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THE STRUCTURE AND POSITION OF THE ORTHODONTIC MINI-IMPLANT AND THEIR INFLUENCING FACTORS ON THE TRAUMA TO THE CORTICAL BONE PLATE DURING ORTHODONTIC LOADING

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Orthodontic implants, as the skeletal anchorage systems, are widely used by orthodontists due to their property to minimize the impact on the patient's teeth. To identify the factors influencing the contact area between the orthodontic implant and bone, as well as bone resorption around the orthodontic implant. The experimental study compared two methods of orthodontic implant placement: leaving the implant's threaded part in the cortical bone plate and inserting the implant's neck into the bone. Using the same pressure on adjacent implants, the condition of the bone surrounding them was assessed. Leaving the implant's threaded portion within the cortical bone plate increases its damage and the implant's mobility under applied load. A smooth surface with an expanded neck of orthodontic implants provides a larger and denser contact with the cortical bone plate, which distributes the orthodontic load more effectively, thereby reducing the traumatic impact on bone tissue under force application.

Key words: implants, primary stability, anchorage, mandible, orthodontic treatment, damage, tooth, bone.

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ФАКТОРИ ВПЛИВУ СТРУКТУРИ ТА ПОЗИЦІЇ ОРТОДОНТИЧНОГО МІНІІМПЛАНТУ НА ТРАВМАТИЗАЦІЮ КОРТИКАЛЬНОЇ ПЛАСТИНКИ КІСТКОВОЇ ТКАНИНИ ПРИ ОРТОДОНТИЧНОМУ НАВАНТАЖЕННІ

Ортодонтичні імпланти як скелетні системи анкоражу широко застосовуються ортодонтами, оскільки мінімізують вплив на зуби пацієнта. Метою дослідження було виявити фактори впливу на площу контакта ортодонтичного імплантата з кісткою та резорбцію кісткової тканини довкола ортодонтичного імплантата. В експериментальному дослідженні порівнювались два способи встановлення ортодонтичних імплантів. Залишаючи імплант різьбовою частиною в кортикальній пластинці кістки та із зануренням шийки імпланта в кісту. Використовуючи однаковий тиск на поряд встановлені імпланти порівнювався стан кістки довкола них. Залишаючи імплантат різьбовою частиною в кортикальній пластинці збільшується її пошкодження та рухомість імплантату при застосуванні навантаження. Гладка поверхня з розширеною шийкою ортодонтичних імплантів має більший та щільніший контакт з кортикальною пластинкою, що при навантаженні краще розподіляє ортодонтичне навантаження, зменшуючи травмуючий фактор на кісткову тканину під дією сил.

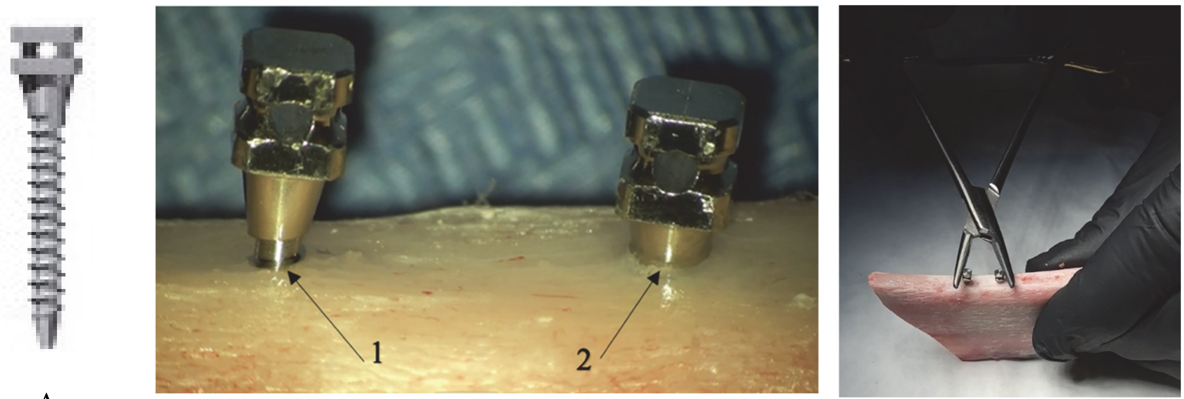
Ключові слова: імпланти, первинна стабільність, анкораж, нижня щелепа, ортодонтичне лікування, пошкодження, зуб, кістка.

