The Temporary Anchorage Device (TAD): A surface characterization study using optical microscopy

Farid Bourzgui1, Hakima Aghoutan1, Mourad Sebbar1, Samir Diouny2 and Bouchaib Aazzab3

1 Department of Dento-Facial Orthopedic, Dental Research Laboratory, Faculty of Dental Medicine, Hassan II Ain Chok University in Casablanca, Morocco
2 Department of English Studies, Faculty of Letters and Humanities Chouaib Doukkali University, El-Jadida, Morocco
3 Dental Research Laboratory Director Faculty of Dental Medicine, Hassan II Ain Chok University in Casablanca, Morocco

The growing demand for minimum compliance and maximum curative effects has made the temporary anchorage device (TAD) more promising as an excellent alternative to traditional orthodontic anchorage. Orthodontic temporary anchorage devices (TADs) are successfully used as compliance-independent anchorage auxiliaries in orthodontics to prevent traditional anchorage methods shortcomings. However, the use of anchoring devices has shown its limits. Such limits include soft tissue inflammation, patient discomfort, specific biomechanics problems and anchoring device stability.

Various studies have claimed that the use of TADs in oral environment is subject to corrosion; they may generate both a progressive biodegradation of the material on the surface, and an oxidation process to release potentially harmful substances. The relationship between surface mini-screws-tribological properties and oral health in orthodontics is poorly understood, and thus, represents a major "challenge". Faced with these problems, it is important to examine the kind of influence oral and orthodontic loads may have on surface properties of mini-screws and its biocompatibility.

The aim of this is two-fold: (1) to investigate the surface quality of different commercially existing mini-implants, and (2) to study the different surface conditions of one kind of existing mini-implants after use in order to emphasize the influence of the oral environment and orthodontic load on surface properties of these devices.

1. Introduction

In orthodontic treatment, reciprocal effects must be evaluated and controlled. The goal is to maximize desired tooth movement and minimize undesirable effects with a maximum of dental three-dimensional control. In this respect, temporary anchorage device (TAD) can be used to obtain absolute anchorage without the need for patient compliance and with minimal associated patient morbidity [1]. This is indicated when absolute anchorage is unattainable with traditional orthodontic mechanics.

With the invention of the onplant in 1995, Block and Hoffman [2] introduced the palate as an anchorage device location. In 1997, Kanomi first described mini-implants derived from surgical screws used to fixate bone fragments during orthognathic and reconstructive surgery [3]. Since then, TAD has become a common practice in orthodontics. However, it is important to note that some clinicians use screws only (miniscrews, mini-implants…), while others use screws in conjunction with miniplates [4]. Therefore, the majority of orthodontists favor mini-screws because they are cheap, easy to place and retrieve, they are small, cause minimal irritation., and allow immediate loading [1] [3] [5]

To date, very few investigations have studied the surface status of miniscrews during usage, including structural changes, modifications of their mechanical properties and different soft-tissue-material interactions, which can be decisive for miniscrew success [6], hence, the present chapter is needed.

This chapter aims, first of all, to investigate the surface states of different commercially existing mini-implants to get an idea about surface quality and eventually the manufacturing defects at the start. A second objective is to study the different surface conditions of one kind of existing mini-implants after use in order to emphasize the influence of the oral environment and orthodontic load on surface properties of these devices.

2. Mini-Screws in Orthodontic treatment

In orthodontic treatment, anchorage control has always been a key requirement for success. The development and incorporation of mini-implants have provided a means of achieving absolute anchorage for labial as well as for lingual orthodontics.

The end of the 20th century marked a new area in implant technology; implants came in smaller size; were easy to place; and relatively cheap. Such factors made osteointegration redundant, reduced healing period, and allowed immediate loading.
2.1 Indications

Defining specific indications of mini-implants has two potential benefits. First, the use of mini-implants appropriately leads to improved treatment results. Second, failure to use them when traditional mechanics could lead to equally satisfying results prevents over-treatment. However, some situations that require traditional mechanics might be treated in a shorter time or at least have a predictable outcome. [6]

When maximum anchorage is necessary, the mini-implants appear to be a good alternative for both horizontal and vertical orthodontic traction. Over the years, researches have measured the breadth of applications enabled by these techniques. Among the most important advantages often cited in the literature are mass retraction (fig 1), correction of gummy smile (fig 2), molar uprighting and molar intrusion (fig 3). Placed in the palatal area, these miniscrews can produce sufficient anchorage for molar distalization. [7] [8]

Mini-implants are particularly useful in adult treatment, when there is a decrease in the number of teeth, in case of pre-prosthetic treatment (fig 4), when the alveolar ridges are more or less absorbed and when a periodontal disease results in more or less important mobility. [9] [10].

