. With the 2.0 mm system, the miniplate kept deforming and elongating until the miniplate broke off from one of the mini-implants and then the force dropped to zero. In the other two wire connection systems, there were two to three sudden decreases in force level before a decrease to zero. Breakage of the resin or wire on one or both of the mini-implants corresponded to the sudden decrease on the force–displacement graph.

Comparison of the pull-out test results of the three systems (Table 1) showed that the maximum pull-out force of the titanium miniplate in the 2.0 mm mini-implants was 529 N which was significantly higher than the 1.6 mm (374 N) and 1.5 mm (316 N) mini-implants connected with SS wire (P < 0.001). There were significant differences in displacement between the 2.0 and 1.6 mm groups and between the 2.0 and 1.5 mm groups (P < 0.001). The titanium miniplate in the 2.0 mm mini-implant system was stiffer than the 1.6 and 1.5 mm systems (P < 0.001). No difference was found between the 1.6 and 1.5 mm groups (P > 0.05). The yield force of the 2.0 mm miniplate system (153 N) was significantly higher than that of the 1.5 mm (88 N) and 1.6 mm (76 N) systems (P < 0.001). The yield displacement was significantly larger in the 1.5 mm system than in the 2.0 mm miniplate system (P < 0.001).

Discussion

This study showed that the connection of two mini-implants with a miniplate provided a stable structure to resist pulling force and deformation. There are case reports in the literature investigating the effects of connecting two mini-implants for increased stability for skeletal anchorage (Chang et al., 2004; Lee et al., 2004), but no study has examined the biomechanical behaviour of the connected mini-implants. In this investigation, the diameter of the mini-implants in the three systems was not the same. However, the testing of the three systems was terminated when fracture occurred at the screw head while the body of mini-implant stayed in the bone. The retention of the mini-implant was not as important as the design of the connecting parts in this experiment. The interpretation of the results should be focused on the loading and failing behaviour of the systems, the design at the screw head, and the connection method. In the comparison of the three connected systems, the 2.0 mm miniplate system had highest maximum pull-out force



Figure 6 The 1.5 mm mini-implant broken at the slot (a) and at the neck (b); failed 1.6 mm connected miniimplants with the connecting wires slipped off (c); failed miniplate system with the miniplate broken off (d); and tilted and distorted 2.0 mm mini-implants after failure (e).

(529 N) compared with the 1.6 mm (374 N) and 1.5 mm (316 N) systems, respectively. It was found that having screw threads in the connecting part between the screw head and the miniplate to 'lock' them together was more advantageous than using an SS archwire and composite resin, as the latter fractured at a lower force. The connecting parts need to be strong enough to withstand the pulling force and to transmit the force to the mini-implants in the bone. The increased tilting with the 2.0 mm mini-implants in the miniplate system might imply a more effective transmission of force to the miniimplants than the other two systems. The mini-implants locked in the miniplate and the bone formed a frame structure with high stability (Gutwald et al., 2003). The fixation of the locking miniplate and mini-implants thus provides a rigid integrated solid system to resist external force. The applied force was transmitted through the connecting part to the 2.0 mm mini-implants which then distorted.

In the 1.6 mm system, the force was transmitted to the connecting parts, which were the composite resin and ligature wire. These broke before the force was transmitted

to the mini-implants, hence less tilting was seen. In the 1.5 mm system, the mini-implant itself broke at the slot or the neck as well as the connecting parts. This could be because of the smaller dimensions of the components at the slot and the neck of the mini-implants in this system compared with the other two systems.

The miniplate system also had the highest stiffness, 266 N/mm, compared with the 1.6 and 1.5 mm systems, which had a stiffness of 128 and 98 N/mm, respectively. The stiffness is the force needed to deform the system per millimetre. This stiffness should be interpreted in conjunction with the yield load and yield displacement. The yield load of the miniplate system was 153 N and the yield displacement 0.68 mm. This means that permanent deformation of the miniplate system began only when the force was as high as 153 N and when the system was deformed more than 0.68 mm. To deform the miniplate system by 1 mm, 266 N of force was needed. The 1.5 and 1.6 mm systems deformed when the force was 88 and 76 N, respectively, as indicated by their yield forces. Normally, the magnitude of orthodontic



Figure 7 Force-displacement graphs of the 1.5 mm (a), 1.6 mm (b), 2.0 mm (c), and all three (d) systems.