The study is a fragment of the research project "Integrated approach to the rehabilitation of patients with dentofacial anomalies and deformities", state registration No. 0122U202088.

In 1969, Branemark and his colleagues demonstrated the successful osseointegration of titanium implants, sparking interest among orthodontists. This breakthrough laid the foundation for the development of orthodontic mini-implants, as a stable anchorage is a key factor in orthodontic practice for tooth movement [6, 8]. Currently, skeletal fixation systems have gained widespread use because they significantly reduce the undesirable effects of orthodontic appliances caused by the application of forces to the patient's teeth [4]. The effectiveness of mini-implants is estimated to range from 70 % to 87 %, depending on their characteristics [5]. A key criterion for success is their ability to remain stationary and withstand applied forces during treatment [10]. It is known that the primary stability of mini-implants is associated with their length embedded in the bone and the density of the cortical plate [7]. Unlike dental implants, orthodontic implants rely entirely on primary stability, which is achieved through mechanical interlocking with the bone during placement. Given this, special attention should be paid to evaluating primary stability and analyzing the factors that may lead to its reduction or loss under orthodontic loads to minimize the risk of disintegration of such implants [9]. Cases of stability loss can result in implant displacement by 1–1.5 mm, Melsen et al. (2005). An overly large hole reduces primary stability, whereas an excessively small hole slows down the healing process due to excessive pressure on the bone during implantation, as noted by Uemura et al. (2012). However, the issue on other factors affecting the cortical plate surrounding the implant remains open and debatable.

The purpose of the study was to identify factors influencing bone resorption around orthodontic implant and to determine factors affecting the contact area between the orthodontic implant and the bone.

Materials and methods. This study was conducted as an experiment using the “Cut” orthodontic implants with a diameter of 1.2 mm, a length of 10 mm, and a standard neck of 1.5 mm, manufactured by “CONNECT®” company (Ukraine) (Fig. 1-A), and bone tissue material from bovine ribs, with a density corresponding to types 2 and 3 of bone according to C. Misch [2]. For drilling the hole in the bone tissue, a recommended 0.8 mm drill was used, which passed through the bone to the full length of the implant. Using a 20:1 angled surgical handpiece and the DTE Implant-X physiodispenser, we installed the implants into the bovine rib bone (Fig. 1-B), setting the torque to 5 Ncm on the physiodispenser. To screw in all the implants, we set the speed to 10 rotations per minute. The experiment was conducted on 17 pairs of orthodontic implants. Each pair consisted of two implants installed next to each other, 10 mm apart. The implants were divided into two groups. Group 1 consisted of implants installed in the bone up to the level of the polished neck, and Group 2 consisted of implants with the neck submerged 1–1.5 mm into the bone (Fig. 1-B). We then marked the areas where the implants with the submerged neck were installed. Using a surgical clamp, we simultaneously applied pressure to the heads of the implants installed next to each other 50 times, ensuring that the same force was applied to each implant (Fig. 1-C). This way, the clamp transmitted equal force to the implant heads, artificially simulating orthodontic loading. After unscrewing the implants, we assessed the condition of the cortical bone using an operating microscope.



A B C

Fig. 1 Orthodontic implant. A – Orthodontic implant with a length of 10 mm and a standard neck of 1.5 mm. B – Photo of implants installed in the bone: 1 – to the level of the neck; 2 – with the neck submerged. C – Photo illustration of clamp pressure applied to the heads of implants.

