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Review

Clinical Significance of Internal Friction Connection and Micro-Threads in Implant-Supported Prostheses: A Literature Review

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Abstract

A connection structure using both a screw and friction is advantageous to secure an abutment to an implant. Understanding the biomechanics of the implant-abutment connection is necessary for the long-term clinical survival of a dental implant with decreased complications. The internal conical friction connection structure and micro-threads have shown favorable biological hard tissue response with exceptional structural features. The internal conical connection structure maintains the soft tissue seal and the marginal bone level around the implant. The durability of the implant wall thickness at the top is balanced via micro-threads with the load-transfer mechanism, resulting in proper peri-implant bone strain. These two structural devices are designed to achieve implant-abutment connection stability by redistributing an external load and by minimizing screw loosening events that cause implant component fractures and marginal bone loss.

Keywords
Dental implants; implant-abutment connection; alveolar bone loss; prosthesis failure; friction; implantology

1. Introduction

In the late 1960s, the emergence of dental implants, introduced by Per-Ingvar Brånemark, proved a milestone in the history of dentistry. Since then, several implants have been introduced, tremendously impacting dental science. Dental implants have significant implications. First, an implant allows a fixed prosthesis in almost every edentulous case that is treated with a removable prosthesis in the past. Thus, it is possible to profoundly improve the comfort of a patient in terms of function, esthetics, and phonetics of an implant [1]. Second, in the case of severe alveolar bone resorption, a removable prosthesis was commonly used in the past, but the use of two or more implants, such as an implant overdenture could offer more stability. In the McGill consensus statement of 2002, the first choice of standard treatment for mandibular edentulous patients was the implant overdenture [2]. Also, an implant can prevent the disuse atrophy of the bone by transferring the occlusal force to the surrounding bone [3]. On the other hand, as dental implants have many different features and biomechanics compared to natural teeth, many complications, such as screw loosening, implant fracture, and bone resorption associated with the implants inevitably may occur [4-8]. These complications are considered to be closely associated with the implant-abutment connection (IAC) [7-9]. Maintaining the stability of the IAC is important for long-term clinical success [10-11]. To prevent complications, the biomechanics of the IAC need closer scrutiny.

Implant systems can be classified by their implant-abutment connections. The systems can be divided according to the connection assemblies: a screw connection, a friction connection, or a screw-friction connection. Bozkaya et al. showed that the Brånemark implant abutment was entirely retained with a screw, and the Bicon implant abutment was solely maintained by friction without a screw [9]. The abutments in many internal connection structures were retained simultaneously by a screw and friction [9].

In order to tightly secure the abutment to the implant, the connection method involving a screw and tapered friction fit system has traditionally been used [9]. For the screw connection system, the connection between the implant and the abutment depends on the screw-preload, which is generated by applying a predetermined amount of torque during installation. The tapered fit provides a wide surface/contact at the implant-abutment interface, which ensures a secure connection with a strong friction. In the screw connection system, screw loosening is one of the most frequent mechanical complications [5]. Screw loosening occurs when the external load exceeds the preload, or creep deformation is observed in the screw-implant interface. However, when a tapered fit is used in the implant-abutment connection, it may decrease the frequency of screw complications [9, 12-13]. The internal conical friction connection between an implant and an abutment, as with the Astra Tech Implant systems (Dentsply Sirona Inc., Charlotte, NC, USA) and Deep Implant System (Deep Implant System, Seongnam, Gyeonggi-do, South Korea), exhibits less screw loosening and bone growth rather than bone resorption [14-19]. This bone gain is an opposite phenomenon to the common implant complications occurring in clinical situations. These features are obtained from the biomechanics of two main structures of frictional interfaces and micro-threads. It is necessary to investigate these two features, theoretically and experimentally [20].

This review explores the nature of the frictional interface-strictly the internal conical friction connection-and of the micro-thread and investigates the effects of these structures on the bone response to the implant.

2. Internal Conical Implant-Abutment Friction Connection

2.1 Characteristics of Internal Conical Friction Connection

The conical friction connection between an implant and an abutment was first introduced by the Astra Tech Implant system to solve the loosening problem of an abutment screw, which frequently appeared in the external hex connection used in the original Brånemark implant system. In the internal conical friction connection, the stability of the implant-abutment connection is established not only by the preload applied to the abutment screw but also by the frictional force between the implant and abutment, which is a major contributor to stability. This is also called a friction-screw-retained connection [20].

