Original papers

Comparison of primary stability of used and unused self-tapping and self-drilling orthodontic mini-implants

Baris Baser[1,A–F], Mehmet Birol Ozel[2,A,F]

[1] Department of Orthodontics, Faculty of Dentistry, Karadeniz Technical University, Trabzon, Turkey
[2] Department of Orthodontics, Faculty of Dentistry, Kocaeli University, Turkey

A – research concept and design; B – collection and/or assembly of data; C – data analysis and interpretation;
D – writing the article; E – critical revision of the article; F – final approval of the article

Advances in Clinical and Experimental Medicine, ISSN 1899–5276 (print), ISSN 2451–2680 (online) *Adv Clin Exp Med*. 2024;33(5):483–489

Address for correspondence
Baris Baser
E-mail: baris.baser@ktu.edu.tr

Funding sources
None declared

Conflict of interest
None declared

Received on February 20, 2023
Reviewed on March 20, 2023
Accepted on July 12, 2023

Published online on September 7, 2023

Abstract

Background. Skeletal anchorage has been the subject of study for many years. Recently, orthodontic mini-implants (MIs) were described as effective tools for anchorage and were named temporary anchorage devices (TADs). The success of MIs depends on their primary stability, which is defined as the lack of mobility in the bone after implant insertion, and the relevant factors affecting primary stability.

Objectives. This study aimed to compare the primary stability of used self-drilling (SD) and self-tapping (ST) MIs with unused ones by performing the insertion torque measurement, Periotest and pull-out test.

Materials and methods. Forty-six used (23 ST, 23 SD) and 46 unused (23 ST, 23 SD) MIs (1.5 mm × 8 mm) were inserted into a synthetic bone with the use of a digital screwdriver. Maximum insertion torque (MIT) values were recorded during the placement of MIs, and then Periotest measurements were made. Following the MIT and Periotest measurements, pull-out tests were performed on all MIs.

Results. The median MIT values (Ncm) of the MIs were as follows: used ST: 17.3, unused ST: 18.9, used SD: 24.1, unused SD: 25.2. The median values obtained after the Periotest were (±): used ST: 0, unused ST: –1, used SD: –3, unused SD: –3. Median pull-out values (N) were: used ST: 148.12, unused ST: 168.12, used SD: 173.12, unused SD: 203.20. Statistically, MIT and pull-out values of the used ST and SD implants were significantly lower compared to those of the unused ST and SD implants ($p < 0.05$).

Conclusions. Used orthodontic MIs showed poor performance compared with unused implants when they were inserted again in the in vitro conditions.

Key words: in vitro, self-tapping, primer stability, self-drilling, orthodontic mini-implant

Cite as
Baser B, Ozel MB. Comparison of primary stability of used and unused self-tapping and self-drilling orthodontic mini-implants. *Adv Clin Exp Med*. 2024;33(5):483–489. doi:10.17219/acem/169511

DOI
10.17219/acem/169511

Background

Skeletal anchorage has been the subject of study for many years.[1] Recently, orthodontic mini-implants (MIs) were described as effective tools for anchorage and were introduced as temporary anchorage devices (TADs).[2] These devices have some important advantages, including simple placement, less traumatic surgery, higher hygiene standards, and immediate loading.[2–6]

The success of orthodontic MIs depends on their primary stability, which is defined as the lack of mobility in bone after MI insertion and some relevant factors that may affect stability.[7] The MI design, the technique of implant placement, the insertion angle, and the diameter of the pilot drill are generally related to the primary stability of orthodontic MIs.[8–10] Currently, 2 types of implants are predominantly used in orthodontic practice: self-tapping (ST) and self-drilling (SD) orthodontic MIs.[11] Self-tapping MIs require a pre-drilled hole with a diameter similar to the implant width, while self-drilling MIs have pointed tips and cutting threads that allow placement without drilling a pilot hole.[12] Many studies have compared the clinical success rate and superiority of these 2 placement techniques.[13–16]

The literature also reports on invasive and non-invasive methods, such as pull-out strength (PS), Periotest and insertional torque (IT) tests, that have been introduced to measure the primary stability of orthodontic MIs.[2,17,18] The IT is directly related to the biomechanical performance of MIs and is defined as the effect of frictional resistance between implant threads and bone.[19–21] Periotest (Medizintechnik Gulden, Modautal, Germany) is an electronic device that was originally developed to express the physiologic or pathologic mobility of the periodontal tissues surrounding the natural tooth.[22] The device has been used to measure the mobility of orthodontic implants. Periotest generates results that are shown digitally as a numeric value.[23] Low values indicate high stability, while high values indicate low stability of the implants.[24] Pull-out strength is another common indicator for evaluating the anchorage control of MIs.[25] Some studies have examined PS as the result of bone–thread integration failure and provided important information regarding primary stability.[26]

