*Original Article*

# A study on orthodontic bone-bonding anchorage

**Xianjv Xie[a]; Yuxing Bai[b]; Ying Lv[c]; Weiming Gao[a]**

**ABSTRACT**

**Objectives:** The study had two objectives: (1) to measure the maximum loading capacity of a new skeletal orthodontic anchorage, designated the "bone-bonding anchorage," and (2) to study its histological basis.

**Materials and Methods:** A total of 81 bone-bonding anchorages were fixed onto the surface of the tibia of 12 big-ear white rabbits with N-2-butyl cyanoacrylate. The 12 animals were divided into groups designated as the immediate, 2-week, 4-week, and 8-week after-surgery groups. The maximum loading capacity of each group was measured, and histological changes were observed.

**Results:** The results indicate a tendency toward an initial decrease and then an increase in the maximum loading capacity of the bone-bonding anchorage. The mean value of the 8-week group reached 45.69 N, which can satisfy orthodontic clinical needs. Histologically, new bone formation was found around the base of the bone-bonding anchorage, which wrapped the base until it was bone-buried, creating the histological basis of the maximum loading capacity. In the experiment, the total failure rate of the bone-bonding anchorage was 13.6%, and no failure occurred in the immediate and 8-week groups.

**Conclusion:** The loading capacity of the bone-bonding anchorage is sufficient for orthodontic use, but whether or not it can be applied to clinical practice merits further study. (*Angle Orthod.* 2010;80:828–834.)

**KEY WORDS:** Anchorage; N-2-butyl cyanoacrylate; Maximum loading capacity; Histology

## INTRODUCTION

Stable anchorage is an important basis of orthodontics. In recent years, implant anchorage has been applied with increasing frequency in the orthodontic clinic, where it has achieved good effect; however, there are risks, such as periodontal membrane damage, maxillary sinus penetration, and nerve injury.[1] Therefore, one focus in orthodontic research is exploration of a safer means of skeletal anchorage. For example, medical adhesive has come into increasing use in this context. Other products, such as biological tissue adhesive, bone cement, or N-2-butyl cyanoacrylate adhesive, have been applied extensively in several contexts, including trauma suturing, hemostasia, and orthopedics.

N-2-butyl cyanoacrylate is a butyl ester of 2-cyano-2-propenoic acid. It is a clear, colorless liquid with a sharp, irritating odor. It is insoluble in water. It polymerizes rapidly in the presence of ionic substances such as moisture, blood, or tissue fluids. Its chief use is as the main component of medical cyanoacrylate glues. It can be encountered under various trade names (eg, Xoin, Gesika, Periacryl, GluStitch, GluShield, VetGlu, Vetbond, LiquiVet, Indermil, Histoacryl, and others). The medical applications of butyl cyanoacrylate include its use as an adhesive for lacerations of the skin in the treatment of bleeding from vascular structures, arteriovenous malformations, and bleeding gastric varices. It also has been used for fixation in a rabbit model of the tripod fracture of a zygomatic bone and a rabbit model of mandibular osteotomy.[2,3] Nevertheless, no reports have addressed the feasibility of its application to orthodontics for anchorage.

To explore a safer clinical orthodontic anchorage, this study presents the concept of bone-bonding anchorage for the first time. This concept includes fixing the specific anchorage device to the bone surface with a medical adhesive. The adhesive force maintains

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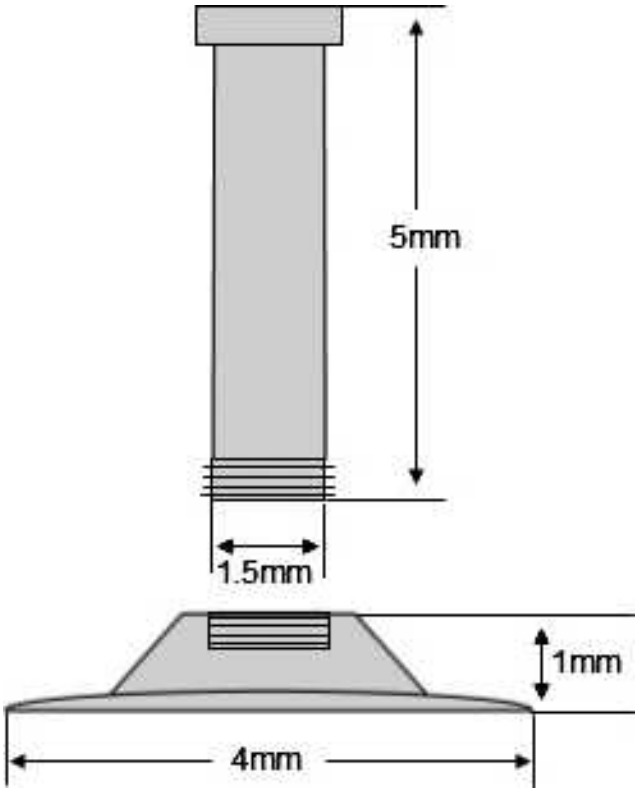