Melsen, 2005 [in 11] suggested using miniscrew implants as anchorage in cases where the forces on the reactive unit would generate adverse side effects, in patients with a need for asymmetrical tooth movements, and in some cases as an alternative to orthognathic surgical procedure. Finally, this concern is equally applicable to lingual orthodontic techniques (fig 5). The use of extra-oral appliances for anchorage reinforcement is highly compliance-dependent and esthetically unacceptable for the majority of patients considering lingual orthodontics. [12]
2.2 Properties
There are over forty manufacturers producing over 700 TADs, with 154 different screw designs available per system (fig6) [1]

Materials must be biocompatible, must have excellent mechanical properties, and must resist to stress and corrosion. Commonly used materials can be divided into 3 categories: Biotolerant (stainless steel, chromium-cobalt alloy), bioinert (titanium, carbon), and bioactive (hydroxylapatite, ceramic oxidized aluminum) [13]. Because of its biological characteristics, titanium is widely used; it allows maintaining the bone implant interface for long. However, pure titanium has less fatigue strength than titanium alloys. Titanium alloy titanium-6 aluminum-4 vanadium is used to overcome this defect (Misch 1999) [in 8].

These orthodontic devices are submitted in oral environment to electrochemical corrosion phenomena that could affect mini-implant stability and efficiency. It is likely to cause progressive biodegradation of the surface material and, by the process of oxidation, release potentially harmful or allergenic substances [14].
2.3 Clinical implications:

After placing mini-implants, they are then bio-integrated in bone tissue by an instant bone-healing phenomenon involving proteins and surface cells [13]. Because mini-screws stability is based on the screwing of the mini implant into bone, immediate loading following placement is possible and does not compromise healing process. However, in study by Motoyoshi and al. (2007) [in 1], adults showed higher success rate versus adolescents with immediate loading, probably because of higher bone density. This suggests that one has to wait for two weeks to begin mini-screws use in adolescents. (Reynders et al., 2009) [1]

Due to their temporary nature, mini-screws are made with a smooth, machine polished surface to prevent osseointegration to allow easy removal. Some authors claim that there is fibro-integration (channel and Salvadori 2008) [15] rather than osseointegration. Others, however, maintain that mini-implant anchorage is essentially mechanical and does not result from osseointegration (Dumoulin 2008).

Anchoring devices have shown clinical success, but a number of disadvantages have been reported, for example, soft tissue inflammation, patient discomfort, mechanics development difficulties and orthodontic appliance on them (springs, chains...), stability problems of anchoring device, and removal. (Philippart et al., 2004) [10] (Wiechmann et al. 2007) [16] (Lai et al. 2014) [17]

It is important to note that miniscrews are too small to cause irreversible bone damage. They can be submitted at any time when the orthodontist or the patient wants and bone healing after removal is done without any incident (Massif et al., 2006, Davarpanah et al., 2007).

3. Surface characterization study using optical microscopy

The relationship between miniscrew surface status and the tribological properties of orthodontic implants has been under investigated as testified by the very small number of publications dealing with this issue. We sought to investigate the influence of the oral biological environment as well as that of orthodontic loading on miniscrew surface properties. However, we deemed it necessary to compare, first of all, the surface states of different commercially existing mini-implants to get an idea about the surface quality and eventually the machining defects at the outset. Then, we studied modifications affecting the surface condition of one of them after use for orthodontic treatment.

3.1 Microscopic comparison of the mini-screw’s surface before clinical use

The aim of this study is to examine the morphological features of commercially available mini-screws.

3.1.1 Material and methods

Four new mini-screws of different manufacturers, including the manufacturer of Miniscrews trademarks patients (Absc Anchor [Dentos, Daegu, South Korea] Infiniti [DB Orthodontics, Silsden, West Yorkshire, UK], Dual TopW [Jeil Medical Corporation, Seoul, Korea], IMTECW [Ardmore, Okla]) were examined under the same microscope to compare their surface characterization before any clinical use.

3.1.2 Results

Despite the smooth look with the naked eye, all new miniscrews showed under optical microscopy, an irregular surface with machining and polishing defects in the form of stripes that could constitute election’s point for electrochemical attacks. These defects are present both in the head and in the coils of the mini-implant (fig8-11)
Fig. 8 Optical microscopy view of mini-screw Dual Top Anchor SystemW (Jeil Medical Corporation, Seoul, Korea): irregular surface showing manufacturing defects and alloy impurities.

Fig. 9 Optical microscopy view of mini-screw IMTECW (Ardmore, Okla.): presence of manufacturing defects in slots and grooves.

