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Biomechanical evaluation of an orthodontic mini-implant with plastic removal cap: an in-vitro experimental testing

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***Abstract*—**This study evaluates the biomechanical interactions of a mini-implant using a plastic revolving cap (PRC) with translation/rotation features for optional orthodontic traction. An orthodontic mini-implant and the PRC consisting of a hexagon connection onto mini-implant with 60 degree switching unit and an extended arm to provide orthodontic wire tied at different positions. The PRC removal force was measured by pull-out testing. The PRC removal force remained larger than three times the finger pulling force (9.3N) after 5 repeated removal tests. The results for the PRC resistant testing showed that the PRC rotational resistant force (20.31±0.83N) is larger than the maximum traction force (about 4.9N) for orthodontic treatment. The mini-implant used with PRC can provide translation and rotation features to change the angles and directions of orthodontic tractions for most effective anchorage preparation under safety consideration.

Keyword: orthodontic, mini-implant, plastic revolving cap.

I. Introduction

Mini-implants have recently been utilized as anchors during orthodontic treatments[1]. Among the numerous advantages of mini-implants include low cost, small dimensions, easy insertion and removal procedures and the possibility of applying immediate load, thereby reducing the total orthodontic treatment time compared with devices that require a healing period[2]. A suitable physiological and anatomy position must be found as the anchorage source for mini-implant placement to perform the optimal orthodontic traction with the concurrent use of orthodontic wire/power chain. However, clinicians often have difficulty in placing a mini-implant at the best position as the anchorage source due to intra-oral space limitations, consequently leading to unexpected traction effects on the tooth movements[3]. In addition, tooth movements keep changing during orthodontic traction over the course of treatment. The original source of anchorage cannot be maintained at the optimal angle and position for traction during total orthodontic treatment time[4].

In general, orthodontic traction has to rely on periodic traction force adjustments with continuous use of the original anchorage source. Effective orthodontic traction would be achievable through an extra temporary anchorage cap placed on the mini-implant head with revolving (translation and rotation) features to provide optional traction angles and positions for most anchorage preparation. To conquer the single/unsuitable anchorage source, an optional cap that can be placed onto the mini-implant head with a revolving (translation and rotation) traction function is proposed in this study. However, the metal alloy cap may generate extremely high manufacturing cost. Therefore, this study proposed plastic material with using injection manufacturing to replace metal alloy to make the revolving cap. However, the safety for using the plastic revolving cap (PRC) is still unknown. For this reason, the safety testing for the PRC is necessary to be executed.

This study evaluates the safety of the PRC by mechanical tests. The mini-implant and PRC were made and assembled for performing PRC removal force and rotational resistant testing to demonstrate the feasibility of this innovative PRC by the in vitro pull-out experimental approach.

II. Materials & Methods

A. Orthodontic mini-implant and PRC innovation

Figure 1 illustrates the mini-implant and PRC design concept proposed in this study. A mini-implant was designed with an external hexagon head. A PRC designed with consisting a structure with an internal hexagon hole and an extended arm including several hooks to provide rotation and translation tractions. The PRC can be assembled on the mini-implant head through an external hexagon connection, hooked onto a bottom of the head to connect tightly and prevent detaching. The PRC permits angular adjustments of 60 degrees as a switching unit and with an extended arm that can be used to provide orthodontic wire attachments from different positions at various distances. Therefore, the PRC provides rotation and translational orthodontic traction (Fig. 1b and 1c). The proposed mini-implant and PRC were manufactured with Ti6Al4V alloy and plastics which were approved by FDA for testing by the manufacturer with ISO13485 quality management systems (Fig. 2).

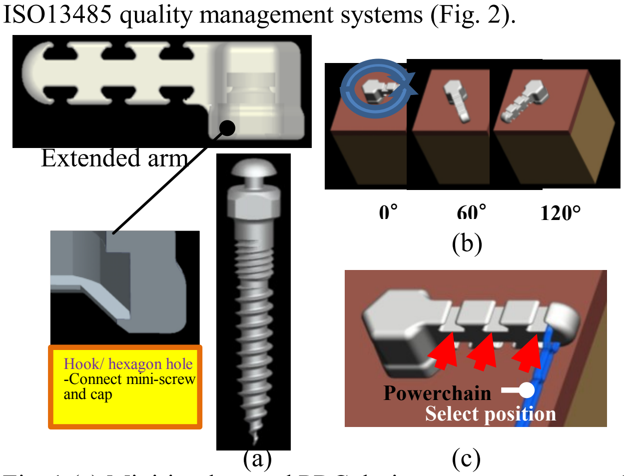

Fig. 1 (a) Mini-implant and PRC designs concept proposed in this study; (b) the PRC assembled with mini-implant head and permitted angular adjustments by optional assembly with 60 degree; (c) the PRC provides translational orthodontic traction.