**Figure 1.** Design of two-section bone-bonding anchorage.

the initial stability of the anchorage and provides stable anchorage during a clinical force application process until the bone-bonding heals and has sufficient loading capacity. The purpose of this work was to conduct a preliminary investigation of the biomechanical performance and histomorphological basis of the bone-bonding anchorage and the development of an experimental basis for its future clinical application.

## MATERIALS AND METHODS

### Animals

Twelve 6-month-old specific-pathogen-free female big-ear white rabbits (3.5 $\pm$ 0.5 kg) were bred in separate cages at an environmental temperature of 20°C and a humidity of 45–50%. The surgical operations began after 1 week of observation and adaptation. Throughout the experimental period, rabbits were fed with pure water and full nutritional grains at the Beijing Stomatological Hospital Animal Room, a specific-pathogen-free facility.

### Two-Section Bone-Bonding Anchorage

A total of 81 anchorages in a two-section structure were made using OCr18Ni9 stainless steel with a base diameter of 4 mm and a thickness of 1 mm (Figure 1). The structures consisted of a mesh bottom and plane,

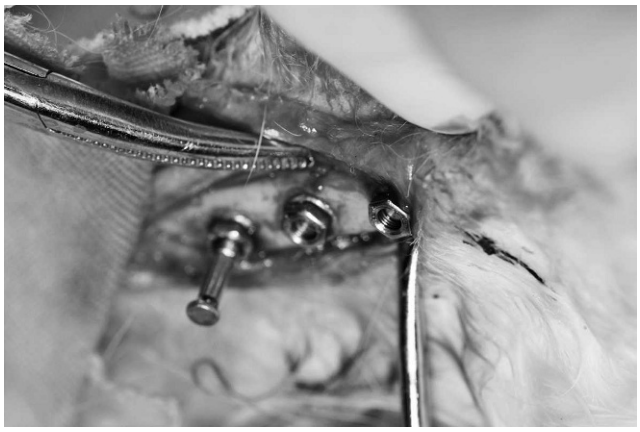

**Figure 2.** Animal in surgery.

with a screw stem diameter of 1.5 mm and a height of 5 mm. The base was fixed to the bone surface. After healing, a secondary operation was performed to install the screw stem on the base for the application of force.

### Animal Grouping Design

The 12 rabbits were divided into four groups according to the time of testing following surgery, as follows: immediate, 2-week, 4-week, and 8-week groups.

### Anchorage Fixation Operation

The operation was conducted in a specific-pathogen-free laboratory animal operating room. After administration of anesthesia a 3–4-cm vertical incision was cut on the inner side of the tibia of each animal. The soft tissues were separated until the surface of the tibia was reached. The periosteum was opened, followed by fixation of three bone-bonding bases to the surface of the cortical bone with 1.3 N-2-butyl cyanoacrylate adhesive (Suncon medical adhesive; Beijing Suncon Medical Adhesive Co, Ltd, Beijing, China), one by one, at intervals of about 10 mm. Five minutes after fixation, a tight suture was made. At the time of suturing, the periosteum was placed as close as possible to the bone-bonding base. After surgery, 400,000 units of penicillin were injected intramuscularly per day for three consecutive days to prevent infection (Figure 2).