The experiment consisted of several parts:

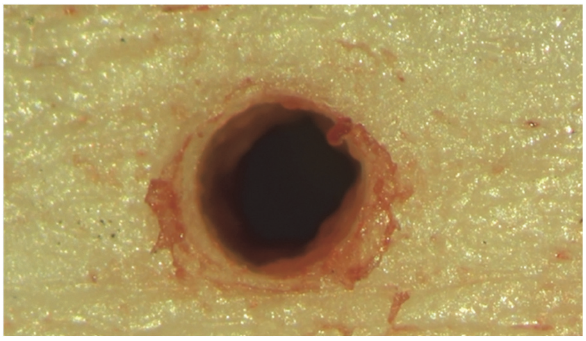
1. Installation of 17 pairs of implants in the bovine rib, with one implant in each pair placed at the neck level and the other with the neck submerged into the cortical bone.
2. Applying pressure 50 times on 2 implants of one pair using a surgical clamp to simulate orthodontic loading.
3. Unscrewing the implants and assessing the bone bed using an operating microscope.
4. Formation of bone blocks for further histological analysis of the two study groups.
5. Analysis of histological material.

The material for microscopic study was taken immediately after the experiment was completed. Pieces of bovine ribs were placed in the appropriate fixatives depending on the planned research methods. The rib bone was carefully separated from the soft tissues, followed by fixation of the material in a 10 % solution of neutral formalin for 24-48 hours in tightly sealed containers. The applied fixative solution prevents autolysis, stabilizes cells and tissues for further use in staining procedures. After fixation, fragments of rib bones underwent decalcification using ethylenediaminetetraacetic acid (EDTA). The influence of disodium salt (Trilon B) caused softening of the bone tissue fragments and did not form gas bubbles, preventing tissue damage. The use of EDTA and its salts prevented the disruption of staining in decalcified bone sample sections. For decalcification of the rib bone fragment, a solution of 250 grams of Trilon B was used, which was first dissolved in 200 ml of distilled water in a water bath. Then, a solution of 50 ml of 40 % NaOH, previously dissolved in 100 ml of distilled water, was added. The solution was brought to complete dissolution of all components while maintaining a pH of 7.4 by adding 750-800 ml of distilled water [3]. The material of the rib bone, 1 cm thick, was placed in gauze fabric and immersed in the decalcifying solution in a suspended state for uniform washing of the tissues over 24-48 hours. The volume of the solution was 25-50 times greater than the volume of all the decalcifying fragments combined. The degree of decalcification was checked with a dissecting needle, which easily passed through the tissue. The structure and metric indicators of the total area of the red bone marrow were determined on paraffin sections. The preparation of paraffin blocks was carried out at the Poltava Regional Pathological Anatomy Bureau of the Poltava Regional Council. The red bone marrow material was impregnated in paraffin using the standard method, and sections of 4-5 μm thickness were made on a sliding microtome MS-2, which were stained with hematoxylin and eosin [1].

The histological preparations were studied using the Biorex 3 light microscope with a digital microfilter and software adapted for these studies (serial number 5605) at the Department of Histology, Cytology and Embryology of Poltava State Medical University

Results of the study and their discussion. When the implant was placed into the bone tissue to the level of the neck under load, we observed a significantly larger volume of cortical plate destruction, with a zone of damage of irregular rounded shape elongated in the direction of force application (Fig.2-A).