The use of artificial bone blocks to evaluate the biomechanical performance of MIs has recently become popular due to ethical reasons.[25,27] Specimens taken from cadavers may have homogeneity problems, although their characteristics are similar to those of in vivo tissues.[28] Some studies have described the use of synthetic materials that have mechanical features similar to the structure of human bone.[29,30]

Despite the general use of orthodontic MIs as TADs and the successful results published in the literature, some studies have indicated changes in the MI surface after clinical use.[31] The physical performance and sterility of orthodontic implants must also be ensured in cases of implant reuse. However, no consensus has been reached regarding the effects of quality changes on the mechanical behavior of orthodontic MIs.[25] Although they are mostly discarded after clinical use, economic factors have led some orthodontists to reuse MIs, similar to orthodontic brackets and wires.[32–34] Few studies have provided clinicians with valuable information regarding the reuse of MIs while also ensuring maximum cost–benefit ratio and efficiency for orthodontic practices.[3] The physical performances of MIs after clinical use and the possible correlations among Periotest, IT and PS evaluations are lacking, although previous research has indicated a relationship between IT and PS values.[35]

Objectives

The aim of this study was to compare the primary stability of re-used SD and ST orthodontic MIs with as-received ones using Periotest, IT and PS tests.

Materials and methods

Study design

A total of 92 ST and SD cylindrical orthodontic MIs (1.5-mm diameter, 8-mm thread shaft; BioMaterials Korea Inc., Seoul, South Korea) were used in this study. The MIs were divided into 2 main groups according to their condition: as-received (unused, n = 46) or retrieved (used, n = 46). Then, they were equally subdivided into 2 subgroups according to the placement technique: ST (n = 23) or SD (n = 23). In total, 46 implants were retrieved from patients after a successful service of between 3.5 and 5.5 months (average: 4.51 months) in a previous study,[31] with no signs of early or late loss. After their removal, each implant was seated in a sterilizing machine (60 min at 134°C; GetinGe 600; Getinge, Göteborg, Sweden) and then stored in a plastic container for reuse. No defects, cracks or corrosion could be established visually for the retrieved implants after the sterilization process. The other 46 MIs were used as received from the manufacturer.

Insertion of the orthodontic implants

A device was made to hold and secure a digital torque meter driver (Geratech TSD-50; Kartal Otomasyon, Kocaeli, Turkey) during the placement of the orthodontic MIs (Fig. 1A). This device allowed for the perpendicular insertion of the implants through a sliding mechanism (Fig. 1B). A total of 92 implantation points were marked on the artificial bone, with enough distance to allow Periotest measurements and the movement of the metal grip designed for the PS test. The self-drilling MIs were placed directly, without a pre-drilling phase. The self-tapping MIs were inserted after drilling a pilot hole (1.2 mm × 31 mm,

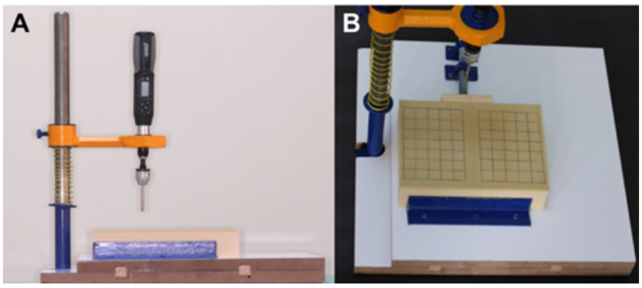

Fig. 1. A. A custom-made device for securing and stabilizing a digital torque meter driver; B. The sliding mechanism and overview of the device

BioMaterials Korea Inc.). The MIs were placed in a custom-made artificial bone block (solid rigid polyurethane foam, 180 mm in length, 13 mm in width and 43 mm in height; Sawbones Pacific Research Laboratories Inc., Vashon, USA) consisting of 2 layers that simulated cortical bone (3-mm thickness with a density of 50 pcf (0.80 g/cc)) and cancellous bone (40-mm thickness with a density of 30 pcf (0.48 g/cc)).[29,36]

Data measurement

All MIs were placed manually by a single operator, and the maximum insertion torque (MIT) value of each implant was recorded in Ncm using a digital torque meter driver. The overinsertion and friction of the orthodontic MIs were avoided during placement by using a U-shaped metal stopper with a thickness of 1.2 mm to simulate soft tissue. After the placement of each MI, Periotest measurements were performed (Fig. 2A). The PS was evaluated by separating the synthetic bone into 2 equal parts and fastening it to a testing machine (Instron 1011; Instron Corp, Canton, USA) (Fig. 2B). A larger base with bilateral metal clamps was fabricated for the bone blocks to ensure full integration with the testing machine. Pull-out strength tests were performed with a loading rate of 1 mm/min using a grip fabricated for implant seizing that allowed vertical forces to be in the same direction as the long axis of the MIs. Maximum PS values for all MIs were recorded in newtons [N] until failure or rupture occurred. During all processes, the operator was blinded to all data, and a separate researcher recorded the values.