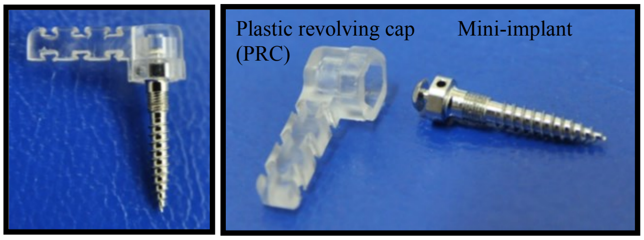

Fig. 2 The real mini-implant and PRC developed in this study.

B. Safety testing for the PRC by in vitro experiment

PRC removal force testing

To ensure whether the PRC connection capability was sufficient to resist the detachment force from tongue, chewing and even hand pull-out disturbances by patients, finger pulling forces, the PRC removal forces, and PRC resistant forces were measured (Fig. 3 and 4).

A load test probe designed according to the PRC outer shape was fixed onto a testing machine (Hung-Ta Co. Ltd., HT 2402EC, Taipei, Taiwan) for measuring finger pulling force. Probe force values pulled by the fingers of three volunteers and repeated five times by each subject were collected.

Three experimental samples were prepared for PRC removal force testing. Each sample with a mini-implant tip placed perpendicular to the artificial bone sample was inserted into the bone block down to the end of the implant thread by rotating the torque tester's rotational axis clockwise. The PRC was then assembled onto the external hexagon implant head, a set of clamping apparatus of hooking the PRC bottom was designed and the upper part of the clamping apparatus positioned on the testing machine (Hong-Ta Co. Ltd., HT 2402EC, Taipei, Taiwan) pulled the PRC out from the mini-implant head at a speed of 1.2mm/min (Fig. 3). This was repeated 5 times and the PRC removal forces recorded from each test sample to evaluate the connection decay capability. Differences between the finger pulling force and the PRC removal force were compared to verify the PRC safety.

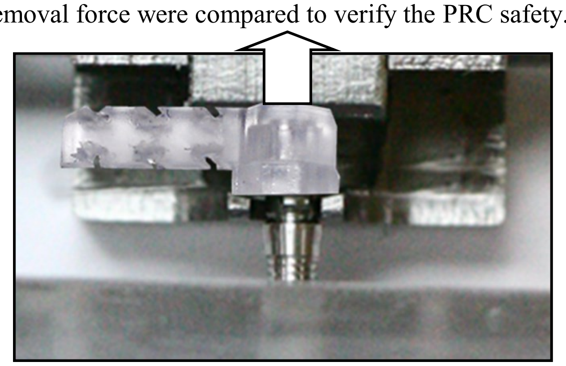

Fig. 3 The appearance of PRC removal forces testing.

PRC rotational resistant testing

Five experimental samples were prepared for PRC rotational resistant testing. Each sample with a mini-implant tip placed perpendicular to the artificial bone sample was inserted into the bone block down to the end of the implant thread by rotating the torque tester's rotational axis clockwise. The PRC was then assembled onto the external hexagon implant head, a metal wire was tied on the end hook of the extended arm to generate a worse lateral orthodontic force to test its rotational resistant. The axis of the metal wire is along the direction of running of the testing machine, and notes to be vertical to extended arm. A pull force was applied on the wire to rotate the PRC out from the mini-implant head at a speed of 1.2mm/min (Fig. 4). The PRC rotational resistant forces recorded from each test sample to evaluate the connection decay capability.

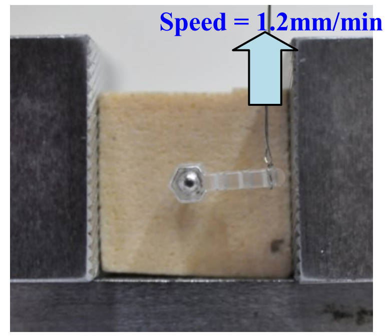

Fig. 4 The appearance of PRC rotational resistant testing.