The external hex connection has an almost universal structure and dimension across manufacturers, whereas the internal friction connection is very different in terms of the design and dimension from manufacturer to manufacturer, especially in terms of the contact length (two-dimensional) or area (three-dimensional) at the interface between the implant and the abutment [21]. For instance, the Astra Tech Implant system has a different contact length according to the implant diameter. In 1990, there were three-step different connection depths: shallow, regular, and deep connection depths at implant diameters of 3.5, 4.0, and above 4.5 mm, respectively. (see Figure 1). As the implant diameter is increased, the connection depth is deepened by 1.25 mm. This shows that the thickness of the upper implant wall and the degree of taper are kept consistent. The deeper the connection depth, the larger the contact surface between the implant and abutment would be. Bozkaya et al. showed that when the length of the interface between abutment and implant was increased, the stability of the connection was increased in proportion to the fourth power of the contact length [22]. Therefore, it is believed that a deep connection depth with a consistent thickness of implant wall withstands lateral force well.

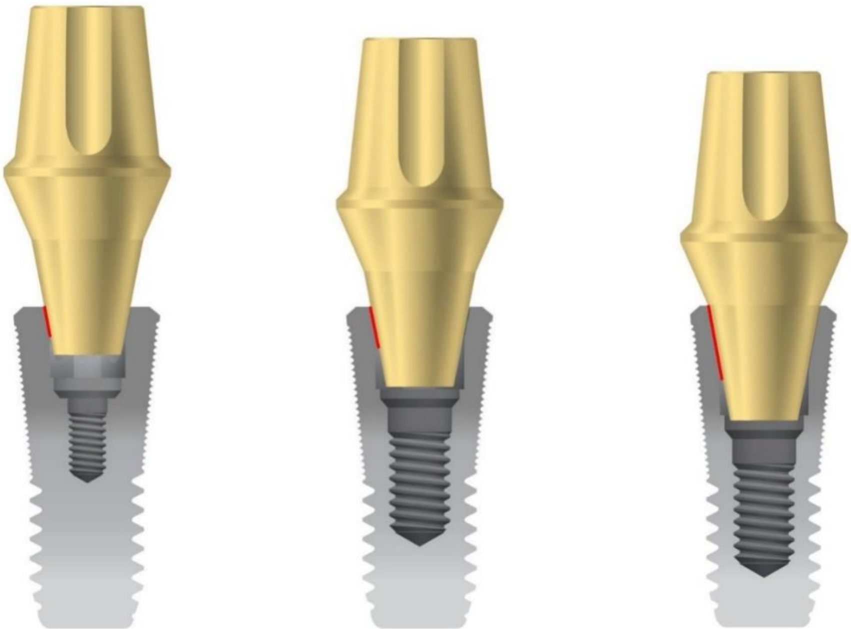

Figure 1 Schematic diagram of a shallow (left), a regular (middle), and a deep (right) connection. Note that the contact length (red lines) is larger in the deep connection than that in the shallow connection. There is no absolute standard to classify the connections into shallow, regular, and deep; however, the important factor is that the larger the contact length is, the more stable the implant-abutment connection would be.

The degree of taper on the inner surface of the implant in contact with the abutment is another important factor in connection stability [22]. If the degree of the taper is increased, the rate of implant fracture gets decreased, but the connection becomes unstable [9, 23]. Furthermore, the ratio of the contribution of internal friction force to the stability decreases, while that of the screw increases. The internal conical friction connection usually has approximately 11° of taper, while there are a few connection structures whose taper angles are less than 8° [21]. This 11° taper is considered to be adequate for optimal clinical results for esthetics and marginal bone resorption, taking into account the emergence profile and bone stimulation [20, 24, 25].

2.2 Implant-Abutment Connection Stability and Biomechanical Problems

When an implant diameter is increased while maintaining the same connection depth, the implant wall gets thickened at the top and becomes more resistant to lateral force and implant fracture. Therefore, in the system of a three-step connection with different connection depths, the deeper the connection depth, the thinner the implant wall, indicating easy fracturability of the implant. However, when the connection depth is deepened, the area of the contact surface is increased to induce stress distribution and thereby reduce the chances of an implant fracture [20, 24].