	1.5 mm system ————————————————————————————————————	1.6 mm system Mean (SD)	2.0 mm system Mean (SD)	One-way analysis of variance
Maximum pull-out force (N)	316 (37) ^a	374 (14) ^a	529 (42) ^b	P<0.001
Maximum displacement at pull-out force (mm)	4.33 (0.792) ^a	3.7 (0.214) ^a	5.35 (0.188) ^b	P<0.001
Stiffness (N/mm)	98 (21) ^a	128 (17) ^a	266 (62) ^b	P<0.001
Yield force (N)	88 (14) ^a	$76(8)^{a}$	153 (13) ^b	P<0.001
Yield displacement (mm)	$1(0.05)^{a}$	0.72 (0.08) ^b	0.68 (0.05) ^b	P<0.001

Table 1Summary of pull-out test results.

Subgroups identified with the same superscript letters within the same row of cells are not significantly different (P>0.05).

force is less than 5 N but the average human bite force could be as high as 200 N. The average force transmitted to a bracket during mastication has been reported to be between 40 and 120 N (Powers *et al.*, 1997; Paphangkorakit and Osborn, 1998). The findings give some insight into the possible force range that a mini-implant might need to withstand in the oral environment. The yield load of 153 N of the miniplate system suggests that it would withstand this range of intraoral masticatory force. The force applied with a rapid maxillary expander can be up to 120 N (Sander *et al.*, 2006). The 153 N yield load of the miniplate may thus also withstand this range of force. In this experiment, the loading force for the mechanical testing was applied in a 'flatwise' manner, i.e. the force was perpendicular to the flat surface. The force needed to deform the system in a flatwise direction is much lower than that required in an edgewise manner (Hegtvedt *et al.*, 1994; Loukota and Shelton, 1995). Thus, the yield force to permanently deform the miniplate would be higher if the miniplate was not loaded flatwise but in other directions. In clinical application, the skeletal anchorage system is usually not loaded in a flatwise direction and a higher yield force would be expected.

The connection of two mini-implants may not only provide a stable anchorage system but also improve the

versatility of the device as well. The relationship between the occlusogingival position of the mini-implants and centre of resistance of the teeth to be moved is important in controlling the mode of movement of teeth (Park *et al.*, 2005). Application of force from different positions along the miniplate connector may allow the direction or mode of tooth movement during treatment to be changed from tipping to torquing, or *vice versa*.

The screw threads on the inside of the holes of the miniplate may allow different customized devices to be screwed onto it. As a result, different attachments could be screwed onto the miniplate, as an alternative to replacement of individual mini-implants with different screw heads. Even an orthodontic attachment such as a bracket may be directly screwed onto the system which could have individualized torque and rotation control without unwanted movement of other teeth (Kyung *et al.*, 2005).

The findings showed that the strength and design of the connecting part were vital to the anchorage device. If the connecting plate and the screw head were made of stronger materials, e.g. SS or a stronger metal alloy, the stability of the anchorage device might be further increased. Having a double-thread design at the screw head is one design which is advantageous in connecting mini-implants but this is not the only one. Further research needs to be conducted to develop more convenient and stronger screw head designs to connect mini-implants for improved stability.

Conclusion

This is the first *in vitro* study to demonstrate that the connection of two mini-implants with a miniplate results in higher pull-out force, stiffness, and yield force to resist pulling force and deformation. Such a set-up could thus provide a stable system for orthodontic skeletal anchorage.

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Funding

The University Strategic Research Theme: Genomics, Proteomics and Bioinformatics, University of Hong Kong (10206152.11222.21700.302.01); a Competative Earmarked Research Grant (CERG) grant (102006968.223 11.08003.324.01).

Acknowledgement

We would like to thank Dr Trevor Lane, Dr Henry Luk, Mr Tony Yuen, Mr C. Y. Yip, and Mr Shadow Yeung for their suggestions and technical support in the research.

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