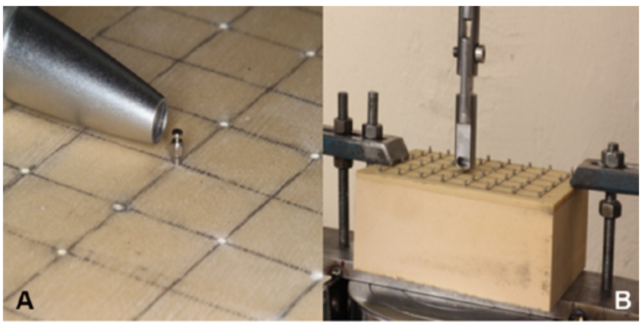

Fig. 2. A. Periotest measurement; B. The installed and separated synthetic bone block fastened to a testing machine for the pull-out test

Statistical analyses

Statistical analyses were performed using SPSS v. 17.0 software (SPSS Inc., Chicago, USA). Descriptive statistical methods (standard deviation, mean, median, minimum, and maximum values) were utilized to analyze the study data. At the data evaluation stage, the Shapiro–Wilk was conducted to assess the normality of the data. The Mann–Whitney U test was performed to determine the statistical significance of differences between the groups. Possible correlations between the MIT, Periotest and PS values were assessed using the Spearman test at the 95% confidence interval (95% CI) level. The level of significance for all statistical tests was predetermined at 0.05.

Results

All orthodontic MIs were placed in the bone without breakage or failure, and all tests were performed successfully. The median MIT of the ST implants was 17.3 Ncm in the retrieved group and 18.9 Ncm in the unused implant group. The median MIT was higher for the new SD implants (25.2 Ncm) than for the used SD implants (24.1 Ncm). The Mann–Whitney U test showed statistically significant differences between the MITs for the ST and SD MIs in both the retrieved ($z = -5.816$, $p = 0.001$) and unused implant groups ($z = -5.814$, $p = 0.001$).

The median values for the Periotest were (±) as follows: retrieved ST: 0, unused ST: –1, retrieved SD: –3, and unused SD: –3. A comparison of Periotest values for the different placement techniques revealed statistically significant differences only for the ST implant groups ($p = 0.001$). None of the SD groups showed any relevant differences, whether retrieved or new ($p > 0.05$).

The axial PS test was performed successfully in all groups. During the test, the SD MIs underwent only plastic deformation without any rupture, whereas 35 of the 46 ST orthodontic MIs detached from the head part. The median PS values for the retrieved ST and SD groups were 148.12 N and 173.12 N, respectively. The values for the unused ST and SD groups were 168.12 N and 203.20 N, respectively. All the PS values were higher for the new MIs than for the retrieved implants, and the differences in PS values were statistically significant for all implant types in both groups ($p = 0.001$). The medians, Q1, Q3, as well as and Z- and p-values of the MIs for the MIT, PS and Periotest are listed in Table 1 and Table 2.

Statistically, the MIT and PS showed a positive correlation in all orthodontic implant groups. A comparison of the PS values for the different insertion techniques revealed a stronger correlation with MIT values in the retrieved ST group ($r = 0.791$, $p = 0.001$) than in the retrieved SD group ($r = 0.457$, $p = 0.028$). By contrast, the correlation between the MIT and PS values was stronger in the unused SD group ($r = 0.615$, $p = 0.002$) than in the unused

Table 1. The medians, Q1, Q3, Z- and p-values of the unused mini-implants for MIT, PS and Periotest

Measurement method	Self-tapping (n = 23)			Self-drilling (n = 23)			Unused implants (n = 46)	
	median	Q1	Q3	median	Q1	Q3	p-value	Z-value
MIT	18.90	18.10	20.10	25.20	24.90	25.90	0.001*	−5.814
Periotest	−1.00	−3.00	0.00	−3.00	−4.00	−3.00	0.001*	−3.752
PS	168.12	152.41	170.98	203.20	199.190	219.670	0.001*	−5.789

Mann–Whitney U test, * p = 0.001; Q1 – 25th percentile; Q3 – 75th percentile; MIT – maximum insertion torque; PS – pull-out strength.