When a lateral force is applied to an implant with the internal conical friction connection structure, the abutment first contacts the upper part of the inner implant wall, and then the upper implant wall is flared due to elasticity [23, 26]. This enables the movement of the abutment in the apical direction, so the lower part of the implant wall comes into more contact with the abutment, resulting in it receiving most of the lateral force (Figure 2). As the lower implant wall is relatively thick, it can endure the external stress well. Therefore, it is necessary to ensure that the preload applied to the abutment screw disappears with the movement of the abutment, such as an abutment sinking and settling effect, so the abutment screw re-tightening should be performed repeatedly until the implant-abutment connection gets stable [27-28]. When the abutment screw is not re-tightened periodically, the screw preload decreases gradually [29]. The friction area in the internal friction connection can prevent connection instability, resulting in peri-implant pocket formation and bone resorption [20]. However, nonadherence to the re-tightening procedure can make the connection unstable resulting in biological failures, such as soft tissue seal breakage and peri-implant bone loss, as well as biomechanical failures, such as the fracture of the components of the abutment and the implant.

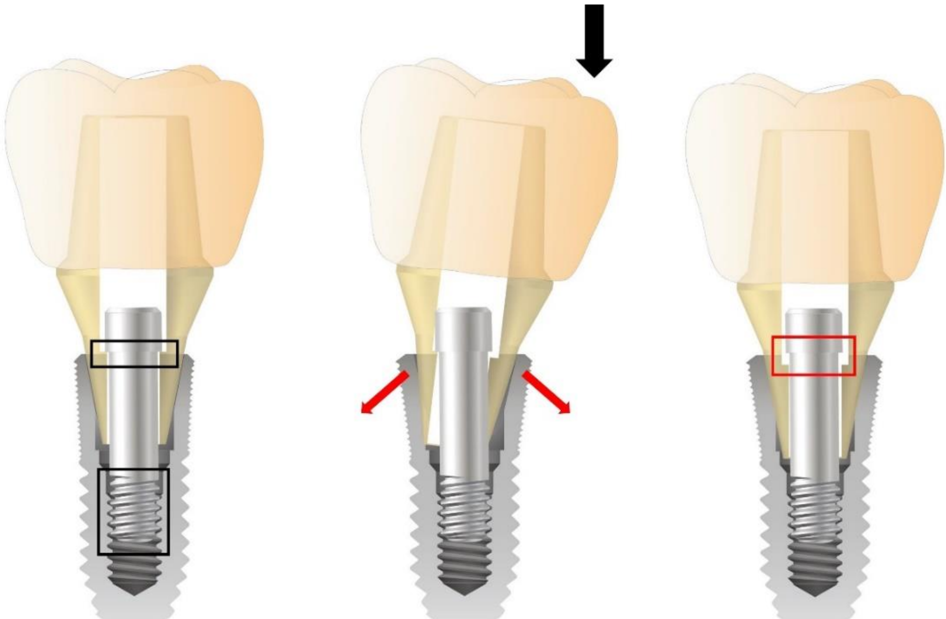

Figure 2 Left figure shows that preload is applied at the head of an abutment screw and between the threads (black rectangles). When the masticatory force is loaded on the implant-supported crown (black arrow), the horizontal vector occurs, and the abutment surface pushes the implant wall. Repetition of this pushing expands the wall (red arrows) in two right abutments, and the abutment sinks. The abutment sinking reduces the screw preload (red rectangle on the right), resulting in screw loosening. Elongation of the abutment screw also occurs.

When the abutment screw is tightened strongly, the preload- the force used to connect strongly between the abutment and implant by the clamping force of the screw- is formed on the abutment screw [9, 28]. Therefore, the preload should be removed for loosening the screw [5, 30]. There are several causes for the loss of preload, of which the elongation of the screw is caused by a lateral force exerted on the implant prosthesis [31]. The lateral force makes the upper implant wall flare at the implant-abutment interface and bends the abutment laterally. When the abutment is bent in the lateral direction, the abutment screw is elongated. After the lateral force is removed, the abutment returns to the original position, so the preload disappears, and the screw loosens [30, 32]. Accordingly, to prevent screw loosening, it is necessary to thicken the implant wall or place the implant-abutment connection in a deep position to redistribute stress [23, 33-34]. Generally, as the width of the alveolar bone is predetermined individually, the increase in the implant diameter is limited. In this limited circumference, the only way to prevent an implant wall flaring is to use a deep implant-abutment connection depth to maximize the stress distribution.

2.3 Alveolar Bone Stimulation

Long-term studies of the Brånemark abutment system (Nobel Biocare, USA) using the external hex connection showed that when the implant was first exposed to an oral cavity, a marginal bone loss around the implant of about 1 or 1.5 mm occurred during the first year [35, 36]. Additionally, 0.2 mm of bone mass was absorbed every year, as revealed in a previous study [37]. Several studies have shown that the marginal bone mass around the internal friction connection, especially for the Astra Tech Implant system, is maintained as time passes [15, 36].