The threads of the implant had a key impact on the cortical bone and increased the damage zone. This was statistically confirmed by us during the study with the operating microscope. When force was applied, the threads, with their sharp edges, created additional pressure on the bone and caused its destruction (Fig. 2-B). Also, around the implants that were inserted to the level of the neck, a microcrack was observed between the threads and the bone after loading (Fig. 3-B).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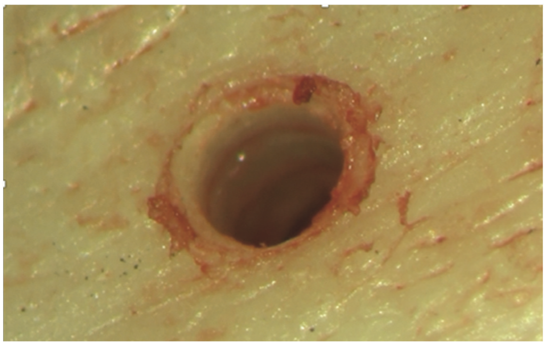
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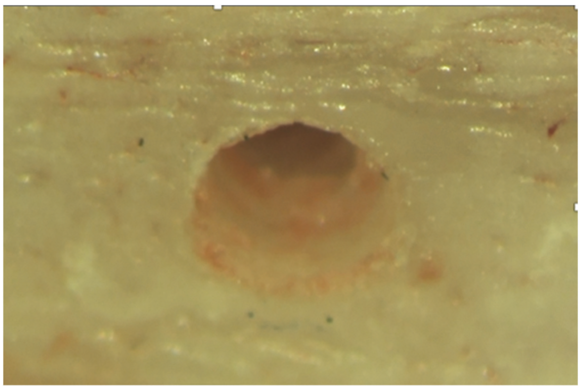
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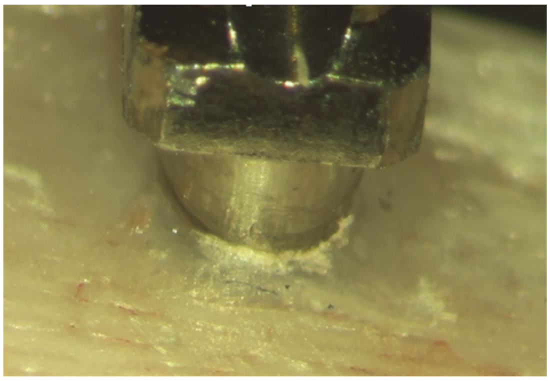
Fig. 2. Microscopic intraoperative image of the bone bed surrounding the implants. A – The view of bone tissue destruction around the implant and the area of greatest damage. B – Operating microscope photo of hole in the bone tissue around the implants with imprint marks of the implant threads on the cortical plate. C – Operating microscope photo demonstrating signs of minimal impact of the implant neck on the cortical plate.

When implants were placed with the neck submerged 1–1.5 mm into the bone tissue and loading was applied, the cortical plate remained of homogeneous structure with no significant signs of damage, and implant mobility was almost nonexistent. This excluded the negative impact of the implant threads on the cortical plate. Imprint marks of the implant threads on the surface of the cortical plate did not form (Fig. 2-C), and nor was there a gap between the bone and the implant (Fig. 3-A)

Imprint marks of the implant threads on the surface of the cortical plate, as well as a gap between the bone and the implant, did not form. In our opinion, this dependence may be related to the larger and more uniform contact area of the machined part of the implant neck, which creates less trauma compared to the aggressive structure of the threaded part, which with its sharp edges caused destruction of the surrounding cortical bone, manifesting as significant implant mobility when the neck was not submerged. Such a loose contact may negatively affect the primary stability of the implant and its subsequent service life.

Histological study of each bone block was conducted in 3 zones, depending on the depth of implant insertion into the bone (Fig. 3-C).

The histological material showed that the bone tissue was represented by a system of bone lamellae. Each lamella consisted of a mineralized amorphous substance with parallel-oriented bundles of collagen fibers. In adjacent bone lamellae, the fiber orientation had a different direction, which provided additional strength to the bone. Osteocytes were noted between the bone lamellae. The cell bodies were localized in lacunae, and the processes were located in the bone canals.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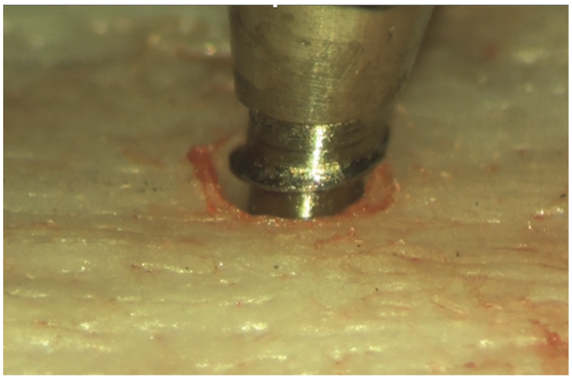
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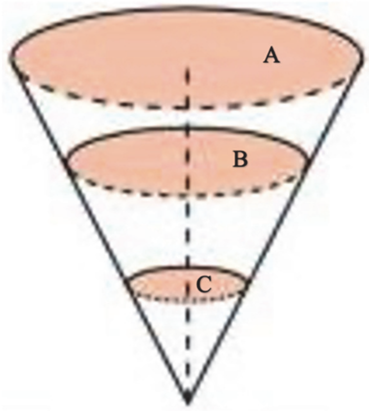

C

Fig. 3 Intraoperative microscopic image demonstrating the effect of the implant neck on the cortical plate, and schematic illustration of the three zones of the bone block. A – No microgap is present between the implant and the bone; the photo was taken through an operating microscope after implant placement. B – Photo of a microgap between the implant and bone, taken through an operating microscope. C – Schematic representation of the 3 zones of the bone block.

