Fundamental factors related to orthodontic micro-implant stability: Review of the literature

Najważniejsze czynniki związane ze stabilizacją mikroimplantów ortodontycznych – przegląd piśmiennictwa

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Abstract

The development and introduction of temporary intraoral anchorage devices (TISAD) in the beginning of the 21st century had a great impact on contemporary orthodontics. The enhancement of the scope of orthodontic treatment, improved efficiency, reduction of both the treatment time and need for the patient's compliance, all of these are the crucial advantages the TISAD have provided to our profession. However, there are also some limiting factors pertaining to this anchorage reinforcement technique which must be borne in mind prior to clinical application. Among some others, premature failure of the micro-implants is the most significant problem related to their utilization, as it entails a repetition of the insertion procedure, increasing the cost and duration of treatment and causing the patient's discomfort. Therefore, recognition of the factors related to the stability of orthodontic micro-implants is necessary for their efficient clinical application and maximum survival rates. Since over the last decade there has been noteworthy progress in the research investigating the issue of micro-implant stability, a review of the most current literature pertaining to this topic was the aim of our article, and ultimately providing clinical recommendations.

Key words: stability, micro-implants, success rates, micro-screws, TAD

Słowa kluczowe: stabilność, mikroimplanty, współczynniki sukcesu, mikrośruby, TAD

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Temporary intraoral anchorage devices (TISAD) constitute a group of modern anchorage reinforcement tools which share a unique feature: the ability to provide absolute and compliance-free anchorage. The development of TISAD at the beginning of 21st century has noticeably extended orthodontic treatment efficacy along with the improvement of the patient's comfort. Nevertheless, as any other anchorage bolstering technique, use of TISAD bears some drawbacks, where loss of stability is the major one. Reported micro-implant success rates range from 75 to 94%, therefore roughly from 1 to 3 out of 10 inserted TISAD become mobile and cannot serve according to intent.^{1–4} As a consequence, the failure of a micro-screw requires another implantation, increasing treatment cost, time and discomfort. Premature loss of orthodontic micro-implants has been a fundamental problem since their introduction to clinical practice, constantly calling for identification of the determinants favoring TISAD instability. The literature from the last decade deals with this issue substantially, thus the aim of this article was an evidence-based appraisal of the most crucial factors related to micro-implant survival, taking into account the most recent scientific findings. A search of the Medline, Scopus, Ebsco and Web of Science electronic databases was performed with all combinations of the key words: micro-implants, mini-implants, micro-screws, mini-screws, TAD and TISAD, and stability, success rate and risk factor. After reviewing the articles published from 2000 to 2016, we have summarized the most important findings in this paper. The determinants discussed were divided into 3 categories encompassing: the properties of a micro-implant, the patient's characteristics and management of TISAD.

Design of a micro-implant

Table 1 summarizes the influence of the orthodontic micro-implant design on its stability. Micro-implants have the shape of a screw with a diameter 1.0–2.0 mm and a length 6–12 mm. The small dimensions are essential since they make possible TISAD placement in narrow interradicular spaces, thus providing an appropriate orthodontic force vector. However, it must be borne in mind that TISAD stabilization depends mostly on their primary stability, thus – theoretically – larger sizes, as opposed to smaller ones, will promote firmness of the micro-screws and there are reports in the literature indeed confirming such thesis. Miyawaki et al.⁵ and Motoyoshi et al.⁶ suggest that screws with a diameter equal to or smaller than 1.0 mm should be avoided, because their failure rate is significantly higher comparing to the screws with larger cross-section areas. The study of Wilmes et al.⁷ supported this result, as the authors similarly found 1.1 mm screw stability fairly lower than 1.6 mm ones. In turn, Chen et al.⁸ and Sarul et al.⁹, while investigating the impact of micro-implant length, concordantly reported that screws

8 mm long are more stable than 6 mm ones. Last but not least, two independent meta-analyses by Crismani et al.¹⁰ and Dalessandri et al.¹¹ have validated these outcomes and stated that sizes of minimum 1.2 × 8 mm and 1.3 × 8 mm, respectively, ensure sufficient primary stability of micro-screws. Therefore, micro-implants with at least such dimensions are advocated for most clinical applications, with exceptional use of the smaller TISAD in carefully selected cases.

As for the TISAD design, Migliorati et al. studied the micro-screw thread shape influence on stability.¹² They evaluated a geometrical TISAD relationship to describe the mechanical properties of miniscrews, calculated as the relationship between the mean thread depth and the pitch (D/P), expressed as a percentage. The authors proved that a higher percentage significantly correlates with better micro-implant stability. Chadad et al. also proved that etching and sandblasting the micro-implant's surface does not increase its stability, which again underscores the crucial role of the screw size.¹³

Patient's characteristics

Sex and age

A summary of the patient's characteristics' impact on the stability of micro-implants is presented in Table 2. Most of the researchers did not find significant differences between men and women in terms of micro-implant stability^{14–18}, which was entirely supported in 2 independent meta-analyses^{10,11} evidently proving that sex does not affect micro-implant loosening.