Fig. 10 Optical microscopy view of mini-screw AbsoAnchor [Dentos, Daegu, South Korea]: presence of stripes and points defects across the entire surface of mini-screw.

Fig. 11 Optical microscopy view of mini-screw Infinitas (DB Orthodontics, Silsden, West Yorkshire, UK): presence of manufacturing defects and alloy impurities.
3.2 Microscopic comparison of the mini-screw’s surface before and after clinical use

This section aimed to investigate the changes affecting the surface condition of recovered mini-screws following orthodontic treatment and comparing these miniscrews to unused ones (Sebbar et al., 2010; Sebbar et al., 2011).

3.2.1 Subjects, Materials and Method

Our study included 13 patients following treatment at Casablanca Dental Clinic Ibn Rochd University Hospital. 28 mini-screws (Dual-Top Anchor System; Lotus Orthodontics, Korea) were inserted for various orthodontic indications (ingression, anterior retraction, decrease in mass, asymmetry correction, etc.). The mini-screws were of different diameters and lengths. Different practitioners placed all mini-screws under the same conditions.

These mini-screws were loaded immediately after installation, using a screwdriver supplied by the manufacturer. An observation sheet was completed for each patient including patient identification, orthodontic diagnosis, treatment schedule and the insertion of mini-screws. The consent of all patients was obtained prior to the mini implant installation. Data collection was performed on an individual record for the study of the surface state.

The locations of mini-screws were chosen after a detailed analysis of treatment goals, a careful historical and radiographical evaluation. The size and the diameter of the mini-screws were chosen according to the anatomical site, depending on the quantity and quality of the bone.

All the mini-screws used were recovered and placed in self-sealed plastic boxes, containing all the information already listed on the computer sheet. A new mini-screw provided by the manufacturer served as control. We chose samples from the same manufacturer in order to limit as far as possible any bias due to differing variables of use.

After cleaning the mini-screws with acetone, they were examined under an optical microscope (Leica DM2500 M) and observed from three perspectives (x5, x10, x20) in order to study the machining defects and changes affecting the state of surface and compare the results of observations with those of the control min-screw. The study was conducted at the Laboratory of Science at Casablanca Dental School.

3.2.2 Results

The 28 miniscrews were placed at different sites. 14 mini-screws were used for molar intrusion, 11 mini-screws for retraction of anterior teeth, 2 mini-screws were shown to raise an incisor overbite and one mini-screw was used to correct asymmetry. 21 mini-screws were placed in the buccal region while 7 mini-screws had a palatal location. 3 mini-screws were placed in front and 25 mini-screws had a posterior position. 25 mini-screws were used in the maxilla and 3 mini-screws were placed in the mandible. 3 mini-screws were used for a period of 1 to 6 months, 9 mini-screws for a period of 6 to 12 months and 16 mini-screws for 12 months or more.

Sample harvesting was performed without any particular complication and with no undesirable impact on the different sites. Postoperative follow-up of the sample sites evidenced complete healing with no sign of inflammation or bleeding.

The miniscrews used in this study were made of titanium or, more accurately, of a titanium-alloy containing aluminum and vanadium (TiA16V4). All miniscrews were fitted and removed without breakage or bending. We noted that the miniscrews were easily removed, thus suggesting absence of osteointegration. After removal, the miniscrews were examined by means of a 113 optical microscope in order to determine their surface status. Observations were made across the entire surface of the miniscrew using three magnifying lenses (5, 10, 20). Image magnification (10, 20) allowed us to better visualize the surface status and pinpoint the various alterations affecting the miniscrew surface.

Despite a smooth appearance to the naked eye, the control miniscrew had surface milling and polishing defects in the form of scratches, which can serve as a starting point for electrochemical attacks. Observations under optical microscopy evidenced signs of corrosion in the form of pitting and crevices, principally at the site of the manufacturing defects (Figure 12.13).

![Fig. 12 Optical microscopy views of the control miniscrew showing a highly irregular surface with manufacturing defects and alloy impurities: a: control miniscrew, magnification 5; b: control miniscrew, magnification 10.](image-url)
Optical microscopy images of the retrieved miniscrews indicated manufacturing defects due to the widening of the scratches because of corrosive attack in the form of pitting and crevices. This inevitably results in a damaged passivation layer following destruction of the protective titanium dioxide film on the surface of the alloy (Figures 14, 15).

All the specimens exhibited loss of gloss and polish and, consequently, a dull surface. Localized pitting was the most frequent form of corrosion observed in our sample.
3.2.3 Discussion

Miniscrew surfaces are subject to corrosion following contact with the electrolyte composition of biological fluids. Surfaces are much more rapidly corroded when miniscrews are loaded while in service. Observation under optical microscopy evidenced signs of corrosion in the form of pitting or crevices principally on account of milling defects. Corrosion not only alters the nature of the surface but also the resistance and other properties of the material. In addition, products of corrosion can result in the formation of fibrous capsule and chronic inflammation and be released into neighboring tissues, inducing local and systemic reactions [18].