### Biomechanical Testing

The tibia was taken immediately after the animal was euthanatized by air embolism through the ear vein. The screw stem was installed on the bone-bonding base, and self-solidification resin was made to fix the stem to the base so that the microforce test

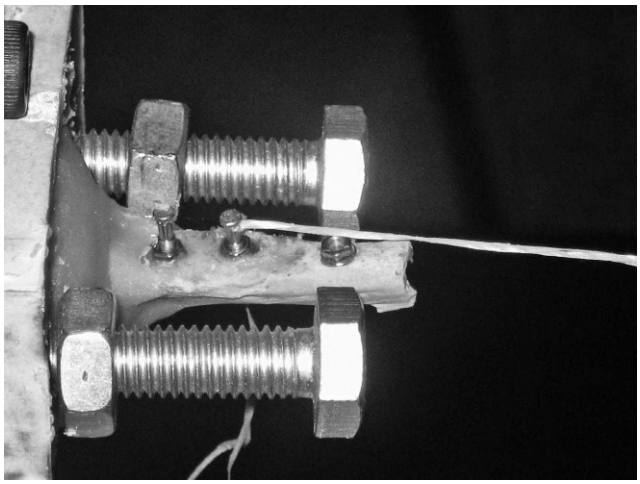

**Figure 3.** Maximum loading capacity test.

machine (Tytron™ 250 Microforce Testing System, Tiffin, Iowa) could apply a horizontal force perpendicular to the major axis of the screw stem. The preload of the test machine was 0 N, given with a velocity of 1 mm/min. Data recorded were the displacement and force curve and the force when initial displacement of the bone-bonding anchorages from the tibiae occurred (ie, the maximum loading capacity [data recording frequency, 20/s]; Figure 3).

### Statistical Analysis

SPSS version 11.5 software (SPSS Inc, Chicago, Ill) was used to conduct statistical analysis of the data among the groups. Mean numbers and standard deviations are given. Analysis of variance was adopted to compare the maximum loading capacity of each group. Among the groups, the data from the 8-week group exhibited no homoscedasticity with data from the other groups, so rank-sum analysis was adopted.

### Histological Analysis

The tibia at the experimental site was taken immediately after the animal was euthanized by air embolism through the ear vein. After tissue fixation, embedding, and sectioning, hematoxylin and eosin (H&E) staining of the decalcified bone section and methylene blue staining of the ground bone section were performed, followed by observation under an optical microscope.

## RESULTS

### Failure Rate of Bone-Bonding Anchorages

During the specimen treatment process, 11 out of the 81 anchorages failed. The total failure rate was 13.6%, and there were no failures in the immediate and 8-week groups. Table 1 gives the mean values of the maximum loading capacities of bone-bonding anchorages of the different groups. A paired comparison among mean values of the maximum loading capacities of bone-bonding anchorages of the immediate, 2-week, 4-week, and 8-week groups showed that the differences among the groups were statistically significant (Table 2).

**Table 1.** Mean Value of the Maximum Loading Capacities of Bone-Bonding Anchorages of Each Group (N)

| Group | Mean Value ± Standard Deviation |
|---|---|
| Immediate | 10.84 ± 2.85 |
| 2-wk | 6.23 ± 4.50 |
| 4-wk | 1.80 ± 1.90 |
| 8-wk | 45.69 ± 25.45 |

### Histological Observation

Figures 4–9 show the histological results for each group. Observation of the ground bone section of the 2-week group showed that periosteum tissues were found creeping over and covering the edge of the bone-bonding anchorage base (Figure 4). The bone surface under the bone-bonding anchorage base showed little difference from the normal bone surface and even appeared to be complete. Bone lacunae were found in only a few areas. In this group, there was a gap with no contact between the bone tissues and bone-bonding anchorage base where no osseointegration had occurred.

The ground bone sections of the 4-week group (Figure 6) showed new bone tissues creeping over the edge of the bone-bonding anchorage base and wrapping around the base. In addition, part of the bone surface under the bone-bonding anchorage base had become irregular, with an obvious bone cement line and bone lacunae occurring in several places. As with the 2-week group, there was a gap, with no contact between the bone tissue and bone-bonding anchorage base. As the decalcified bone section of the 4-week group indicates (Figure 7), the new bone around the edge of the bone-bonding anchorage base had a relatively low density, loose structure, abundant capillary vessels, and many osteocytes. Also, there was an obvious boundary between the new bone and the normal bone tissues.

The ground bone section of the 8-week group (Figure 8) indicated that the newly formed bone tissues had completely engulfed the bone-bonding anchorage base. The deep tissues of the newly formed bone had ossified well, and, typically, a highly calcified Haversian system structure was evident, with little difference from normal bone tissues. In addition, the surface tissues formed a trabecular structure. Howev-

**Table 2.** Paired Comparison Among the Maximum Loading Capacity of Bone-Bonding Anchorage of Each Group

| Comparison Groups | *P* |
|---|---|
| Immediate and 2-wk | .006** |
| Immediate and 4-wk | .000** |
| 2-wk and 4-wk | .008** |
| Immediate and 8-wk[a] | .002** |
| 2-wk and 8-wk[a] | .000** |
| 4-wk and 8-wk[a] | .000** |

[a] Indicates that this pair adopts rank-sum test.
** $P < .01$ indicates that the difference has statistical significance.

er, the bone surface under the bone-bonding anchorage base was irregular, with many protuberances and a few bone lacunae, and as with the other groups, there was a gap, with no contact between all bone tissues and the bone-bonding anchorage.