In regard to age, Chen et al.¹⁶ observed significantly more frequent micro-screw instability in 20 to 30 year-old patients, contrary to Lee et al.¹⁷ who noted the highest success rates in such individuals. Apart from these 2 reports, the majority of the studies did not reveal any relationship of micro-implant stability and the patient's age,^{4,5,14,15} again: 2 meta-analyses endorse such outcomes.^{10,11} And although Dalessandri et al.¹¹ indicate a higher failure rate in patients under 20 years of age, the difference is minor and insignificant.

Table 1. Influence of micro-implant design on its stability

Micro-implant design	Influence on the stability of the micro-implant
Diameter	diameter of at least 1–2 mm improves the stability of micro-implants
Length	length of at least 8 mm promotes the stability of micro-implants
Thread shape factor	higher values of thread shape factor increase the stability of micro-implants
Surface preparation	etching and sandblasting does not enhance the stability of micro-implants

Bone anatomy and histology

Micro-implants installed in the mandible have been reported to fail significantly more often than those placed in the maxilla.^{14–18} Cheng et al. has suggested that the thick cortical plate in the mandible conduces to a rapid raise of the temperature during hole drilling, which may result in bone overheating.¹⁵ Another issue resulting from greater cortical thickness is a risk of ischemia of the bone due to the high pressure exerted by the micro-implant.¹⁹ Both the high temperature and high pressure result in necrosis and degeneration of the bone supporting the micro-implant, which subsequently loses primary stability and requires replacement. On the other hand, there are some studies that did not reveal any differences in micro-implant stability in the maxilla or the mandible. Chen et al.²⁰ stated that the quality of the bone itself rather than location is paramount for micro-screw fixation, which is in accordance with the studies published by Miyawaki et al.⁵, who similarly concluded that cortical thickness overrides the issue of location itself. Nevertheless, the results of the meta-analyses clearly indicate that orthodontic micro-implants placed in the mandible have a higher risk of failure.^{10,11} Thus, already at the stage of treatment planning, one needs to consider another anchorage reinforcement method, applicable when loosening of the TISAD in the mandible emerges.

The role of bone quality and quantity in achieving primary stability, so crucial for micro-screw survival, seems quite obvious. The ability to hold the screw in the bone is defined by parameters such as: 1. tightening torque and 2. pull out force. Experimental studies have revealed a positive correlation between these two variables and the thickness and density of the cortical plate and density of the cancellous bone,^{21–24} further supported by the results of research on human cadavers.²⁵ Motoyoshi et al. have established that the critical thickness ensuring sufficient primary stability is 1 mm.²⁶ The results of the meta-analysis conducted by Marquezan et al.²⁷ confirmed a positive correlation between cortical bone thickness and the sta-

bility of micro-implants, though the authors emphasized the need for more high-quality clinical studies to support the final conclusion. Motoyoshi et al. demonstrated that the optimal placement torque values lie in the limit from 5 to 10 N/cm.²⁸ According to those authors, a lower number indicates insufficient mechanical fixation of the micro-screw, whereas a higher number reflects very strong pressure exerted by the implant on the bone, which may result in ischemic osteonecrosis. A meta-analysis by Meursinge Reynders et al. did not reveal any ideal micro-implant placement torque rate, however this may be partly caused by a very limited number of studies meeting the criteria and included in the analysis.²⁹

Susceptibility to inflammation

The detrimental influence of the inflammatory process of tissues surrounding the micro-implants has been widely emphasized as well.^{2,5,15,20,30–32} Experimental studies show that a penetrating inflammatory process results in degeneration of the bone supporting the micro-implant that finally loses its stability.^{32,33} Dalessandri et al. proved that peri-micro-implantitis entails an almost 9-fold increase of the risk of micro-screw failure and seems to be one of the most important factors responsible for this complication.¹¹ The phenomena may develop as a consequence of infection from oral micro-flora or may be caused by proximity or tight contact with the adjacent root.³⁴ Therefore, a fully aseptic and precise micro-implant placement procedure, along with meticulous hygiene of micro-screw surrounding tissues is paramount for a reduction of inflammation-related failures. As shown by Kuroda et al., the incidence of inflammations is higher when the micro-implant is placed in free mucosa, thus localization in attached gingiva is also recommended whenever applicable.³⁵

Nicotine addiction

Bayat and Baus showed that patients who smoke more than 10 cigarettes a day have a significantly higher risk of micro-implant failure than non-smokers or those who smoke less.³⁶ Therefore, a medical questionnaire should help to investigate the presence and intensity of nicotine addiction and the number of cigarettes smoked, which – if severe or high – ought to be considered while estimating the potential stability of micro-screws applied in a given individual.