The ideal biomaterial for miniscrew implants should exhibit excellent corrosion resistance, biocompatibility and sufficient mechanical strength to enable orthodontic miniscrews to withstand the torsional forces during insertion and removal. Though miniscrews often break at the neck in a clinical setting, such fractures are often the result of miniscrew design.

To determine the optimum safety factor for miniscrew implants, variations in mechanical properties and forms of deterioration such as torsional fatigue during tooth displacements or corrosion of fitted implants, must be considered [19].

The internal microstructure and metal composition of mini-screws are also an important aspect to consider since bubbles, flaws and cracks could cause fractures mainly during placement of the mini-implant or putting them in charge [20].

Eliades et al. (2009) [19] analyzed 11 retrieved miniscrew implants used in various orthodontic indications. The sample was used for an average active treatment time ranging between 3.5 and 17.5 months; it was removed with no sign of failures such as peri-implant soft-tissue inflammation, implant mobility or premature loss. Miniscrews matched by brand, type and size served as controls. All miniscrews were examined under stereomicroscopy to detect possible microscopic cracks. The structure of both retrieved and control miniscrews was analyzed by high-resolution X-ray computer tomography (CT). The miniscrews were studied under electron microscopy to determine their morphological status. Optical microscopy showed loss of gloss with variable discoloring. Scanning electron microscopy and X-ray microanalysis revealed morphological changes with layers of sodium, potassium, chlorine, iron, calcium and phosphorus deposited on the miniscrew surface. Two-dimensional micro tomography X-ray images reconstructing the longitudinal cross-section of a control miniscrew showed no defects in the form of pores or cracks due to surface loading in the mouth. This analysis also suggested that calcium and iron precipitates were induced by contact of the miniscrew with blood and biological fluids.

Surface characterization of retrieved miniscrews revealed an ageing process, as seen in numerous biomaterials ranging from polymers [21] to orthodontic alloys, which basically involves the absorption of protein layers which has later become calcified and precipitated as phosphorus and calcium. [6]

Oral placement of miniscrews causes several phenomena:

- pH reduction during the initial exudative phases;
- cell activation, including for granulocytes, neutrophils and macrophages;
- release of proteins, enzymes and oxidative agents, which could significantly modify the implant’s surface reactivity (Eliades et al., 1999) [21].

Prolonged exposure of miniscrews in the mouth generates harder and more calcified precipitates than shorter exposure length does. Depending on patient and oral conditions, the metal surface is covered with a layer of protein, which conceals the surface topography of the alloy, the extent of the protein varying according to the conditions prevailing in the mouth of each patient (Hanning et al., 1999) [22].

This surface layer significantly alters the morphology, surface composition and electronic reactivity of the implant. Mineralized areas can serve as a protection shielding the alloy substrate, particularly if pH or corrosion levels are low ([Oshida et al., 1992] [23].

The key advantage of Ti alloys is the rapid formation of a dense and amorphous film of passive titanium dioxide (Eliades, 1999). Stress exerted on a miniscrew during healing can have severe adverse effects, depending on the duration of the stress. We hold the opinion that poorly inserted miniscrews respond by developing reparative fibrous tissue.

Implant micro movement is an important factor in bone regeneration and has a much greater influence on bone healing and the properties of biomaterials [13]. In the absence of micro-movements, osseointegration of the bone-biomaterial interface is more likely to be linked to potential inherent bone healing than to a single phenomenon induced by the biomaterial of which the implant is made.

Surface modifications to retrieved miniscrews are difficult to explain (Schliephake et al., 1993) [24]. In their study, Rangert and Langer (1995) [25] found that miniscrew failures were caused by fatigue. Another study by Glauser et al. (2005) [26] showed the presence of linear scoring pointing to the development of fatigue cracks, probably induced by repeated tractive stresses.
4. Conclusion

Despite a smooth appearance to the naked eye, the miniscrews all displayed milling defects in the form of scratches. Observations of the status of the surface of these screws revealed the presence, after usage, of pitting or crevice-type corrosion principally at the site of milling defects. It follows that improved surface treatment of orthodontic miniscrew implants would enhance corrosion resistance.

The patients' number and mini-screws analyzed in this study were too small to be representative; more studies involving larger number of patients and mini-screws are necessary.

Due to large variation in our sample, the site of implantation, type of mini-screws and surgical orthodontic movement desired, the amount of force applied and the use of immediate loading, findings of the study are quite limited. Therefore, further studies are needed.

References