Table 2. The medians, Q1, Q3, and Z- and p-values of the used mini-implants for MIT, PS and Periotest

Measurement method	Self-tapping (n = 23)			Self-drilling (n = 23)			Used implants (n = 46)	
	median	Q1	Q3	median	Q1	Q3	p-value	Z-value
MIT	17.30	16.90	19.10	24.10	23.70	24.90	0.001*	−5.816
Periotest	0.00	0.00	1.00	−3.00	−3.00	−2.00	0.001*	−5.959
PS	148.12	137.49	159.26	173.12	161.25	177.54	0.001*	−3.965

Mann–Whitney U test, * p = 0.001; Q1 – 25th percentile; Q3 – 75th percentile; MIT – maximum insertion torque; PS – pull-out strength.

Table 3. Correlations between used self-tapping and self-drilling mini-implants

Used implants	Self-tapping		Self-drilling	
	r	p-value	r	p-value
MIT-Periotest	−0.459	0.028*	−0.495	0.016*
MIT-Pull-Out	0.791	0.001**	0.457	0.028*
Periotest-Pull-Out	−0.530	0.009*	−0.389	0.066

r – Spearman's correlation; * p < 0.05; ** p = 0.001.

Table 4. Correlations between unused self-tapping and self-drilling mini-implants

Unused implants	Self-tapping		Self-drilling	
	r	p-value	r	p-value
MIT-Periotest	−0.466	0.025*	−0.625	0.001*
MIT-Pull-Out	0.548	0.007*	0.615	0.002*
Periotest-Pull-Out	−0.559	0.006*	−0.383	0.071

r – Spearman's correlation; * p < 0.05; ** p = 0.001

ST group (r = 0.548, p = 0.007). A negative correlation was found between the MIT and Periotest values of both the retrieved and new implant groups, regardless of the placement technique. The Periotest values were significantly and negatively correlated with PS for both the retrieved and new ST implants. However, according to the Spearman's rank test, the correlation between Periotest and PS values was not statistically significant for any of the SD implant groups (p > 0.05). The correlations between the different drilling types (ST or SD) and conditions (retrieved or new) for assessing MI stability are given in Table 3 and Table 4.

Discussion

The use of orthodontic MIs to achieve anchorage is becoming more common in orthodontic practice.[36] Their properties and differences in use, such as their dimensions, designs and placement protocols, are also becoming more varied to allow clinicians to use them more efficiently.[37] Some studies have focused on the influence of the dimensions, insertion angles, cortical thickness, and density of bone on determining the success of MIs and decreasing their failure rate.[25] Although many studies have investigated the relationships between the physical properties of implants or the variations in bone and the primary stability of implants, only a few studies have explored the reuse of implants and their success after prior use.[25] In the present study, the implant placement protocol was the same as in a previous study[31] that assessed the mechanical performance of ST compared to SD implants. The latter is currently the most common choice, given that the drilling phase is eliminated during placement. The MIs were also divided into groups to evaluate their mechanical performance according to their condition: as-received (control) or retrieved (experimental). This allowed for the assessment of each implant in terms of condition alone while maintaining all other characteristics.

Although the reuse of invasive medical devices, such as orthodontic MIs, in different patients can be seen as an ethical problem, the reuse of MIs in the same patient may be necessary for economic reasons.[31] However, no studies focusing on the reuse of orthodontic MIs after their clinical use and how to ensure their primary stability while controlling all other conditions have been conducted. In our study, we examined MIs that had been retrieved and sterilized as our experimental treatment, while the control group received new implants of the same type and with the same properties as the ones used in a previous study.[31] This raises the intriguing question of whether the condition of the orthodontic MI (retrieved compared to as-manufactured) or the placement technique is what ultimately determines the primary stability of the orthodontic implants.

Synthetic materials are more suitable testing materials than human and animal cadaver materials due to ethical reasons.[28] According to the American Society for Testing and Materials (ASTM) standards F1839-08, the homogeneity and consistent features of rigid polyurethane foam make it an ideal material for comparative testing of implants replacing specimens taken from human and animal cadavers.[38] Although the use of synthetic bone allowed us to recreate in vitro conditions and perform some tests, synthetic material cannot imitate the biological environment provided by organic models.[28] In our study, the use of a homogeneous and uniform artificial material overcame the variability of organic specimens. Our study was not intended to represent the biological response of bone tissue, such as osseointegration of dental implants, since the stability of MIs depends on mechanical locking with the bone. Some researchers have reported a density of the mandibular posterior area of 0.64 g/cc.[39] Based on these parameters, MIs were placed in a custom-made synthetic block with 2 layers that simulated the cortical bone (3-mm thickness, with a density of 50 pcf (0.80 g/cc)) and the cancellous bone (40-mm thickness with a density of 30 pcf (0.48 g/cc)).