An intact soft tissue around the implant helps preserve a healthy environment [20]. When the mucosal seal formed around an implant is broken, microbes may penetrate the internal space and increase the likelihood of peri-implant diseases and bone resorption [38-41]. Mobility at the implant-abutment connection can destroy the mucosal seal due to the abutment screw loosening. This loosening often occurs in implants with an external hex connection, where the lateral force is concentrated on the abutment screw [42]. In the internal friction connection, the lateral force is distributed along with the implant-abutment interface, leading to less screw loosening with abutment immobility.

In natural teeth, periodontal ligaments transfer some stress to the alveolar bone for adequate stimulation, allowing the alveolar bone to be maintained in a healthy state. As with periodontal ligaments, when the implant stimulates around the alveolar bone appropriately, the peri-implant bone can be well-preserved. Harold M. Frost's theory can be applied to the alveolar bone as well as to other bones in the human body [43-44]; therefore, under proper strain conditions, osteoblasts can be activated, impacting the bone status. This concept was first applied to the implant systems with the internal conical friction connection with a slope of 11°, well-balanced with the implant wall thickness at the top to transfer the proper strain to the peri-implant bone. When the occlusal force is applied to the abutment, it is transferred through the implant wall to the alveolar bone as the strain for proper stimulation [45]. The mechanism of stimulation is that the abutment is sunk downward by occlusal force, causing the upper implant wall to flare and the peri-implant bone to stimulate appropriately. This stimulation prevents alveolar bone resorption and even induces growth.

3. Micro-Thread

3.1 Role of Implant Thread

Before the advent of the screw-shaped implant system, most of the implants were blade-shaped or cylindrical without threads. These implants showed very poor success rates with many complications and gradually disappeared [46, 47]. The screw-shaped endosseous implant, originally developed by Dr. Brånemark, was the first system to demonstrate successful long-term and predictable clinical results. This screw-shaped implant has a thread on the implant surface by which the occlusal force is delivered around the alveolar bone as the favorable condition [46, 47]. There are three types of loads at the implant-bone interface: compressive, tensile, and shear stress [48].

Of the three loads, the compressive stress is the most beneficial load increasing the degree and strength of osseointegration [48]. In the plain-shaped implants, the occlusal force is transformed to shear stress, which is likely to destroy interface contact at the implant-alveolar bone interface. In contrast, the thread of the implant possibly transforms the shear stress into compressive stress, stimulating the bone around threads and producing a stable bone condition [20, 49]. However, it is noteworthy that the surface parallel to the implant axis always causes shear stress, despite the presence of threads. According to Faegh et al., threads could cause various stress states along with the implant-bone interface but could not cause a reduction in shear stress [50]. Besides, implant thread shape affects the type of force at the implant-bone interface [49]. According to Bumgardner et al., the amount of shear force produced by the thread increased as the thread face angle increased [51]. Several studies have shown that the compressive stress intensity of the V-shape thread was lower than that of the square shape thread [52, 53].

Threads of the implant also improve stability by reducing the micromotion [54]. When an implant exhibits large micromotion, a large portion of the implant-bone interface is differentiated into a soft tissue, reducing the amount of bone tissue available for remodeling [55].

3.2 Definition of Micro-Thread

To develop an implant, thread depth, a critical factor, need to be considered. In the original Brånemark implant system, the thread depth was 0.375 mm. Since then, a depth of approximately 0.3 mm has been regarded as standard and applied to many implants. Thereafter, various thread dimensions have been introduced.

The micro-thread was first introduced and employed by the Astra Tech Implant System. It is emphasized that definitions of micro-threads or macro-threads include the thread depth, although there have been no obvious criteria for dividing these two dimensions to date (see Figure 3). Astra Tech implants have macro-threads (0.66 mm in pitch and 0.3 mm in depth) and micro-threads (0.22 mm in pitch and 0.1 mm in depth).