Zone A (the outer segment, or the base of the damage cone) histologically, we found damage in the lamellar part of the bone, which was larger in volume in Group 1 (Fig. 4-A). Histological evaluation showed uneven damage to the surface and changes in the contour of the bone tissue. In the second group, larger and thicker lamellae were visualized compared to the first group. A disruption of the contour between the damaged and undamaged areas of the bone tissue was also observed, indicating a more traumatic extent of the destructive process in the tissue around the implants in the first group.

Zone B in the histological preparations of the two experimental groups, a clear distinction is observed between the areas of bone damage and the undamaged tissue. In the areas where cavernous spaces form during the insertion of the micro-implant, limiting septa of connective tissue are found, containing osteoclast-like cells and bone trabeculae of varying maturity. The number of osteoblasts and fibroblast-like cells that are mitotically dividing and well visualized varies. Hemorrhages and hemosiderin granules are also present in different proportions in the preparations of the two experimental groups (Fig. 4-B, C).

Zone C. A distinctive feature of this zone is the presence of thick bundles of collagen fibers, called osteoid fibers. They lack a clear orientation within the mineralized matrix, which gives the bone a coarse structure. Between the bundles of osteoid fibers, osteocytes are located, with their cell bodies in bone cavities and their processes in the bone canals. In the area of damage, a reduction in the volume of reticulofibrous bone tissue and the number of cellular elements of the fibroblastic line is observed, particularly mature fibroblasts (Fig. 4-D).

Histological analysis of the obtained micropreparations from the two experimental groups showed that the bone tissue trauma covers all zones of contact between the implant and the bone tissue. The boundary between the edges of the defect and the actual osteogenic architectural component of the bone is clearly identified. At the edges of the drilling, the most numerous cavities filled with damaged bone tissue were found. Along the studied contact area of the bone with the implant, significant areas of intensive bone tissue damage were observed, accompanied by a reduction in the relative amount of bone tissue and cellular elements, particularly mature osteoblasts, in the affected area. However, the degree of damage in the two experimental groups varied depending on the distribution zones. Therefore, adequate assimilation of the biomechanical impact of the implants on the bone under angular loading is observed, leading to the formation of a homogeneous damaged bone tissue, which, under prolonged functional load, may result in disturbances in the volume of osseointegration and decreased functional stability in the group of implants without the neck submerged in the bone.