## DISCUSSION

### Presentation and Improvement of the Concept of a Safer Bone-Bonding Anchorage

In an effort to address the various risks of implant anchorage intrusion into bone tissues and to explore a safer clinical anchorage, this study presented the concept of a bone-bonding anchorage for the first time. The original purpose of a bone-bonding anchorage was to provide stability for anchorage using the adhesive force of a medical adhesive when fixing the anchorage to the bone surface, as in orthodontic clinical anchorage. The adhesive force of a medical adhesive is unstable, however, and this instability worsens with time, precluding long-term clinical use. We find, however, that the healing ability of bone tissues can substitute for the adhesive to provide the long-term stability required by anchorage. The medical adhesive provides the adhesive force that confers the initial stability for the device, allowing bone tissues to heal better. After healing, the mechanical interlocking force between bone tissues and the device provides long-term stability for anchorage. In fact, the surgery involving a bone-bonding plate does not invade the bone structure. All the surgery is completed on the surface of the bone. So there is not any risk of periodontal membrane damage, maxillary sinus penetration, or nerve injury.

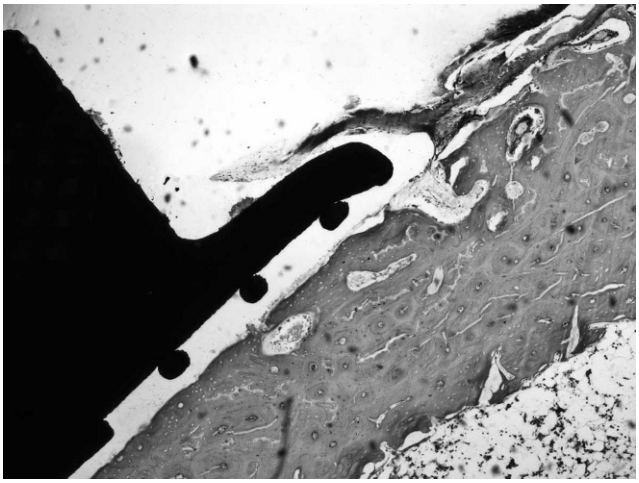

**Figure 4.** Methylene blue staining of ground bone section 2 weeks after surgery (magnified 40×).

**Figure 5.** H&E staining of decalcified bone section 2 weeks after surgery (magnified 40×).

### Histological Basis of Bone-Bonding Anchorage

The results indicate that after the bone-bonding anchorage is fixed to the bone surface, the periosteum will creep over the edge of the bone-bonding anchorage base. Next, the interstitial cells of the periosteum will differentiate into osteoblasts and osteoclasts, forming new bone and reconstructing bone under the base. Newly formed bone will then cover the surface of the bone-bonding anchorage base, mature gradually, and form a Haversian system structure similar to that of normal bone tissues, ultimately winding up ''bone-buried'' at about 8 weeks postfixation. As the H&E-stained bone section in Figure 7 shows, there is an obvious boundary between the newly formed bone and the surface of the original rabbit tibia. Bone tissues under the base have an obvious cement line, which is equal in height to the original tibia, demonstrating that the development of this ''bone-buried'' state is based on bone proliferation rather than bone resorption.

Bone formation under the periosteum is the mechanism for healing of the bone-bonding anchorage. Because this experiment used OCr18Ni9 stainless steel, which results in no osseointegration, the results with the ground bone section show that there is a gap between all bone tissues and the bone-bonding