III. Results and Discussion

The innovative mini-implant and PRC with adjustable angles and positions to provide multiple orthodontic traction force directions along with reduced treatment time were developed in this study. The safety test results for the PRC addressed the PRC removal force remained larger than 30 N after 5 times repeated removal testing. This value was three times the average finger pulling force (9.3 ± 2.10N) and indicated that the connection capability between the mini-implant and PRC was sufficiently high to prevent the PRC from detaching from the implant head by tongue, chewing and even hand pull-out disturbances by patients.

The results for the PRC resistant testing showed that the PRC rotational resistant force (20.31±0.83N) is larger than the maximum traction force (about 4.9N) for orthodontic treatment. When used with the PRC, the mini-implant still withstood the maximum traction force (4.9N) for orthodontic treatment without causing damage in the bone mass; suggesting that the mini-implant developed in this study is feasible for clinical applications. The results can prove the safety of the PRC.

The innovative PRC is optional, providing translation and rotation features to change the orthodontic traction force angles and directions during the orthodontic treatment process. The treatment efficiency increased because the optimal traction angle and position can be maintained in spite of the anatomany/physiological limitation and changing teeth movements during total orthodontic treatment time. The PRC can also be used as a multiple anchorage source at the same time (angles) because several holes on the extended arm can be used to provide different orthodontic wire anchors. One of the clinical applications is shown in Figure 5. Figure 5(a) shows an impacted canine places in unsuitable maxillary area.

Mini-implant cannot place in the optimal position to trace the maxillary canine due to the anatomical limitation. The mini-implant was then placed in another area to serve as the original anchorage source for tooth traction by power chain (Fig. 5b). However, the suitable anchor position for orthodontic efficiency might change during the time of tooth traction. Figure 5 (c) indicates that the orthodontic traction force can be changed to find a better direction to improve the orthodontic efficiency when the PRC was assembled on the mini-implant head. The PRC can provide extension arm for tooth traction by power chain with the optimal direction. The canine can move with the most effective anchorage preparation.

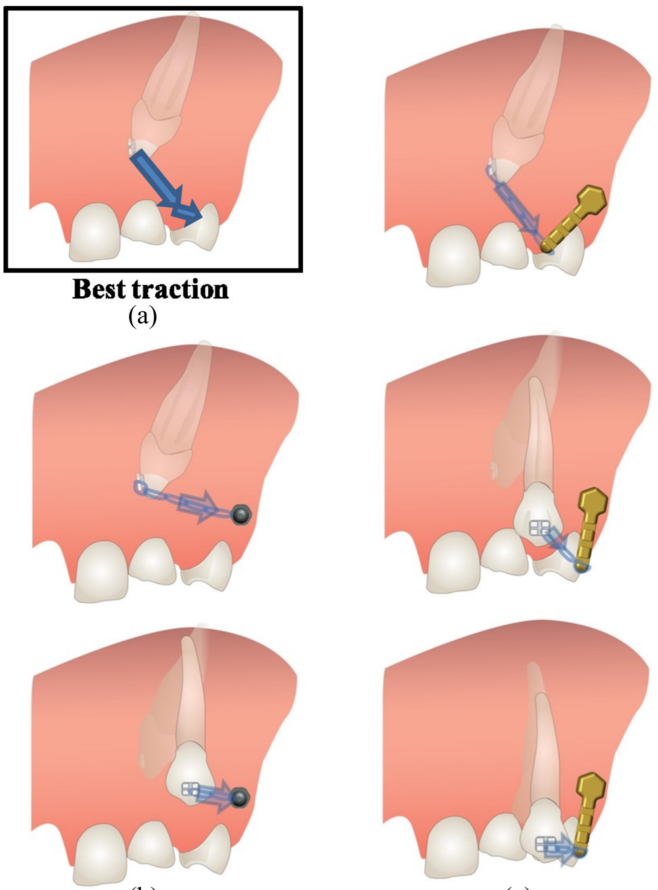

Fig.5 Clinical application (a) shows the best traction direction for the tooth (b) shows a mini-implant cannot place in the optimal position to trace the maxillary canine. (c) Right part shows the orthodontic traction force can be changed to find a better direction to improve the orthodontic efficiency when the PRC was assembled on the mini-implant head.

Only the using safety of the PRC was considered in this study. More studies about implant stability are necessary to be discussed in future. Suitable torque values should be continuously evaluated to minimize bone damage and provide sufficient anchorage for the orthodontic forces within a range that the bone can withstand.

IV. Conclusion

In conclusion, the mini-implant and PRC developed in this study can provide (revolving) translation and rotation features to change the angles and directions of orthodontic tractions during treatment to increase efficiency in safety consideration (under PRC dethatched force) by in vitro testing.

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