Management of TISAD

Placement procedure

The influence of micro-implant management on its stability is shown in Table 3. There are multiple surgical protocols of micro-implant placement reported in the lit-

Table 2. Influence of patient characteristics on the stability of micro-implants

Factor	Influence on the stability of the micro-implant
Sex	sex has no influence on the stability of micro-implants
Age	age has no or very little impact on the stability of micro-implants
Location	micro-implants are more stable in maxilla compared to mandible
Bone quality and quantity	thicker cortical plate and higher bone density promote stability of the micro-implants
Placement torque	values ranging from 5 to 10 N/cm correlate with higher stability of the micro-implants
Nicotine addiction	smoking of 10 or more cigarettes a day impairs the stability of micro-implants

erature and the basic differentiation concerns pre-drilling (self-tapping) and drill-free (self-drilling) methods.^{30,37} Experimental studies on dogs showed higher stability of the micro-implants placed with the drill-free approach, and subsequent histological analysis revealed more tight contact between the screw and the surrounding bone.³⁸ Similar results were obtained in clinical studies, which compared the success rates of 1.4 mm micro-implants placed in the self-tapping method with 0.9 or 1.1 mm pilot bur and without pre-drilling.³⁹ Statistically significant differences in success rates were noted: the highest in case of micro-screws placed without pre-drilling and the lowest in case of TISAD inserted in a hole drilled with 1.1 mm bur. The results of the cited studies indicate that micro-implant placement without pre-drilling promotes stability, however these outcomes should be interpreted with caution due to the limited number of micro-screws analyzed. It seems that in the maxilla, due to thin cortical and thick cancellous bone, skipping the drilling may enhance the bone-screw contact and improve stability. On the other hand, in the presence of very thick cortical bone in the mandible, micro-implantation without pre-drilling entails a high risk of inducing excessive pressure on the bone, likely resulting in ischemia and necrosis, which is why pre-drilling is necessary in the mandible. Miyawaki et al.⁵ and Kuroda et al.³⁵ compared the surgical protocols with and without muco-periosteal flap elevation and found a higher survival rate of micro-implants inserted using the flapless procedure. Furthermore, postoperative pain and swelling were also significantly lower in patients who received the less invasive, flapless surgery.³⁵ Therefore, a small (2–3 mm) vertical stab incision of the mucosa, preceding TISAD insertion, which exposes the bone surface and prevents the soft tissues from winding around a pilot drill, seems to be the optimal soft tissue management, which is confirmed by Antoszewska et al., who utilized such protocol and obtained very high success rates, exceeding 93%.⁴

Loading protocol

In contrast to prosthetic implants, requiring a healing period lasting several months and the necessity for osseointegration, orthodontic micro-implants may be loaded much earlier because their fixation relies mostly on primary, not on secondary stability. Some osseointegration indeed occurs in the case of TISAD, however it does not play a major role in their immovability.⁴⁰ The timing of the loading recommended in the literature ranges from immediate to 3 months post-operatively, although most of the authors deemed immediate loading possible and rational, provided a low force value is applied.^{2,5,38–42} The meta-analysis by Crismani et al. made it possible to determine the optimal conditions of loading the micro-implants: several days after placement with a force up to 200 g.¹⁰ Early loading is further validated by the meta-analysis of Dalessandri et al., who showed no

Table 3. Influence of micro-implant management on their stability

Micro-implant management	Influence on the stability of the micro-implant
Self-drilling vs Self-tapping	in the maxilla: smaller or no pilot drilling promotes stability in the mandible: pilot drilling with a bur-screw difference of 0.3–0.5 mm indicated
Flap preparation	flapless surgery ensures higher stability of the micro-implants
Loading protocol	allowed immediate loading with forces up to 200 g

difference in stability between micro-implants loaded within or over 4 weeks after insertion.¹¹ Nevertheless, it seems reasonable to postpone loading for 2 weeks after micro-implant placement, in order to allow uneventful healing of the mucosa around the TISAD heads, which is crucial to prevent inflammation: one of the major causes of micro-screw failures.

Operator's experience

Lim et al. demonstrated that the experience of the operator has a significant impact on the stability of micro-implants.³⁷ The authors reported that clinicians who had inserted at least 20 micro-screws had a 3.6 times higher chance of achieving primary stability, compared to operators who had performed fewer procedures.³⁷ Jung et al. proved that the clinician's experience also plays a role in placing the TISAD on the palate.⁴³ What is more, Cho et al. found that the higher the number of performed micro-implantations, the lower the risk of damaging an adjacent root.⁴⁴ A comparison of the stability of micro-implants inserted by a maxillofacial surgeon and an orthodontist showed no significant differences, indicating that orthodontists are fully capable of performing successful micro-implantations after they have gained the necessary experience.²⁰

Summary

Temporary Intraoral Skeletal Anchorage Devices have gradually achieved widespread use in contemporary orthodontics; therefore awareness of the factors affecting the stability of the micro-implants is crucial for full utilization of the potential they offer. According to the most up-to-date research, bone quality and quantity, use of micro-screws of at least 1.2 × 8 mm dimensions and prophylaxis of inflammation are fundamental for micro-implant survival, whereas unadaptable factors such as age and sex do not have a significant impact on micro-screw loosening, which to this day occurs more frequently in the mandible. Greater experience in the surgical procedure improves the stability of inserted micro-implants; hence it is necessary to improve the learning curve in order to maximize the success rates of the micro-screws.

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