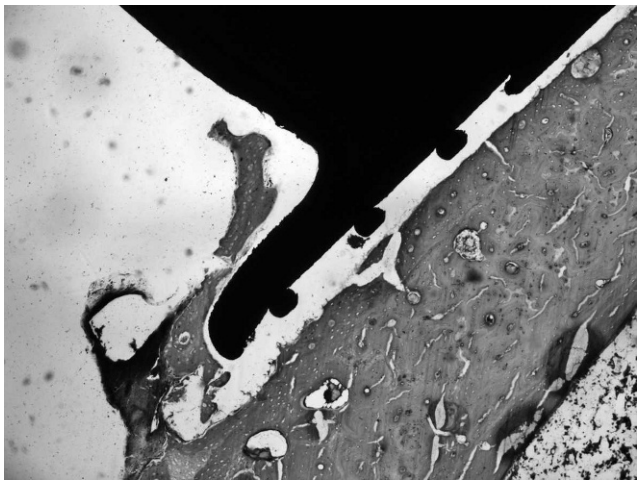

**Figure 6.** Methylene blue staining of ground bone section 4 weeks after surgery (magnified 40×).

anchorage, forming no osseointegration. Therefore, the retention force of the bone-bonding anchorage does not arise from osseointegration but from the mechanical interlocking strength formed after the new bone buries the base of the bone-bonding anchorage. In this experiment, the ''bone-buried'' phenomenon is the histological basis for the loading of the bone-bonding anchorage.

### Variation in the Maximum Loading Capacities of the Bone-Bonding Anchorage of Different Groups

The mean values of the maximum loading capacities of the bone-bonding anchorages of each group in this experiment are ordered as follows: 8-week group (45.69 N) > the immediate group (10.84 N) > 2-week group (6.23 N) > 4-week group (1.80 N). Statistical analysis showed that the variances among the mean values of all groups were significant. The maximum loading capacity of the bone-bonding anchorage experienced a process of gradual initial decrease, followed by an increase. These results show that force application cannot be carried out immediately within 8 weeks of bone-bonding anchorage surgery and that a certain period of healing is required.

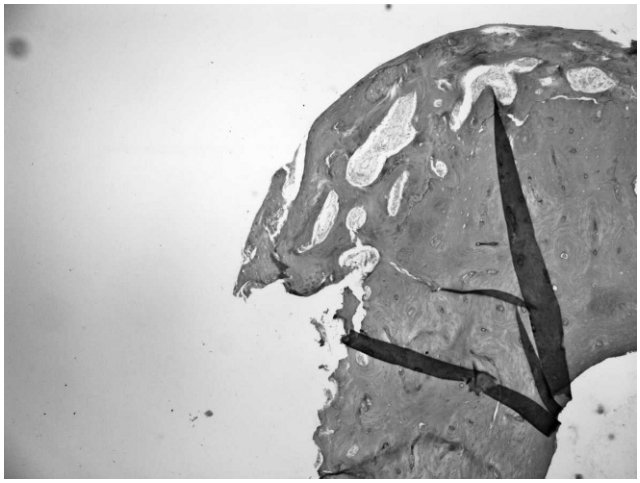

**Figure 7.** H&E staining of decalcified bone section 4 weeks after surgery (magnified 40×).

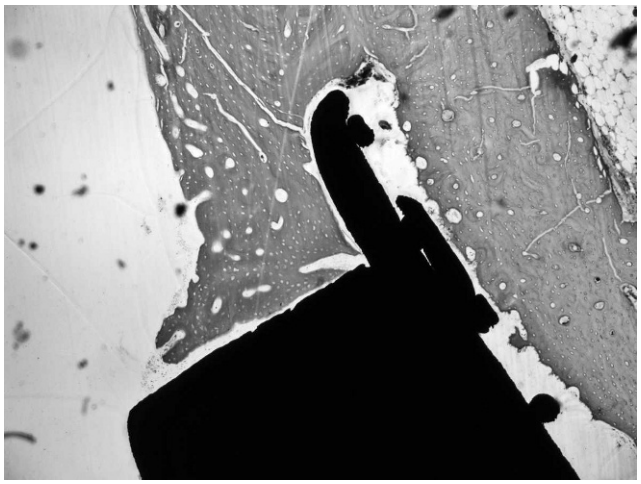

**Figure 8.** Methylene blue staining of ground bone section 8 weeks after surgery (magnified 40×).

This tendency for the maximum loading capacity to decrease during the process of change arose from the decrease in the adhesive force of N-2-butyl cyanoacrylate, the initial retention force of the bone-bonding anchorage. This decrease occurred gradually, along with hydrolysis of the N-2-butyl cyanoacrylate into microformaldehyde, cyanoacetate, and ethanol. These factors resulted in a gradual decrease of the maximum loading capacity of the bone-bonding anchorage.