In various studies, robotic systems equipped with machine drivers have been used for the placement of orthodontic MIs at the same angle, tour and speed for standardization.[36] In our study, the implants were inserted precisely and manually using a custom-made device that stabilized the digital torque meter driver to keep it vertical to the bone surface, as in previous studies.[40] The MIT values were lower for the retrieved and autoclaved MIs than for the unused implants, and statistically significant differences were detected between the MIT values of all MIs, regardless of the placement technique ($p = 0.005$, $p < 0.05$, $p = 0.001$). These findings indicate that the prior use or sterilization procedures significantly altered the MIT values of the implants. Similarly, the drilling phase before placement of a MI could decrease the insertion torque, although a technique that eliminates drilling enhances the stability of the thin MI.[41] However, some studies have reported that the insertion torque had a weak relationship with implant stability.[42]

The comparison of the Periotest values of all implants using different placement techniques revealed statistically significant differences for the ST implants only ($p = 0.001$). The unused and the retrieved SD implants did not show any statistically significant differences ($p > 0.05$). The statistical variation between the insertion techniques may be attributed to the intimate bone–implant contact achieved by the SD implants, which results in more stable values for the Periotest scores compared to the ST implants. These findings confirm that the Periotest scores were more stable for the new MIs than for the retrieved implants. This can be explained by changes in surface morphology due to cleaning and/or mechanical damage during prior placement and removal, as these changes could markedly alter osteoblastic growth and differentiation. Primary implant stability is known to be influenced by the microscopic and macroscopic morphology of the implant.[43] However, our findings are in contrast with the results obtained by Kim et al.,[44] who found markedly lower Periotest values for SD orthodontic MIs. The differences in the Periotest values and reports might reflect the inconsistency of the Periotest measurements on implants.[45,46]

In our study, the PS tests were performed by applying vertical forces oriented parallel to the long axis of the orthodontic MIs.[39] The application of pull-out tests in the axial direction does not provide a realistic reflection of the clinical situation because it is almost impossible to load MIs in the axial direction in a patient.[47] However, these tests are widely accepted as a method for comparing different types of implants in the orthopedic, maxillofacial surgery and orthodontic fields.[48] In our study, the pull-out values were significantly greater in all the unused implant groups than in the retrieved implant groups ($p = 0.001$). Moreover, the pull-out values for the unused implants, especially for the SD ones, were all substantially higher than the values for the unused MIs. The results regarding the PS values confirmed the importance of the implantation procedure and the implant condition in establishing primary stability since the results for the unused SD implants had the highest PS values (203.20 N).

For all implant groups, the Spearman's rank-order correlation performed for the MIT and PS values confirmed a strong, positive and statistically significant correlation between them. However, correlation assessments showed a negative relationship between the MIT and Periotest values for both the retrieved and new implant groups, regardless of the placement technique. The reason for this negative correlation is that lower Periotest values indicated higher implant stability. This finding suggests that the increase in MIT values and the corresponding decrease in Periotest values are evidence of increased primary stability.

Limitations

The stability of the orthodontic MIs might be affected by various biological and mechanical factors, such as bone density, soft tissue condition, oral hygiene, insertion method, and surface treatment.[2] Other factors, including the chemical composition, surface morphology, chemical composition of the saliva, biofilm formation, pH of the oral environment, protein adsorption, physical and chemical properties of foods, medicines taken by the patient, and oral hygiene habits, can affect the mechanical behavior of the MIs.[49,50] However, such analysis was not the objective of this study. Nevertheless, these factors must be considered and evaluated in future studies. This study tested unused and used orthodontic MIs employing different placement techniques to compare primary stability based on MIT, PS and Periotest values. No other parameters were analyzed, such as removal torque, lateral displacement, surface alterations, histological analysis, or resonance frequency analysis. These parameters must also be considered and evaluated in further studies.

Conclusions

Used orthodontic MIs showed poor performance compared to unused implants inserted under in vitro conditions.

ORCID iDs

Baris Baser https://orcid.org/0000-0002-3052-9023
Mehmet Birol Ozel https://orcid.org/0000-0002-2984-9468

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