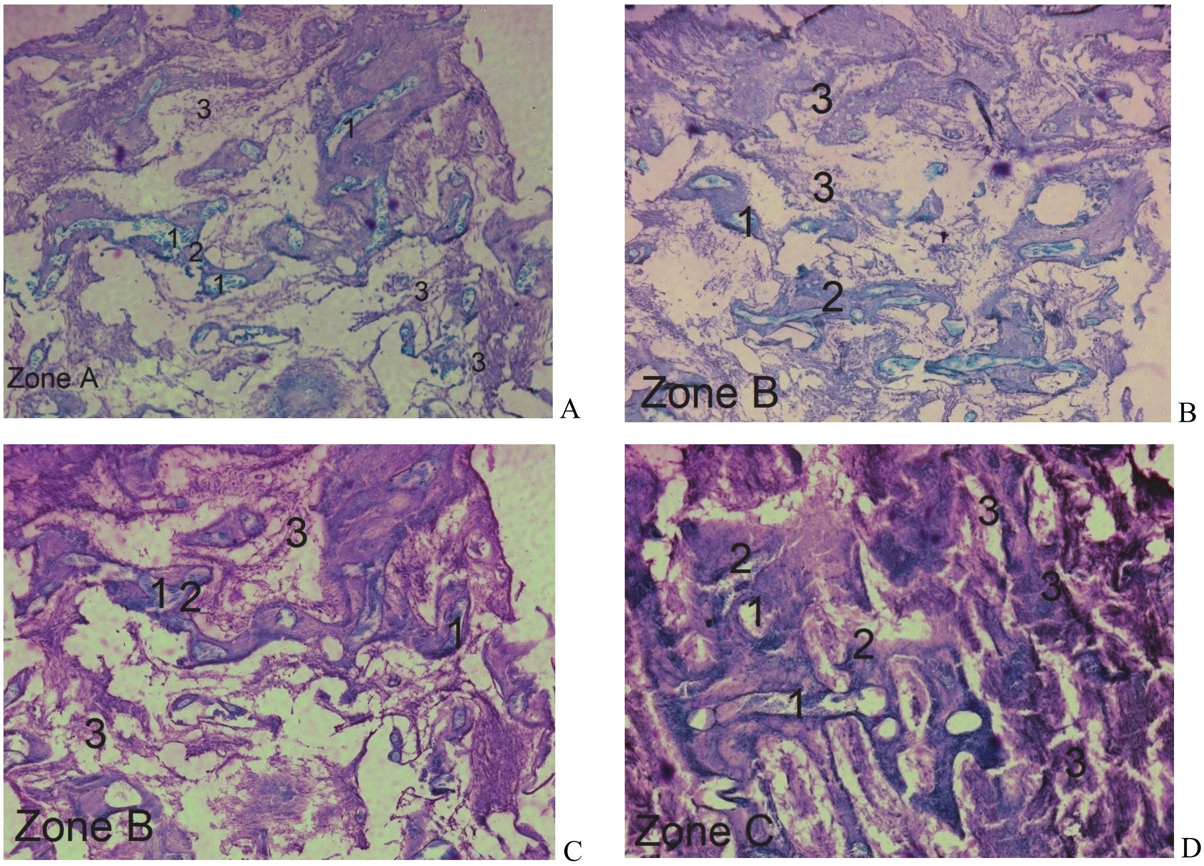

Fig. 4. Total damage of lamellar bone tissue of experimental group 1. Zones A, B, C. A – Zone A; B, C – Zone B; D – Zone C. 1 – haversian canal, 2 – layer of outer circumferential lamellae; 3 – interstitial lamellae. Hematoxylin-eosin staining. Magnification x10.

The study by Derton et al. (2021) [4] emphasizes the necessity of a comprehensive approach to orthodontic treatment planning, which involves considering both the anatomical and mechanical characteristics of the patient. Our findings confirm the effectiveness of the implant placement technique with submerged necks, which helps reduce bone tissue trauma and likely ensures greater longevity of orthodontic anchorage. Increasing the implant’s contact area with the bone, achieved by submerging its neck, enhances primary stability, aligning with modern concepts of optimizing the mechanical interlocking of implants with bone structures [7]. The structural features of the implant, specifically the smooth surface of the extended neck, reduce the risk of bone tissue damage compared to the area with a sharp-threaded section. This approach minimizes the negative impact on the cortical plate and corresponds with methods reported in the publications [5, 8].

The study by Singh et al. (2018) [9] highlights the importance of accurately measuring the primary stability of mini-implants. Our histological data demonstrate that modifications in implant placement techniques influence the structural integrity of bone tissue, which can be further validated using methods proposed in contemporary research [2].

Conclusion

The use of orthodontic implants is a relatively modern and predictable treatment method, the success of which depends on the primary stability in the jawbone tissue. In turn, we can influence the level of primary stability by using orthodontic implants considering their profile, structure and surface type. The analysis of the obtained objective data and histological material indicates a significant relationship between the method of implant placement (to the level of the neck or with the neck submerged in the cortical plate) and the degree of destruction of the cortical plate under the load applied to the implant.

Leaving the implant with the threaded part in the cortical bone (without submerging the neck) reduces the contact area between the implant and the bone, increases the damage to the cortical plate, and the mobility of the implant under load, which may negatively affect its longevity and the stability of the orthodontic support. The smooth surface with an expanded neck of orthodontic implants (Group 2) provides a larger and denser contact with the cortical plate, which, under load, better distributes the orthodontic load, reducing the traumatic effect on the bone tissue under the action of forces and may become an important factor in preventing complications, ensuring the long-term effectiveness of the anchorage.

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