An increase followed this decrease. At 8 weeks postsurgery, new bone tissues around the base had matured gradually and become ''bone-buried'' around the bone-bonding anchorage, providing a stronger mechanical interlocking force. This process is the fundamental reason that the mean value of the maximum loading capacities of bone-bonding anchorages increased significantly in the later phase.

### Feasibility of Clinical Application of a Bone-Bonding Anchorage

In this experiment, the mean value of maximum loading capacities of the bone-bonding anchorages in the 8-week group was 45.69 ± 25.45 N (4622 ± 2597 g). Of these values, the specimen with the highest maximum loading capacity reached 82.46 N (8414 g), and the specimen with the lowest maximum loading capacity reached 11.97 N (1221 g). Because the light clinical orthodontic force is below 60 g and the medium force is between 60 g and 350 g, it can be

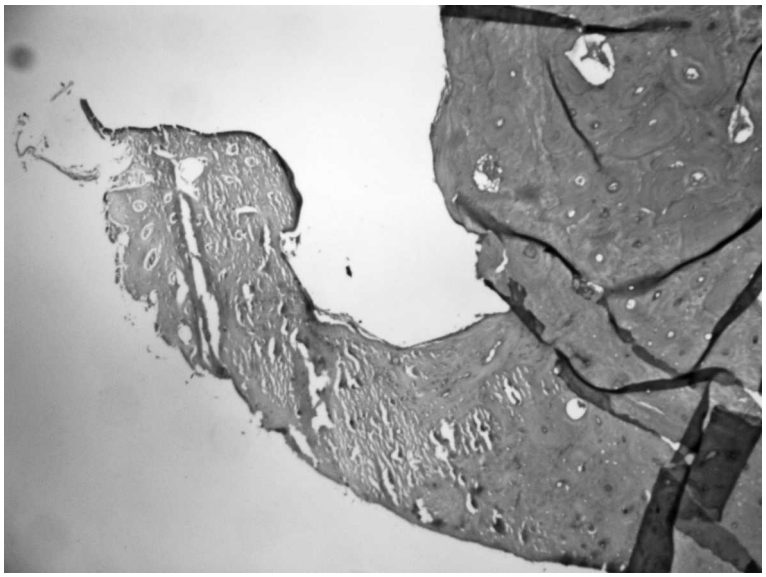

**Figure 9.** H&E staining of decalcified bone section 8 weeks after surgery (magnified 40×).

concluded that the bone-bonding anchorage of the 8-week group could meet the basic requirement for clinical orthodontic force.

It is notable that in this experiment, the material for the bone-bonding anchorage was OCr18Ni9 stainless steel, which is a nonbioactive material that cannot engage in osseointegration. A titanium alloy material theoretically would still leave space for an increase in the maximum loading capacity, but further verification of this theory is needed.

A total of 11 out of the 81 anchorages failed during the specimen treatment process. All failures occurred in the 2-week and 4-week groups. Analysis indicates that this failure is related to the fact that the adhesive force decreased as a result of hydrolysis of the adhesive agent while the ''bone-buried'' phenomenon had not yet developed. The total failure rate of the bone-bonding anchorages was 13.6%, while the failure rate of implant anchorages ranges from 11% to 30%.[4–7] Therefore, the failure rate of the bone-bonding anchorage is acceptable for orthodontic needs.

### Comparison Between the Bone-Bonding Anchorage and Other Orthodontic Implant Anchorages

An implant anchorage under the periosteum is the only implant anchorage system among all clinical implant anchorages that does not intrude into cortical bone. This system consists of an implant plate with a diameter of 7.7 mm or 10 mm and thickness of 2 mm and a base pile. The implant plate has a mesh bottom that is coated with hydroxyapatite and has a screw hole in the center for fitting of the base pile.[8] The area of the base of the bone-bonding anchorage is 0.13 $cm^2$, only 6.7% of that of the implant anchorage under the periosteum. The bone-bonding anchorage is also more flexible in terms of choosing the fixation location; the implant under the periosteum relies on the pressure of soft tissues to acquire initial stability, requiring a surgical separation from a location distant from the surgical site before anchorage insertion. In addition, the bone-bonding anchorage relies on the adhesive force of N-2-butyl cyanoacrylate to acquire initial stability, so that the surgical operation is simpler, and close contact of the base with the bone surface is guaranteed.

## CONCLUSION

- The loading capacity of the bone-bonding anchorage is sufficient for orthodontic use, but whether or not it can be applied to clinical practice merits further study.

## ACKNOWLEDGMENT

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