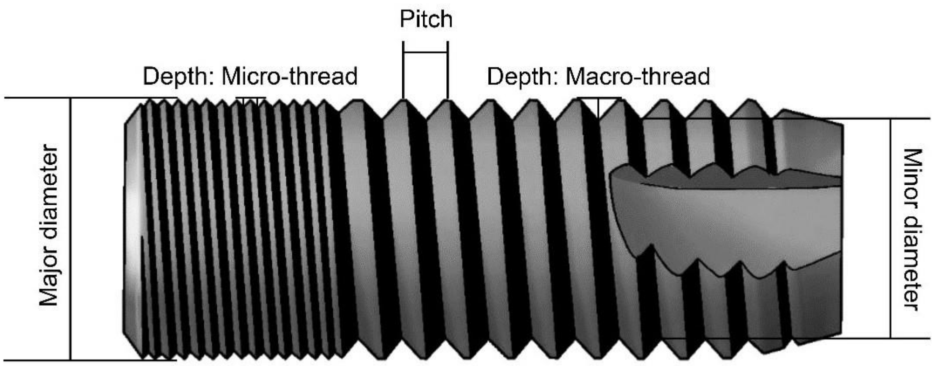

Figure 3 The definitions of thread depth and pitch. Notably, the difference between micro and macro-threads is thread depth. This figure also shows the major and minor diameters of a screw. It is notable that, in implantology, the implant diameter means the major diameter.

The definitions of macro and micro-threads are often confused with those of single and multiple threads. When an implant is turned once, the distance of vertical advancement parallel to the implant axis is defined as a lead. When one lead has the same value as the distance between adjacent threads, i.e., pitch, the implant is defined as a single-threaded implant. When a lead is equal to twice the pitch, this implant is double-threaded, and it belongs to the multiple-threaded category. For example, the micro-threads of the Astra Tech implants are triple-threaded because the threads have a lead (0.66 mm) equal to thrice the pitch (0.22 mm). Consequently, Astra Tech implants are characterized by triple micro-threads at the upper part and single macro-threads at the lower part.

3.3 Characteristics of Micro-Thread

Stig Hansson, the inventor of the original Astra Tech Implant System, reported the significance of the micro-threads. Thereafter, several studies exploring the advantages of the micro-threads have been performed [56]. Few studies have shown that the micro-threads were beneficial in maintaining marginal bone level [57-63].

The micro-threads have immense critical significance and clinical applications. First, the micro-threads allow tightening and adequate implant wall thickness. The implant thread is developed by milling technique using a milling machine or a computer numerical control machine and related tools. As the micro-threads have low thread depth, the amount subtracted by milling is insignificant. As mentioned above, the width of the implant is limited by the predetermined individual osteotomy site. Therefore, the implant wall at the micro-threaded area is thicker than when this area is milled to become macro-threaded. The thick implant wall of the micro-threads allows a deep implant-abutment connection without the loss of mechanical strength, guaranteeing a larger contact surface. Therefore, the external force, including the occlusal force, gets properly distributed. If the implant wall is thinned by forming the macro-thread, the implant-abutment connection depth would be shallowed to secure a proper thickness of the implant wall and become unstable. If the connection is deepened, the implant wall gets thinner; this may create many strength problems and cause disastrous clinical complications.

Second, the micro-threads convert shear stress to compressive stress more effectively by increasing the number of threads engaged in the bone [64]. The thread depth is closely associated with the pitch in terms of the number of threads engaged in the unit area or volume due to the bone response to a dimension [65]. When the thread depth is more, and the thread pitch is small, the alveolar bone is unable to grow into the space between the threads. Therefore, the pitch should be enhanced for alveolar bone growth for the deep threads, causing a decrease in the number of the engaged threads and the bone contact area. The pitch of micro-threads in an implant system is designed to be smaller than that of macro-threads, hinting at a larger number of micro threads included in a unit region than in macro-threads. Such an increase in the number of engaged threads is advantageous for converting the shear portion of the occlusal load to the compressive portion at the bone-implant interface. Furthermore, the occlusal force transmitted to one micro-thread is decreased when compared to that transmitted to a macro-thread. Consequently, the unit strain is applied to a thread, and the bone is optimally controlled in the micro-threaded implant system.

4. Conclusions

The internal conical friction connection structure and micro-threads have shown favorable biological hard tissue responses via their exceptional structural features such as the thickened implant wall, deepened implant-abutment connection, and an increased number of threads. These two designed structures make it possible to minimize clinical complications, including screw loosening, the fracture of implant components, and marginal bone loss. Dental clinicians must understand the internal conical friction connection and the micro-thread comprehensively.

Overall, this review highlights that the comprehension of these structures may help dental clinicians to select an appropriate implant system and to obtain the long-term predictability of implants inserted into their patients' mouths. This paper will prove useful to clinicians and researchers and may lead to better prosthetic devices with minimal complications.

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Writing-original draft preparation, K.-W.J. and J.C.K.; writing—review and editing, I.-S.L.Y.

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Competing Interests

The authors have declared that no competing interests exist.

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